



Open Access Multidisciplinary Online Magazine

Agri-India TODAY

Monthly Magazine-cum-eNewsletter

ISSN : 2583-0910

Volume 06 | Issue 03 | March 2026



www.agriindiatoday.in



Editorial Board

Editor-in-Chief

Prof. S. K. Laha

Associate Editor

Dr. Maimom Soniya Devi

International Advisory Members

Dr. Ahmed Ibrahim Abd-EL-Bary Ibrahim Heflish

Prof. Paul Bernard

Dr. Shree Prasad Vista

Dr. Biswanath Dari

Dr. Janak Dhakal

Dr. Arnab Bhowmik

Dr. Saroj Kumar Sah

Dr. Yassmine Moemen El-Gindy

Dr. Deepti Pradhan

Dr. Subhankar Mandal

Editorial Board Members

Dr. Raj Kiran

Er. Wungshim Zimik

Dr. Pranay Rai

Dr. Surajit Khalko

Dr. Swati M. Shedage

Dr. Satyajit Hembram

Dr. Aditya Pratap Singh

Dr. Shubh Laxmi

Dr. Vijay Kumar Mishra

Editorial Office

Mr. Biswajit Talukder
Magazine & Website Manager

Dr. Biplov Chandra Sarkar
Technical Manager

Dr. Rakesh Yonzon
Founding Editor

Article No	Title	Page No.
06/III/01/0326	STAKEHOLDER ANALYSIS IN PLURALISTIC AGRICULTURAL EXTENSION: CONCEPTS, APPROACHES, AND IMPLICATIONS FOR DEVELOPMENT INTERVENTIONS Saumyadip Chakraborty, Litan Das, Ainul Bari Malitha, Krishnendu Mondal and Swapnamay Ghosh	1-7
06/III/02/0326	ANTIOXIDANT DEFENSE SYSTEMS AS A PROTECTIVE STRATEGY AGAINST DROUGHT-INDUCED OXIDATIVE STRESS Chaithra B. S, Laxmi P. S, Khushal B. Muradi	8-11
06/III/03/0326	STEM RESERVE MOBILIZATION AS A DROUGHT ADAPTIVE MECHANISM Chaithra B. S, Yogesh V. Wayal and Banka Vaishnavi	12-14
06/III/04/0326	CARBON CREDITS IN INDIAN AGRICULTURE: PATHWAYS FOR CLIMATE MITIGATION AND RURAL TRANSFORMATION Bhagirath Das, Poulami Ray and Umakanta Dash	15-19
06/III/05/0326	PLANKTON, POLLUTION, AND PEOPLE: READING A RIVER THROUGH ITS MICROORGANISMS Vandana Pal, Jeetendra Kumar, Vikas Kumar and Amitabh Chandra Dwivedi	20-21
06/III/06/0326	GENOME EDITING IN AGRICULTURE: A PRECISION TOOL FOR FUTURE FOOD SECURITY Chaithra B. S., Vibin Sankar, Athira S.	22-25
06/III/07/0326	NUMTS AND NUPTS: SECRET AGENT RESHAPES THE PLANT GENOME EVOLUTION K. Bhrundha, Banka Vaishnavi and Vibin Sankar	26-30
06/III/08/0326	MULTI-TRAIT CROPS VIA GENE STACKING: A STEP TOWARDS SUSTAINABLE AGRICULTURE K. Bhrundha, Kishanth Kanna V and R. Jeevanraj	31-34
06/III/09/0326	SUCROSE HOMEOSTASIS: REGULATION AND CROSS TALK BETWEEN THE HORMONE SIGNALLING K. Bhrundha, Chaithra B. S and Yogesh V. Wayal	35-39
06/III/10/0326	BACTERIAL BIO-AGENTS: ECO-FRIENDLY WARRIORS FOR PLANT HEALTH PROTECTION R. P. Singh, Abhik Patra, R. M. Ram, B.K. Singh, Himanshu Singh and Ashutosh Kumar	40-48
06/III/11/0326	MOLECULAR BREEDING AND TRANSGENIC APPROACHES FOR TRAIT INTROGRESSION V. Kishanth Kanna, R. Jeevanraj and Chaithra B. S	49-52
06/III/12/0326	SOLAR RADIATION CONVERSION INTO DRY MATTER PRODUCTION V. Kishanth Kanna, Vibin Sankar and Athira S	53-56
06/III/13/0326	MARKER FREE TRANSGENIC: A SUSTAINABLE PATH TO CROP IMPROVEMENT V. Kishanth Kanna, Yogesh V. Wayal and Banka Vaishnavi	57-61
06/III/14/0326	HIGH-THROUGHPUT PHENOTYPING OF PLANTS FOR CROP IMPROVEMENT R. Jeevanraj, Athira S and Laxmi P. S	62-66
06/III/15/0326	TRANSGENICS FOR IMPROVING NITROGEN FIXATION: A FRONTIER IN SUSTAINABLE AGRICULTURE R. Jeevanraj, Banka Vaishnavi and Vibin Sankar	67-70
06/III/16/0326	DECODING THE STAPLE CROP: GENOME SEQUENCING OF RICE (<i>Oryza sativa</i>) R. Jeevanraj, Chaithra B. S and Yogesh V. Wayal	71-74
06/III/17/0326	FROM LAB TO LAND: HOW NEW CROP VARIETIES ARE DEVELOPED Yogesh V. Wayal, Banka Vaishnavi and Vibin Sankar	75-78
06/III/18/0326	GROWING MORE WITH LESS WATER: HOW FARMERS CAN BEAT DROUGHT THROUGH SMART PRACTICES Yogesh V. Wayal, Athira S and Laxmi P. S	79-81

Article No	Title	Page No.
06/III/19/0326	CAN PLANTS FIGHT CLIMATE CHANGE? THE HIDDEN POWER OF ROOTS Yogesh V. Wayal, Deshmukh Sarita Babarao and Choudhari Balaji Keshavrao	82-85
06/III/20/0326	EDIBLE FLOWERS IN MODERN CUISINE Vibin Sankar, Deshmukh Sarita Babarao and Choudhari Balaji Keshavrao	86-90
06/III/21/0326	WHY TREES ARE THE BACKBONE OF LANDSCAPING? Vibin Sankar, Khushal B. Muradi and K. Bhrundha	91-96
06/III/22/0326	BURLAPPING: GIVING TREES A NEW HOME Vibin Sankar, Athira S and Laxmi P. S	97-104
06/III/23/0326	CARBON SEQUESTRATION POTENTIAL OF URBAN ORNAMENTAL LANDSCAPES Athira S, K. Bhrundha and Chaithra B. S	105-108
06/III/24/0326	NANOTECHNOLOGY-DRIVEN INNOVATIONS FOR ENHANCING THE POSTHARVEST LONGEVITY OF FLOWERS Athira S, Laxmi P. S and Deshmukh Sarita Babarao	109-113
06/III/25/0326	BIOMIMETIC LANDSCAPING: DESIGNING GARDENS INSPIRED BY NATURAL ECOSYSTEMS Athira S, Choudhari Balaji Keshavrao and Khushal B. Muradi	114-117
06/III/26/0326	BIOFERTILIZERS AND MICROBIOME MANIPULATION: REVOLUTIONIZING SUSTAINABLE AGRICULTURE Choudhari Balaji Keshavrao, Chaithra B. S and Yogesh V. Wayal	118-120
06/III/27/0326	ADVANCES IN NUTRIENT USE EFFICIENCY IN AGRONOMIC CROPS: MECHANISMS, CHALLENGES, AND FUTURE PROSPECTS Choudhari Balaji Keshavrao, V. Kishanth Kanna and R. Jeevanraj	121-123
06/III/28/0326	BIOSTIMULANTS IN CEREAL CROPS: ENHANCING GROWTH, YIELD, AND SUSTAINABILITY Choudhari Balaji Keshavrao, Khushal B. Muradi ² and K. Bhrundha	124-127
06/III/29/0326	INTEGRATED NUTRIENT MANAGEMENT IN PULSES Deshmukh Sarita Babarao, K. Bhrundha and V. Kishanth Kanna	128-131
06/III/30/0326	ROLE OF BIOFERTILIZERS IN SUSTAINABLE AGRICULTURAL PRODUCTION Deshmukh Sarita Babarao, Choudhari Balaji Keshavrao and Khushal B. Muradi	132-136
06/III/31/0326	INTEGRATED NUTRIENT MANAGEMENT (INM) IN OILSEED CROPS Deshmukh Sarita Babarao, R. Jeevanraj and Chaithra B. S	137-141
06/III/32/0326	AI IN THE COLD ROOM: HOW SMART TECHNOLOGY IS REVOLUTIONIZING POSTHARVEST STORAGE Laxmi P. S, Deshmukh Sarita Babarao and Choudhari Balaji Keshavrao	142-145
06/III/33/0326	TURNING POSTHARVEST WASTE INTO PROFIT: VALUE ADDITION FROM PEELS AND POMACE Laxmi P. S, V. Kishanth Kanna and R. Jeevanraj	146-149
06/III/34/0326	POSTHARVEST LOSSES AND CLIMATE CHANGE: THE HIDDEN CONNECTION Laxmi P. S, Khushal B. Muradi and K. Bhrundha	150-153
06/III/35/0326	PHYSIOLOGY OF NUTRIENT USE EFFICIENCY IN VEGETABLES Khushal B. Muradi, K. Bhrundha and V. Kishanth Kanna	154-158
06/III/36/0326	RESPIRATION AND RIPENING PHYSIOLOGY IN VEGETABLES: MECHANISMS AND POSTHARVEST IMPLICATIONS Khushal B. Muradi, R. Jeevanraj and Chaithra B. S	159-164
06/III/37/0326	HOW PLANT BREEDING HELPS FARMERS GROW BETTER CROPS Khushal B. Muradi, Yogesh V. Wayal and Banka Vaishnavi	165-171
06/III/38/0326	PHYTOREMEDIATION: NATURE'S CLEANUP CREW - HOW PLANTS DETOXYFY POLLUTED SOIL AND WATER Banka Vaishnavi, Laxmi P. S and Deshmukh Sarita Babarao	172-175

Article No	Title	Page No.
06/III/39/0326	AI IN PLANT BREEDING: FROM DATA TO BETTER CROPS Banka Vaishnavi, Vibin Sankar and Athira S	176-178
06/III/40/0326	MOLECULAR BIOTECHNOLOGY IN BREEDING: TOOLS THAT CHANGED THE GAME Banka Vaishnavi, Choudhari Balaji Keshavrao and Khushal B. Muradi	179-181
06/III/41/0326	A NEW FRONTIER: CULTIVATING BUFFALO GOURD IN INDIA'S ARID ZONES Udham Singh, Jayshree Singh, Manish Kumar Singh, Shweta Soni and Ajeet Singh	182-185
06/III/42/0326	ADVANCES IN REMOTE SENSING AND GIS FOR AGRO-METEOROLOGICAL ADVISORY AND CLIMATE-SMART AGRICULTURE Ekanshi Shreshtha, Shubham Pandey, Sita Ram Mishra, Shivani Pandey and Anamika Rajput	186-188
06/III/43/0326	WHAT BUDGET 2026 MEANS FOR INDIAN FARMERS AND FOOD SECURITY K. N. Tiwari	189-199
06/III/44/0326	APOMIXIS AND ITS ROLE IN FIXING HETEROSIS Boddu Aruna and Koyya Unnathi Madhuri	200-203
06/III/45/0326	APPLICATION OF SIMPLE RANDOM SAMPLING TECHNIQUES WITH AND WITHOUT REPLACEMENT USING MS-EXCEL Nathina P, Surulivel L and Aanand S	204-208
06/III/46/0326	AQUACULTURE AND VIKSIT BHARAT 2047: HOW FISH FARMING CAN POWER INDIA'S GROWTH STORY Md Meraj, Indulata Tekam, Pravesh Kumar and Roshan Kumar Ram	209-213
06/III/47/0326	BIOCONTROL AGENTS AND PEST MANAGEMENT IN ORGANIC FARMING Aman Kumar and Radheshyam Ramkrishna Dhole	214-217
06/III/48/0326	FRUIT FLY: IMPORTANT PEST IN HORTICULTURE AND ITS MANAGEMENT Aman Kumar and Radheshyam Ramkrishna Dhole	218-221
06/III/49/0326	THE ANCIENT HERB: HOW TEA SHAPES HUMAN HEALTH AND COGNITION Dipankar Barai, Barnita Adhikari, Sudipta Mahato, Shahil Reza and Rakesh Yonzone	222-227
06/III/50/0326	SUSTAINABLE LAND MANAGEMENT PRACTICES FOR DEGRADED LANDSCAPES Neekita and Ravinder Kaur	228-232
06/III/51/0326	THANATOSIS: A DEFENSE BEHAVIOR IN INSECTS Varsha Kumawat, Usha and Priyanka Kaundal	233-235
06/III/52/0326	CONJUNCTIVE USE OF SALINE AND FRESH WATER FOR SUSTAINABLE IRRIGATION IN ARID AND SEMI-ARID REGIONS: LESSONS FOR HARYANA AND BEYOND Mohinder Singh, Jitender Kumar, Sandeep Yadav Babita and RamAvtar	236-239
06/III/53/0326	VERTICAL FARMING OF EXOTIC VEGETABLES: A FUTURE PERSPECTIVE Saurabh Sonkar, Satya Prakash, Neetu and Akash Kumar	240-245
06/III/54/0326	WOMEN SCIENTISTS IN GENETICS AND PLANT BREEDING Aprajita Singh and Radheshyam Ramkrishna Dhole	246-249
06/III/55/0326	THE DARK SIDE OF SHINY GRAINS: WHEN POLISHING STEALS OUR NUTRITION Yogavarsha M, R. Pungavi, J Poojakrishna and Febavarghese	250-251
06/III/56/0326	UNVEILING BIOACTIVE PEPTIDES IN GERRES FILAMENTOUS: A NOVEL APPROACH TO FUNTIONAL FOOD DEVELOPMENT S. T. Dhivya Bharathi, L. Vinoth Kumar, G. Dhivagar, E. K. Devipriya, M. Dhanu Pradeep and R. Gayathri	252-254

Article No	Title	Page No.
06/III/57/0326	ROLE OF VEGAN AND CRUELTY-FREE CERTIFICATIONS IN SHAPING ETHICAL CONSUMPTION Kishor Anerao, Monali Joshi, Amol Dukare and Pratyush Kumari Rath	255-257
06/III/58/0326	ROLE OF UNDER WATER VIDEO TECHNIQUE AND ROBOTICS IN FISHERIES Vishva Barad, Kailas Rathod and Niharika Chudasma	258-263
06/III/59/0326	WASTE TO WEALTH: USING AGRICULTURAL RESIDUES TO GROW MUSHROOMS FOR SUSTAINABLE RURAL DEVELOPMENT Ayandip Maity and Nandita Das	264-267
06/III/60/0326	WEED SEED BANK DYNAMICS AND ITS IMPLICATION FOR MANAGEMENT Balamurugan S, R. V. A. Reddy, Malothu Chandu Lal and Gourav Sabharwal	268-270
06/III/61/0326	SUSTAINABLE LAND MANAGEMENT PRACTICES FOR DEGRADED LANDSCAPES. Neekita and Ravinder Kaur	271-274
06/III/62/0326	BAMBOO SHOOTS: NUTRITIONAL, MEDICINAL AND VALUE-ADDED POTENTIAL Ankit Yadav, K.N. Shah, Indra Jeet Chaudhary, D.K. Rana and Abhay Singh	275-278
06/III/63/0326	INTERVENTIONS OF NANOTECHNOLOGY IN HORTICULTURE H. Bhavana, S. Akshitha, B. Ashok, P. Parameshwar, R. Preetham Goud and D. Naga Harshitha	279-283
06/III/64/0326	CABLE BACTERIA: THE LIVING ELECTRICAL WIRES BENEATH OUR FEET Ganga Nair and Aleena Joy	284-287
06/III/65/0326	CAPERS: THE UNTAPPED MEDITERRANEAN SPICE WITH EMERGING POTENTIAL FOR INDIAN AGRICULTURE Enugula Naveen, Manchyala Divya and Y. Deepthi	288-291
06/III/66/0326	CROSS-KINGDOM RNA INTERFERENCE AND THE ROLE OF PATHOGEN-DERIVED SMALL RNAs IN MODULATING HOST DEFENSE Enugula Naveen, Ujwala Chennareddy, Ch Eshwar Sai Prasad and Pulla Pavani	292-295
06/III/67/0326	CLIMATE-RESILIENT VEGETABLE CROPS FOR SUSTAINABLE HORTICULTURE Karakambadi Vaishnavi, Syed Sadarunnisa, Siriki Anusha and Sangaraju Reddy Veera Nagaveni	296-299
06/III/68/0326	COMPARATIVE DISTRIBUTION AND ABUNDANCE OF SCYLLA OLIVACEA IN PICHAVARAM AND SUNDARBANS MANGROVE ECOSYSTEMS E.K.Devipriya, L.Vinoth Kumar, G.Dhivagar, M.Dhanu Pradeep, R.Gayathri and S.T.Dhivya Bharathi	300-302
06/III/69/0326	DAIRY SECTOR DEVELOPMENT IN NORTH-EAST INDIA: BRIDGING THE YIELD GAP FOR INCLUSIVE GROWTH Poulami Ray, Bhagirath Das and Ajmer Singh	303-307
06/III/70/0326	REVIVING TRADITIONAL FERMENTED FOODS AT HOME: A DIY KIT APPROACH Kishor Anerao, Deshpande H. W, Sachin Giri and Dukare Amol	308-311
06/III/71/0326	STATISTICAL ANALYSIS OF DISSOLVED OXYGEN AND TEMPERATURE IN RELATION TO FISHERIES AND AQUACULTURE R. J. Abisha and L. Surulivel	312-315
06/III/72/0326	EFFECT OF FEED QUALITY ON FISH FLESH Shivkumar Swamy, Dhanalakshmi M, A. Chandrasekhara Rao ¹ , Sashti Risha K, K. Bheemeshwarrao and Paneerselvan Dheeran	316-321
06/III/73/0326	POTENTIAL ROLE OF GUT MICROFLORA IN FISH Khushbu Kumari, Sarvendra Kumar, Sagarika Swain, Aishwarya Sharma & Parmanand Prabhakar	322-327
06/III/74/0326	FRENCHBEAN CULTIVATION GUIDE Lalthazuali and Banridamon K Sohkhia	328-330

Article No	Title	Page No.
06/III/75/0326	GANODERMA LUCIDUM – THE “MUSHROOM OF IMMORTALITY” Sanchita Gautam, Sachin Upmanyu and Savita Jandaik	331-333
06/III/76/0326	GENETICS AND PLANT BREEDING APPROACHES FOR CLIMATE-RESILIENT CROPS Aprajita Singh and Radheshyam Ramkrishna Dhole	334-336
06/III/77/0326	HEALTH-ENHANCING INGREDIENTS IN FUNCTIONAL FOODS: ROLE, BENEFITS AND FUTURE PERSPECTIVES Anerao Kishor K, Deshpande H. W and Pratyush Kumari Rath	337-340
06/III/78/0326	ENHANCING FARM INCOME THROUGH SHORT-DURATION GREEN GRAM CULTIVATION UNDER RESIDUAL SOIL MOISTURE CONDITIONS Shubham Pandey, Rashmirekha Senapati, S.R. Mishra, Abhishek Tiwari and Ekanshi Shreshtha	341-344
06/III/79/0326	ROLE OF AGRICULTURE IN THE INDIAN ECONOMY Jasmine Keziah Puli, Jassica Keren Puli and Davuluri Babysridivya	345-348
06/III/80/0326	IMPACT OF INDIA'S BLUE REVOLUTION PROGRAMME ON FISHERIES PRODUCTION: A DECADAL ASSESSMENT (2015–2025) Jayasri Ravi and L. Surulive	349-352
06/III/81/0326	JOURNEY OF BUTTON MUSHROOM CULTIVATION AT COMMERCIAL LEVEL Simran	353-357
06/III/82/0326	MAHOGANY FARMING IN INDIA: THE NEW GREEN GOLD Sachin Kumar, Rahul Yadav, Chandana S and Seema Kousar	358-362
06/III/83/0326	MAKHANA: THE AQUATIC GOLD AND THE PRIDE OF BIHAR Ravi Kumar Rman, Avinash Kumar and Nitu Kumari	363-366
06/III/84/0326	FUTURE OF WATER MANAGEMENT: INNOVATIONS AND EMERGING TECHNOLOGIES IN NAGALAND S. Niamkoi Khamniungan and Krishna Kumar	367-370
06/III/85/0326	RECENT ADVANCES IN BIOFORTIFICATION OF FRUIT CROPS: A SUSTAINABLE APPROACH TO NUTRITIONAL SECURITY Parul Bhopal and Kripal Chand	371-374
06/III/86/0326	MEDICINAL FLOWERS: NATURE'S HEALING BLOOMS Arshi Sultanpuri, Kritika Thakur and Neha Rani	375-378
06/III/87/0326	MICROBIAL SUCCESSION IN EARLY DEVELOPMENTAL STAGES OF PENAEUS INDICUS: A CRITICAL ANALYSIS R. Gayathri, L. Vinoth Kumar, G. Dhivagar, E. K. Devipriya, M. Dhanu Pradeep and S. T. Dhivya Bharathi	379-381
06/III/88/0326	MODERNIZATION OF OLD PROCESSING TECHNIQUES IN THE FOOD INDUSTRY Radha Lolge and Vedprakash Surve	382-386
06/III/89/0326	MOLECULAR AND METABOLIC MECHANISMS OF CAPSAICIN SUPPLEMENTATION IN ENHANCING TRANSITION COW HEALTH AND PRODUCTIVITY Kiran Shinde, Suhana Parvin Muquit and Chandrakant Kale	387-390
06/III/90/0326	MOLECULAR TOOLS FOR ASSESSING GENETIC DIVERSITY Tharringwon Marchang Ningshen, Pritam Das and Pranab Dutta	391-394
06/III/91/0326	MOOD SWINGS – ARE THEY CONTROLLED BY GUT MICROBIOME? Uthara S and Ganga Nair	395-398
06/III/92/0326	PREDICTION OF PRODUCTION PERFORMANCE IN DAIRY ANIMALS USING BODY MORPHOMETRIC TRAITS Suryakant Sori and Deeksha Pal	399-400
06/III/93/0326	MULCHING TEHNOLOGY FOR PEST SUPPRESSION Ayushi Kumari and Radheshyam Ramkrishna Dhole	401-404

Article No	Title	Page No.
06/III/94/0326	MULTI-OMICS IN AGRICULTURE: THE NEXT FRONTIER FOR SMART CROP IMPROVEMENT J. R. Patel and P. J. Kandoriya	405-409
06/III/95/0326	NANO ENCAPSULATED BIO PESTICIDES Ayushi Kumari and Radheshyam Ramkrishna Dhole	410-413
06/III/96/0326	NUTRITIONAL EVALUATION OF SILLAGO SIHAMA: A COMPARATIVE STUDY WITH OTHER MARINE FISHES G. Dhivagar, L. Vinoth Kumar, E. K. Devipriya, M. Dhanu Pradeep, R. Gayathri and S. T. Dhivya Bharathi	414-416
06/III/97/0326	AN OVERVIEW OF MICROPLASTICS IN FOOD: ENVIRONMENTAL PATHWAYS, DETECTION, AND HEALTH IMPACTS Ayna Inayat	417-420
06/III/98/0326	IMPORTANCE OF PHOSPHATE-SOLUBILIZING BACTERIA IN SUSTAINABLE FRUIT CULTIVATION Shahil Reza, Prerna Baraily, Rakesh Yonzone, Barnita Adhikary, Dipankar Barai, Sudipto Mahata and Hasina Begam	421-425
06/III/99/0326	PROPAGATION STRUCTURES FOR EFFICIENT PLANT MULTIPLICATION Koyya Unnathi Madhuri and Boddu Aruna	426-429
06/III/100/0326	FIBRE EXTRACTION FROM DIFFERENT ORNAMENTAL FLOWERS C. Nagamallika and Jassica Keren Puli	430-433
06/III/101/0326	THE “BIO-GLUE” ECONOMY: MICROBES AS ARCHITECTS OF THE PLANT–SOIL INTERFACE P. J. Kandoriya and J. R. Patel	434-441
06/III/102/0326	PROXIMATE COMPOSITION OF ETROPLUS SURATENSIS: INSIGHT INTO PROTEIN, LIPID AND MINERALS M. Dhanu Pradeep, L.Vinoth Kumar, G. Dhivagar, E. K. Devipriya, R. Gayathri and S.T. Dhivya Bharathi	442-443
06/III/103/0326	RISING CO₂ AND CROP RESILIENCE: OPPORTUNITIES AND RISKS FOR GLOBAL AGRICULTURE Vijay Gahlaut, Vandana Jaiswal and Sundeep Kumar	444-447
06/III/104/0326	ROLE OF GENETICS AND PLANT BREEDING IN IMPROVING CROP QUALITY Aprajita Singh and Radheshyam Ramkrishna Dhole	448-451
06/III/105/0326	SEAWEED EXTRACTS – PLANT RESILIENCE BOOSTERS K.G. Shilpa Shree, T.R. Rupa, M.D. Prathibha and T. Anupa	452-454
06/III/106/0326	HOW TO CONSTRUCT A HISTOGRAM USING FREQUENCY DISTRIBUTION IN MICROSOFT EXCEL Suwetha P, Surulivel L and Aruna S	455-458
06/III/107/0326	TALAROMYCES: THE EMERGING FUNGAL WARRIOR AGAINST PLANT DISEASES Heyram S.P.	459-463
06/III/108/0326	WHAT AILS THE DOMESTIC EDIBLE OIL ECONOMY-WHETHER STAGNATION ON PRODUCTION FRONT OR WEAK FARMER, PRO -CONSUMER HEALTH SUPPORTIVE POLICY INTERVENTIONS? Ranga Rao Veerapaneni	464-466

STAKEHOLDER ANALYSIS IN PLURALISTIC AGRICULTURAL EXTENSION: CONCEPTS, APPROACHES, AND IMPLICATIONS FOR DEVELOPMENT INTERVENTIONS

**Saumyadip Chakraborty^{1*}, Litan Das², Ainul Bari Malitha¹,
Krishnendu Mondal¹ and Swapnamay Ghosh¹**

¹Ph.D. Research Scholar, Department of Agricultural Extension,
Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, West Bengal-736165, India

²Assistant Professor, Department of Agricultural Extension,
Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, West Bengal-736165, India

*Corresponding Email: chakraborty.pavel321@gmail.com

Abstract

The current scenario in agricultural extension is characterized by a complex and increasingly pluralistic setting in which farmers' choices are influenced by a variety of market, social, and institutional actors, rather than by a single advisory body. Technology and policy measures alone are not adequate to ensure sustainable development outcomes without a proper understanding of the interests, power relations, and interactions of stakeholders. Stakeholder analysis (SA) is a systematic and flexible methodology to identify and prioritize key stakeholders, evaluate their roles and power, and establish worthwhile strategies for their coordination. The approach is gaining importance, with its application in various research and development activities like agricultural insurance schemes, value chains management, and natural resource management. The pivotal role of extension agents as facilitators, knowledge managers, and coordinators in the context of stakeholder analysis is also crucial. Institutionalized stakeholder analysis strengthens effective extension policies and leads to impactful outcomes in future.

Keywords: Stakeholder analysis, Pluralistic Agricultural Extension, Prioritization, Development Activities, Extension Agents' Facilitation Role

Introduction

Agricultural extension has traditionally been seen as a way to transfer better technologies from research institutions to farmers. However, it has become gradually clear that farmers' decisions depend on much more than just technical advice. Markets, institutions, social relationships, risk perceptions, policy environments, and various service providers all influence farmers' behavior and choices about adoption. As a result, extension systems have evolved into complex arrangements with many parts. Research and field experience show that many extension initiatives fail, not because of poor technologies, but due to weak coordination among actors, limited involvement of key stakeholders, and a lack of understanding of power dynamics in the system. Studies focused on agricultural innovation and development stress that ignoring stakeholder interactions leads to disjointed outcomes (Chinseu *et al.*, 2022). In this situation, stakeholder analysis has become an important planning and management tool for improving agricultural extension and rural development efforts.

Concept of Stakeholder : A Theoretical Background

The idea of stakeholders has become significant in various fields, such as management, development studies, and natural resource governance. The term 'stakeholder' was first recorded

in 1708. It referred to 'a person who holds the stake or stakes in a bet' (Ramirez, 2001). Stakeholders are any individual or group that can influence or is influenced by an organization's goals (Freeman, 1984). In development programmes, stakeholders are usually seen as individuals, groups, or institutions interested in a project. This includes both those who benefit directly and those who may be affected indirectly or negatively (ODA, 1995).

In the context of rural development and natural resource management, the scope of stakeholders expands beyond farmers and includes intermediaries, service providers, policy makers, regulatory bodies, and institutions which regulate access to resources and decision-making processes (Röling & Wagemakers, 1998). Scholars have further classified stakeholders into primary stakeholders (directly affected groups such as farmers), secondary stakeholders (intermediaries such as extension agencies, banks, and NGOs), and tertiary stakeholders, whose actions indirectly shape outcomes.

A globally accepted integrative definition describes stakeholders as actors who affect or are affected by a decision or intervention, and whose interests and influence vary across contexts (Reed *et al.*, 2014). Such distinctions matter a lot in agricultural extension. Implementation of initiatives often involve many players with different, and sometimes conflicting, interests.

Stakeholder Analysis : Meaning and Approach

Stakeholder Analysis (SA) is a method for finding key players in a project and understanding how their interests, power, and relationships affect the project's feasibility and outcomes (Reed *et al.*, 2014). It does more than just list stakeholders; it helps anticipate risks, manage conflicts, and create effective participation and engagement strategies. SA improves project planning by guiding engagement processes, supporting negotiations, and clarifying roles and expectations through tools like customized Terms of Reference. It focuses on finding stakeholders, looking at their interests, and assessing how these interests impact project risks and results (ODA, 1995). While it is commonly used in business and project management, SA is also valuable in rural development, agricultural extension, natural resource management, and policy analysis (Chevalier, 2001). The process generally involves identifying stakeholders, prioritizing them based on their importance and influence, and choosing suitable participation strategies at different project stages (Basu & Goswami, 2006). Since stakeholder roles and influence change over time, SA is a flexible and responsive process. In agricultural extension, it aligns well with the Agricultural Innovation System perspective, which sees innovation as a result of interaction, learning, and institutional change, rather than a straightforward transfer of technology (Chinseu *et al.*, 2022).

The Stakeholder Analysis Tool

The Victorian Department of Primary Industries (DPI) set up the Practice Change Capacity Development (PCCD) team in 2007 to help projects meet government policy goals. PCCD mainly acts as a support unit, offering DPI project teams social science knowledge to guide project design, development, and implementation. As part of its role, PCCD looked at how DPI teams planned and carried out their projects, focusing especially on stakeholder management methods. The review showed that most project teams did not use a systematic or strategic approach to identifying and engaging the human and social resources needed to achieve project goals. Among the options available, the stakeholder analysis framework created by Grimble and Wellard (1996) stood out as the most thorough and useful, serving as the basis for the initial PCCD models. Over the next eight years, this framework was gradually updated to meet the specific needs of Victorian state

government programs. In 2007, the new PCCD team released a revised stakeholder analysis tool (Howden, 2007). This tool includes five steps and results in both a stakeholder matrix and a stakeholder analysis table.

The process requires careful analysis and thorough completion of all related tables and spreadsheets, and it works best when done collaboratively rather than individually.

- 1. Step One: Identifying Stakeholders:** The first step is to identify all individuals involved in the project. The team should discuss why their participation matters for achieving project goals. The focus should be on people and their roles rather than just on organizations or job titles. This is important because individuals in the same organization may have different levels of influence, responsibility, and relationships with the project team. Ultimately, it is people—not institutions—who create networks and shape outcomes.
- 2. Step Two: Prioritizing Stakeholders:** In this step, the team ranks stakeholders using a simple matrix (See **Figure 1**) based on how crucial they are to the project's success. Prioritizing helps the team decide where to spend their time and effort. It ensures that communication and engagement activities focus on those stakeholders most likely to impact project results.

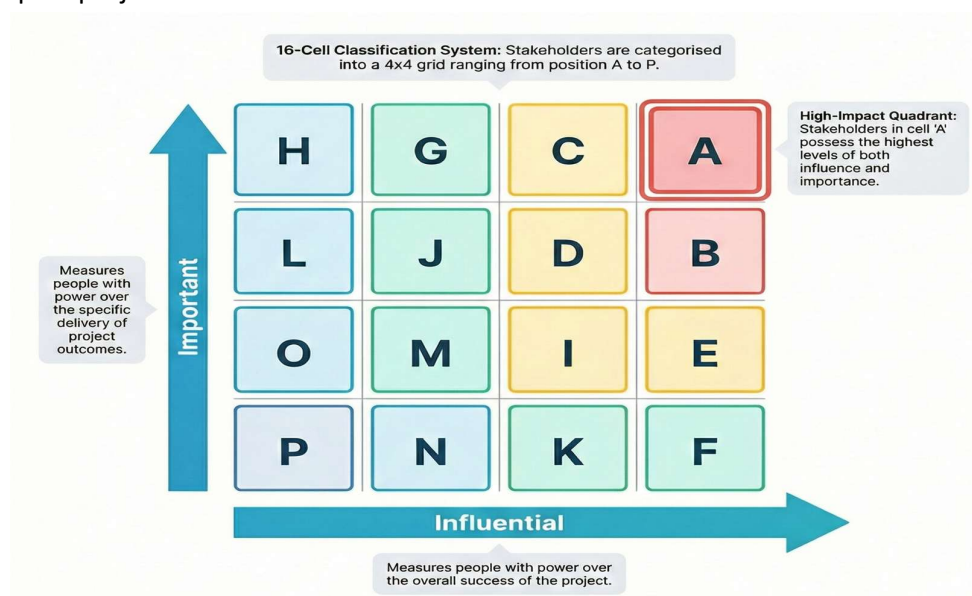


Figure 1: Stakeholder Prioritization Matrix (adapted from Kennon *et al.*, 2009)

The matrix is built around two dimensions: *Influential* and *Important*.

- *Influential* stakeholders are those who can affect a project's success through their authority, resources, or persuasive power.
 - *Important* stakeholders are critical to achieving project outcomes. These include opinion leaders, technical experts, providers of enabling resources (e.g., mapping technology), and those directly involved in implementing innovations.
- 3. Step Three: Understanding and Managing Stakeholders:** This stage involves evaluating stakeholders' attitudes toward the project, their relationships with the project team, and any potential risks from their involvement. With this information, the team can adjust

engagement strategies to minimize risks, build trust, and enhance stakeholders' sense of ownership and commitment to the project.

4. **Step Four: Setting Goals and Assigning Responsibilities:** Here, the team clearly defines communication goals, assigns responsibilities for each engagement activity, and sets realistic timelines. This step makes sure that tasks related to stakeholders are planned, organized, and properly resourced.
5. **Step Five: Evaluation and Revision:** Stakeholder analysis is not a one-time task and should be reviewed regularly throughout the project lifecycle. Periodic checks help identify new stakeholders, changes in influence or importance, and shifts in perceptions of the project. Updating the analysis ensures that stakeholder engagement stays relevant and responsive over time.

Throughout these steps, participants should fill in a stakeholder analysis table. (e.g. Table 1).

Name	Role	Why are they important?	Rank	Current attitude	Desired Action	Key Messages	Tactics	When	Who
Sarah	Local Supplier	Critical for supply chain stability and local economic buy-in.	I	Hesitant regarding long-term project viability.	Sign a preferred partner agreement and advocate to peers.	Our project ensures local business growth and stable revenue.	One-to-one procurement briefing.	15 th Nov	Claire

Table 1: Stakeholder Analysis Table (adapted from Kennon *et al.*, 2009)

Managing networks of stakeholders for expected outcomes can be complex. Research and practical experience show that integrating the views of people with different expertise, backgrounds, and problem-solving styles properly can be challenging.

Why Stakeholder Analysis Matters

1. Managing Pluralism

Modern agricultural extension systems encompass public departments, private firms, financial institutions, insurance agencies, farmer organizations, NGOs, and local governance structures. Without a clear understanding of their roles and interrelationships, extension efforts shall go in vain. Stakeholder analysis helps to visualize this complexity and facilitates coordinated strategies instead of isolated efforts (Chinseu *et al.*, 2022).

2. Improving Participation and Ownership

Participatory development literature consistently demonstrates that projects designed without meaningful stakeholder involvement can not provide fruitful result. Stakeholder analysis enables extension systems to identify who should be informed, consulted, actively involved, or supported at different stages, so that it can enhance ownership, accountability, and sustainability of programmes.

3. Addressing Power and Conflict

Stakeholders differ widely in terms of power and influence. While some actors dominate decision-making processes, others remain marginalized despite being significantly affected. Stakeholder

analysis supports anticipation of conflicts, identification of potential risks, and design of mechanisms for negotiation, consensus building, and conflict management (Reed *et al.*, 2014).

4. Improving Relevance of Extension Interventions

Technically sound recommendations often fail when they do not match with farmers' realities or institutional contexts. By incorporating diverse stakeholder perspectives, extension initiatives become more context-specific, socially acceptable, and practically applicable.

5. Enhancing Innovation and Democratic Legitimacy

Well-connected stakeholder networks promote learning, knowledge sharing, and innovation by bringing together different viewpoints. Inclusive participation also boosts legitimacy, builds trust, and supports flexible responses in complex agricultural settings.

Application of Stakeholder Analysis In Research and Development Measures

1. Agricultural Insurance Systems

Agricultural insurance systems involve multiple stakeholders, including farmers, extension personnel, banks, insurance companies, and government departments. Research has shown that understanding stakeholders' roles, interests, and communication gaps is crucial for improving farmers' awareness, attitudes, and participation in insurance schemes (Priyadarsinee *et al.*, 2023). Stakeholder analysis in such systems helps identify bottlenecks and strengthens coordination among service providers.

2. Farmer-Inclusive Value Chain Development

Stakeholder analysis has been considerably implemented in value-chain related investigations to examine relationships among producers, intermediaries, processors, traders, and consumers. Such approaches are increasingly relevant for market-oriented agricultural extension.

3. Rural Development and Natural Resource Management

In rural development programmes, stakeholder analysis supports participatory management by clarifying roles, facilitating negotiation, and enabling collective decision-making. Evidence suggests that such approaches enhance coordination, resource mobilization, and sustainability of interventions.

4. Learning, Innovation and Extension Performance

Agricultural innovation studies highlight that learning occurs through interaction among stakeholders rather than through one-way communication. Stakeholder analysis helps create spaces for dialogue and collective learning (Chinseu *et al.*, 2022).

Case Illustration: Stakeholder Analysis for Mango Value Chain Development in Kerala

Mango farming in the Palakkad district of Kerala, especially in the Muthalamada region, is a key source of income for small and medium farmers. Despite good weather conditions and high market demand, farmers face ongoing challenges. These include the strong presence of intermediaries, limited access to market information, post-harvest losses, and weak bargaining power. These issues lower the farmers' share of profits and hinder the overall efficiency of the mango value chain.

A study by Nadhika and Krishnankutty (2017) looked at the mango value chain using stakeholder analysis and SWOC analysis to understand the roles, interests, and power dynamics of

stakeholders. The research evaluated key participants, including growers, input suppliers, collection agents, traders, processors, exporters, extension personnel, and local organizations through importance-influence ranking. The results showed that intermediaries like collection agents and traders had more influence over the value chain, while farmers and development personnel had less decision-making power.

The study, based on stakeholder perceptions, recommended several strategic actions. These actions included improving value addition, promoting branding, enhancing farmer competitiveness through training, and raising quality standards for export. This case demonstrates how stakeholder analysis can help extension systems recognize power imbalances and create strategies that include farmers in the value chain.

Role of Extension Agents

Within stakeholder-focused extension systems, extension agents serve as technology promoters and facilitators of participation, knowledge brokers, and coordinators of stakeholder relationships. Their main tasks include organizing stakeholder meetings, mediating different interests, building institutional connections, and making sure that feedback from the field influences higher-level decision-making. Extension professionals also help translate complex policies and programmes into meaningful actions for local contexts by building trust among stakeholders. Therefore, skills in communication, negotiation, participatory planning, and stakeholder analysis are essential for modern extension practice. Their role can be implied as follows-

- **The Facilitator:** They manage the "dialogue space," ensuring that diverse interests are heard without conflict.
- **The Translator:** They bridge the linguistic and conceptual gap between the laboratory and the furrow, making complex science "compatible" with local tradition.
- **The Network Builder:** They use digital tools and interpersonal channels to weave together fragmented actors into a cohesive support system for the farmer.

This evolution requires a new suite of "soft" competencies: negotiation, systems thinking, and social empathy.

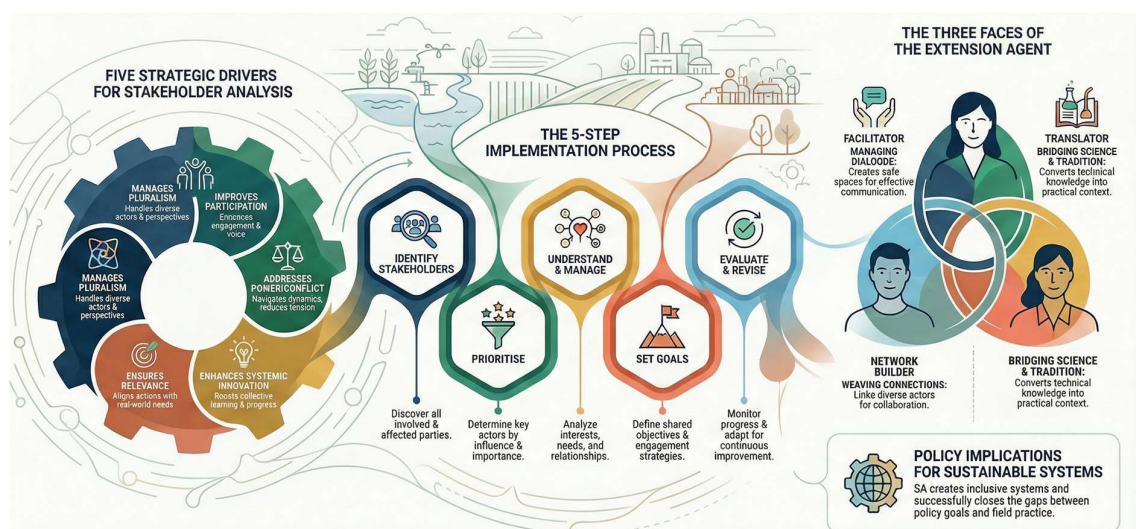


Figure 2 : Stakeholder Analysis- key to Impactful Agricultural Extension
Policy Implications and Way Forward

From a policy perspective, stakeholder analysis offers a clear framework for creating inclusive and responsive extension systems. Policies that support stakeholder participation, encourage cooperation between agencies, and build the skills of extension staff are more likely to produce sustainable results. Including stakeholder analysis in extension planning, monitoring, and evaluation can help close the gaps between policy goals and actual conditions in the field (Chinseu *et al.*, 2022).

Conclusion

Stakeholder analysis is no longer just an optional task; it is now a practical necessity for modern agricultural extension. By clearly identifying stakeholders, understanding their interests and influence, and creating suitable participation strategies, extension systems can be more inclusive, coordinated, and productive. Regularly including stakeholder analysis in extension practices and policies will be essential for turning various agricultural innovations and development programmes into relevant and effective activities in the field in the future.

References

- Basu, D. and Goswami, R. (2006). Participation in development: Concept and strategy. Participatory planning and project management in extension sciences, Agrotech Publishing Academy, Udaipur, India.
- Chevalier J M (2001). Stakeholder analysis and natural resource management.
- Chinseu E L, Dougill A J and Stringer L C (2022). Strengthening conservation agriculture innovation systems in sub-Saharan Africa: Lessons from a stakeholder analysis. *International Journal of Agricultural Sustainability* 20(1): 17–30.
- Freeman R E (1984). Strategic management: A stakeholder approach. Pitman Publishing, Boston, USA.
- Grimble R and Wellard K (1997). Stakeholder methodologies in natural resource management: a review of principles, contexts, experiences and opportunities. *Agricultural systems*, 55(2): 173-193.
- Howden P F (2007). A critical stakeholder analysis process, Practice Change. Department of Primary Industries, Bendigo, Australia.
- Kennon, Nicole, Peter Howden, and Meredith Hartley. "Who really matters?: A stakeholder analysis tool." *Extension Farming Systems Journal* 5.2 (2009): 9-17.
- Marshke M and Nong-Kim H (2003). Adaptive co-management and local participation.
- Nadhika K and Krishnankutty J (2017). Stakeholder analysis for farmer-inclusive value chain development in mango. *Journal of Extension Education* 29(1): 5797–5805.
- ODA (1995). Guidance note on how to do stakeholder analysis of aid projects and programmes. Overseas Development Administration, London, UK.
- Priyadarsinee S, Basu D, Ghosh A and Guha S (2023). Stakeholders' analysis in agricultural insurance service system: A special focus on farmers' knowledge and attitude. *Indian Research Journal of Extension Education* 23(2): 86–90.
- Ramirez, R. (1999). Stakeholder analysis and conflict management.
- Reed M S, Graves A, Dandy N, Posthumus H, Hubacek K, Morris J, Prell C, Quinn C H and Stringer L C (2014). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management* 90: 1933–1949.
- Röling N and Wagemakers M A E (1998). Facilitating sustainable agriculture. Cambridge University Press, Cambridge, UK.
- Sasidhar P V K (2021). Stakeholders Engagement and Participation. In: CSR Programme Planning (Unit-3). Indira Gandhi National Open University, New Delhi. Available via <https://egyankosh.ac.in/handle/123456789/77394>.

ANTIOXIDANT DEFENSE SYSTEMS AS A PROTECTIVE STRATEGY AGAINST DROUGHT-INDUCED OXIDATIVE STRESS

Chaithra B. S¹, Laxmi P. S² and Khushal B. Muradi^{3*}

¹Assistant Professor, Kadiri Baburao College of Agriculture,
C. S. Puram - 523112, Andhra Pradesh, India.

²Department of Postharvest Management, College of Agriculture,
Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Department of Vegetable Science, College of Agriculture,
Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Introduction

Drought is one of the most serious environmental constraints affecting agricultural productivity worldwide. In rainfed regions especially, limited water availability reduces plant growth, impairs physiological processes, and ultimately leads to significant yield losses. While the external symptoms of drought such as wilting, reduced leaf area, and poor grain filling are clearly visible, the internal biochemical disturbances are more damaging. One of the most critical consequences of drought stress is the excessive production of reactive oxygen species (ROS), which cause oxidative stress within plant cells. To survive under such harsh conditions, plants activate complex antioxidant defense systems that protect cellular structures and maintain metabolic balance.

Drought-Induced Oxidative Stress in Plants and its Consequences

Under normal environmental conditions, plants continuously produce small amounts of reactive oxygen species including superoxide radicals, hydrogen peroxide, hydroxyl radicals, and singlet oxygen. These molecules are natural by-products of photosynthesis and respiration and play useful roles in cellular signaling. However, during drought stress, stomatal closure reduces carbon dioxide availability, disrupting photosynthetic processes. Excess light energy cannot be efficiently utilized, leading to leakage of electrons and enhanced ROS production in chloroplasts, mitochondria, and peroxisomes.

When ROS accumulate beyond safe levels, they attack membrane lipids, proteins, nucleic acids, and chlorophyll molecules. This results in lipid peroxidation, enzyme inactivation, membrane leakage, and impaired photosynthesis. The overall effect is reduced growth, poor reproductive development, and lower yield. Therefore, managing oxidative stress is essential for plant survival under drought conditions.

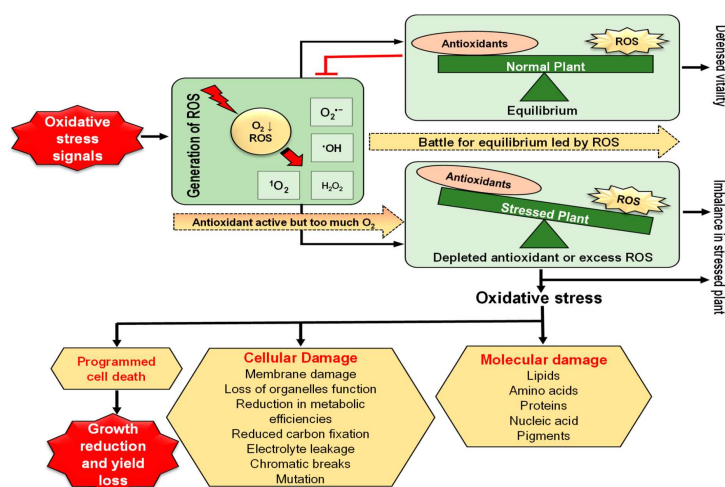


Fig 1: Oxidative stress in plants and its consequences

Components of the Antioxidant Defense System

Plants possess a highly organized antioxidant defense mechanism that includes enzymatic and non-enzymatic components. These systems work together to detoxify reactive oxygen species and maintain redox homeostasis within the cell. The efficiency of this defense system largely determines the degree of drought tolerance in different plant genotypes.

Enzymatic Antioxidants: The First Line of Defense

Enzymatic antioxidants are specialized proteins that catalytically convert harmful reactive oxygen species into less toxic forms. Superoxide dismutase (SOD) is considered the primary defense enzyme because it converts superoxide radicals into hydrogen peroxide. Although hydrogen peroxide is still reactive, it is comparatively less harmful and can be further detoxified.

Catalase (CAT) and ascorbate peroxidase (APX) play major roles in decomposing hydrogen peroxide into water and oxygen. Catalase is particularly effective when hydrogen peroxide concentrations are high, whereas APX functions efficiently even at low concentrations and is closely linked with the ascorbate–glutathione cycle. Glutathione reductase (GR) helps regenerate reduced glutathione, ensuring continuous functioning of antioxidant pathways. Enhanced enzyme activity helps maintain membrane stability and photosynthetic efficiency during water deficit.

The Ascorbate-Glutathione Cycle

One of the most important antioxidant pathways in plants is the ascorbate–glutathione cycle. This cycle involves ascorbic acid, glutathione, and several enzymes that work together to neutralize hydrogen peroxide. Ascorbate acts as an electron donor to reduce hydrogen peroxide to water, and glutathione helps regenerate ascorbate in its active form. This cyclic process ensures sustained protection against oxidative stress, especially in chloroplasts where ROS production is high during drought. Efficient functioning of this cycle is strongly associated with improved stress tolerance and yield stability.

Non-Enzymatic Antioxidants: Supporting Molecules

In addition to enzymes, plants produce various non-enzymatic antioxidants that directly scavenge reactive oxygen species. Ascorbic acid (vitamin C) is a water-soluble antioxidant that protects cellular components and supports enzyme activity. Glutathione, a tripeptide molecule, plays a key role in maintaining cellular redox balance and detoxifying harmful compounds.

Carotenoids are important pigments located in chloroplasts that protect the photosynthetic machinery by quenching singlet oxygen and dissipating excess light energy. Tocopherols (vitamin E) are lipid-soluble antioxidants that protect membrane lipids from peroxidation. Another important compound, proline, accumulates in plants under drought stress. Besides its role in osmotic adjustment, proline also stabilizes proteins and membranes and helps scavenge free radicals. The combined action of these non-enzymatic antioxidants enhances the overall protective capacity of the plant under stress conditions.

Oxidative stress indicators and assessment

To understand the extent of drought-induced oxidative damage, researchers measure specific biochemical markers. Malondialdehyde (MDA) is commonly used to estimate lipid peroxidation levels. Increased MDA content indicates membrane damage. Electrolyte leakage tests are used to assess membrane stability, while hydrogen peroxide estimation provides information about ROS accumulation.

In drought-tolerant plants, lower MDA levels and reduced membrane injury are observed due to efficient antioxidant activity. Therefore, antioxidant enzyme assays are widely used in drought screening programs.

Role of antioxidants in maintaining photosynthesis and yield

Photosynthesis is highly sensitive to drought stress. Oxidative damage to chlorophyll and thylakoid membranes reduces photosynthetic efficiency, affecting biomass production and grain filling. A strong antioxidant defense system protects chloroplast structures, maintains chlorophyll content, and preserves the integrity of photosystem components.

By minimizing oxidative damage, antioxidant systems help maintain better source–sink relationships and efficient assimilate partitioning. Consequently, tolerant genotypes exhibit lower yield reduction and better yield stability under water-limited conditions. Thus, antioxidant capacity is closely linked with crop productivity under drought stress.

Molecular regulation of antioxidant responses

Recent advances in molecular biology have revealed that antioxidant defense mechanisms are regulated at the genetic level. Drought stress triggers the activation of stress-responsive genes and transcription factors that enhance antioxidant enzyme synthesis. Hormonal signals, particularly abscisic acid (ABA), play an important role in regulating these responses.

Genetic engineering approaches have demonstrated that overexpression of antioxidant enzyme genes such as SOD, APX, and CAT can improve drought tolerance in several crops. These findings open new opportunities for developing climate-resilient cultivars through molecular breeding and biotechnology.

Integration with other stress adaptation mechanisms

Antioxidant defense systems do not function independently. They operate in coordination with other adaptive mechanisms such as osmotic adjustment, deeper root growth, stomatal regulation, and hormonal signaling. The integration of physiological, biochemical, and molecular responses ensures better survival under prolonged drought stress.

Conclusion

Drought-induced oxidative stress is a major limiting factor in crop productivity. Excessive accumulation of reactive oxygen species damages vital cellular components, leading to impaired growth and reduced yield. However, plants possess a sophisticated antioxidant defense system comprising enzymatic and non-enzymatic components that detoxify harmful molecules and maintain cellular stability.

Enhanced antioxidant activity protects photosynthetic machinery, preserves membrane integrity, and supports metabolic functions under water deficit conditions. Understanding and strengthening these protective mechanisms through breeding, biotechnology, and agronomic interventions is essential for developing drought-resilient crops. In the face of increasing climate variability, antioxidant defense systems represent a vital natural strategy that ensures plant survival and sustainable agricultural production.

References

Caverzan A, Casassola A and Brammer S P, 2016. Antioxidant responses of wheat plants under stress. *Genetics and Molecular Biology*, 39(1): 1-6.

- Davies W J, Bacon M A, Thompson D S, Sobeih W and Rodriguez L G, 2000. Regulation of leaf and fruit growth in plants growing in drying soil: Exploitation of the plant's chemical signalling system. *Australian Journal of Plant Physiology*, 27(7): 635-643.
- Foyer C H and Noctor G, 2005. Oxidant and antioxidant signalling in plants: A re-evaluation of the concept of oxidative stress in a physiological context. *Plant, Cell and Environment*, 28(8): 1056-1071.
- Gill S S and Tuteja N, 2010. Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiology and Biochemistry*, 48(12): 909-930.

STEM RESERVE MOBILIZATION AS A DROUGHT ADAPTIVE MECHANISM

Chaithra B. S^{1*}, Yogesh V. Wayal² and Banka Vaishnavi³

¹Assistant Professor, Kadiri Baburao College of Agriculture,
C. S. Puram - 523112, Andhra Pradesh, India.

² & ³Department of Genetics and Plant Breeding, College of Agriculture,
Vellayani, Kerala Agricultural University, Thiruvananthapuram - 695522, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Introduction

Climate change has intensified the frequency and severity of drought episodes, posing a serious threat to global food security. In rainfed agriculture, particularly in pulse crops such as chickpea, terminal drought during flowering and grain filling severely reduces yield. Under such stress conditions, photosynthesis declines due to stomatal closure, chlorophyll degradation, and reduced carbon assimilation. As a result, the developing grains suffer from insufficient assimilate supply. To overcome this challenge, plants have evolved adaptive mechanisms. One such important physiological strategy is Stem Reserve Mobilization (SRM), the translocation of stored carbohydrates from vegetative tissues to developing reproductive organs during stress. This mechanism plays a crucial role in maintaining grain filling and stabilizing yield under drought conditions.

During favorable growth conditions, plants accumulate assimilates such as soluble sugars and starch in stems and other vegetative tissues. These stored reserves act as a “buffer” during stress periods. When drought occurs, especially at the reproductive stage, current photosynthesis becomes limited, and plants remobilize stored carbohydrates from stems. These assimilates are translocated to developing pods or grains. Thus, stem tissues function as temporary storage organs that support reproductive development when photosynthetic supply is compromised.

Physiological basis of stem reserve mobilization

The physiological basis of stem reserve mobilization lies in the plant's ability to store and later remobilize non-structural carbohydrates (NSCs), primarily starch and soluble sugars, from vegetative tissues to developing reproductive organs, especially under stress conditions such as drought or terminal heat. During the vegetative phase, when photosynthesis exceeds immediate growth demands, excess assimilates are stored in stems as starch within parenchyma cells. During grain filling or pod development, particularly when current photosynthesis is limited due to moisture deficit, these stored reserves are hydrolyzed into soluble sugars through the action of enzymes such as amylases and sucrose synthase. The mobilized sugars are then translocated via the phloem to sink organs (grains or pods), driven by source-sink gradients and regulated by hormonal signals like abscisic acid (ABA), which increases under drought stress. Efficient mobilization depends on strong sink demand, vascular connectivity, enzyme activity, and the plant's capacity for assimilate partitioning. Thus, stem reserve mobilization serves as a critical adaptive mechanism that supports yield stability by compensating for reduced photosynthetic activity during stress conditions. The effectiveness of SRM depends on the following factors.

Source: Sink relationship

The balance between source and sink plays a central role in determining the direction and efficiency of assimilate flow within a plant. Source tissues, primarily mature leaves, produce carbohydrates through photosynthesis, while sink organs such as developing grains, pods, or seeds require a continuous supply of assimilates for growth and development. Under drought conditions, photosynthetic activity declines due to stomatal closure, reduced chlorophyll content, and impaired metabolic processes, thereby weakening the source capacity. However, sink demand especially during grain filling remains high. In such situations, stored non-structural carbohydrates in the stem act as an alternative source, compensating for the reduced current photosynthesis. Efficient genotypes are characterized by their ability to maintain strong sink strength, sustain phloem loading and translocation, and partition assimilates preferentially toward reproductive organs rather than vegetative tissues. This coordinated regulation of source-sink dynamics enhances yield stability under moisture stress conditions.

Enzymatic regulation

Enzymatic regulation is a critical component of stem reserve mobilization, particularly during reproductive stages or under stress conditions. Enzymes such as amylases catalyze the hydrolysis of stored starch in stem parenchyma cells into simpler sugars like maltose and glucose. These soluble sugars are then further converted into sucrose, the primary form of carbohydrate transported through the phloem. Invertases and sucrose synthase play essential roles in sucrose metabolism by regulating its breakdown and utilization at sink sites. Invertases cleave sucrose into glucose and fructose, enhancing sink strength by maintaining a concentration gradient that favors continued assimilate translocation. The coordinated activity of these enzymes ensures efficient conversion of stored carbohydrates into transportable forms, thereby supporting grain or pod development when current photosynthesis is limited, such as under drought or terminal stress conditions.

Hormonal regulation

Hormonal regulation plays an important role in controlling stem reserve mobilization, particularly under stress conditions. Among plant hormones, abscisic acid (ABA) is especially significant during drought stress. As soil moisture declines, ABA levels increase in plant tissues, triggering adaptive responses such as stomatal closure to reduce water loss and modulation of gene expression related to stress tolerance. Elevated ABA also influences carbohydrate metabolism by activating enzymes involved in starch breakdown and sucrose transport, thereby promoting the remobilization of stored stem reserves toward developing reproductive organs. In addition, ABA helps maintain sink strength and supports survival by prioritizing assimilate allocation to grains or seeds during terminal stress. Thus, hormonal regulation, especially through ABA signaling, coordinates physiological and metabolic adjustments that enhance drought adaptation and yield stability.

Importance in drought adaptation

Stem reserve mobilization contributes to:

- Maintaining grain weight under stress
- Reducing yield loss during terminal drought
- Improving harvest index
- Enhancing yield stability in rainfed environments

Studies in cereals and pulses have shown that genotypes with higher stem reserve mobilization capacity exhibit better drought tolerance. However, efficient remobilization must be accompanied by proper partitioning to reproductive sinks; otherwise, assimilates may remain in vegetative tissues without contributing to yield.

Measurement and Evaluation

Stem reserve mobilization can be assessed by:

- Measuring stem dry weight before and after grain filling
- Calculating remobilization efficiency
- Estimating contribution of pre-anthesis assimilates to grain yield
- Using drought tolerance indices such as Yield Stability Index (YSI), Stress Tolerance Index (STI), and Drought Susceptibility Index (DSI)

Modern analytical tools such as multivariate analysis (PCA) help identify genotypes with superior remobilization traits.

Role in crop improvement

Physiological breeding approaches increasingly incorporate stem reserve mobilization (SRM) as a key selection criterion to improve crop performance under abiotic stress, particularly drought. Rather than selecting genotypes based solely on yield under stress conditions, breeders now emphasize physiological traits that contribute to stress adaptation and yield stability. These include relative water content (RWC), which reflects plant water status; chlorophyll stability index (CSI), indicating the ability to maintain photosynthetic activity; proline accumulation, which functions in osmotic adjustment and cellular protection; and assimilate translocation efficiency, which determines how effectively stored carbohydrates are mobilized from stems to developing reproductive sinks. In pulse crops like chickpea, where terminal moisture stress commonly limits grain filling, enhanced SRM enables the plant to compensate for reduced photosynthesis by supplying stored reserves to pods and seeds. Therefore, integrating SRM with complementary physiological traits provides a more reliable strategy for developing climate-resilient, drought-tolerant varieties suited to rainfed environments.

Conclusion

Stem reserve mobilization is a vital adaptive mechanism that allows crops to withstand drought during critical reproductive stages. By ensuring continued assimilate supply to developing grains when photosynthesis is restricted, this trait contributes significantly to yield stability. Incorporating stem reserve mobilization into crop improvement programs will strengthen efforts toward climate-resilient and sustainable agriculture.

References

- Bidinger, F.R., Musgrave, R.B. and Fischer, R.A. (1977). Contribution of stored pre-anthesis assimilate to grain yield in wheat and barley. *Nature*, 270(3): 431-433.
- Davies, W.J., Bacon, M.A., Thompson, D.S., Sobeih, W. and Rodríguez, L.G. (2000). Regulation of leaf and fruit growth in plants growing in drying soil. *Journal of Experimental Botany*, 51(7): 1617–1626.
- Turner, N.C., Wright, G.C. and Siddique, K.H. (2001). Adaptation of grain legumes to water-limited environments. *Advances in Agronomy*, 71(3):193–231.

CARBON CREDITS IN INDIAN AGRICULTURE: PATHWAYS FOR CLIMATE MITIGATION AND RURAL TRANSFORMATION

Bhagirath Das¹, Poulami Ray^{2*} and Umakanta Dash¹

¹ICAR-Indian Agricultural Research Institute-Assam, Dirpai, Gogamukh, 787035, Assam, India.

²Ranchi Agriculture College, Birsa Agricultural University, Ranchi, 834006, Jharkhand, India.

*Corresponding Email: ray.poulami2@gmail.com

Abstract

Agriculture stands at the intersection of climate vulnerability and mitigation opportunity. In India, where nearly half of the population depends on farming, the sector contributes significantly to greenhouse gas emissions while remaining highly exposed to climate variability. Carbon credits have emerged as a market-based mechanism that incentivizes emission reductions and carbon sequestration through sustainable agricultural practices. By assigning economic value to climate-friendly interventions such as agroforestry, conservation agriculture, alternate wetting and drying (AWD) in rice cultivation, and improved livestock management, carbon markets offer farmers an additional income stream while supporting national climate commitments. India's evolving carbon market architecture, including the Carbon Credit Trading Scheme (CCTS) and the voluntary carbon market framework for agriculture, provides institutional momentum for scaling such initiatives. However, challenges related to smallholder aggregation, measurement and verification complexity, additionality, price volatility, and equity concerns must be addressed to ensure inclusive participation. Digital platforms, robust regulatory oversight, and farmer-centric aggregation models will be critical for enhancing credibility and accessibility. If effectively implemented, carbon credits can transform Indian agriculture into a climate-responsive sector that balances environmental sustainability with rural economic resilience.

Keywords : Carbon credits; Voluntary carbon market; Climate-smart agriculture; Soil carbon sequestration.

Introduction

Anthropogenic climate change has intensified over the past century, with global surface temperatures rising approximately 1.1°C above pre-industrial levels (Intergovernmental Panel on Climate Change [IPCC], 2023). The agriculture, forestry, and other land use (AFOLU) sector contributes nearly 22% of total global greenhouse gas emissions (IPCC, 2023). Methane (CH₄) from enteric fermentation and rice paddies, nitrous oxide (N₂O) from nitrogen fertilizers, and carbon dioxide (CO₂) from land-use change remain principal contributors (Crippa *et al.*, 2021). India faces a dual challenge. Agriculture accounts for a significant share of national emissions while supporting approximately 45–50% of the population's livelihoods (Government of India, 2023). India has committed to reducing the emissions intensity of its GDP by 45% by 2030 relative to 2005 levels and achieving net-zero emissions by 2070 (Government of India, 2022). Meeting these targets requires sectoral transitions that do not undermine food security or farmer incomes.

Carbon credits offer an institutional mechanism to align environmental performance with economic incentives by monetizing emission reductions and carbon sequestration activities.

Conceptual Foundations of Carbon Credits

A carbon credit represents one metric tonne of carbon dioxide equivalent (CO₂e) reduced, avoided, or removed from the atmosphere. Carbon markets are broadly categorized into compliance markets—regulated under emissions trading schemes—and voluntary markets, driven by corporate sustainability commitments (World Bank, 2024).

As of 2024, carbon pricing mechanisms operate across more than 70 jurisdictions worldwide, covering nearly 23% of global emissions (World Bank, 2024). Voluntary carbon markets (VCMs) have grown rapidly, with increasing demand for nature-based solutions including agricultural carbon sequestration (Ecosystem Marketplace, 2022).

For agriculture, carbon credits function as payments for ecosystem services, rewarding measurable ecological outcomes rather than subsidizing inputs.

India's Climate Commitments and Carbon Market Framework

India ratified the Paris Agreement in 2016 and updated its Nationally Determined Contribution (NDC) in 2022, enhancing its emissions intensity reduction target to 45% by 2030 (Government of India, 2022). Additionally, India has pledged to create an additional carbon sink of 2.5–3 billion tonnes of CO₂ equivalent through forest and tree cover expansion.

The Energy Conservation (Amendment) Act, 2022, provides the legal basis for a domestic Carbon Credit Trading Scheme (CCTS). The Bureau of Energy Efficiency (BEE) has been designated as the implementing authority (Bureau of Energy Efficiency, n.d.). Although initial phases focus on energy-intensive sectors, agriculture is recognized as a future offset opportunity.

India has also been an active participant under the Clean Development Mechanism (CDM), accounting for a significant share of registered projects globally (Shrivastava *et al.*, 2024).

Mitigation Pathways in Indian Agriculture

a. Agroforestry

Agroforestry integrates trees within cropping and livestock systems, enhancing biomass carbon storage and soil organic carbon. Empirical estimates suggest that agroforestry systems in India can sequester between 0.25 and 19 Mg C per hectare per year depending on ecological conditions (Dhyan *et al.*, 2016). Such systems also enhance biodiversity, soil fertility, and income diversification.

The National Agroforestry Policy (2014) provides institutional backing for scaling these systems, aligning with India's carbon sink commitments.

b. Conservation Agriculture

Conservation agriculture (CA) emphasizes minimal soil disturbance, residue retention, and crop diversification. Evidence from the Indo-Gangetic Plains indicates that CA enhances soil carbon fractions and improves productivity (Mishra *et al.*, 2024). Reduced tillage also lowers fuel consumption, thereby decreasing CO₂ emissions.

Despite covering nearly 2 million hectares in India, adoption remains regionally concentrated (Gupta *et al.*, 2021). Carbon-linked incentives may accelerate wider diffusion.

c. Alternate Wetting and Drying (AWD) in Rice

Flooded rice systems are significant methane sources. Alternate Wetting and Drying (AWD) irrigation reduces methane emissions by approximately 30–50% compared to continuous flooding (IPCC, 2019; Setyanto *et al.*, 2018). While minor increases in nitrous oxide emissions may occur, the net global warming potential remains substantially lower.

Given India's large rice-growing area, AWD presents a scalable mitigation opportunity with co-benefits for water conservation.

e. Livestock and Methane Mitigation

Livestock contributes nearly 32% of anthropogenic methane emissions globally (United Nations Environment Programme [UNEP], 2023). India, as the world's largest milk producer (Government of India, 2023), must focus on emission intensity reduction rather than herd contraction.

Improved feeding practices, better manure management, and biogas adoption can significantly reduce methane emissions per unit of output. Carbon credit revenues may support adoption costs.

How Carbon Credit works

Carbon credits function as a market-based mitigation instrument that assigns economic value to verified greenhouse gas (GHG) emission reductions or carbon sequestration. In agriculture, mitigation activities—such as agroforestry, conservation agriculture, improved nutrient management, methane reduction in livestock, or alternate wetting and drying in rice systems—generate measurable reductions in carbon dioxide equivalent (CO₂e). These reductions are quantified using standardized methodologies and undergo monitoring, reporting, and verification (MRV) by accredited agencies. Upon validation, one carbon credit is issued for each tonne of CO₂e reduced or removed. These credits are then traded in compliance or voluntary carbon markets, where regulated entities or corporations purchase them to meet emission targets or net-zero commitments. Revenue generated from credit sales is transferred to participating farmers or aggregating institutions, thereby linking climate mitigation outcomes with rural income support. The effectiveness of this mechanism depends on additionality, permanence, transparency, and institutional oversight to ensure environmental integrity and equitable benefit distribution.

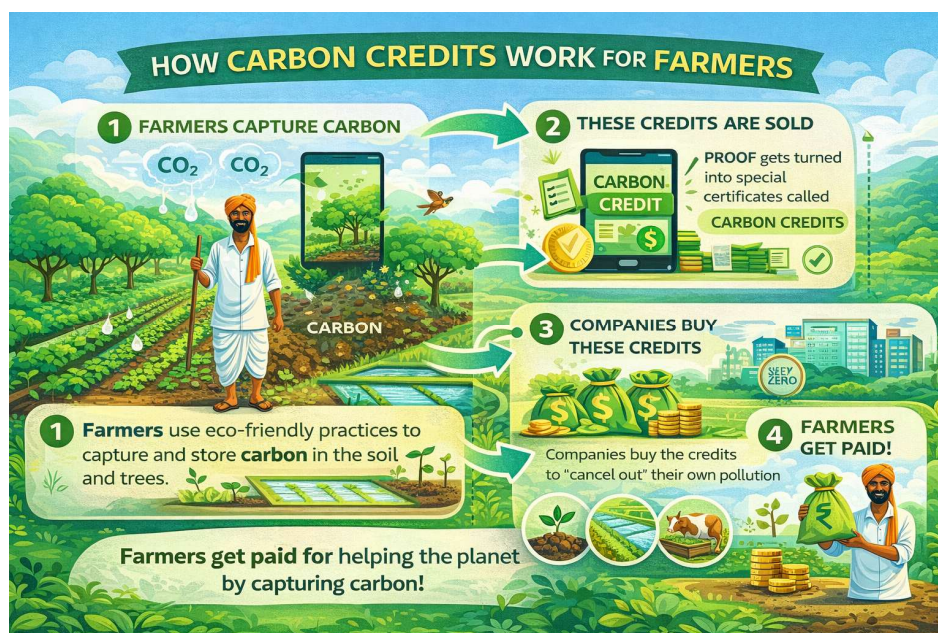


Fig- The carbon credit cycle in agriculture—verified emission reductions from climate-smart practices are converted into tradable credits, purchased by emitters, and translated into income for farmers.

Voluntary Carbon Market and Farmer Participation

India's Ministry of Agriculture and Farmers Welfare released a Framework for Voluntary Carbon Markets in Agriculture in 2024, outlining eligibility criteria, registry mechanisms, and carbon accounting methodologies (Department of Agriculture & Farmers Welfare, 2024).

Global voluntary carbon markets traded approximately 520 million credits in 2021, valued at nearly USD 2 billion (Ecosystem Marketplace, 2022). However, carbon prices remain volatile, and transaction costs are substantial. Smallholder fragmentation—over 85% of farmers operate on less than two hectares (Press Information Bureau, 2023)—necessitates aggregation through Farmer Producer Organizations (FPOs). Concerns regarding additionality, permanence, and verification integrity also influence market credibility (Wongpiyabovorn *et al.*, 2023).

Structural and Equity Considerations

Carbon markets risk excluding marginal farmers due to high upfront costs and complex verification procedures. Farmer awareness and institutional capacity remain limited (Cariappa & Krishna, 2024). Additionally, concerns about over-crediting and greenwashing underscore the need for transparent methodologies and regulatory oversight (United Nations Development Programme, 2022).

Digital platforms such as AgriStack may enhance monitoring, land identification, and benefit transfer mechanisms (Ministry of Agriculture & Farmers Welfare, 2024).

Conclusion

Carbon credits provide Indian agriculture with an opportunity to align mitigation with rural development. By incentivizing agroforestry, conservation agriculture, methane reduction, and water-efficient irrigation, carbon markets can transform farms into climate assets.

However, robust measurement systems, institutional aggregation models, equitable benefit-sharing, and regulatory safeguards are essential for scaling. If integrated thoughtfully within national development strategies, agricultural carbon markets can contribute meaningfully to India's climate commitments while enhancing long-term sustainability.

References

- Bureau of Energy Efficiency. (n.d.). *Carbon market*. <https://beeindia.gov.in>
- Cariappa, A. A., & Krishna, V. V. (2025). Carbon farming in India: are the existing projects inclusive, additional, and permanent?. *Climate Policy*, 25(5), 756–771.
- Crippa, M., Solazzo, E., Guizzardi, D., et al. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, 2(3), 198–209.
- Department of Agriculture & Farmers Welfare. (2024). *Framework for voluntary carbon market in agricultural sector*. Government of India.
- Dhyan, S. K., Ram, A., & Dev, I. (2016). Potential of agroforestry systems in carbon sequestration in India. *Indian Journal of Agricultural Sciences*, 86(9), 1103–1112.
- Ecosystem Marketplace. (2022). *State of the voluntary carbon markets 2022*.
- Government of India. (2022). *India's updated nationally determined contribution*. Ministry of Environment, Forest and Climate Change.
- Government of India. (2023). *Agricultural statistics at a glance 2023*. Ministry of Agriculture & Farmers Welfare.

- Gupta, N., Pradhan, S., Jain, A., & Patel, N. (2021). *Sustainable agriculture in India 2021*. Council on Energy, Environment and Water.
- Intergovernmental Panel on Climate Change. (2019). *2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories*.
- Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report*.
- Press Information Bureau. (2023). Improving condition of small and marginal farmers. Government of India.
- Setyanto, P., et al. (2018). Alternate wetting and drying reduces methane emissions from rice paddies. *Soil Science and Plant Nutrition*, 64(1), 23–30.
- Shrivastava, A., et al. (2024). Clean Development Mechanism: Indian step ahead for sustainable environment. *E3S Web of Conferences*, 491, 02017.
- United Nations Development Programme. (2022). *What are carbon markets and why are they important?*
- United Nations Environment Programme. (2023). *Global methane assessment 2023 update*.
- Wongpiyabovorn, O., Plastina, A., & Crespi, J. M. (2023). Challenges to voluntary agricultural carbon markets. *Applied Economic Perspectives and Policy*, 45(2), 1154–1167.
- World Bank. (2024). *State and trends of carbon pricing 2024*. World Bank.

PLANKTON, POLLUTION, AND PEOPLE: READING A RIVER THROUGH ITS MICROORGANISMS

Vandana Pal^{1*}, Jeetendra Kumar², Vikas Kumar² and Amitabh Chandra Dwivedi¹

¹Nehru Gram Bharati University, Department of Zoology, Prayagraj, Uttar Pradesh- 211505, India

²ICAR- Central Inland Fisheries Research Institute, 24, Panna Lal Road, Prayagraj, Uttar Pradesh-211002, India

*Corresponding Email: vandanapal0635@gmail.com

Abstract

Rivers often signal ecological stress at the microscopic scale before visible symptoms such as fish kills or foul odour appear. This article highlights how phytoplankton communities, such as diatoms, green algae, cyanobacteria, and other microalgae, serve as sensitive bioindicators that integrate the effects of nutrient enrichment, organic pollution, altered flow velocity, and hydraulic regulation. Plankton responds quickly to changes in residence time, light, temperature, and oxygen dynamics, making their composition a time-integrated record of river health that complements conventional physico-chemical monitoring. The dominance of pollution-tolerant genera can reveal organic stress even without sophisticated instrumentation. Barrages and dams transform flowing stretches into lake-like environments, promoting eutrophication and cyanobacterial proliferation with cascading consequence of zooplankton, fish diversity, fisheries livelihoods. By “reading” rivers through their microorganisms, managers, students, and the public can detect early ecological degradation and make informed decisions for river conservation.

Keywords: Phytoplankton, Bioindicators, Palmer Pollution Index, Eutrophication, Barrages, River health, Fisheries ecology

Introduction

Suspended in every drop of river water is a living community of phytoplankton— diatoms, green algae, cyanobacteria, and desmids — responding continuously to changes in flow, nutrients, light, and pollution. These microorganisms act as biological sensors integrating hydrological and chemical changes over time (Kumar et 2022 and Pal et al 2024). To the unaided eye, river water may appear clear or uniformly green, but through a microscope, it provides an ecological diary that continues to be written.

Plankton Tell The Truth About Pollution

Phytoplankton respond quickly to nutrient enrichment, reduce flow velocity, organic pollution and altered oxygen regimes. Plankton communities integrate environmental conditions over longer time scales (days and weeks) than many physico-chemical parameters (hours). Genera such as *Euglena*, *Oscillatoria*, *Chlorella*, *Scenedesmus*, and *Nitzschia* are commonly associated with organically polluted waters, forming the basis of algal bioindication (Palmer, 1969).

The Palmer Pollution Index: A Microscope-Based Report Card

Palmer (1969) proposed a pollution index based on algal genera tolerant to organic pollution. Dominance of these taxa in a sample provides reliable evidence of organic stress even without

detailed chemical analysis. This approach remains one of the simplest biological tools for assessing river pollution.

When Rivers Start Behaving Like Lakes

Hydraulic structures, such as barrages, reduce current velocity and increase water residence time, creating a lentic-like environment within lotic systems. These changes promote phytoplankton growth, increase chlorophyll-a and often favour the proliferation of cyanobacteria (Kumar et al 2026). The plankton community is the first to reflect this transformation of the ecological character from flowing to stagnant.

From Microorganisms To Fish Decline

Dense algal growth and cyanobacterial dominance contribute to oxygen depletion, particularly at night, and reduce food quality for zooplankton. These changes ultimately affect fish diversity, replacing rheophilic and sensitive species with tolerant forms, thereby reducing fishery quality (Allan & Castillo, 2007).

People Who Read Rivers Without Microscopes

Traditional fisher communities often report “green water”, foul smell during low flow, and declining fish catches upstream of barrages. These observations closely match scientific interpretations derived from plankton analysis, demonstrating the convergence of ecological science and traditional knowledge.

Simple Science That Citizens Can Do

Sedimentation methods using Lugol’s solution for preservation of phytoplankton samples are standard in limnology and suitable for educational and citizen-science monitoring (Wetzel, 2001). Even basic microscopes allow identification of major groups linked to river health.

Plankton Monitoring: Why River Management Must Follow

Although physico-chemical data offer instantaneous views of water condition, plankton communities reflect more integrated ecological responses to environmental stressors over time, often transmitting signals of impairment sooner than fish or macro invertebrate surveys.

Conclusion

Phytoplankton act as historians of river health, recording the combined effects of pollution and hydrological alteration. Reading these microorganisms enables early detection of ecological stress and supports informed river conservation.

References

- Allan, J.D.; & Castillo, M.M. (2007). *Stream Ecology: Structure and Function of Running Waters*. Springer.
- Palmer, C.M. (1969). A composite rating of algae tolerating organic pollution. *Journal of Phycology*, 5, 78–82.
- Wetzel, R.G. (2001). *Limnology: Lake and River Ecosystems* (3rd ed.). Academic Press.
- Kumar, J.; Das, B. K.; Langde, A. T., Alam, A., Saha, A., Bhusan, S., Kumar, V., Bhatt, R. H. Borah, S. & Sharma, N. K. (2026). Advanced Machine Learning and Statistical Modelling for the Assessment of Water Quality and Trophic Dynamics in the Upper and Middle Ganga River Basin. *Water, Air, & Soil Pollution*, 237(5), 275.
- Pal, V., Kumar, J; Dwivedi, A. C., & Kumar, D. (2024). Diversity of phytoplankton from the Ganga River at Rasulabad ghat and Sangam, Prayagraj, Uttar Pradesh. *J Inland Fish Soc India*, 56, 145-154.

GENOME EDITING IN AGRICULTURE: A PRECISION TOOL FOR FUTURE FOOD SECURITY

Chaithra B. S^{1*}, Vibin Sankar² and Athira S³

¹Assistant Professor, Kadiri Baburao College of Agriculture,
C. S. Puram – 523112, Andhra Pradesh, India.

^{2&3}Department of Floriculture and Landscaping, College of Agriculture,
Vellanikkara, Kerala Agricultural University, Thrissur – 680656, Kerala, India.

³Athira S., Ph.D. Scholar, Department of Floriculture and Landscaping,
College of Agriculture, Vellanikkara, Kerala Agricultural University,
Thrissur – 680656, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Introduction

With the global population expected to cross 9 billion by 2050, ensuring food and nutritional security has become a major challenge. Climate change, declining arable land, water scarcity, and emerging pests and diseases further threaten agricultural productivity. Conventional breeding has significantly improved crop yield over decades; however, it is time-consuming and limited by the available genetic variation within species. Genome editing has emerged as a revolutionary tool that enables precise modification of DNA sequences in plants. Unlike traditional genetic modification, genome editing allows targeted changes without introducing foreign genes, making it a powerful and promising approach for sustainable agriculture.

It is a modern biotechnology tool that enables scientists to precisely modify specific genes in an organism's genome. It works like a "molecular scissor" that can cut DNA at a specific location, allowing insertion, deletion, or alteration of genetic material.

The most widely used genome editing tools include:

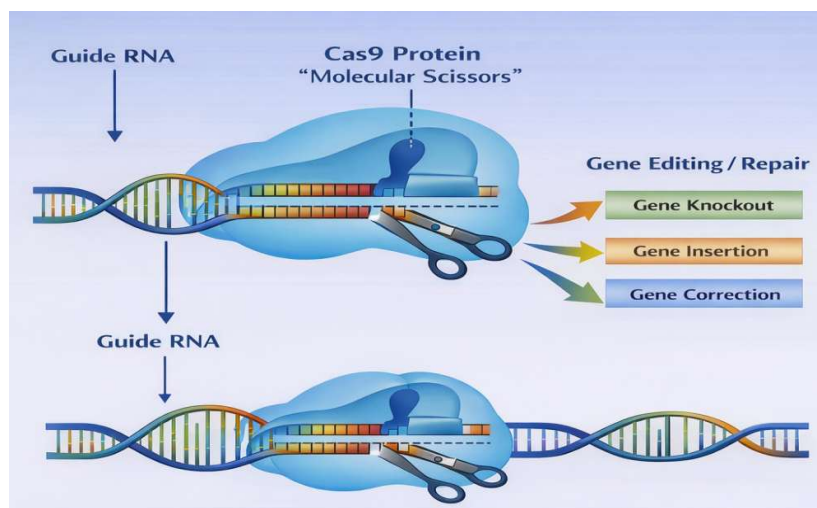
- CRISPR-Cas9
- TALENs (Transcription Activator-Like Effector Nucleases)
- Zinc Finger Nucleases (ZFNs)

Among these, CRISPR-Cas9 is the most popular due to its simplicity, cost-effectiveness, and high precision.

How CRISPR-Cas9 Works

CRISPR-Cas9 technology, often described as a "molecular scissor." This system works by using a small guide RNA that identifies a specific DNA sequence within the plant genome. The Cas9 protein then cuts the DNA at that exact location. Once cut, the plant's natural repair mechanism takes over. During repair, specific genes can be turned off (gene knockout), slightly modified, or fine-tuned to enhance desirable traits. Unlike transgenic technology, genome editing does not necessarily introduce foreign DNA; instead, it modifies the plant's existing genetic material. This makes the technology more precise and, in many cases, closer to conventional mutation breeding but with far greater accuracy.

To understand this mechanism visually, the diagram below illustrates how CRISPR-Cas9 identifies a target DNA sequence, makes a precise cut, and allows repair that leads to trait improvement.



Applications of genome editing in agriculture

1. Developing drought and stress tolerant crops

Genome editing enables modification of genes responsible for drought tolerance, heat resistance, and salinity tolerance. For example, genes regulating stomatal conductance, osmotic adjustment, and stress signaling pathways can be altered to improve resilience under climate stress.

2. Disease and pest resistance

By editing susceptibility genes, crops can be made resistant to major pathogens and insect pests. This reduces dependency on chemical pesticides and promotes eco-friendly agriculture.

3. Improving yield and plant architecture

Genes controlling plant height, branching, flowering time, and grain size can be modified to develop high-yielding varieties with ideal plant architecture.

4. Enhancing nutritional quality

Genome editing can improve nutritional traits such as increased protein content, enhanced micronutrients (iron, zinc) and reduced anti-nutritional factors. This supports biofortification and nutritional security.

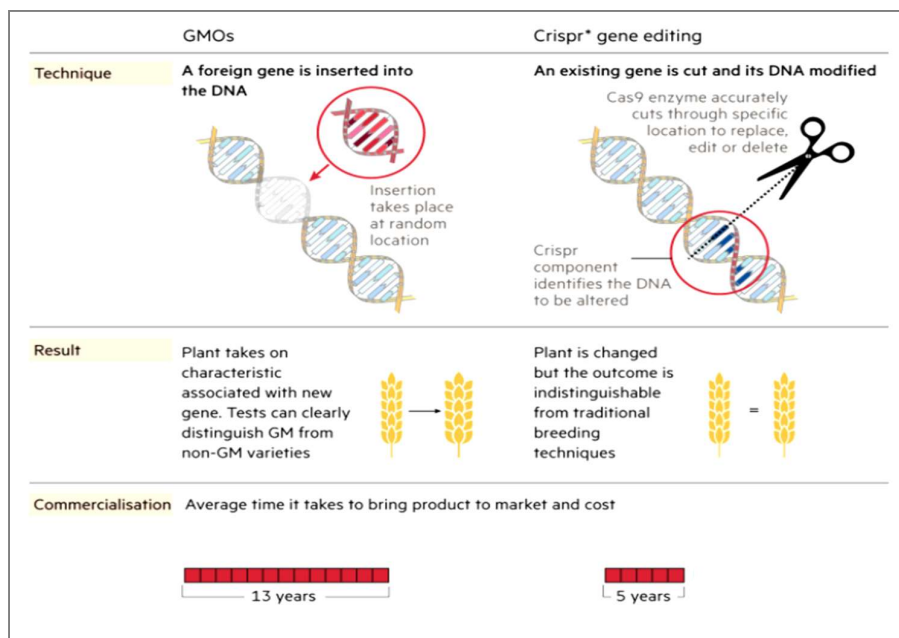
5. Shelf life improvement

Editing genes involved in fruit ripening can extend shelf life, reduce post-harvest losses, and improve market value.

Genome editing vs Genetic modification (GM Crops)

Unlike traditional transgenic crops, which involve the introduction of foreign DNA from unrelated organisms, genome editing technologies such as CRISPR-Cas9 enable precise modifications within the plant's own genetic material. These techniques can create targeted mutations, deletions, or small insertions without permanently incorporating external genes into the genome. As a result, many genome-edited crops are genetically similar to those developed through conventional breeding or natural mutations, but achieved in a faster and more precise manner. Because no foreign DNA is necessarily present in the final product, genome-edited crops are often viewed as less controversial and, in some countries, are subject to simpler regulatory frameworks compared to transgenic genetically modified organisms (GMOs). This distinction may also contribute to

greater public acceptance, as the modifications mimic natural genetic variation rather than introducing genes from other species.



Advantages of genome editing

The rapid growth of the global population, coupled with climate change, shrinking arable land, and increasing environmental stresses, poses a serious challenge to food security. Conventional breeding methods have played a vital role in improving crop yields over the past decades; however, their pace may not be sufficient to meet the projected rise in food demand in the coming years. The gap between food production and consumption continues to widen in many parts of the world, contributing to hunger and nutritional insecurity. Genome editing offers a promising solution to this challenge by enabling precise, efficient, and faster crop improvement. Through targeted modification of genes associated with yield, stress tolerance, disease resistance, and nutritional quality, genome editing can significantly enhance agricultural productivity. Unlike traditional approaches, it allows scientists to make specific improvements without lengthy breeding cycles.

By integrating genome editing with advanced breeding, physiological research, and sustainable agronomic practices, it is possible to develop high-yielding, climate-resilient, and resource-efficient crop varieties. Such innovations can help stabilize food production, reduce dependency on chemical inputs, and support the global goal of achieving zero hunger.

Challenges and Ethical Considerations

- Despite its advantages, genome editing faces certain challenges:
- Regulatory uncertainties in different countries
- Public perception and ethical concerns
- Off-target effects (though rare with advanced tools)
- Need for strong biosafety guidelines

Conclusion

Genome editing represents a transformative tool for modern agriculture. When supported by appropriate policies, regulatory frameworks, and public awareness, it has the potential to strengthen food security and promote sustainable agricultural development for future generations.

References

- Ahmar S, Gill R A, Jung K H, Faheem A, Qasim M U, Mubeen M and Zhou W, 2020, Conventional and molecular techniques from simple breeding to speed breeding in crop plants: Recent advances and future outlook. *International journal of molecular sciences*. 21(7): 25-49.
- Wang F, Wang C, Liu P, Lei C, Hao W, Gao Y, Liu Y G and Zhao K, 2016, Enhanced rice blast resistance by CRISPR/Cas9-targeted mutagenesis of the ERF transcription factor gene OsERF922. *PloS one*. 11(4): 15-34.
- Zeng Y, Wen J, Zhao W, Wang Q and Huang W, 2020, Rational improvement of rice yield and cold tolerance by editing the three genes OsPIN5b, GS3, and OsMYB30 with the CRISPR–Cas9 system. *Frontiers in plant science*. 13(10): 16-29.
- Zhang A, Liu Y, Wang F, Li T, Chen Z, Kong D, Bi J, Zhang F, Luo X, Wang J and Tang J, 2019, Enhanced rice salinity tolerance via CRISPR/Cas9-targeted mutagenesis of the OsRR22 gene. *Molecular breeding*. 19(39): 1-10.

NUMTS AND NUPTS: SECRET AGENT RESHAPES THE PLANT GENOME EVOLUTION

K. Bhrundha^{1*}, Banka Vaishnavi² and Vibin Sankar³

¹Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur-680656, Kerala, India.

²Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram-695522, Kerala, India

³Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur-680656, Kerala, India.

*Corresponding Email: bhrundhakrishnan98@gmail.com

Introduction

Three genetic compartments coexist in plant cells: The nucleus and two cytoplasmic organelles, namely plastid and mitochondria. The nucleus harbours the majority of the genetic material, whereas chloroplasts and mitochondria contain relatively small but essential genomes. DNA transfer that occurs among these three genetic compartments and can be classified into five types:

- I. Mitochondrion-to-nucleus
- II. Plastid-to-nucleus
- III. Plastid-to-mitochondrion
- IV. Nucleus-to-mitochondrion
- V. Mitochondrion-to-plastid

Among these, the integration of mitochondrial and chloroplast DNA into the nuclear genome occurs at a high frequency, particularly in flowering plants, whereas the other types of transfer are relatively rare. The Transfer of DNA from the mitochondria or plastids to the nucleus has played a significant role in eukaryotic genomes. Such intracellular gene transfer has contributed to genome expansion, gene regulation, and the evolution of novel gene functions in plants.

Nuclear Integrants of Mitochondrial DNA (NUMT) & Nuclear Integrants of Plastid DNA (NUPT)

DNA transfer from organelles contributes significantly to gene and genome evolution and represents a major source of genetic diversity. The transfer of genetic material from mitochondria to the nucleus, resulting in the integration and recombination of mitochondrial DNA (mtDNA) into the nuclear genome, gives rise to nuclear integrants of mitochondrial DNA (NUMTs). Similarly, the transfer of genetic material from plastids to the nucleus, leading to the integration of plastid DNA (ptDNA) into the nuclear genome, results in nuclear integrants of plastid DNA (NUPTs). Organellar DNA transfer into the nuclear genome is not restricted to the early establishment of endosymbiosis but continues to occur actively during evolution.

Characterization of Organellar DNA-Derived Sequences

Nuclear integrants of organellar DNA were first reported in a study in which a mitochondrial ATPase subunit gene was identified in both the nuclear and mitochondrial genomes of *Neurospora crassa*. NUMTs and NUPTs provide raw material for genome complexity and contribute substantially to chromosome evolution. The availability of a extensive plant organellar

and nuclear genome sequence data has enabled large-scale investigations into the prevalence and characteristics of NUMTs and NUPTs in plants. To date, NUPTs have been identified in 199 plant genomes, while NUMTs have been reported in 91 plant genomes. NUMTs are widespread across animals, plants, fungi, and protists, whereas NUPTs are specific to plants.

Number and Size Distribution of NUMT & NUPT

The number and size distribution of NUMTs and NUPTs vary markedly among different species. The average size of NUPTs ranges from 57bp (*Chlorella variabilis*) to 3,382bp (*Porphyra umbilicalis*), while the total NUPT length ranges from 1,038bp (*Phaeodactylum tricomutum*) to 9.83Mb (*Triticum urartu*). NUPTs are abundant in most flowering plants, with the highest number found in *Triticum urartu*. In *Gossypium hirsutum*, the longest NUPT identified was a 135-kb integrant. Similarly, the cumulative length of NUMTs in plant genomes varies from 327bp (*Cyanidioschyzon merolae*) to 11.42 mb (*Capsicum annuum*). In *Arabidopsis thaliana*, the longest NUMT was a 620-kb integrant. Zhang et al. (2021) reported a positive correlation between nuclear genome size and both the cumulative length and the total number of NUPTs and NUMTs. Nevertheless, NUMTs and NUPTs may not yet be completely characterized in many plant genomes.

Organization and Distribution Patterns

NUPTs and NUMTs are organized into three major patterns:

- Continuous fragments of nuclear DNA that are collinear with mitochondrial or chloroplast DNA
- Rearranged NUPTs/NUMTs originating from different regions of a single organelle genome, often with non-uniform orientation
- Mosaic structures containing both NUPTs and NUMTs. The presence of such mosaics indicates that DNA fragments from different organelles may form long continuous DNA molecules, sometimes containing multiple copies of the same sequence linked in series prior to nuclear insertion.

NUPTs and NUMTs are preferentially distributed in:

- Centromeric regions
- Pericentromeric regions, which are characterized by low gene density and high heterochromatin content. These regions are generally transcriptionally less active and may provide a stable genomic environment for the maintenance of alien, organelle-derived DNA.

The existence of diverse organizational patterns of NUPTs and NUMTs in plant genomes suggests that their origins and evolutionary trajectories may differ.

Modification Pattern of NUPTs/NUMTs

NUPTs and NUMTs can cause host genome instability, genomic region reshuffling, genome size expansion and heterochromatinization. Analyses of NUPT mutation patterns in several plant species have revealed a bias toward cytosine (C) → thymine (T) transitions on one DNA strand and guanine (G) → adenine (A) substitutions on the complementary strand. These mutations are primarily attributed to the hypermethylation of cytosine residues followed by deamination. DNA methylation therefore plays an essential role in regulating integrated organellar DNA, mainly through the transcriptional suppression of organelle-derived sequences. Methylation-modified

NUPTs and NUMTs may help maintain the stability of plant nuclear genomes by mitigating the potential disruptive effects of organellar DNA insertions and may play an important role in maintaining functional symbiosis between nuclear and organelle genomes.

Genetic Consequence and Fate of NUPTs/NUMTs

Once organellar DNA is integrated into the nuclear genome, the inserted sequences enter a new genomic environment and undergo gradual amelioration to adapt to the host genome. Most NUPTs and NUMTs begin to decay because they are not under strong selective pressure. Analyses of the organization, dynamics, and interspecific variation of NUPTs and NUMTs in plant genomes suggests five major post-integration fates of organellar DNA: (a) Elimination, (b) Mutation, (c) Fragmentation, (d) Rearrangement, and (e) Proliferation.

Elimination

Given the high frequency of organellar DNA transfer to the nuclear genome and the relatively low proportion of NUPTs and NUMTs in plant genomes, it is expected that a substantial number of transferred organellar DNA fragments are eliminated to prevent excessive genomic expansion. The loss of organellar DNA occurs during both meiosis and mitosis and may contribute to interspecific genomic variations. Thus, the nuclear genome maintains a dynamic balance between continual integration and rapid deletion of organellar DNA. Rapid elimination serves as a counterbalancing mechanism of the frequent integration of plastid-derived DNA. Replication slippage has been proposed as one mechanism underlying these deletion events, as short direct repeats are frequently observed in the flanking regions of deleted sequences.

Mutation

Mutation represents a predominant post-integration fate of organelle DNA. The mutation rate of organellar DNA in plant species is considerably lower than that of the nuclear genome. However, mutations accumulate in NUPTs and NUMTs over time until they are no longer recognizable as organelle-derived sequences due to extensive divergence their ancestral organellar DNA. Hypermethylation of 5-methylcytosine, resulting in C → T transitions on one DNA strand and G → A transitions on the complementary strand, is considered a major mechanism underlying the mutational decay of newly integrated organellar sequences. Organellar DNA evolves at a rate of approximately one or fewer mutations per kb per million years, whereas the nuclear genome exhibits a substantially higher mutation rate of about seven mutations per kb per million years.

Fragmentation

Sequence similarity between NUPTs and NUMTs and their original chloroplast or mitochondrial DNA decreases over evolutionary time which shows a positive correlation with NUPTs and NUMTs size. Initial insertions are typically large and subsequently break into smaller fragments. The insertion of transposable elements (TEs) and other non-organelle-derived DNA sequences into NUPTs and NUMTs plays a significant role in this fragmentation process. Consequently, some NUPT and NUMT clusters are formed through repeated organellar DNA insertions followed by fragmentation and the incorporation of non-organellar DNA.

Rearrangement

Many NUPTs and NUMTs are organized as tandem arrays composed of sequences originating from different regions of plastid and/or mitochondrion genomes. The transfer of organellar sequences may involve rearrangements occurring before and/or after their insertion into the nuclear genome, often mediated by homologous recombination between repetitive sequences.

Proliferation

Integrated organellar DNA sequences can undergo amplification, leading to an increased copy number within nuclear genome. These amplified fragments may be arranged in tandem arrays or distributed at separate locations throughout the host genome. NUPTs and NUMTs themselves are not capable of autonomous duplication; instead, their proliferation in the nuclear genome is likely facilitated through co-amplification with neighboring retrotransposons. Retrotransposons are evolutionarily widespread genetic elements that replicate via reverse transcription of an RNA intermediate and readily increase their copy number through a “copy-and-paste” mechanism, integrating newly synthesized DNA into novel sites within the host genome.

Effects of NUMT/NUPT on the nuclear genome structure and evolution

- Organelle DNA transfer is a continuously ongoing process, and the insertion of organelle-derived sequences constitutes a dynamic component of plant nuclear genomes.
- NUMT/NUPT sequences that fuse with non-organelle-derived nuclear DNA can be transcribed, suggesting that they may remodel genes and their products by contributing novel exons
- NUMTs/NUPTs may also associated with gene regulatory elements potentially influencing gene expression.
- Some organellar DNA sequences are integrated within introns as well as upstream (5') and downstream (3') regions of nuclear genes; where they may alter gene regulation.
- In dioecious plants, NUPTs and NUMTs accumulate more extensively on sex chromosomes than in autosomes, potentially facilitating structural differentiation, recombination suppression, and Y-chromosome degeneration.
- Such accumulation may further Promote recombination suppression between sex chromosomes

Mechanisms of organellar DNA integration

Organellar DNA sequences can be transferred to the nucleus through several pathways:

- Degradation of abnormal mitochondria
- Lysis of the mitochondrial compartment
- Encapsulation of mitochondrial DNA within the nucleus
- Direct physical association between mitochondria and the nucleus, membrane fusion events
- Entry of mitochondrial DNA into the nucleus followed by integration into nuclear chromosomes

Among these mechanisms the degradation of abnormal mitochondria is the most widely supported pathway. Following entry into the nucleus, mitochondrial DNA (mtDNA) can be integrated into nuclear chromosomes during the repair of double-strand breaks through a mechanism known as non-homologous end-joining (NHEJ). This insertion process involves two DSB repair events, which may occur with or without the involvement of short regions of microhomology. In microhomology-mediated NHEJ, short complementary base-pair sequences between the NUMT and the chromosome ends facilitate integration, analogous to the sticky ends generated by restriction enzymes.

Conclusion

NUMTs and NUPTs play functional roles in gene and genome evolution. Experimental analyses of organelle-to-nucleus DNA transfer have so far been conducted only in tobacco and yeast. Similar to TEs, organellar DNA integrated into the nuclear genome is considered alien genetic material.

The presence of such sequences may lead to nuclear genome instability, thereby triggering host genome defense mechanisms. However, the precise mechanisms underlying organellar DNA transfer, the extent and diversity of its effects on gene regulation, and the genome instability and defense responses induced by organellar DNA integration remain poorly understood.

References

Zhang, G.J., Dong, R., Lan, L.N., Li, S.F., Gao, W.J. and Niu, H.X. (2020). Nuclear integrants of organellar DNA contribute to genome structure and evolution in plants. *International journal of molecular sciences*, 21(3): 707.

MULTI-TRAIT CROPS VIA GENE STACKING: A STEP TOWARDS SUSTAINABLE AGRICULTURE

K. Bhrundha^{1*}, Kishanth Kanna V¹ and R. Jeevanraj¹

¹Department of Plant Physiology, College of Agriculture,
Vellanikkara, Kerala Agricultural University, Thrissur-680656, Kerala, India

*Corresponding Email: bhrundhakrishnan98@gmail.com

Introduction

Genetic variability is the foremost important requirement for any crop improvement programme. Desired variability has to be created in two ways, i.e. either goes for inter-specific or inter-generic cross by conventional hybridization method also known as hybrid stacking or producing the transgenic plant with the help of genetic engineering which is known to be molecular stacking by taking the considerations of newer breeding methods use genetic variability as source material, very specific changes in existing plant genes, ability to transfer defined pieces of plant's genetic material, greater chances of survival and flourishing, reduces the incidence of unfavorable inherited traits. The sources of variability such as local germplasm, obsolete variety, wild species/ wild variety and inter/ intergeneric species.

Gene stacking

Gene stacking is a type of gene cloning that refers to the process of combining two or more genes of interest into a single plant. The emerging combined traits from this process are called stacked traits. Overcoming the numerous of problems in the field such as insect pests, diseases, weeds, and environmental stresses so that farmers can increase their productivity.

Need for gene stacking

- Enhancing Crop Resistance (Multiple disease resistance, Insect resistance, Herbicide tolerance).
- Improving Crop Quality (Nutritional enhancement, Post-harvest traits).
- Addressing Climate Change and Environmental Stress (Drought, salinity, and heat tolerance; Carbon and nitrogen efficiency).

Examples of Gene stacking

- The first stack that gained regulatory approval was a dual hybrid stack by combining the glyphosate resistance gene epsps with the insect resistance gene Cry1Ab gene in 1995.
- In Golden rice - 3 carotenoid biosynthesis genes which include one bacterial gene and two daffodil genes have been successfully engineered into 'Golden rice' to allow it to produce provitamin A.
- In GR1- 2 genes Phytoene synthase gene from daffodil and carotene desaturase from Soil bacterium are engineered. And in GR2 phytoene synthase gene from Maize and the carotene gene from GR1 are engineered which produce 23 times more carotenoid than the GR1

Global status of approved GM crops with stacked genes:**Table 1.** List of commercialized stacks produced in different plant species to improve the traits

S. no	Trait	Crop	Genes	Method	Company
1	Herbicide tolerance + fertility restoration	Canola	<i>Bar</i> ; <i>barnase</i> or <i>barstar</i> ; <i>neo</i>	<i>Agrobacterium</i> linked gene, 1 t-DNA	Aventis crop science
2	Herbicide tolerance+ fertility restoration	Chicory	<i>bar</i> ; <i>barnase</i> ; <i>neo</i>	<i>Agrobacterium</i> /linked gene, 1 T- DNA	Bejo zaden BV
3	Multiple virus resistance	Squash	Neo*; CP-CMV; CP-ZYMV;;CP-WMV2	<i>Agrobacterium</i> /linked gene, 1 T-DNA	Asgrow (USA);seminis vegetable Inc.(canada)
4	Multiple virus resistance	Squash	Neo*; CP-ZYMV;;CP-WMV2	<i>Agrobacterium</i> /linked gene, 1 T- DNA	Upjohn (USA);seminis vegetable Inc.(canada)
5	Modified colour + herbicide tolerant†	Carnation	<i>surB</i> †; <i>dfr</i> ; <i>hfl</i>	<i>Agrobacterium</i> /linked gene, 1 T- DNA	Florigene Pty Ltd.
6	Modified colour + herbicide tolerant†	Carnation	<i>surB</i> †; <i>dfr</i> ; <i>bp40</i>	<i>Agrobacterium</i> /linked gene, 1 T- DNA	Florigene Pty Ltd.
7	Insect resistance + herbicide tolerance	Cotton	<i>Bxn</i> ; <i>cry1Ac</i> ; <i>neo</i>	<i>Agrobacterium</i> /linked gene, 1 T- DNA	Calgene Inc.
8	Insect + viruse resistant	Potato	<i>cer3A</i> ; <i>PLRVrep</i> ; <i>ne o</i> or <i>EPSPS</i>	<i>Agrobacterium</i> /linked gene, 1 T- DNA	Monsanto
9	Insect resistance + herbicide tolerance	Maize	<i>Bar</i> ; <i>cry1Ac</i> ; <i>pin</i> / <i>†</i>	Biolistics/3 plasmid co-transformation	Dekalb genetics corporation
10	Insect resistance + herbicide tolerance	Maize	<i>cry1Ab</i> ; <i>EPSPS</i> ; <i>g ox</i>	Biolistics/3 Plasmid co-transformation	Monsanto
11	Insect resistance + herbicide tolerance + Nutritional quality	Rice	<i>Cry1Ab</i> , <i>Cry1Ac</i> , <i>bar</i> , <i>crt1</i> , <i>psy1</i>	<i>Agrobacterium</i> /linked gene, 1 T- DNA	Syngenta

Strategy for gene stacking:

The strategy for gene stackings is to improve the tolerant genotypes via conventional marker-assisted selection one of the easiest and quickest ways to stack up genes into a plant is to make crosses between parental plants that have different biotech traits, an approach also known as hybrid stacking. It is also known as molecular stacking that involves the introduction of gene constructs simultaneously or sequentially into the target plant by standard delivery systems such as *agrobacterium*-mediated and biolistic methods. In some stacks, molecular stacking has been done with conventional breeding approaches to put together the desirable traits.

1. Hybrid stacking - Sexual hybridization

Sexual hybridization is a conventional breeding approach which is also known as sequential introduction methods. Plants containing several transgenes can be produced by crossing parents with different transgenes until all the required genes are present in the progeny. Development of

a multi-stack hybrid occurs via iterative hybridization. It can be achieved through recurrent selection, pedigree crossing, and Backcross breeding. (eg., Maize: Agrisure™ Viptera™ 3220 (Bt11 x MIR162 x TC1507 x GA21)).

Limitations

- The introduced transgenes will be integrated randomly in different genomic positions, which can result in a lack of coordination between the expression levels of different transgenes.
- Each unlinked transgene introduced would double the size of the breeding population
- Obtaining homozygous plants for all transgenes difficult
- Increased breeding costs
- Labour-intensive and time consuming

2. Molecular stacking - Re-transformation

Re-transformation is the process that involves the transformation of an already transgenic plant to insert a new characteristic. Re-transformation which is also known as sequential introduction methods had multi-trait or combined trait events with separate inserts. The transgenic inserts are integrated with multiple loci. Multiple transgenes either harboured within different T-DNA in a single Agrobacterium strain or harboured separately within different strains. The advantage of re-transformation is that the stacking of transgenes is independent of sexual crossing. (eg., Cotton: Bollgard™ II (MON15985)).

Limitations

- Re-transformation can induce transgene silencing
- One of the difficulties of this process involves the marker genes. The availability of relatively few marker genes in addition to the presence of multiple marker genes or multiple copies of the same marker gene in the transgenic plant may not be of interest and end up hampering the regulatory process of these plants
- With each new transformation, the use of different marker genes facilitates the selection of the transformed plants.

3. Co-transformation

Introduction of several genes in the same process of genetic transformation which comes under the Simultaneous introduction method. This has been a very promising approach and exhibits obvious advantages of a one-step procedure for the introduction of multiple target genes simultaneously into one plant. The best examples are the removal of selectable marker gene cassettes to obtain marker-free GE plants.

- One of the most efficient strategies for the introduction of multi genes it can be done either by **single plasmid co-transformation** of the linked transgene, performed by introducing a single genetic construction with all genes, each with its own promoter and terminator, in the same plasmid. All genes tend to be integrated together in the same plant genome site(s)
- **Multiple plasmid co-transformation** of unlinked transgenes: In this process, several constructions are made, each with one or a few genes, and each construct is inserted into a separate plasmid. The plasmids can be used in genetic transformation by bombardment or A. tumefaciens delivery system

Limitations

- Difficulty in assembling complex plasmids with multiple gene cassettes (Francois *et al.*, 2002). The size of the T-DNA to be introduced in the plant and the engineering necessary to the gene building with many genes requiring the use of convenient restriction sites, promoters and terminators.
- High copy number
- Multiple tandem repeat or inverted repeat – the same promoter is used repeatedly for multiple gene expression, the alteration in the gene expression and gene silencing become a problem. This can be overcome by using the vectors of transformation with linked genes that are regulated by a single promoter. This type of gene construction allows the simultaneous expression of the genes of interest and avoids the repetitive use of the promoter such a complex integration pattern leads to transgene silencing
- Transgene derived from different sources typically integrate at different locations in the plant genome, which may lead to various expression patterns and possible segregation of the transgene in the offspring.

This limitation can be overcome by *GAENTRY* which is an excellent platform for genetic engineering of plants and manipulating large constructs (10s of Kbs) by stably stacking multiple genes in the T-DNA of *Agrobacterium* plasmids.

GAENTRY (Gene Assembly in Agrobacterium by Nucleic acid Transfer using Recombinase technology).

GAENTRY provides a simple, precise and versatile tool for transgene stacking in rice and potentially other cereal grain crops. The assembly of cargo sequences within the *GAENTRY*'s T-DNA requires three types of components such as

1. *Agrobacterium* strain
2. Two cloning plasmids (B and P Donors) for the insertion of sequence(s) of interest
3. Two accessory plasmids (B and P Helpers) that carry an operon expressing two of the recombinases

Conclusion

- A number of conventional and more novel techniques already exist for the stacking of genes, no single method is ideal as yet.
- Co-transformation is an effective method for gene stacking as compared
- Chimeric transgenes with fused sequences of several 'Effect genes' under the control of single promoter offer very significant advantages
- *GAENTRY* system provides a simple and reliable method to generate large T-DNA constructs that can be efficiently used to produce high-quality transgenic rice and cereal crops.

References

- Halpin, C. (2005). Gene stacking in transgenic plants—the challenge for 21st century plant biotechnology. *Plant biotechnology journal*, 3(2): 141-155.
- Hathwaik, L.T., Horstman, J., Thomson, J.G. and Thilmony, R. (2021). Efficient Gene Stacking in Rice Using the *GAENTRY* System. *Rice*, 14(1): 17.
- Shailani, A., Joshi, R., Singla-Pareek, S.L. and Pareek, A. (2021). Stacking for future: Pyramiding genes to improve drought and salinity tolerance in rice. *Physiologia Plantarum*, 172(2): 1352-1362.

SUCROSE HOMEOSTASIS: REGULATION AND CROSS TALK BETWEEN THE HORMONE SIGNALLING

K. Bhrundha^{1*}, Chaithra B. S² and Yogesh V. Wayal³

¹Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur-680656, Kerala, India.

²Assistant Professor. Kadiyil Baburao College of Agriculture, C. S. Puram-523112, Andhra Pradesh, India

³Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram-695522, Kerala, India

*Corresponding Email: bhrundhakrishnan98@gmail.com

Introduction

In plant physiology, maintaining balanced nutrients is crucial for optimal growth and development. Among these, sucrose produced by photosynthesis plays a central role. It is a primary energy source, a signalling molecule, and a building block for many metabolic pathways. Regulation of sucrose levels, or sucrose homeostasis, involves mechanisms that maintain stable sucrose concentrations in cells and tissues through a balance of production, transport, and consumption. Plants constantly adjust these processes to match changing environmental conditions, developmental stages, and metabolic demands. Past and present selection on sucrose and related carbohydrate metabolism and homeostasis components for wheat yield has been documented, including traits involving trehalose 6-phosphate (T6P) metabolism. This is significant in regulating tissue levels of sucrose are sugar transporters, enzymes involved in the synthesis and breakdown of sucrose, and the underlying regulatory systems, such as trehalose 6-phosphate (T6P) signalling that interacts with SNF1-related protein kinase1 (SnRK1) and TOR (target of rapamycin) kinase master regulators. Selection forces about sucrose homeostasis and allocation, particularly for the setup and filling of reproductive structures, are probably different for crops than for plants in their natural habitat. Gene duplication and proliferation, such as those of the trehalose phosphate synthase (TPS) and trehalose phosphate phosphatase (TPP) genes, may be involved. Adequately providing more sucrose to harvested plant parts, such as grain, seed, or tubers, seems to have a high degree of influence over high yields after photosynthesis.

Regulation of Sucrose Homeostasis in Source Leaves

Sucrose is the first major end product of photosynthesis, generated from triose phosphate exported from chloroplasts, counter-exchanged with inorganic phosphate from the cytosol. The flux of triose phosphate towards sucrose is catalyzed by fructose 1,6-bisphosphatase (FBPase) as a major control point regulated by fructose 2, 6-bisphosphate (F26BP). F26BP regulates partitioning between sucrose and starch in fluctuating light and temperature in Arabidopsis but not in wheats. Sucrose phosphate synthase (SPS) catalyzes the next highly regulated step of carbon flux from photosynthesis to sucrose. Overexpression of SPS can increase sucrose accumulation independently of photosynthetic rate at the expense of starch and amino acids in tomato. However, this transgenic strategy may not be readily reproducible and has not been deployed in crop improvement. Sucrose phosphate phosphatase (SPP) shows more promise for increasing

sucrose content and yield. Higher expression of TaSPP-5A in wheat seedling leaves was associated with increased sucrose content and spike thousand-grain weight.

Selection of favourable SPP haplotypes may provide opportunity in breeding programs. Once synthesised in the cytosol, sucrose can be transiently stored in the vacuole in leaves to high levels. Sugar exchange with vacuoles is enabled by tonoplast monosaccharide transporters (TMT), plant sucrose/H⁺ cotransporters (SUT or SUC), vacuolar glucose transporters, early response to dehydration-like (ERDL) monosaccharide transporters, and SWEETs. In a transgenic approach, sugars were relocalized from the vacuole by modifying the tonoplast transporters TMT and tonoplast sucrose/H⁺ cotransporter and SUC4 expression in Arabidopsis. This may be a strategy to alter the accumulation of end products in plants.

Invertases and a chloroplastic H⁺ sugar antiporter may facilitate sucrose and hexose homeostasis between chloroplasts and cytosol in chloroplasts. However, little is known about sucrose partitioning between sub-cellular compartments. Transitory starch in chloroplasts provides carbon storage and buffering of sucrose, further regulating sucrose homeostasis.

T6P-SnRK1 and TOR: Musketeer for Sugar Homeostasis

Trehalose 6-phosphate (T6P) is a sugar signal that plays a crucial role in sucrose utilization in plants and crops. It is a universal mechanism that integrates sucrose supply into metabolism, development, and physiology, thereby regulating sucrose homeostasis. Both SnRK1 and TOR sense carbon and nutrient status and act as master regulators of metabolic homeostasis, acting as antagonistic promoters and inhibitors of catabolism and anabolism, respectively.

T6P inhibits SnRK1 to regulate metabolic pathways to promote anabolism at the transcriptional level. In Arabidopsis rosettes, T6P regulates the enzymatic activity of key enzymes like phosphoenol pyruvate carboxylase (PEPC) and nitrate reductase, starch metabolism through post-translational redox activation of AGPase, and starch degradation, thereby regulating sucrose homeostasis.

T6P inhibition of SnRK1 is unique in plants, as activities of closely related AMPK and SNF1 of other organisms are not affected by T6P. T6P inhibits SnRK1 in all Arabidopsis tissues except mature leaves and particularly strongly in sinks such as young inflorescences. In photosynthetic tissue, T6P levels are still related to SnRK1 marker gene transcripts. Interacting factors, such as upstream protein kinase and class II TPSs, may modulate SnRK1 response to T6P, but the exact mechanisms in mature leaves or growing tissues are still incomplete. The sugar-phosphates glucose 6-phosphate and glucose 1-phosphate also inhibit SnRK1 in an additive and synergistic manner with T6P.

T6P plays a crucial role in cellular sucrose homeostasis in actively growing sink tissue, promoting growth and development, and regulating plant architecture and crop yield. Variation in SnRK1 and TOR has been directly associated with crop yield, but these associations may be rare due to their conserved nature. A more effective approach to modify carbon/energy signalling for yield through SnRK1 and TOR may involve specific targeting or expression control of SnRK1/TOR at certain developmental time points, TPSs and TPPs that alter T6P levels and signalling, or chemical intervention of T6P. Emerging data suggests that T6P likely enables the commitment of sucrose to reproductive development, which forms the basis of cereal yields. Targeting the T6P pathway presents a great opportunity for optimizing sucrose allocation for yield. TPS and TPP genes are

associated with grain yield traits, but their detailed mode of action is not known. TB1 plays a crucial role in regulating architecture, sucrose homeostasis, and T6P in wheat. Allelic variation of TB1 in wheat affects spikelet meristem formation, affecting spike fertility and the number of spikelets. T6P also regulates new lateral roots from lateral root pericycle tissue. Recent research has found several interactors with T6P and SnRK1, such as a new regulatory module linking SnRK1 and a TPP gene through a bHLH111 transcription factor OsSGI1 in rice. Knockout mutants have larger grains, enhanced seed germination, and vegetative growth. In maize, heterologous expression of a rice TPP decreased T6P during early reproductive development, altering sucrose allocation towards the developing grain. This modification also resulted in higher photosynthesis and increased grain number retention and yield. The T6P/sucrose nexus is strongly tissue and developmental-dependent, enhancing yield and photosynthesis.

Cross-talk between Sugars and Hormone Signalling

Auxin & sugar

Auxin, or indole-3-acetic acid (IAA), is vital for plant growth, influencing cell proliferation, expansion, differentiation, hypocotyl elongation, and anther development. The complex relationship between sugar and auxin involves metabolism, transport, and signalling pathways. The first link was found in Arabidopsis *hvk/gin2* hypocotyl explants, which are insensitive to auxin-induced proliferation and root formation. Glucose affects many auxin-related genes; some are insensitive to glucose alone but become glucose-responsive in the presence of auxin. Exogenous glucose supply enhances defects in the induction of lateral root growth, root hair elongation, and gravitropism in mutants of auxin sensing and signalling.

Auxin and turanose, a non-metabolizable analogue of sucrose, regulate the expression of the WOX5 transcription factor, a Wushel-related homeobox gene required for sustaining local auxin maxima in the root apical meristem. S1bZIP11-related transcription factors (bZIP1, -11, and -44) are downregulated by sugar and upregulated by low energy levels through SnRK1 kinase activity. These transcription factors directly up-regulate the expression of IAA3/SHY2, a key negative regulator of root growth. The glucose-dependent activation of the heterotrimeric G-protein and the auxin-activated TOR-kinase signalling pathway is thought to result from the glucose-dependent interaction in root growth and development.

Cytokinin & Sugars

Cytokinins (CKs) are crucial in plant development, influencing cell proliferation, source/sink relationships, leaf senescence, apical dominance, root growth, nutritional signalling, and responses to abiotic and biotic stresses. They can cross-influence their metabolism and transport, potentially impinging on signalling pathways. Studies have shown that glucose and CKs act both agonistically and antagonistically on gene expression, with glucose having a strong effect on genes involved in cytokinin metabolism and signalling. The first direct interplay between sugar and CKs was observed in Arabidopsis seedlings, with the *hvk1/gin2* mutant showing decreased sensitivity to sugar and increased sensitivity to CKs. This suggests an antagonistic effect of CKs. CKs and sugar also play important roles in the regulation of different cell cycle phases, including the G1/S transition and the G2/M transition. In Arabidopsis, a balance between auxin's antagonistic effects and CK's mediating effects establishes the root meristem. In contrast, in the shoot meristem, CKs promote stem cell proliferation and inhibit differentiation, while auxin triggers organ primordia initiation. The activation of root and shoot apical meristems relies on distinct glucose and light signals.

Gibberellins & Sugars

Gibberellins (GAs) are plant hormones that regulate photosynthesis, carbohydrate metabolism, growth, development processes, and responses to biotic and abiotic stresses. They directly regulate plant carbon status through their effect on photosynthetic activity and sugar metabolic activity. Sugar can affect GA metabolism in different biological contexts. Sugar and GA signalling compete to regulate α -amylase expression in cereal seeds. DELLA proteins, central repressors of the GA response, play a role in dark-induced hypocotyl elongation and the anthocyanin biosynthesis pathway. DELLA proteins could be a main actor in hormonal and sucrose-dependent molecular networks.

Ethylene & Sugars

Ethylene plays a crucial role in plant processes, including seed germination, organ senescence, and responses to biotic and abiotic cues. In Arabidopsis, there is a tight, antagonistic interaction between sugar and ethylene signalling. Mutants with non-functional ethylene receptors or altered signal transduction proteins are hypersensitive to sugar-mediated photosynthesis repression, while constitutive triple response 1 is glucose insensitive. This interaction explains glucose's ability to stimulate the degradation of ETHYLENE-INSENSITIVE3 (EIN3), a key transcriptional regulator in ethylene signalling, and promote plant growth. The antagonistic interplay between sucrose and ethylene pathways is involved in sustaining sugar-dependent circadian rhythms in darkness through post-transcriptional regulation of the circadian oscillator GIGANTEA (GI). Both ethylene- and sugar-signalling pathways can work cooperatively, with sucrose-dependent protection against atrazine requiring active ethylene signalling and possibly involving a hexokinase-independent pathway.

ABA & Sugars

Abscisic Acid (ABA) is a crucial plant hormone that regulates various plant adaptive responses to environmental constraints. It is particularly important in the interaction with sugar signals, as many mutations affecting sugar sensing and signalling are allelic to genes encoding components of the ABA synthesis or ABA transduction pathways. In Arabidopsis, ABA-deficient and ABA-insensitive mutants are allelic to glucose insensitive1 (*gin1*)/impaired sucrose induction 4 (*isi4*)/sugar insensitive1 (*sis1*), respectively. The crosstalk between sugar and ABA can involve synergistic effects with *ApL3*, *ASR*, and many photosynthesis-related genes, as well as agonistic effects. *ABI4*, a transcription factor of the AP2/ERF family, plays a prominent role in glucose and ABA signalling. *SnRK1* plays a key role in glucose and ABA signalling, with over-expressing plants displaying hypersensitivity to glucose and ABA during early seedling development.

Conclusion

Sucrose homeostasis is essential for plant growth and development. Hormonal signalling pathways regulate sucrose levels, involving auxins, gibberellins, and cytokinin. These hormones interact to influence sucrose production and usage, responding to various stimuli. Auxins aid in sucrose mobilization, while gibberellins boost its production. Cytokinin regulate sucrose uptake and use, maintaining balance. This hormonal interplay allows plants to adapt and sustain homeostasis. Understanding these pathways enhances knowledge of plant growth and stress responses. This insight is valuable for agriculture, as hormonal manipulation may boost crop yield and resilience. Further research into the molecular mechanisms underlying this hormonal crosstalk will deepen our understanding of plant physiology and enhance our ability to manage sucrose homeostasis in various agricultural contexts.

References

- Miret, J.A., Griffiths, C.A. and Paul, M.J., 2024. Sucrose homeostasis: Mechanisms and opportunity in crop yield improvement. *Journal of Plant Physiology*, 154188.
- Morales-Herrera, S., Jourquin, J., Coppé, F., Lopez-Galvis, L., De Smet, T., Safi, A., Njo, M., Griffiths, C.A., Sidda, J.D., Mccullagh, J.S. and Xue, X., 2023. Trehalose-6-phosphate signalling regulates lateral root formation in *Arabidopsis thaliana*. *Proceedings of the National Academy of Sciences*, 120(40), e2302996120.

BACTERIAL BIO-AGENTS: ECO-FRIENDLY WARRIORS FOR PLANT HEALTH PROTECTION

R. P. Singh*, Abhik Patra, R. M. Ram, B.K. Singh, Himanshu Singh and Ashutosh Kumar

RPCAU-Krishi Vigyan Kendra, West Champaran-II

(Dr Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar)

*Corresponding Email: rpskvk.22@gmail.com

Abstract

Ensuring food and nutritional security for the growing global population presents a significant challenge, particularly when factor productivity continues to decline, environmental pollution escalates, and natural resources remain finite. Plant pathogens pose serious and persistent threats to sustainable agricultural production and ecosystem stability worldwide. Currently, chemical pesticides serve as effective and reliable tools for disease control in agricultural systems. Although these chemicals offer high efficacy and convenience, they create substantial risks for environmental health and all life forms. Furthermore, these chemical agents function as selective pressures, promoting pathogen resistance and enabling their persistence. Consequently, developing alternative approaches that complement conventional disease management strategies while minimizing adverse effects on human health and the environment becomes essential. Biological control agents offer safer and more sustainable options for achieving profitable agricultural productivity. Various bacterial-based pesticides derived from different strains of *Pseudomonas fluorescens*, *Pseudomonas putida*, and *Bacillus* spp. are commercially available for sustainable agriculture. Research has demonstrated their growth-promoting abilities and antagonistic activities against diverse pathogens through *in vitro*, greenhouse, and field studies. Disease suppression by these bacterial pesticides results from multiple mechanisms including plant growth promotion (PGP), antibiosis, competition for space and nutrients, pathogen lysis, and induced resistance mechanisms such as SAR (Systemic Acquired Resistance) and ISR (Induced Systemic Resistance).

Keywords: Bacterial bioagents, mode of action, eco-friendly disease suppression

Introduction

Agriculture plays a vital role in developing nations worldwide. This sector remains crucial for livelihood security and nutritional needs of expanding populations while contributing significantly to national economic development. In India, the Green Revolution introduced advanced agricultural technologies, particularly chemical pesticides, to enhance crop production and productivity. However, continuous and extensive utilization of pesticides and fertilizers over decades has created serious risks for human health and ecosystems while adversely affecting soil microbial communities. Agricultural crop production faces increasing vulnerability from pest attacks including insects, bacteria, fungi, nematodes, and viruses. Plant diseases represent major constraints affecting both quality and quantity of crop production. Global food production losses ranging from 27 to 42% result from plant diseases caused by various pathogens, highlighting the critical importance of effective disease management strategies (Singh, 2014; Alizadeh *et al.*,

2020). Traditional agricultural practices including disease-resistant varieties, seed treatment, crop rotation, cover cropping, proper seedbed preparation, and weed management have been employed for disease control. However, these practices often prove insufficient for preventing crop losses.

Current approaches employ diverse strategies for managing and mitigating various pathogens. Microbial pesticides represent one of the most effective eco-friendly strategies for disease control. Numerous bacterial and fungal-based biopesticides have been identified and developed, though effective adoption and further development remain necessary. Growing consumer concern regarding pesticide-free safer foods has accelerated the emergence of environmentally sustainable disease management strategies. Several beneficial bacterial-based biopesticides are now widely commercialized in agriculture. Bacterial bioagents including *Pseudomonas fluorescens*, *Pseudomonas aureofaciens*, *Pseudomonas chlororaphis*, *Pseudomonas putida*, *Bacillus subtilis*, *Bacillus cereus*, *B. pasteurii*, *B. pumilus*, *B. mycoides*, *B. sphaericus*, *B. amyloliquefaciens*, *Burkholderia cepacia*, *Streptomyces lydicus*, *Arthrobacter* sp., and *Agrobacterium radiobacter* suppress numerous plant pathogens across diverse hosts (Table 1). Commercial bacterial bioagents with manufacturers are listed in Table 2.

Table 1: Various disease controlled by bacterial bio-agents

Crop Name	Disease Name	Target pathogens	Effective Bacterial bioagents
Cereal crops			
Rice	Sheath rot	<i>Sarocladium oryzae</i>	<i>Pseudomonas fluorescens</i>
	Sheath blight	<i>Rhizoctonia solani</i>	<i>Pseudomonas fluorescens</i> , <i>P. putida</i>
	Blast	<i>Magnaporthe grisea</i>	<i>Bacillus</i> sp.
	Bacterial leaf blight	<i>Xanthomonas oryzae</i> pv. <i>oryzae</i>	<i>Pseudomonas fluorescens</i> , <i>B. subtilis</i>
	Leaf and Neck blast	<i>Pyricularia oryzae</i>	<i>Pseudomonas fluorescens</i>
	Leaf spot	<i>Helminthosporium oryzae</i>	<i>Pseudomonas fluorescens</i>
Barley	Take-all	<i>Gaeumanomyces graminis</i> var. <i>tritici</i>	<i>Pseudomonas fluorescens</i>
Wheat	Root rot	<i>Sclerotium rolfsii</i> , <i>Fusarium oxysporum</i>	<i>Pseudomonas fluorescens</i>
	Loose smut	<i>Ustilago segatum tritici</i>	<i>Pseudomonas fluorescens</i>
	Take-all	<i>Gaeumanomyces graminis</i> var. <i>tritici</i>	<i>Pseudomonas fluorescens</i>
	Wilt	<i>Fusarium graminearum</i>	<i>Lysobacter enzymogenes</i>
Maize	Damping off	<i>Pythium ultimum</i>	<i>Pseudomonas fluorescens</i>
	Wilt	<i>Fusarium oxysporum</i>	<i>B. amyloliquefaciens</i>
	Maize rot	<i>Fusarium verticillioides</i>	<i>Burkholderia</i> sp.
Pearl millet	Downy mildew	<i>Sclerospora graminicola</i>	<i>B. subtilis</i> , <i>B. pumilus</i>
Sorghum	Wilt	<i>Fusarium oxysporum</i>	<i>Paenibacillus</i> sp.
Pulse crops			
Chickpea	Wilt, seed rot, root rot	<i>Fusarium oxysporum</i> f. sp. <i>ciceris</i> , <i>R. bataticola</i> , <i>Pythium</i> sp.	<i>Bacillus subtilis</i>
	Grey mould	<i>Botrytis cineria</i>	<i>Brevibacillus brevis</i>
Pigeon pea	Wilt	<i>Fusarium udum</i>	<i>Bacillus subtilis</i>

Crop Name	Disease Name	Target pathogens	Effective Bacterial bioagents
Oilseed crops			
Rye	Vascular wilt	<i>Fusarium culmorum</i>	<i>Pseudomonas fluorescens</i>
Rapeseed	Stem rot	<i>Sclerotinia sclerotiorum</i>	<i>Bacillus subtilis</i> EDR4
Groundnut	Late leaf spot	<i>Phaeoisariopsis personata</i>	<i>Pseudomonas fluorescens</i>
Castor	Grey rot	<i>Botrytis cinerea</i>	<i>Pseudomonas fluorescens</i>
Fruit crops			
Apple and Pear	Fire blight	<i>Erwinia amylovora</i>	<i>Bacillus subtilis</i> QST 713, <i>Pantoea agglomerans</i> C9-1, <i>Pantoea agglomerans</i> E325
Apple	Root rot	<i>Fusarium</i> sp.	<i>Bacillus subtilis</i> Y-1
Stone fruit	Crown gall disease	<i>Agrobacterium tumefaciens</i>	<i>Agrobacterium radiobacter</i> K84
Banana	Bunchy top disease	<i>Banana bunchy top virus</i>	<i>Pseudomonas fluorescens</i>
	Sigatoka	<i>Mycosphaerella musicola</i>	<i>Bacillus subtilis</i>
	Wilt	<i>F. oxysporum</i> f. sp. <i>cubense</i>	<i>B. amyloliquefaciens</i>
Avacado	Root rot	<i>Dematophora necatrix</i>	<i>Pseudomonas fluorescens</i>
Citrus	Post-harvest decay	<i>Penicillium</i> sp.	<i>Bacillus subtilis</i> PPCB001
Vegetable crops			
Tomato	Foot and root rot	<i>Fusarium oxysporum</i> f. sp. <i>radicislycopersici</i>	<i>Pseudomonas chlororaphis</i>
	Mosaic disease	<i>Cucumber mosaic virus</i>	<i>Bacillus pumilus</i> , <i>B. amyloliquefaciens</i> , <i>B. subtilis</i>
	Tomato mottle disease	<i>Tomato mottle virus</i>	<i>B. amyloliquefaciens</i> , <i>B. subtilis</i> , <i>B. pumilus</i>
	Foliar diseases	<i>Corynespora cassiicola</i>	<i>B. cereus</i>
	Wilt	<i>Fusarium oxysporum</i>	<i>Collimonas fungivorans</i> , <i>Pseudomonas fluorescens</i>
	Root rot	<i>Rhizoctonia</i> spp.	<i>Pseudomonas fluorescens</i>
	Bacterial wilt	<i>Ralstonia solanacearum</i>	<i>B. amyloliquefaciens</i>
Cucumber	Damping off/powdery mildew	<i>Pythium ultimum</i> / <i>Sphaerotheca fuliginea</i>	<i>Pseudomonas fluorescens</i>
	Damping off	<i>Rhizoctonia solani</i>	<i>Bacillus pumilus</i>
	Bacterial wilt	<i>Erwinia tracheiphila</i>	<i>Bacillus pumilus</i>
	Grey mould	<i>Botrytis cinerea</i>	<i>Brevibacillus brevis</i>
	Root and crown rot	<i>Pythium aphanidermatum</i>	<i>L. enzymogenes</i>
	Wilt	<i>Fusarium oxysporum</i> f. sp. <i>cucumerinum</i>	<i>Bacillus subtilis</i>
Potato	Late blight	<i>Phytophthora infestans</i>	<i>Pseudomonas fluorescens</i>
	Soft rot	<i>Erwinia amylovora</i>	<i>Pseudomonas fluorescens</i>
	Bacterial wilt	<i>Ralstonia solanacearum</i>	<i>Bacillus cereus</i> , <i>B. subtilis</i>
Squash	Blight	<i>Phytophthora capsici</i>	<i>Bacillus</i> sp.
Brinjal	Wilt, damping off	<i>F. solani</i> , <i>P. aphanidermatum</i>	<i>Pseudomonas fluorescens</i>
Chilli	Damping off	<i>Pythium aphanidermatum</i>	<i>Pseudomonas fluorescens</i>
Radish	Wilt	<i>Fusarium</i> sp.	<i>Pseudomonas putida</i>
Pea	Damping off, root rot	<i>Pythium</i> sp. and <i>Aphanomyces</i> sp.	<i>Burkholderia cepacia</i>

Crop Name	Disease Name	Target pathogens	Effective Bacterial bioagents
	Wilt	<i>Fusarium oxysporum</i> f. sp. <i>pisi</i>	<i>Pseudomonas fluorescens</i>
Okra	Wilt	<i>Fusarium oxysporum</i>	<i>Pseudomonas fluorescens</i>
Cauliflower	Damping off	<i>R. solani</i> , <i>P. aphanidermatum</i>	<i>Pseudomonas fluorescens</i>
Cabbage	Damping off	<i>R. solani</i>	<i>Pseudomonas fluorescens</i>
Bottle gourd	Collar rot	<i>Sclerotinia sclerotiorum</i>	<i>B. subtilis</i>
Fenugreek	Root rot	<i>R. solani</i>	<i>Pseudomonas fluorescens</i>
Bean	Seedling rot	<i>Pythium</i> sp., <i>S. sclerotiorum</i> , <i>R. solani</i> , <i>B. cineria</i>	<i>Pseudomonas fluorescens</i>
	Root rot	<i>R. solani</i>	<i>Pseudomonas fluorescens</i>
	Southern blight	<i>Sclerotium rolfsii</i>	<i>Aeromonas caviae</i>
Plantation crops			
Tobacco	Blue mould	<i>Peronospora tabacina</i>	<i>Bacillus pumilus</i>
	Bacterial wilt	<i>Ralstonia solanacearum</i>	<i>Brevibacillus brevis</i> , <i>Streptomyces rochei</i>
Areca nut palm	Fruit rot	<i>Phytophthora</i> spp.	<i>Pseudomonas fluorescens</i>
Cash crops			
Sugarcane	Red rot	<i>Colletotrichum falcatum</i>	<i>Pseudomonas fluorescens</i> VPT4, ARRIG, and EP1, <i>Pseudomonas putida</i> KKM1
Carrot	Root rot	<i>Athelia rolfsii</i>	<i>Pseudomonas fluorescens</i>
Sugar beet	Damping off	<i>Pythium ultimum</i>	<i>Pseudomonas fluorescens</i> , <i>Enterobacter cloacae</i> , <i>Stenotrophomonas maltophilia</i>
Cotton	Root rot	<i>Rhizoctonia solani</i>	<i>Bacillus cereus</i> , <i>Enterobacter agglomerans</i>
	Root rot	<i>R. solani</i> and <i>F. oxysporum</i> f. sp. <i>vasinfectum</i>	<i>Aeromonas caviae</i>
	Root rot	<i>Macrophomina phaseolina</i>	<i>Pseudomonas fluorescens</i>
	Damping off	<i>Pythium ultimum</i> , <i>Phoma betae</i>	<i>Pseudomonas fluorescens</i>
	Wilt	<i>Verticillium dahliae</i>	<i>Bacillus subtilis</i>
Spices crops			
Bell pepper	Blight	<i>Phytophthora capsici</i>	<i>Bacillus</i> sp.
Pepper	Blight	<i>Botrytis cinerea</i>	<i>B. amyloliquefaciens</i>

Table 2: Commercial products of Bacterial bioagent in plant disease management

Trade Name	Bacterial strains/species	Manufacturer
Galtrol	<i>Agrobacterium radiobacter</i> strain 84	AgBioChem, Inc., USA
Dygal	<i>Agrobacterium radiobacter</i>	Agbioresearch Ltd.
Nagol	<i>Agrobacterium radiobacter</i> strain K1026	Bio-care
Nogall	<i>Agrobacterium radiobacter</i>	New Bioproducts
GB 34	<i>Bacillus subtilis</i> strain GB34	Gustafon, Inc., USA
Kodiac companion	<i>Bacillus subtilis</i> strain GB03	Growth products, USA
Frostban	<i>Pseudomonas fluorescens</i> strain A 506	Plant health technologies
Bio-jet, Spot less	<i>Pseudomonas fluorescens</i> strain TX-1	Eco-Soil Systems Inc.

Trade Name	Bacterial strains/species	Manufacturer
Ballad Plus	<i>Bacillus pumilus</i>	Agraquest Inc.
Serenade	<i>Bacillus subtilis</i>	Agraquest Inc.
Rhizo-plus	<i>Bacillus subtilis</i> strain FZB 24	FZB Biotechnik, GmbH
Intercept	<i>Pseudomonas cepacia</i>	Soil Tech.
Conquer	<i>Pseudomonas fluorescens</i>	Mauri Foods
Bio-jet	<i>Pseudomonas + Azospirillum</i>	Eco-Soil
Deny	<i>Burkholderia cepacia</i>	Stine Microbial Products
Avo Green	<i>Bacillus subtilis</i>	Ocean Agriculture, South Africa
Bio-safe	<i>Basillus subtilis</i>	Laboratorio de Biocontrole Farroupilha, Brazil
Subtilex/Pro-Mix	<i>B. subtilis</i>	Premier Horticulture Inc., Canada
Bioshield	<i>Pseudomonas fluorescens</i>	Anu Biotech International Ltd., Faridabad, India
Biotok	<i>Bacillus subtilis</i>	Tocklal Experimental Station, Tea Research Associantion, Jorhat, Assam, India
Plant Bio-control Agent-3	<i>Pseudomonas fluorescens</i>	Department of Plant Pathology, G.B. Pant Uni. of Agric. And Tech., Pantnagar, Uttarakhand, India
HiStick N/T, Subtilex	<i>Bacillus subtilis</i> strain MB 1600	Becker Underwood, Ames, IA, USA
Bio Yield	<i>B. subtilis + B. amyloliquefaciens</i>	Gustafson Inc., Dallas, USA
Ecoshot	<i>Bacillus subtilis</i>	Kumiai Chemical Industry, Japan
Mycostop	<i>Streptomyces griseoviridis</i>	Kemira Oy, Finland
Actinovate	<i>Streptomyces lydicus</i>	Natural Industries, Inc., USA
Biobest	<i>Bacillus subtilis</i>	Appliedchem, Thailand
Biosave 10LP, 110	<i>Pseudomonas syringae</i>	Village Farms LLC
EcoGuard	<i>Bacillus licheniformis</i>	Novozymes, Denmark
Larminar	<i>B. subtilis</i>	Appliedchem, Thailand
Rhapsody	<i>B. subtilis</i>	AgraQuest, USA
Sonata	<i>B. pumilus</i>	AgraQuest, USA
Subtilex	<i>B. subtilis</i>	Becker Underwood, USA
Taegro	<i>B. amyloliquefaciens</i>	Novozymes, Denmark
YiedShield	<i>Bacillus pumilus</i> GB34	Gustafson Inc., USA

Mechanism of Action of Bacterial Bio-agents

Plant diseases result from interactions among three components of the disease triangle: host, pathogen, and environment. Biological control agents interact with these components to manage diseases. Bacterial biocontrol agents employ various unique and complex mechanisms (Junaid *et al.*, 2013) described below:

Antibiosis

Antibiosis involves production of low molecular weight compounds, antibiotic-like substances, or other chemical metabolites by microorganisms that directly affect plant pathogen growth. Bioagents produce three antibiotic types: nonpolar/volatile, polar/non-volatile, and water-soluble compounds. Volatile antibiotics demonstrate greater effectiveness as they function at sites distant from production locations (Lo, 1998; Pal and Gardener, 2006). For example:

Different *Pseudomonas fluorescens* strains produce Phenazine-1-Carboxylic Acid (PCA), Pyrrolnitrin, Pyocinine, Pyoluteorin, Oomycin-A, 2,4-Diacetyl-phloroglucinol (DAPG), and Idionine; Various *Bacillus subtilis* strains produce Bacillomycin D, Iturin A, Surfactin, Fengycin, and Mycosubtilin; *Bacillus cereus* produces Zwittermycin A; *Agrobacterium radiobacter* produces Agrocin 84; *B. amyloliquefaciens* produces Bacillomycin and Fengycin; *Burkholderia cepacia* produces Pyrrolnitrin and Pseudane antibiotic-like substances.

Competition

Bio-control agents and pathogens compete for nutrients, oxygen, space, and other requirements for environmental establishment. This competitive process represents indirect interaction between pathogens and bio-control agents, wherein pathogens are excluded through nutrient depletion and physical site occupation. Regarding nutrient competition, bio-control agents compete for scarce but essential micronutrients, particularly iron and manganese in highly oxidized and aerated soils. Iron remains essential for both plant and microorganism growth and development. In natural form, iron exists as insoluble ferric compounds unavailable to plants and microorganisms (Junaaid *et al.*, 2013). For instance, different *Pseudomonas fluorescens* strains synthesize siderophores-microbial iron transport agents functioning as chelating compounds with micronutrient-binding capacity. These extracellular low molecular weight compounds bind iron molecules, converting insoluble forms to soluble states while facilitating iron uptake by plants and beneficial microorganisms. During this process, iron becomes less available or unavailable to pathogens, ultimately controlling disease development. Examples include Ferribactin, Ferrichrome, Ferroxamine B, Pseudobactin, Pyochelin, and Pyoverdine (soluble fluorescent pigment). *Bacillus subtilis* produces catecholate siderophores-2 (bacillibactin), 3-dihydroxybenzoate, and 2,3-dihydroxybenzoyl glycine.

Lysis

Lysis represents another mechanism employed by biocontrol agents against soil-borne pathogens, involving production of cell wall-degrading enzymes or other metabolites. Numerous microorganisms release lytic enzymes capable of hydrolyzing diverse polymeric compounds including chitin, proteins, cellulose, hemicellulose, and DNA. Expression and secretion of these enzymes by different microbes can directly suppress plant pathogen activities. Besides antibiotic production and systemic resistance elicitation, biocontrol strains of plant growth-promoting rhizobacteria (PGPR) including *Pseudomonas fluorescens* and *Bacillus* spp. produce enzymes with strong lytic activity such as chitinase, β -1,3-glucanase, cellulase, and protease. These enzymes exert direct inhibitory effects on fungal pathogen hyphal growth. Cell wall-degrading enzymes from rhizobacteria affect structural integrity of target pathogen walls. Additional microbial by-products contribute to pathogen suppression. Hydrogen cyanide (HCN) production by certain fluorescent pseudomonads participates in root pathogen suppression. *P. fluorescens* CHA0 produces antibiotics, siderophores, and HCN, though suppression of tobacco black rot caused by *Thielaviopsis basicola* appears primarily attributable to HCN production (Junaaid *et al.*, 2013).

Induced Resistance

Plants actively respond to diverse environmental stimuli including gravity, light, temperature, physical stress, water availability, and nutrient conditions. Plants possess an array of active defence mechanisms responding to various chemical stimuli produced by soil and plant-associated microbes (PGPR). Such stimuli induce biochemical changes enhancing resistance against subsequent pathogen infection. Triggering defence mechanisms before pathogen infection

reduces disease development. Induced resistance represents a state of enhanced defensive capacity developed by plants upon appropriate stimulation. Systemic acquired resistance (SAR) and induced systemic resistance (ISR) constitute two forms of induced resistance wherein plant defences are preconditioned by prior infection or treatment, resulting in resistance against subsequent pathogen challenge.

Systemic Acquired Resistance (SAR): This resistance form activates throughout plants after exposure to elicitors (pathogen cell wall components capable of inducing phytoalexin synthesis) from virulent, avirulent, or non-pathogenic microbes, or artificial chemical stimuli such as chitosan or salicylic acid (SA). SAR functions through SA-dependent pathways (Singh, 2014) activated by specific molecules secreted by microorganisms, referred to as elicitors. These include cell wall polysaccharides, salicylic acid, cyclic lipopeptides, siderophores, antibiotics, and N-acyl homoserine lactones (Perez-Montano *et al.*, 2014). Elicitors trigger defense responses including physical cell wall thickening through lignification, callose deposition, phytoalexin accumulation (antimicrobial low-molecular-weight compounds produced by plants during infection), and synthesis of various proteins including chitinases, glucanases, peroxidases, and other pathogenesis-related (PR) proteins (PR-1, PR-2). These PR proteins possess antimicrobial properties, cause invading cell lysis, reinforce cell membranes against infection, or induce localized cell death.

Induced Systemic Resistance (ISR): This resistance mechanism activates through infection and operates independently of direct pathogen killing or inhibition, instead enhancing host plant physical or chemical barriers. Beneficial rhizosphere microbes trigger ISR through salicylic acid-independent pathways, with jasmonic acid (JA) and ethylene (ET) serving as central mediators induced by non-pathogenic bacteria. ISR typically functions without PR protein activation.

Combining ISR and SAR can enhance protection against pathogens resisted through both pathways while extending protection to broader pathogen spectra compared to either mechanism alone. Certain *Pseudomonas fluorescens*, *Pseudomonas putida* strains, and specific strains of *Bacillus amyloliquefaciens*, *B. subtilis*, *B. pasteurii*, *B. cereus*, *B. pumilus*, *B. mycoides*, and *B. sphaericus* significantly reduce disease incidence or severity through induced resistance across diverse hosts (Chaudhary *et al.*, 2007).

Methods of Bacterial Bio-agent Application

1. Seed Treatment

Seed treatment functions similarly to vaccination in animals and humans, providing protection to seeds and plants while improving healthy crop establishment. For larger seeds, apply bacterial formulation @ 8-10 g per kg seed before sowing; for small seeds, use @ 6-8 g per kg seed. Mix seeds thoroughly with bacterial formulation ensuring uniform coating. Shade dry treated seeds for 20-30 minutes before sowing. Seed treatment effectively controls seed and soil-borne diseases.

2. Seed Bio-priming

This biological seed treatment process involves slurry treatment of seeds with bioagents in presence of gum arabica, jaggery, or FYM powder. Dissolve 100 g jaggery in one liter water, add bacterial formulation @ 10 g per kg seed, and mix thoroughly. Next day, mix required seed quantity properly with culture medium. Fill treated seeds in polythene bags, heap, cover with moist jute sack, and incubate at 25-32°C for 48 hours maintaining high humidity. During this

period, bioagents adhering to seed surfaces grow and form protective coatings on seed coats. This technique offers advantages over simple seed coating by promoting rapid and uniform seedling emergence. Seed biopriming benefits tomato, brinjal, chickpea, soybean, and similar crops.

3. Seed Material Treatment

Apply bacterial formulation @ 10 g or 10 ml with one liter water for treating seed materials like sugarcane setts, banana suckers, turmeric rhizomes, ginger rhizomes, and potato tubers. Dip for approximately 30 minutes before sowing. Shade dry treated materials for 20-30 minutes before sowing.

4. Soil Application

Mix 2-2.5 kg bacterial powder formulation or 500-1000 ml liquid formulation with 25-50 kg farm yard manure (FYM). Thoroughly mix, cover with jute bags, sugarcane leaves, or paddy straw, and keep in shade for 2-3 weeks for proper multiplication. Maintain moisture and turn mixture every 3-4 days before field broadcasting. Optimal moisture ensures better bioagent multiplication. Apply well-decomposed bacterial-enriched FYM to fields 15 days before sowing. This mixture suits furrow, pit, or pot application during transplanting or sowing, covering one acre.

5. Cutting/Seedling Root Dip Application

Mix 10 g bacterial powder formulation or 10 ml liquid formulation in one liter water. Dip cuttings and seedling roots for approximately 30 minutes before transplanting. Root dipping effectively controls soil-borne diseases.

6. Nursery Bed Treatment

Mix 500 g bacterial bioagents (powder formulation) with 10-15 kg well-decomposed FYM, compost, or vermicompost. Broadcast over one acre during evening hours under proper moisture conditions.

7. Soil Drenching

Mix 1-2 kg bacterial formulation in 200 liters water for drenching one acre, or use 10 g or 10 ml per liter water for soil drenching. Maintain optimal soil moisture during application.

8. Horticultural Crops

Mix 50-100 g bacterial formulation with sufficient FYM, compost, vermicompost, or field soil. Apply mixture per plant in effective root zone of fruit trees. Adjust doses based on plant age.

9. Foliar Application

Prepare bacterial formulation @ 10 g/L water (powder) or 10 ml/L water (liquid). Spray uniformly during cooler hours, 35-40 days after transplanting, particularly for cereals, pulses, and oilseeds. Apply 2-3 sprays at 10-12 day intervals depending on disease incidence.

Benefits

1. Bacterial bio-agents prove safer for both environment and applicators, preventing soil, air, and water pollution by leaving no toxic residues.
2. Bio-control agent manufacturing proves comparatively easier and sometimes less expensive than chemical agent production.
3. Bio-control agents effectively eliminate specific pathogens from infection sites and can combine with bio-fertilizers.

4. These agents cause no plant toxicity; instead, they increase crop yields by enhancing root and plant growth through beneficial microflora encouragement in the rhizosphere. They also facilitate plant nutrient mobilization and availability.
5. Bio-control agents prevent resistance development problems and induce systemic resistance among crop species, providing protection against invading pathogens.

References

- Alizadeh, M., Vasebi, Y., and Safaie, N. (2020). Microbial antagonists against plant pathogens in Iran: A review. *Open Agriculture*, 5: 404-440.
- Chaudhary, D. K., Prakash, A., and Johri, B. N. (2007). Induced systemic resistance (ISR) in plants: mechanism of action. *Indian Journal of Microbiology*, 47: 289-297.
- Junaid, J. M., Dar, N. A., Bhat, T. A., Bhat, A. H., and Bhat, M. A. (2013). Commercial biocontrol agents and their mechanism of action in the management of plant pathogens. *International Journal of Modern Plant and Animal Sciences*, 1(2): 39-57.
- Lo, C. T. (1998). General mechanisms of action of microbial biocontrol agents. *Plant Pathology Bulletin*, 7: 155-166.
- Pal, K. K. and Gardener, B. M. (2006). Biological control of plant pathogens. *The Plant Health Instructor*, DOI: 10.1094/PHI-A-2006-1117-02.
- Perez-Montano, F., Alias-Villegas, C., et al. (2014). Plant growth promotion in cereal and leguminous agricultural important plants: from microorganism capacities to crop production. *Microbiological Research*, 169: 325-336.
- Singh, H. B. (2014). Management of plant pathogens with microorganisms. *Proceedings of the Indian National Science Academy*, 80(2): 443-454.

MOLECULAR BREEDING AND TRANSGENIC APPROACHES FOR TRAIT INTROGRESSION

V. Kishanth Kanna^{1*}, R. Jeevanraj² and Chaithra B. S³

^{1&2} Department of Plant Physiology, College of Agriculture,
Vellankkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Assistant Professor, Kadiri Baburao College of Agriculture,
C. S. Puram - 523112, Andhra Pradesh, India.

*Corresponding Email: kishanthkanna@gmail.com

Abstract

Trait introgression plays a vital role in crop improvement by transferring desirable genes from donor sources into elite cultivars. Conventional backcross breeding, though effective, is time-consuming and less precise. Advances in molecular breeding, including marker-assisted selection (MAS), marker-assisted backcrossing (MABC), genomic selection, and genome-wide association studies (GWAS), have significantly improved the efficiency and accuracy of gene transfer. These approaches enable precise selection of target genes, rapid recovery of the recurrent parent genome, and reduction of linkage drag. In addition, transgenic technologies such as Agrobacterium-mediated transformation and modern genome editing tools like CRISPR/Cas9 facilitate the direct and precise incorporation of beneficial traits. Together, these molecular and transgenic strategies accelerate breeding cycles, enhance genetic gain, and support the development of high-yielding, stress-tolerant crop varieties. Cost reduction and improved accessibility of marker technologies remain essential for wider adoption, particularly in developing countries.

Keywords: Trait introgression, Marker-assisted backcrossing, Genomic selection, Transgenic breeding, Genome editing.

Introduction

The permanent incorporation of genes from one differentiated population into another compatible population via hybridization and backcrossing over multiple generations. Introgression, also known as introgressive hybridization. Introgression is important in the evolution of flowering plants. It is also important in plant breeding where a desirable trait can be transferred from wild to crop species.

Molecular approach

1) Marker assisted selection

Selection for the desirable allele of a gene/quantitative trait locus (QTL) on the basis of molecular marker(s) linked to it in the place of phenotype generated by this allele is known as marker-assisted selection (MAS). This term was first used by Beckman and Soller (1983). Molecular breeding, on the other hand, is a more general term; it involves the use of molecular marker data for enhancing the effectiveness of various breeding activities, including planning and execution of breeding programs and improving selection efficiency. In plant breeding, molecular marker data are used for the following five groups of activities: (1) characterization of germplasm; (2) diversity analyses, and selection of parents for hybridization; (3) gene introgression, gene pyramiding, and

trait stacking; (4) MAS in segregating populations, including combined MAS; and (5) testing for genetic purity. MAS has been extensively used for transgene introgression (e.g., introgression of cry genes into maize inbred, cotton, etc., lines), germplasm conversion, introgression of genes for resistance to biotic stresses, and accumulation of QTLs having significant effects on the target trait. It is the process whereby DNA marker data is used to assist in the selection of breeding material in conjunction with or as a substitute for phenotypic screening.

2) Marker assisted backcrossing

Backcross breeding is a well-established method used to introgress a specific target gene from a donor line into the genomic background of a recipient (recurrent) parent (RP). The primary objective of this method is to reduce the donor genome content (DGC) in successive generations through repeated backcrossing, while retaining the desirable characteristics of the recipient parent (RP). Marker-assisted backcrossing (MABC) enhances the efficiency and precision of conventional backcross breeding by utilizing DNA markers. MABC is particularly effective for transferring single genes or major quantitative trait loci (QTLs) with large phenotypic effects. It enables precise introgression of a trait of interest while accelerating the recovery of the recurrent parent genome. The main goal of MABC is to integrate a specific gene from an agronomically inferior donor source into an elite breeding line, such that the final improved line contains only the desired gene from the donor, while the remainder of the genome is identical to the recipient parent. One of the earliest recognized advantages of molecular markers in plant breeding was their ability to accelerate the backcrossing process by reducing the number of generations required to recover the recurrent parent phenotype. The efficiency of MABC depends on several factors, including the size of the backcross population, the genetic distance between markers and the target locus, and the number of background markers used for genome recovery. Studies have shown that combining foreground and background selection leads to faster recovery of the recurrent parent genome compared to conventional backcrossing. However, recovery of the recurrent parent genome is slower on the chromosome carrying the target locus due to linkage between the donor allele and nearby genomic regions, which makes recombination events necessary to break this linkage. The three major selection steps in MABC are:

Foreground Selection

Foreground selection involves selecting plants that carry the donor allele at the target locus using tightly linked markers. The target gene is maintained in a heterozygous condition during backcross generations. After the final backcross, plants are selfed to obtain individuals homozygous for the donor allele. It is also called positive selection because it ensures the presence of the desired gene.

Recombinant Selection

Recombinant selection aims to reduce the size of the donor chromosome segment around the target gene. It identifies recombination events between the target gene and flanking markers. This helps minimize linkage drag, which refers to the transfer of undesirable genes along with the target gene.

Background Selection

Background selection uses markers unlinked to the target gene to accelerate recovery of the recurrent parent (RP) genome. It helps eliminate unwanted donor genome regions and reduces the number of backcross generations required. It is also called negative selection and is used for rapid variety enhancement or line conversion.

3) Genomic Selection

Genomic selection begins with the development of a representative training population that captures the genetic diversity of the target breeding program. The individuals in this training population are genotyped using a large number of evenly distributed molecular markers covering the entire genome at adequate density. Along with genotyping, the same individuals are extensively phenotyped for target traits of agronomic or economic importance. Phenotypic evaluation is carried out in replicated trials to minimize experimental error and improve data reliability. These trials are conducted across multiple locations to account for environmental variation. Preferably, phenotyping is also repeated over different years to enhance the accuracy of trait assessment. The high-quality phenotypic and genotypic data generated from the training population are then combined. This combined dataset is used to train the genomic selection model. During model training, statistical relationships between markers and traits are established. Marker effects are estimated using appropriate prediction models. The estimated model parameters are retained for subsequent use. The breeding population is then genotyped using the same set of markers employed in the training population. Unlike conventional selection methods, the breeding population is not subjected to phenotypic evaluation. Marker genotype data of the breeding population are used to predict genomic estimated breeding values. These GEBVs represent the genetic potential of each individual for the target traits. Based on the GEBV estimates, superior individuals or lines are identified. The selected individuals are advanced for further breeding or variety development. This approach enables faster selection cycles and accelerates genetic gain in plant breeding programs.

4) Genome- wide association selection

Genome-wide association studies, or whole genome association studies, investigate a genome-wide set of genetic variants in different varieties to see if any variant is associated with a trait. GWAS usually emphasize associations between SNPs and traits, for example, DNA of plant varieties is compared with different phenotypes for a particular trait. GWAS implementation is based on designs, genotyping technologies, and statistical concepts for analysis, replication, interpretation, and follow-up of association results. Linkage (group of alleles/genes) of the hereditary unit for traits in a population is passed on from parent to progeny. Changes in the linkage are due to mutations/breakage of linkage/SNPs and can be measured as linkage disequilibrium (LD). The concept behind GWAS is to assess SNPs in the genome-influencing phenotype. SNPs influencing phenotypes are assessed in two ways: either by direct association, or indirect association. When the SNP-influencing phenotype is directly genotyped and is statistically associated with the trait it is known as direct association; whereas, if the SNP is not directly genotyped, but is statistically associated to the phenotype, it is referred to as an indirect association. The correlation between allele and SNP in a population is performed for single-locus or multi locus analysis. If an association between each SNP and phenotype is examined independently, then it is a single-locus statistic test. If the association between each SNP and phenotype/trait is examined, then it is multi locus analysis.

Transgenic approach

1) Agrobacterium mediated transformation

Agrobacterium tumefaciens-mediated transformation begins when wounded plant cells release signaling molecules such as sugars, phenolic compounds, and acetosyringone. These plant signals are perceived by the bacterial sensor proteins ChvE and VirA present on the *Agrobacterium* cell membrane. Signal perception activates the VirA–VirG two-component regulatory system through phosphorylation. Activated VirG induces the expression of virulence (*vir*) genes located on the Ti

plasmid. The Ti plasmid carries the T-DNA region flanked by border sequences along with vir genes essential for transfer. Upon vir gene activation, the VirD1/VirD2 complex nicks the T-DNA borders and generates a single-stranded T-DNA molecule. VirD2 remains attached to the 5' end of the T-DNA, forming the initial T-DNA strand. The single-stranded T-DNA is coated by VirE2 proteins, producing a stable T-DNA complex. VirF and other effector proteins also associate with the T-DNA complex. The T-DNA and virulence proteins are transported out of the bacterial cell through the type IV secretion system (T4SS) formed by VirB and VirD4 proteins. The T-DNA complex is delivered into the plant cell cytoplasm. Inside the plant cell, host factors interact with the virulence proteins to facilitate transport. Nuclear localization signals present on VirD2 and VirE2 guide the T-DNA complex toward the nucleus. The T-DNA and effector proteins are actively imported into the plant nucleus. Once inside the nucleus, the T-DNA integrates into the plant genome through illegitimate recombination. The integrated T-DNA genes are expressed under plant cellular machinery. Expression of auxin and cytokinin biosynthetic genes leads to tumor (crown gall) formation. Opine synthesis genes are also expressed in transformed plant cells. The produced opines are secreted and taken up by *Agrobacterium* through opine permeases. *Agrobacterium* utilizes opines as a unique carbon and nitrogen source. This completes the *Agrobacterium*-mediated gene transfer and stable plant transformation process.

2) Genome editing approaches

Genome editing enables precise introgression of desirable traits into elite crop varieties without linkage drag. Target genes controlling agronomic traits are first identified using genomic and functional studies. Sequence-specific nucleases such as CRISPR/Cas9 are designed to target these genes. The genome editing construct is delivered into plant cells through suitable transformation methods. The nuclease creates site-specific double-strand breaks at the target locus. Cellular DNA repair mechanisms introduce precise mutations or desired edits. Edited plants are regenerated and screened for the target modification. Off-target effects are minimized through careful guide RNA design. The edited trait is stably inherited in subsequent generations. Genome editing thus accelerates trait introgression compared to conventional breeding methods.

Conclusion

Careful selection of starting material for genetic transformation and precise gene integration can maximize the benefits of crop improvement. Before marker-assisted backcrossing (MABC), a major cost involves developing genetic linkage maps. Identifying genes or QTLs associated with economically important traits also requires significant investment. These costs are often prohibitively high for developing countries. Breeders in developing regions require much higher returns on investment due to limited resources and infrastructure. The high cost of molecular markers currently restricts the wide adoption of MABC. Reducing marker costs through new marker technologies can greatly enhance marker-assisted selection. Therefore, developing efficient and cost-effective MABC systems is crucial for combining important agronomic traits from diverse genetic sources.

Reference

- Singh, Brahma Deo, and Ashok Kumar Singh. "Marker-assisted plant breeding: principles and practices." (2015): 978-81.
- Visarada, K.B.R.S., Meena, K., Aruna, C., Srujana, S., Saikishore, N. and Seetharama, N. 2009. Transgenic breeding: perspectives and prospects. *Crop Science*, 49(5): 1555-1563.

SOLAR RADIATION CONVERSION INTO DRY MATTER PRODUCTION

V. Kishanth Kanna^{1*}, Vibin Sankar² and Athira S³

¹ Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

^{2&3} Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: kishanthkanna@gmail.com

Abstract

Solar radiation is the primary source of energy driving photosynthesis and dry matter production in crops. The interception and utilization of radiation depend on leaf area index (LAI), canopy structure, radiation intensity, spectral quality, and duration. Photosynthetically Active Radiation (PAR; 400–700 nm) plays a crucial role in biomass accumulation, flowering, and physiological regulation. Radiation use efficiency (RUE), defined as biomass produced per unit of intercepted radiation, varies among crops and determines productivity. Factors such as cloud cover, temperature, water availability, and nutrient status influence radiation interception and conversion efficiency. Excess radiation combined with high temperature may reduce tillering, whereas adequate radiation during grain filling enhances yield components. Crop growth models help isolate the specific effects of solar radiation on yield formation. Among major crops, sugarcane exhibits comparatively higher radiation use efficiency due to its C₄ photosynthetic pathway.

Keywords: Solar radiation, PAR, Radiation Use Efficiency, Leaf Area Index, Dry matter production

Introduction

Sunlight is a key environmental factor in almost all ecosystems, and the many ecological effects of visible and infrared wavelengths have long been known. Along with water and nutrients, solar radiation (sunlight) is an essential input for plant growth. Plant leaves absorb sunlight and use it as an energy source in the process of photosynthesis. The photosynthetic apparatus of some plant species appears to be well-protected from direct damage from UV-B radiation. A crop's ability to collect sunlight is proportional to its leaf surface area per unit of land area occupied, or its "leaf area index (LAI)". At "full canopy" development, a crop's LAI and ability to collect available sunlight are maximized. From full canopy through the reproductive period, any shortage of sunlight is potentially limiting to yield.

Solar Radiation

Solar radiation is radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy. The spectrum of solar radiation is close to that of a black body with a temperature of about 5800 K. About half of the radiation is in the visible short-wave part of the electromagnetic spectrum.

Solar Constant

Solar constant, the total radiation energy received from the sun per unit of time per unit of area on a theoretical surface perpendicular to the sun's rays and at earth's mean distance from the sun. 1.951 cal./Min/cm², or 1.951 langley per minute.

Importance of The Solar Radiation For The Crop Production

Solar radiation is the primary driving force and sole energy source for photosynthesis in crop production. However, its effective utilization is limited by factors such as low atmospheric carbon dioxide, poor canopy structure causing mutual shading, and insufficient water or mineral nutrients. Solar radiation (SRAD) significantly influences biomass production, yield, and grain quality. Adequate SRAD during stem elongation and grain filling enhances 1000-grain weight, whereas low radiation during grain filling reduces yield. Conversely, excessive SRAD combined with high temperature and saturation deficit may reduce tiller formation. Establishing a direct statistical relationship between SRAD and grain yield is difficult due to interactions with cloud cover, rainfall, temperature, and management practices. Crop growth models help isolate the specific role of SRAD in yield formation by minimizing interference from other environmental and agronomic factors.

Solar Radiation Interception By Plants

SI.NO	CROP	ALBEDO (%)
1	RICE	11-21
2	WHEAT	16-23
3	MAIZE	16-23
4	COTTON	20-22
5	ALFALFA	2-5
6	GRASS (DRY)	31-33
7	GRASS (GREEN)	26-27

Three Aspects of Solar Radiation Are Biologically Significant

The shorter-than-visible wavelength radiation segment in the solar spectrum is chemically very active. When plants are exposed to excessive amounts of this radiation, the effects are detrimental. However, the atmosphere acts as a regulator in this type of solar radiation. Solar radiation in the higher-than-visible wavelength segment, referred to as infrared radiation, has thermal effects on plants. In the presence of water vapours, this radiation does not harm plants; rather, it supplies the necessary thermal energy to the plant environment. The third spectrum, lying between the ultraviolet and infrared, is the visible part of solar radiation and is referred as light. This segment of solar radiation plays an important part in plant growth and development through the processes of chlorophyll synthesis and photosynthesis and through photosensitive regulatory mechanisms such as phototropism and photoperiodic activity.

- **The first is the intensity of radiation**, the amount of radiant energy falling on a unit of surface area in a unit of time.
- **The second is the spectral distribution of radiation** that governs the photochemical process of photosynthesis.
- **The third aspect is the radiation distribution in time**, which is important for photoperiodic phenomenon.)

The intensity of radiation and spectral distribution of radiation within crop canopies is important because of its control of the photosynthetic process and the microclimate of the plant community. The rate of photosynthesis is dependent on the availability of PAR. The rate of transpiration is also controlled by radiation energy. The capture of radiation and its use in dry matter production

depends on the fraction of the PAR. PAR is the amount of light available for photosynthesis which is light of 0.4 μm or 400 nm wave length to 0.7 μm or 700nm wave length. PAR changes seasonally and arises depending on latitude and time of a day. Higher PAR promotes the plants growth and it is important to ensure that plants are receiving adequate light. PAR at night is 0. PAR values range from 0 to 300 millimoles/ m^2 . PAR is measured by silicon photovoltaic detector. Thus, detector measures the light in 400 to 700 nm range. Intercepted radiation (S_i) is often estimated as the difference between the quantity incident radiation (S) and that transmitted through the canopy of the soil (S_t).

$$S_i = S - S_t$$

The quantity of radiation intercepted (S_i) depends on the amount received by the canopy, canopy size duration and fraction interception (f). f is defined as S_i/S .

Factors Affecting The Distribution of Solar Radiation Within The Plant Canopy

The distribution of radiation in a plant canopy is determined by several factors, such as transmissibility of the leaf, leaf arrangement and inclination, plant density, plant height and the angle of the sun. Leaves of deciduous trees, herbs and grasses (including cereals) have transmissibility ranging from 5 to 10%. The broad leaves of ever green plants have a value 2 to 8%. Transmissibility varies slightly with the age of the leaf. The transmissibility of young leaf is relatively high. With the maturing of the leaf, it declines but then rises again as the leaf turns yellow. The transmissibility of a leaf directly related to its chlorophyll content. Plant height is also having an important part. In case of young plants, the % of light interception is low but when height increases, interception of light by the canopy increases. This governs by Beer's law.

$I = I_0 e^{-kf}$; Where, I =Intensity of light at a particular height within the canopy, I_0 =Intensity at the top, k =Extension coefficient, $f=LAI$.

Light of the correct intensity, quality, and duration is essential for normal plant development. Poor light availability is frequently responsible for plant abnormalities and disorders. Virtually all plant parts are directly or indirectly influenced by this part of the spectrum. It affects the production of tillers; the stability, strength, and length of the culms; the yield and total weight of plant structures and the size of leaves and root development. The length of day or the duration of the light period determines flowering and has a profound effect on the content of soluble carbohydrates present. The majority of plants flower only when exposed to certain specific photoperiods. It is on the basis of this response that the plants have been classified as short-day plants, long-day plants, and day-neutral plants. When other environmental factors are not limiting it, photosynthesis increases with longer duration of the light period.

Radiation use efficiency: Defined as the quantity of biomass produced per unit of intercepted radiation (g MJ^{-1}). Radiation use efficiency (RUE, $\text{g} \cdot \text{mJ}^{-1}$) is defined as the ratio of accumulated crop mass (i.e. Dry matter) to cumulative intercepted solar radiation. It is a key factor in the determination of the photosynthetic performance of plants growing in any environment. Leaf area development is critical for maximum interception of solar radiation and the achievement of high crop productivity. Daily radiation absorbed by the canopy was then determined from the calculated. Extinction coefficient, incoming and reflected PAR, and interpolated leaf area index estimated between radiation measurements. Accumulated dry matter (DM) is a function of accumulated daily absorbed PAR and radiation use efficiency (RUE). The efficiency of solar radiation utilization can be computed by comparing the calorific value of organic matter produced

per unit of cultivated area, with the incident radiation on the same area during the same period. A leaf exposed to full sunlight cannot be expected to be completely efficient in the utilization of light energy for photosynthesis. For example, in sugar beet at very low light intensity, the efficiency is as high as 17%, which declines to about 2% when the light intensity is increased to 400 lux/day.

Dry matter production, and efficiency of radiation utilization for several crops

Crop	Yield(tons/hectare)	Efficiency (%)
Potato	9.6	0.5
Winter wheat	10.45	0.52
Sugar beet	16.00	0.92
Corn	15.52	1.05
Sugarcane	129.48	1.43

Conclusion

The efficiency of radiation utilization by crops generally decreases with increasing light intensity beyond the optimum level, mainly due to saturation of the photosynthetic apparatus and increased photorespiration. Different crops vary in their ability to convert intercepted radiation into biomass, and among them, Sugarcane exhibits one of the highest radiation use efficiencies because of its C₄ photosynthetic pathway, which allows better carbon fixation under high light and temperature conditions. Photosynthetically Active Radiation (PAR), which includes wavelengths between 400–700 nm, plays a crucial role in plant growth and development, particularly in photosynthesis and the regulation of flowering. Within the PAR region, blue and red wavelengths are especially important, as red light is highly effective in driving photosynthesis, while blue light regulates stomatal opening, chlorophyll synthesis, and photomorphogenic responses. Therefore, both the quantity and quality of light significantly influence crop productivity and physiological performance.

References

- Amthor, J. S. (2010). From sunlight to phytomass: on the potential efficiency of converting solar radiation to phyto-energy. *New Phytologist*, 188(4), 939-959.
- Zhu, X. G., Long, S. P., & Ort, D. R. (2008). What is the maximum efficiency with which photosynthesis can convert solar energy into biomass?. *Current opinion in biotechnology*, 19(2), 153-159.

MARKER FREE TRANSGENIC: A SUSTAINABLE PATH TO CROP IMPROVEMENT

V. Kishanth Kanna^{1*}, Yogesh V. Wayal² and Banka Vaishnavi³

¹ Department of Plant Physiology, College of Agriculture, Vellanikkara,
Kerala Agricultural University, Thrissur - 680656, Kerala, India.

^{2&3} Yogesh V. Wayal, Ph.D. Scholar, Department of Genetics and Plant Breeding,
College of Agriculture, Vellayani, Kerala Agricultural University,
Thiruvananthapuram - 695522, Kerala, India.

*Corresponding Email: kishanthkanna@gmail.com

Abstract

Marker-free transgenic technology represents a sustainable and biosafety-oriented approach to crop improvement. Although selectable marker genes such as antibiotic and herbicide resistance genes are essential for identifying transformed cells, their presence in final products raises regulatory and public concerns. This article highlights major strategies for developing marker-free transgenic plants, including complete avoidance of marker genes, replacement with screenable or non-toxic markers, co-transformation, site-specific recombination systems (Cre/lox, FLP/FRT), and transposon-based approaches (Ac/Ds). These techniques enable precise removal or segregation of marker genes while retaining the gene of interest. Marker-free systems facilitate transgene pyramiding, reduce biosafety risks, and enhance public acceptance of genetically engineered crops. Despite technical and regulatory challenges, continuous advancements in molecular tools are expected to simplify approval processes and expand the adoption of clean transgenic technologies for sustainable agriculture.

Keywords: Marker-free transgenics, Selectable marker genes, Site-specific recombination, Co-transformation, Crop improvement.

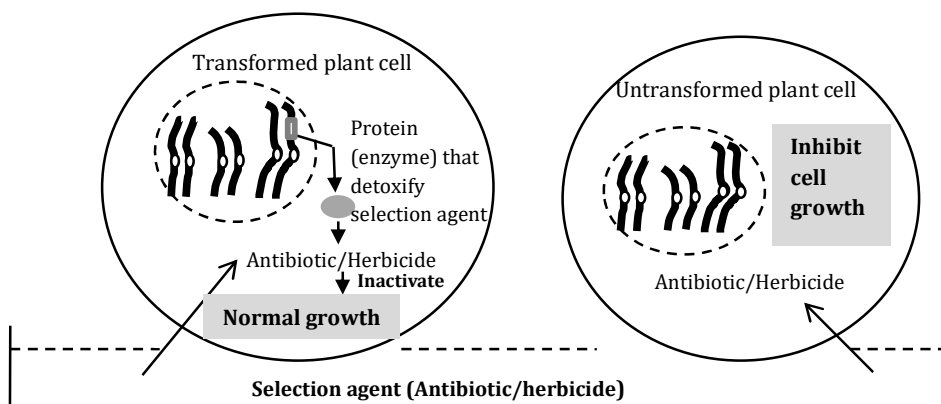
Introduction

Plant transformation is the introduction of foreign genetic material into plant cells using biological vectors like *Agrobacterium tumefaciens* or physical methods such as biolistics, enabling stable gene integration and expression. It is widely used to develop crops with improved traits like stress tolerance, disease resistance, higher yield, and enhanced nutritional quality, which are difficult to achieve through conventional breeding. During transformation, marker genes are introduced along with the target gene to identify and confirm successful DNA transfer, since transformation occurs at low frequency and transformed cells cannot be visually distinguished. Marker genes help in selecting transformed cells from a large population of non-transformed cells. They are classified into two types as selectable markers and screenable markers.

A. Selectable marker genes

The selectable marker genes (SMGs) are widely used during early stages of transformation because they allow transformed cells to survive in selective media containing toxic agents, while untransformed cells die, thereby simplifying and accelerating the screening process. Commonly used antibiotic resistance marker genes include *nptII*, which confers resistance to kanamycin, and *hpt*, which provides resistance to hygromycin, due to their reliability and effectiveness across many plant species. In addition, herbicide resistance marker genes such as *bar*, conferring

resistance to phosphinothricin (Basta), and *EPSPS*, providing resistance to glyphosate (Roundup), are employed for efficient selection at both laboratory and field levels, making marker genes indispensable tools in plant genetic transformation.



B. Screenable marker genes

Screenable marker genes are used to identify transformed cells without eliminating non-transformed cells. Unlike selectable marker genes, they do not confer lethality, but instead produce easily detectable visual signals, making the screening process non-destructive. These markers are considered safer alternatives to selectable marker genes (SMGs), especially in plant biotechnology. They allow researchers to distinguish transformed tissues based on color development, fluorescence, or light emission, without affecting cell viability. For examples of screenable marker genes such as β -glucuronidase, green fluorescence protein, luciferase.

Marker free transgenic strategies

Strategy 1: Complete Avoidance of Marker Genes

This strategy aims to generate transgenic plants without the use of selectable or screenable marker genes. Instead of relying on antibiotic or herbicide resistance for selection, putative transformants are directly identified using molecular detection techniques. Transgenic events are confirmed by analyzing the presence, copy number, and integration of the target gene at the DNA level. Commonly employed molecular techniques include PCR for rapid detection of the transgene, Southern blotting to confirm stable integration and copy number, Real-time qPCR for quantitative assessment of transgene presence.

This approach completely eliminates biosafety concerns associated with marker genes and results in “clean” transgenic plants. This strategy faces several practical constraints such as very low transformation efficiency, highly labor-intensive and time-consuming, requiring screening of a large number of regenerants, unsuitable for large-scale or commercial applications, particularly in crops with poor regeneration efficiency.

Strategy 2: Replacement of Selectable Marker Genes (SMGs) with Screenable or Non-Toxic Markers

In this strategy, antibiotic or herbicide resistance genes are replaced with screenable or non-toxic markers. Unlike conventional selectable markers that kill non-transformed cells, these markers provide a metabolic or developmental advantage, allowing identification of transformed cells

without lethal selection. This approach is considered more biosafety-friendly and reduces physiological stress on plant tissues, sometimes improving regeneration efficiency.

Types of Screenable / Non-Toxic Markers

1. Enzyme-Based Markers

These markers encode enzymes whose activity can be easily detected or exploited for selective growth:

- GUS (β -glucuronidase): Produces a blue coloration in the presence of X-Gluc, allowing histochemical identification of transformed tissues.
- Xylose Isomerase: Enables transformed cells to metabolize xylose as a carbon source, providing a growth advantage under selective conditions.
- Phosphomannose Isomerase (PMI): Allows utilization of mannose by converting it into fructose-6-phosphate, thereby supporting the growth of transformed cells while non-transformed cells show restricted development.

2. Phytohormone-Related Markers

These markers influence plant growth and regeneration by altering hormone metabolism or sensitivity:

- ipt (isopentenyl transferase) gene: Increases endogenous cytokinin levels, promoting shoot formation and enhanced regeneration of transformed tissues.
- rol A, B, and C genes: Modify cellular sensitivity to plant growth regulators, resulting in distinctive morphological traits that facilitate visual identification of transformants.

Limitations: Though safer, these markers still introduce foreign DNA and may affect normal plant growth.

Strategy 3: Co-Transformation

Co-transformation involves the simultaneous delivery of two independent T-DNAs into the plant genome during a single transformation event:

- One T-DNA carries the selectable marker gene (SMG)
- The other T-DNA carries the gene of interest (GOI)

Since the two T-DNAs often integrate at unlinked genomic loci, normal Mendelian segregation during sexual reproduction enables the separation of the GOI from the SMG in subsequent generations. As a result, progeny plants containing only the GOI and lacking the SMG can be identified.

Methods of Co-Transformation:

1. **Two Agrobacterium strains:** Each strain harbors a different binary vector—one containing the SMG and the other containing the GOI.
2. **Two vectors in the same Agrobacterium strain:** A single Agrobacterium strain carries two separate binary vectors, each delivering a different T-DNA.
3. **Two-T-DNA system within one binary vector:** Both the SMG and GOI are present on separate T-DNAs within the same plasmid, allowing independent integration.

Limitations: Requires sexual reproduction, making it unsuitable for vegetatively propagated crops or trees with long generation cycles. Time-consuming due to the need for progeny screening

Strategy 5: Site-Specific Recombination (SSR)

Site-specific recombination is one of the most precise and widely used strategies for the elimination of selectable marker genes (SMGs) from transgenic plants. In this system, the SMG is flanked by short, specific DNA recognition sequences, and the expression of a corresponding recombinase enzyme catalyzes recombination between these sites. This recombination event leads to the accurate excision of the marker gene, leaving behind the gene of interest (GOI) in the plant genome. The recombination reaction is highly specific and does not require host factors, making SSR systems effective across a wide range of plant species.

Major Site-Specific Recombination Systems

System	Source Organism	Recognition Site	Recombinase Enzyme
Cre/lox	Bacteriophage P1	loxP (34 bp)	Cre recombinase (≈38 kDa)
FLP/FRT	Yeast (2μ plasmid)	FRT (34 bp)	FLP recombinase
R/RS	Yeast recombinase system	RS	R recombinase

In all systems, directly oriented recognition sites result in marker excision, while inverted orientations can cause inversion of the intervening DNA segment.

Strategy 6: Transposon-Based Removal of Selectable Marker Genes (Ac/Ds System)

The transposon-based strategy exploits the maize Activator/Dissociation (Ac/Ds) transposable element system for the elimination of selectable marker genes (SMGs). In this system worked as two system such as Ac (Activator) element is an autonomous transposon that encodes the transposase enzyme required for transposition. The Ds (Dissociation) element is non-autonomous and can transpose only in the presence of Ac-encoded transposase.

Application in Transgenic Plants:

During transformation, both the SMG and the gene of interest (GOI) are introduced within the same T-DNA region, with either the SMG or GOI placed inside the Ds element. Expression of the Ac transposase triggers mobilization of the Ds element, leading to transposition events such as relocation of the GOI to a new genomic locus, allowing segregation of the SMG in subsequent generations and relocation of the SMG to a different locus, enabling its removal while retaining the GOI. Through genetic segregation or molecular screening, plants containing only the GOI and lacking the marker gene can be identified.

Advantages: Effective in vegetatively propagated crops, where sexual segregation-based methods are not feasible. Does not rely on recombinase systems or inducible promoters.

Disadvantages and Limitations: Random and unpredictable insertion sites, increasing the risk of insertional mutagenesis. Potential genome instability due to continued transposase activity. Labour-intensive and costly, requiring extensive screening and molecular characterization.

Conclusion and future prospects

Removal of marker genes from transgenic plants allows multiple transformation cycles and facilitates transgene pyramiding for crop improvement. Several reliable strategies for marker elimination have been developed and successfully demonstrated. These approaches help address biosafety concerns and improve public acceptance of genetically engineered crops. Although no marker-free transgenic crop has yet been commercially released due to regulatory and technical limitations, ongoing advances in marker-free technologies are expected to ease approval

processes. Overall, marker-free transgenics hold great potential for strengthening future crop improvement and biotechnology programs.

Reference

- Darbani, B., Eimanifar, A., Stewart Jr, C. N., & Camargo, W. N. (2007). Methods to produce marker-free transgenic plants. *Biotechnology Journal: Healthcare Nutrition Technology*, 2(1), 83-90.
- Puchta, H. (2003). Marker-free transgenic plants. *Plant Cell, Tissue and Organ Culture*, 74, 123-134.
- Tuteja, N., Verma, S., Sahoo, R. K., Raveendar, S., & Reddy, I. B. L. (2012). Recent advances in development of marker-free transgenic plants: regulation and biosafety concern. *Journal of biosciences*, 37, 167-197.

HIGH-THROUGHPUT PHENOTYPING OF PLANTS FOR CROP IMPROVEMENT

R. Jeevanraj^{1*}, Athira S² and Laxmi P. S³

¹Department of Plant Physiology, College of Agriculture, Vellanikkara,
Kerala Agricultural University, Thrissur - 680656, Kerala, India.

²Department of Floriculture and Landscaping, College of Agriculture,
Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Department of Postharvest Management, College of Agriculture,
Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: jeevanrajasekar19@gmail.com

Introduction

The agricultural sector faces unprecedented challenges in the 21st century, including the need to feed a growing global population and ensure sustainable food production systems. Modern plant breeding programs have become increasingly sophisticated, leveraging genomic tools and molecular markers to accelerate crop improvement. A technological gap limits these techniques. Even though genotyping is now fast and cheap, the ability to measure observable crop traits (phenotyping) has not advanced at the same speed. This gap, called the "phenotyping bottleneck," is a major challenge in modern plant science.

High-throughput phenotyping (HTP) has emerged as a transformative approach to address this challenge. By integrating advanced imaging technologies, sensors, robotics, and data analytics, HTP enables the automated, non-destructive measurement of plant traits at scales and speeds previously unattainable through conventional manual methods. This technological revolution is fundamentally changing how researchers and breeders evaluate plant performance, moving from subjective visual assessments to objective, quantitative measurements of hundreds or thousands of traits simultaneously. The implications extend beyond efficiency gains; HTP provides access to phenotypic information that would be impossible to capture manually, including subtle temporal changes, three-dimensional architectural features, and physiological responses invisible to the human eye.

The significance of HTP becomes clear when considered within the broader framework of plant biology and breeding. Understanding the relationship between genotype and phenotype is essential for crop improvement, yet this relationship is mediated by complex gene-environment interactions that vary across developmental stages and environmental conditions. High-throughput phenotyping provides the temporal resolution and environmental coverage needed to dissect these dynamic relationships, generating the rich phenotypic datasets required to exploit genomic information and accelerate breeding cycles fully.

Fundamental Concepts in Plant Genetics and Phenotyping

The genotype refers to the specific genetic makeup of an organism, representing the set of alleles it possesses for a particular gene or set of genes. These genetic instructions are inherited and encoded within the DNA, forming the blueprint from which all biological characteristics potentially arise. For example, in a pea plant, the genotype for flower color could be expressed as

homozygous dominant (GG), heterozygous (Gg), or homozygous recessive (gg). The genotype remains constant throughout an organism's lifetime and is determined at conception, though different portions of the genetic code may be activated or silenced depending on developmental stage and environmental conditions. In modern plant breeding, genotyping has become highly efficient through next-generation sequencing technologies, enabling the rapid identification of genetic variants associated with desirable agronomic traits.

The phenotype is the observable physical manifestation of an organism's genotype, encompassing all of the organism's observable characteristics, including appearance, development, and behavior. Importantly, the phenotype results from the interaction between the genotype and environmental factors, making it inherently dynamic and context-dependent. While a pea plant's genotype (GG or Gg) might code for purple flowers, the actual purple color observed is its phenotype. Environmental conditions such as temperature, light intensity, water availability, and nutrient status can significantly influence how genetic potential is realized in observable traits. This genotype-by-environment interaction explains why the same genetic variety may perform differently across locations or growing seasons, and underscores the importance of phenotyping under relevant environmental conditions.

The phenome is defined as the complete set of all phenotypes expressed by an organism throughout its life. Unlike the phenotype, which often refers to a single trait or small group of traits at a particular time point, the phenome encompasses all traits across all developmental stages, from metabolic processes and disease resistance to growth rate and yield. The phenome represents the entire dynamic state of an organism as it interacts with its environment over its lifespan. This concept recognizes that plant characteristics are not static but change continuously in response to internal developmental programs and external environmental cues. For instance, the phenome of a wheat plant includes germination vigour, early seedling growth, tillering capacity, flowering time, grain-filling rate, and final yield, along with countless biochemical and physiological processes occurring simultaneously.

Phenomics is the large-scale, systematic study of the phenome. It involves the high-throughput collection of complex phenotypic data from entire organisms or populations, often measuring thousands of traits simultaneously. Modern phenomics utilizes advanced technologies such as multispectral and hyperspectral imaging, LiDAR sensors, thermal cameras, fluorescence detection systems, and robotics to capture comprehensive phenotypic information in an automated, non-destructive manner. The goal of phenomics is to link specific genotypes to their corresponding phenomes, providing a deeper understanding of how genes are expressed and how they interact with environmental factors. This systems-level approach generates datasets of unprecedented size and complexity, requiring sophisticated computational tools and statistical methods for data management, analysis, and interpretation.

Plant Phenotyping

Plant phenotyping is the process of precisely measuring and analyzing a plant's observable physical traits. The primary objective is to identify and select plants with desirable characteristics, such as high yield, disease resistance, drought tolerance, or improved nutrient use efficiency. Traditional phenotyping methods relied heavily on manual measurements and visual scoring, which were time-consuming, labour-intensive, subjective, and limited in the number of plants and

traits that could be evaluated. These conventional approaches often became the rate-limiting step in breeding programs, particularly when large segregating populations needed to be screened across multiple environments. The evolution from traditional plant phenotyping to high-throughput phenotyping represents a paradigm shift that is enabling plant scientists to measure more traits, on more plants, more frequently, and with greater accuracy than ever before.

Need for Plant Phenotyping

To meet the demands of a global population projected to reach nearly 10 billion by 2050, food production must increase by 25%–70%. However, this goal is severely compromised by biotic threats, such as pests and diseases, and abiotic stressors like drought, extreme temperatures, and salinity. Plant phenotyping emerges as a critical solution to these challenges by providing the essential data needed to breed resilient crop varieties. By quantifying how different genotypes respond to environmental stress, breeders can select for traits that maintain high productivity under adverse conditions, thereby ensuring a stable future food supply.

Significance of High-Throughput Phenotyping

High-Throughput Phenotyping (HTP) revolutionizes agricultural science by overcoming the limitations of manual assessment. It enables rapid, automated, and non-destructive data acquisition on a large scale. This multidisciplinary approach integrates plant breeding, genetics, and physiology with engineering and bioinformatics to efficiently measure complex traits. HTP acts as a bridge between genomics and phenomics to link genetic information to observable performance. This connection facilitates targeted crop improvement. Automated systems enhance data reproducibility and minimize human error, which allows for the detection of subtle phenotypic variations. Additionally, advanced imaging technologies enable the non-invasive analysis of root architecture and growth dynamics to improve understanding of nutrient and water uptake.

Technological Platforms for Phenotyping

HTP implementation relies on diverse platforms tailored to specific research needs. Ground-based systems often utilize robotics to navigate fields or greenhouses and capture high-resolution measurements of individual plants. Unmanned Aerial Vehicles (UAVs) equipped with multispectral sensors offer a cost-effective solution for monitoring crop health and stress responses across vast areas. For post-harvest analysis, specialized yield quality platforms employ non-destructive technologies such as X-ray Computed Tomography (CT). These tools assess internal economic traits, including grain filling and fruit composition, without compromising sample integrity.

Sensors Used in High-Throughput Phenotyping:

Sensor Type	Function & Application
2D & Stereo Vision Cameras	Measures physical traits such as plant height, leaf area, and 3D canopy structure. These systems provide a visual representation of plant morphology.
Infrared Thermal Imaging	Detects water stress by measuring the temperature of a plant's leaves. When a plant is stressed, it closes its stomata, causing its temperature to rise, which can be detected early with this sensor.

Sensor Type	Function & Application
Near-Infrared (NIR) Imaging	Used to assess overall vegetation health. It is highly sensitive to changes in a plant's chlorophyll and water content, which are key indicators of stress or disease.
Chlorophyll Fluorescence Imaging	Measures the efficiency of photosynthesis by analyzing the light re-emitted by chlorophyll. This provides a highly sensitive, non-invasive method for detecting early signs of stress before visible symptoms appear.
Hyperspectral Imaging	A powerful sensor that captures data across hundreds of narrow spectral bands. This allows for detailed analysis of a plant's biochemical composition, nutrient status, and disease diagnostics, and can also be used for yield forecasting.
Fluorescence Imaging	Maps the location and concentration of secondary metabolites and can be used to monitor gene expression through autofluorescence, providing insights into a plant's metabolic state.
LIDAR (Light Detection and Ranging)	An active sensor that uses laser pulses to generate precise 3D models of a plant's canopy, allowing for accurate measurement of plant architecture, volume, and biomass. It is especially useful for capturing a plant's physical structure without the need for ideal lighting conditions.

Field-Based High-Throughput Phenotyping

Field-based HTP employs sensor-integrated platforms such as ground vehicles, cable robots, and drones to evaluate plant populations under realistic agronomic conditions. Unlike controlled greenhouse settings, this approach captures the complexity of variable field environments and enables the rapid screening of vast germplasm collections. Most importantly, it facilitates the analysis of Genotype $\times$ Environment (G $\times$ E) interactions, which provides breeders with critical data to develop crop varieties optimized for actual farming landscapes.

Conclusion

The future of crop improvement depends on the seamless integration of genotyping and phenotyping. High-Throughput Phenotyping (HTP) serves as a transformative technology that drives the development of resilient and productive crop varieties. To maximize the potential of HTP, researchers must prioritize the continuous standardization and calibration of methods to ensure data quality across diverse platforms. Looking ahead, the field anticipates major advancements through the integration of AI and machine learning for real-time trait prediction.

Reference

- Abebe, A.M., Kim, Y., Kim, J., Kim, S.L. and Baek, J., 2023. Image-based high-throughput phenotyping in horticultural crops. *Plants*, 12(10), p.2061.
- Araus, J.L. and Cairns, J.E., 2014. Field high-throughput phenotyping: the new crop breeding frontier. *Trends in plant science*, 19(1), pp.52-61.

- Gill, T., Gill, S.K., Saini, D.K., Chopra, Y., de Koff, J.P. and Sandhu, K.S., 2022. A comprehensive review of high-throughput phenotyping and machine learning for plant stress phenotyping. *Phenomics*, 2(3), pp.156-183.
- Yang, W., Feng, H., Zhang, X., Zhang, J., Doonan, J.H., Batchelor, W.D., Xiong, L. and Yan, J., 2020. Crop phenomics and high-throughput phenotyping: past decades, current challenges, and future perspectives. *Molecular plant*, 13(2), pp.187-214.

TRANSGENICS FOR IMPROVING NITROGEN FIXATION: A FRONTIER IN SUSTAINABLE AGRICULTURE

R. Jeevanraj^{1*}, Banka Vaishnavi² and Vibin Sankar³

¹Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

²Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram - 695522, Kerala, India.

³Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: jeevanrajasekar19@gmail.com

Introduction

Nitrogen (N) is a fundamental macronutrient essential for all living organisms, serving as a primary constituent of amino acids, nucleic acids (DNA and RNA), and chlorophyll. Although dinitrogen gas comprises approximately 78% of Earth's atmosphere, it is metabolically inaccessible to most plants due to the stability of its triple bond. Historically, the discrepancy between crop nitrogen demand and soil availability has been bridged by synthetic fertilizers produced via the Haber-Bosch process. While this industrial method successfully synthesizes ammonia under high temperature and pressure, it is energetically exorbitant and environmentally deleterious, contributing significantly to greenhouse gas emissions and aquatic eutrophication. This unsustainable reliance on chemical inputs highlights the urgent need to harness Biological Nitrogen Fixation (BNF) natural enzymatic process mediated by prokaryotes that reduces atmospheric nitrogen to ammonia under ambient conditions.

Mechanisms and Classification of Nitrogen Fixation

The transformation of atmospheric dinitrogen (N₂) into biologically available nitrogen is a fundamental process sustaining terrestrial and agricultural ecosystems. This conversion occurs through four principal pathways, among which biological nitrogen fixation (BNF) constitutes the predominant natural mechanism, accounting for nearly 90% of global nitrogen inputs. In contrast, physical fixation driven by lightning accounts for approximately 8%, while photochemical reactions involving ozone constitute a minor fraction (~2%).

Within agricultural systems, BNF is mediated by diazotrophic microorganisms that harbour the nitrogenase enzyme complex capable of reducing N₂ to ammonia. These microorganisms are traditionally classified according to the nature and extent of their association with plant hosts.

Free-living diazotrophs, including genera such as *Azotobacter* and *Clostridium*, fix nitrogen autonomously in soil. Although the fixed nitrogen is primarily utilized for microbial metabolism, it becomes available to plants indirectly through microbial turnover and subsequent mineralization processes. Associative diazotrophs, exemplified by *Azospirillum* spp., colonize the rhizosphere or root surfaces without forming specialized symbiotic structures. Their proximity to plant roots limits nitrogen transfer and promotes plant growth through combined nutritional and hormonal effects.

In contrast, symbiotic diazotrophs represent the most efficient and evolutionarily advanced nitrogen-fixing systems. Members of genera such as *Rhizobium* establish highly specialized mutualistic relationships with leguminous plants, resulting in the formation of root nodules. These nodules function as dedicated organs for nitrogen fixation, enabling direct and regulated nutrient exchange between the host and the microsymbiont. Due to their high efficiency, legume–rhizobia symbioses serve as a model for contemporary efforts to engineer or enhance nitrogen-fixing capabilities in non-leguminous crop species.

Genetic Regulation of Nitrogen Fixation

Biological nitrogen fixation is governed by a tightly regulated network of bacterial and host-derived genes that ensure efficient nitrogen reduction while protecting the oxygen-sensitive nitrogenase complex. Among these, nodulation (*nod*) genes play a critical role during the early stages of symbiosis, mediating host recognition, infection thread formation, and root nodule organogenesis. In contrast, nitrogen fixation (*nif*) genes encode the structural components of the nitrogenase enzyme complex, including *nifH*, *nifD*, and *nifK*, as well as accessory proteins required for enzyme assembly, maturation, and electron transfer. Complementing this system, *fix* genes regulate nitrogenase expression and activity, particularly under microaerobic conditions, thereby coordinating nitrogen fixation with cellular respiration.

The nitrogenase enzyme itself is composed of two metalloproteins: the Fe protein (dinitrogenase reductase) and the MoFe protein (dinitrogenase). Together, these components catalyze the ATP-dependent reduction of atmospheric N₂ to ammonia, a process that requires a substantial energy input of approximately 16 ATP molecules per N₂ molecule reduced. To protect nitrogenase from oxygen inactivation while sustaining bacterial respiration, leguminous plants synthesize leghemoglobin, an oxygen-binding protein that buffers free oxygen levels within root nodules.

Limitations of Natural Biological Nitrogen Fixation

Despite its ecological significance, natural BNF is largely restricted to leguminous crops, whereas major cereal species such as rice, wheat, and maize remain dependent on synthetic nitrogen fertilizers. Moreover, the efficiency of BNF is highly sensitive to environmental stresses, including drought and salinity, which impair both microbial activity and host–symbiont interactions. These constraints highlight the need to expand nitrogen-fixing capacity beyond legumes to improve nitrogen-use efficiency, reduce fertilizer inputs, and mitigate environmental pollution. However, such efforts are challenged by the complexity of nitrogen fixation gene networks, the oxygen sensitivity of nitrogenase, high metabolic costs, and the requirement for precise spatial and temporal regulation of gene expression within plant hosts.

Transgenic and Synthetic Strategies to Enhance Nitrogen Fixation

Recent advances in plant biotechnology and synthetic biology have enabled multiple strategies aimed at improving or introducing nitrogen fixation in non-leguminous crops. One approach involves the direct transfer of *nif* gene clusters from diazotrophic bacteria into plant nuclear or chloroplast genomes. Chloroplast-based expression is particularly promising due to the organelle's ATP-rich environment, reduced oxygen levels, and lower propensity for gene silencing.

An alternative strategy focuses on enhancing plant–microbe associations by modifying host traits that favour colonization by nitrogen-fixing bacteria. This includes engineering root exudate composition and manipulating immune signalling pathways to promote beneficial microbial

interactions. Building on this concept, synthetic symbiosis approaches aim to reconstruct key elements of legume nodulation signalling in non-legume crops, such as Nod factor perception and downstream signalling cascades, to generate pseudo-nodules capable of housing nitrogen-fixing bacteria.

In parallel, chloroplast engineering has emerged as a viable platform for expressing core nitrogenase genes (*nifH*, *nifD*, and *nifK*), providing a controlled intracellular environment conducive to nitrogenase function. Additionally, microbiome engineering and synthetic biology approaches seek to optimize plant–microbe interactions by tailoring root exudates (e.g., flavonoids or rhizopines) and programming diazotrophic bacteria to express nitrogen fixation genes under plant-derived regulatory control.

Recent years have witnessed significant experimental progress toward extending biological nitrogen fixation (BNF) to non-leguminous crops. A major breakthrough has been the heterologous expression of legume Nod factor receptors in cereals such as rice and maize, which enabled these plants to perceive rhizobial signals and activate early symbiotic signalling pathways. These studies provided the first functional evidence that core components of legume symbiosis can operate in non-legume genetic backgrounds, thereby overcoming a long-standing recognition barrier.

Parallel advances have been achieved through direct genetic engineering of nitrogen fixation pathways. Chloroplast transformation approaches have successfully expressed core *nif* genes in tobacco and rice, demonstrating partial nitrogenase activity in a low-oxygen, ATP-rich intracellular environment. In addition, the transfer of minimal *nif* gene clusters into *Arabidopsis* resulted in detectable nitrogenase function, marking an important step toward autonomous nitrogen fixation in plants and validating the feasibility of simplified genetic architectures.

Beyond plant-centric strategies, microbiome and synthetic ecology approaches have expanded the scope of nitrogen fixation in cereals. Engineered barley lines capable of secreting rhizopines have been shown to selectively activate nitrogenase expression in associative bacteria, while synthetic bacterial consortia have been developed that contribute fixed nitrogen within cereal xylem sap. These experimental advances are being integrated into large-scale, collaborative research initiatives aimed at translating laboratory success into field-level performance for staple crops. Collectively, these breakthroughs demonstrate that transgenic, synthetic, and microbiome-based strategies are converging toward the long-term goal of sustainable nitrogen fixation in cereals.

Table 1: Engineering Root System Architecture for better nitrogen uptake

Trait	Details	Effect/Benefit
OsTOND1 (Thaumatin-like protein)	Enhances root elongation under nitrogen deficiency	Boosts root length, plant height, chlorophyll content, grain yield, and nitrogen uptake
DRO1 (Deeper Rooting 1)	Promotes deeper root growth for drought tolerance and improved nutrient access	Enhances yield by ~10% under low nitrogen conditions

Trait	Details	Effect/Benefit
OsMADS25	Key transcription factor regulating root growth and nitrogen signaling in rice	Increases biomass and growth under low nitrogen
TAR2.1 in Wheat	Involved in auxin biosynthesis and lateral root formation	Knockdown mutants have impaired lateral root growth critical for nitrogen foraging

Conclusion

Future efforts to engineer biological nitrogen fixation in crops will focus on overcoming oxygen sensitivity, metabolic cost, and regulatory complexity. Key strategies include constructing synthetic intracellular compartments to shield nitrogenase from oxygen, stacking synthetic gene modules with custom promoters for precise spatial and temporal control, and deploying CRISPR–Cas–based genome editing to insert and optimize *nif* gene clusters in crop genomes. Complementary approaches such as engineering leghemoglobin or alternative oxygen-scavenging proteins in non-legumes and designing custom root microbiomes to enhance associative nitrogen fixation are expected to further improve system efficiency and robustness, particularly under field conditions.

In conclusion, the convergence of genetic engineering, synthetic biology, microbiome manipulation, and root system optimization provides a realistic pathway toward sustainable nitrogen fixation in cereal crops. Transgenic and gene-editing technologies enable stable, targeted expression of nitrogen fixation pathways, while continued resolution of metabolic and regulatory constraints will be essential for large-scale deployment. Collectively, these advances have the potential to substantially reduce dependence on synthetic nitrogen fertilizers, lower environmental impacts, and support global food security through more sustainable agricultural systems.

References

- Guo, K., Yang, J., Yu, N., Luo, L. and Wang, E., 2023. Biological nitrogen fixation in cereal crops: Progress, strategies, and perspectives. *Plant Communications*, 4(2).
- Lal, S.K., Gaggar, P., Kumar, S., Mallikarjuna, M.G., Vishwakarma, C., Rakshit, S., Pandey, A., Achary, V.M.M. and Mehta, S., 2024. Recent Advancements in Nitrogen Use Efficiency in Crop Plants Achieved by Genomics and Targeted Genetic Engineering Approaches. *Plant Molecular Biology Reporter*, 42(3), pp.435-449.
- Sandhu, N., Sethi, M., Kaur, H., Dhillon, A., Kumar, A., Kaur, A., Kaur, S., Bentley, A.R. and Chhuneja, P., 2023. Mining natural genetic variations for nitrogen use efficiency utilizing nested synthetic hexaploid wheat introgression libraries. *Environmental and Experimental Botany*, 212, p.105394.
- Wan, T.E.N.G., Xue, H.E. and Yi-ping, T.O.N.G., 2017. Transgenic approaches for improving use efficiency of nitrogen, phosphorus and potassium in crops. *Journal of integrative agriculture*, 16(12), pp.2657-2673.

DECODING THE STAPLE CROP: GENOME SEQUENCING OF RICE (*Oryza sativa*)

R. Jeevanraj¹, Chaithra B. S² and Yogesh V. Wayal³

¹Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

²Assistant Professor, Kadiri Baburao College of Agriculture, C. S. Puram - 523112, Andhra Pradesh, India.

³Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram - 695522, Kerala, India.

*Corresponding Email: jeevanrajasekar19@gmail.com

Introduction

Understanding the genetic architecture of plants is central to modern agriculture, evolutionary biology, and food security. Genome sequencing, the systematic determination of the complete DNA sequence of an organism, provides a foundational reference that enables researchers to identify, characterize, and manipulate genes controlling virtually every aspect of plant biology. From photosynthesis and nutrient uptake to disease resistance and grain quality, nearly all agriculturally relevant traits have a genetic basis that can only be fully interrogated once a reference genome is available.

Before genome sequencing became feasible, plant geneticists relied on classical Mendelian approaches and molecular markers to map traits to chromosomal regions. While powerful, these approaches lacked resolution. Genome sequences transformed this landscape by providing base-pair-level maps that allow researchers to clone genes directly, compare genomes across species, and apply computational tools to predict gene function at scale. For crop improvement, sequencing is no longer an academic exercise but a practical necessity underpinning modern plant breeding pipelines.

Historical Background of the Rice Genome Project

Rice (*Oryza sativa* L.) is cultivated on over 160 million hectares worldwide and serves as the primary caloric source for more than 3.5 billion people. Its biological characteristics made it an attractive target for the first crop genome sequencing effort: a relatively small genome of approximately 389 megabases (Mb), a diploid chromosome number of $2n = 24$, and a short generation time that facilitated experimental validation. Two major subspecies dominate global agriculture: japonica, grown in temperate East Asia, and indica, prevalent across tropical and subtropical Asia.

In 1998, a ten-nation consortium formed the International Rice Genome Sequencing Project (IRGSP) with the explicit goal of producing a high-quality, publicly available genome sequence of the japonica subspecies (cultivar Nipponbare). After seven years of coordinated effort, the finished sequence was published in *Nature* in 2005, covering approximately 370 Mb of the 389 Mb genome with greater than 99.99% accuracy. Concurrently, draft sequences of japonica and indica were released by Monsanto (2000) and the Beijing Genomics Institute (2002), respectively,

accelerating research even before the finished sequence was available. The rice genome thus became the reference standard against which all other grass genomes would be anchored.

Clone-by-Clone vs. Whole-Genome Shotgun Sequencing

The IRGSP chose the hierarchical shotgun sequencing strategy, commonly known as clone-by-clone sequencing. This approach begins by constructing a physical map of the genome using large-insert clones housed in bacterial artificial chromosomes (BACs), each containing 100 to 150 kilobases (kb) of genomic DNA. Individual BAC clones, selected to provide overlapping coverage of each chromosome, were shotgun-sequenced independently and assembled into contiguous sequences (contigs). The ordered, minimally overlapping set of BAC clones, called a tiling path, was then merged to reconstruct each chromosome.

The primary advantage of clone-by-clone sequencing is accuracy and long-range assembly continuity. By working with discrete, mapped chromosomal segments, researchers could resolve repetitive sequences that would otherwise collapse or mismatch in a global assembly. The principal disadvantage is cost and time: generating, fingerprinting, and sequencing thousands of individual BAC clones required extensive infrastructure and international coordination.

In contrast, whole-genome shotgun (WGS) sequencing, used by the private efforts, randomly shears genomic DNA into small fragments, sequences them in parallel, and uses computational algorithms to assemble overlapping reads into a draft genome. WGS is substantially faster and cheaper but was prone, at the time, to assembly errors in repeat-rich regions. For rice, the WGS drafts provided useful gene catalogs but lacked the structural accuracy and chromosomal continuity of the IRGSP finished sequence.

Sequencing Platforms and Technologies

All sequencing carried out by the IRGSP used Sanger sequencing, the capillary electrophoresis-based method developed by Frederick Sanger in the 1970s. Sanger sequencing generates reads of 600 to 1,000 base pairs with very high per-base accuracy, typically exceeding 99.9%. These reads, generated from sub-cloned BAC shotgun libraries, were assembled using software such as Phrap and Consed, and finished through targeted resequencing of gaps and low-quality regions until each BAC met the stringent quality threshold of fewer than one error per 10,000 bases.

Since the completion of the IRGSP project, sequencing technology has undergone a revolution. Next-generation sequencing (NGS) platforms, particularly Illumina short-read sequencing, produce hundreds of millions of short reads (100 to 300 bp) per run at dramatically reduced cost, enabling the re-sequencing of thousands of rice accessions for population-level studies. More recently, long-read platforms, including Pacific Biosciences (PacBio) Single-Molecule Real-Time (SMRT) sequencing and Oxford Nanopore Technology (ONT), produce reads spanning tens of thousands of base pairs. These long reads are especially valuable for resolving repetitive regions, centromeres, and structural variants that remained intractable with short-read methods.

Genome Size, Gene Number, and Structure

The finished IRGSP sequence spans approximately 370 Mb of euchromatin distributed across 12 chromosomes, with the total genome estimated at 389 Mb when heterochromatic regions are included. Gene prediction algorithms identified between 32,000 and 38,000 protein-coding genes, a surprisingly high number given the compact genome size. This density reflects the evolutionary pressure on grasses toward genomic parsimony, in stark contrast to the bloated genomes of crops

like wheat (~17,000 Mb) and maize (~2,300 Mb). The rice genome thus emerged as the ideal reference model for the grass family (Poaceae), enabling comparative genomic studies across economically important cereals.

Chromosomal structure analysis revealed that gene-rich regions are concentrated toward chromosome arms, while centromeric and pericentromeric regions are relatively gene-sparse and heavily loaded with transposable elements. Gene density varies across the genome, with some chromosomal arms exhibiting markedly higher gene content than others. This structural information has since guided efforts to prioritize chromosomal regions for detailed functional analysis.

Repeat Sequences and Transposable Elements

Repetitive sequences constitute approximately 35 to 40% of the rice genome, a proportion far lower than that of maize (approximately 85%) but still substantial. The dominant repeat class consists of long terminal repeat (LTR) retrotransposons, which replicate via an RNA intermediate and can expand genome size rapidly. The two main LTR superfamilies, Gypsy and Copia elements, show distinct chromosomal distributions: Gypsy elements are enriched in centromeric and pericentromeric heterochromatin, while Copia elements are more dispersed. Centromeric regions of all 12 chromosomes contain characteristic satellite repeats interspersed with Gypsy-class retrotransposons, a feature shared across many grass genomes.

Understanding repeat content is not merely an academic exercise. Repetitive elements can disrupt gene function through insertion, drive genomic rearrangements, and confound assembly algorithms. The IRGSP dataset provided the first detailed annotation of rice transposable elements, enabling downstream studies into the role of epigenetic silencing (particularly DNA methylation and small RNA pathways) in suppressing transposon activity throughout the plant life cycle.

Notable Gene Families and Traits

Beyond raw gene counts, the rice genome sequence enabled systematic identification of gene families with agricultural significance. The nucleotide-binding site leucine-rich repeat (NBS-LRR) gene family, responsible for recognizing pathogen-derived effector proteins and triggering immunity, was found to contain over 500 members, many clustered in resistance gene hotspots on chromosomes 6 and 11. The cytochrome P450 superfamily, involved in hormone metabolism, detoxification, and biosynthesis of secondary metabolites, comprises more than 350 members. Expansins and receptor-like kinases (RLKs) involved in developmental signalling were also substantially larger gene families than those found in the dicot model plant *Arabidopsis thaliana*.

Comparative genomics between japonica and indica subspecies, made possible by the availability of both genome sequences, revealed approximately 80,000 single-nucleotide polymorphisms (SNPs) and more than 50,000 insertion-deletion variants (indels) between the two. These data immediately underscored the genetic breadth existing within a single species and highlighted the importance of sequencing diverse accessions beyond a single reference genome.

Breeding Improvements

The rice reference genome catalyzed a new era of gene-based breeding. Map-based cloning, the identification of a gene solely through its chromosomal map position, became routine. This approach led to the isolation of genes with enormous agricultural impact. Sub1A, a transcription factor on chromosome 9, was found to confer submergence tolerance for up to two weeks in

flooding conditions, a trait critical for farmers in flood-prone regions of South and Southeast Asia. Its characterization led directly to the development of Swarna-Sub1, a submergence-tolerant version of the popular Swarna variety, now grown across millions of hectares. Xa21, encoding a receptor-like kinase that confers broad-spectrum resistance to bacterial blight caused by *Xanthomonas oryzae*, was among the first resistance genes cloned in any crop and has been introduced into elite varieties by marker-assisted backcrossing.

Genome-wide association studies (GWAS) expanded the toolkit further. By combining genome sequences (or high-density SNP arrays) with phenotypic measurements across hundreds or thousands of diverse rice accessions, researchers have mapped hundreds of quantitative trait loci (QTLs) for traits including grain length, heading date, panicle architecture, nitrogen use efficiency, and arsenic accumulation. This population-level genomic approach replaced the earlier laborious QTL mapping in biparental crosses, providing finer resolution and broader applicability across breeding programs.

Conclusion

Despite the success of the project, the 2005 IRGSP assembly left centromeric, telomeric, and rDNA regions unresolved, either collapsed into consensus repeats or left as sequencing gaps due to their highly repetitive nature. These are not trivial omissions: centromere function, telomere stability, and rDNA copy number variation carry real biological consequences that remained inaccessible for decades.

Genome assembly becomes substantially more difficult in polyploid cereals. Bread wheat, a hexaploid with three sub-genomes (A, B, and D) totalling roughly 15,000 Mb, demanded over a decade of international effort to produce a working reference, and disambiguating homeologous genes across sub-genomes remains an open problem. The rice genome, far more tractable by comparison, served as both the methodological blueprint and the comparative anchor for these more demanding efforts.

References

- Xu, K., Xu, X., Fukao, T. *et al.* *Sub1A* is an ethylene-response-factor-like gene that confers submergence tolerance to rice. *Nature* 442, 705–708 (2006).
- International Rice Genome Sequencing Project., Sasaki, T. The map-based sequence of the rice genome. *Nature* 436, 793–800 (2005).
- Wen-Yuan Song *et al.* A Receptor Kinase-Like Protein Encoded by the Rice Disease Resistance Gene, *Xa21*. *Science* 270, 1804–1806 (1995).

FROM LAB TO LAND: HOW NEW CROP VARIETIES ARE DEVELOPED

Yogesh V. Wayal^{1*}, Banka Vaishnavi² and Vibin Sankar³

¹Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram -695522, Kerala, India.

²Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram - 695522, Kerala, India.

³Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: jeevanrajasekar19@gmail.com

Abstract

The development of new crop varieties is essential for ensuring food security, climate resilience, and sustainable agricultural production. With increasing challenges such as drought, heat stress, soil degradation, and emerging pests, plant breeding plays a vital role in strengthening crop performance. This article explains the complete journey of how a new crop variety is developed from identifying problems in farmers' fields to parent selection, crossing, generation advancement, stress screening, multi-location trials, and final release. The process, which often takes eight to twelve years, reflects the dedication and scientific effort behind every improved seed that reaches farmers' fields.

Keywords : Plant Breeding; Crop Improvement; Genetic Variation; Variety Release; Food Security

Agriculture in an Era of Uncertainty

Agriculture has always been dependent on nature, but today it faces greater uncertainty than ever before. Climate change has altered rainfall patterns, increased the frequency of droughts, and raised average temperatures. In many regions, farmers struggle with water scarcity and declining soil fertility. At the same time, new pests and diseases are emerging due to changing climatic conditions. These challenges threaten crop productivity and farmers' livelihoods.

In such a situation, improving crop varieties becomes one of the most powerful solutions available. A strong variety can tolerate stress, resist diseases, and provide stable yields even under difficult conditions. Unlike fertilizers or pesticides, which require continuous application, genetic improvement is a long-term and sustainable solution. Once a superior variety is developed and adopted, its benefits continue for years.

The Beginning: Identifying the Need

The journey of a new crop variety begins not in a laboratory, but in farmers' fields. Scientists observe crop performance, interact with farmers, and study production constraints. Sometimes yields are declining due to drought. Sometimes disease outbreaks cause severe damage. In other cases, traditional varieties may not meet modern market demands.

Clearly identifying the problem is the foundation of the breeding program. For example, if farmers frequently face water shortages, the objective may be to develop drought-tolerant varieties. If a

particular disease spreads rapidly, resistance breeding becomes the focus. Without a clear objective, breeding efforts cannot be effectively directed.

This stage connects research institutions with real agricultural needs. It ensures that scientific work remains practical and farmer-oriented.

Exploring Genetic Resources

Once the objective is defined, breeders search for suitable genetic material. This may include local varieties, advanced breeding lines, or even wild relatives of the crop. Genetic diversity is the raw material of plant breeding. Without variation, improvement is impossible.

Some plants may possess deep root systems that help them survive drought. Others may carry genes for disease resistance. These valuable traits are identified through evaluation and experimentation. Germplasm collections maintained in research institutes play an important role at this stage, as they preserve a wide range of genetic diversity for future use.

Parent Selection and Controlled Crossing

After identifying promising genetic resources, breeders select parent plants that complement each other. One parent may have high yield potential, while another may show strong stress tolerance. The goal is to combine the best traits from both into a single improved line.

Controlled pollination is then carried out to ensure accurate crossing. This involves transferring pollen from one selected parent to the flower of another. The seeds produced from this cross represent the F1 generation. These plants usually show uniform growth due to the combination of parental genes.

Although the F1 generation is important, it does not yet represent the final product. The real opportunity for selection begins in subsequent generations.

Genetic Recombination and Selection

The F2 generation is where genetic diversity becomes clearly visible. Due to recombination of genes, plants show wide variation in height, flowering time, yield, stress response, and other traits. Some plants may inherit favorable combinations of genes that make them superior.

Breeders carefully observe each plant and select the most promising individuals. Undesirable plants are removed. The selected plants are advanced to the next generation. This process of selection continues through F3, F4, F5, and sometimes F6 generations.

With each generation, plants become more uniform and stable. However, this requires patience, careful record-keeping, and repeated field trials. Generation advancement alone may take several years, depending on the crop and breeding method used.

Evaluating Performance Under Stress

A promising plant must prove its strength under real stress conditions. If drought tolerance is the objective, plants are grown under limited irrigation to test their response. Researchers observe wilting behavior, root growth, flowering stability, and yield under stress.

Similarly, if disease resistance is required, plants are exposed to the target pathogen under controlled conditions. Only those lines that show consistent resistance are selected.

This stage ensures that the new variety is not only productive under ideal conditions but also resilient under practical farming environments. Stability under stress is a key requirement for variety release.

Multi-Location Trials and Stability Testing

Agricultural environments vary greatly across regions. Soil type, rainfall distribution, temperature range, and farming practices differ from one location to another. Therefore, a variety that performs well in one place must be tested in several environments before release.

Multi-location trials are conducted to evaluate adaptability and stability. Data on yield performance, resistance level, and quality traits are collected from different sites. Statistical analysis helps determine whether the variety consistently outperforms existing checks.

This stage is crucial because farmers depend on reliability. A variety must perform steadily across seasons and locations to gain farmers' trust.

Quality Assessment and Farmer Acceptance

In addition to yield and resistance, quality parameters are also evaluated. Grain size, color, cooking quality, nutritional value, and market acceptability are important factors. A high-yielding variety may not succeed if it does not meet consumer preferences.

In some cases, participatory trials are conducted where farmers evaluate promising lines under their own field conditions. Their feedback helps researchers understand practical performance and acceptability.

Official Release and Seed Multiplication

After successful testing, detailed performance data are submitted to the variety release committee. Experts evaluate whether the new line offers significant improvement over existing varieties. If approved, the variety is officially released and notified.

Seed multiplication begins immediately after release. Breeder seed is produced first, followed by foundation seed and certified seed. Agricultural extension agencies and seed corporations play a vital role in distributing seeds to farmers.

Only after this entire process does the variety finally reach farmers' fields.

Time, Dedication, and Scientific Commitment

The development of a new crop variety typically takes eight to twelve years. Behind every improved seed lies the dedication of plant breeders, scientists, field technicians, and agricultural workers. Thousands of plants are grown, observed, and evaluated before one superior line is selected.

This long journey reflects the commitment of agricultural research toward ensuring food security and farmer welfare. Each improved variety represents a solution to a real agricultural problem.

A Sustainable Future Through Plant Breeding

In the face of climate change and resource limitations, plant breeding offers hope for sustainable agriculture. Developing varieties that require less water, resist diseases, and produce stable yields is essential for feeding future generations.

The journey from lab to land is not just a scientific process—it is a bridge between research and rural livelihoods. Every improved crop variety tells a story of perseverance, innovation, and dedication. When farmers sow a new variety, they sow years of research and the promise of a better harvest.

References

- Sun, L., Lai, M., Ghouri, F., Nawaz, M. A., Ali, F., Baloch, F. S., ... & Shahid, M. Q. (2024). Modern plant breeding techniques in crop improvement and genetic diversity: From molecular markers and gene editing to artificial intelligence—A critical review. *Plants*, 13(19), 2676.
- Cooper, M., & Messina, C. D. (2023). Breeding crops for drought-affected environments and improved climate resilience. *The Plant Cell*, 35(1), 162-186.
- Begna, T., & Teressa, T. (2024). Genetic variability and its benefits in crop improvement: A review. *Middle East Journal of Agriculture Research*, 13(1), 128-136.

GROWING MORE WITH LESS WATER: HOW FARMERS CAN BEAT DROUGHT THROUGH SMART PRACTICES

Yogesh V. Wayal^{1*}, Athira S² and Laxmi P. S.³

¹ Department of Genetics and Plant Breeding College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram, Kerala 695522

²Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³ Department of Postharvest Management, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: hushalmuradi2361998@gmail.com

Abstract

Water scarcity and drought are increasingly affecting farms across many regions. This article explains, in simple, farmer-friendly language, practical approaches for managing water efficiently, improving crop performance under drought, and enhancing agricultural sustainability. It highlights field-tested practices such as soil moisture improvement, crop selection, rainfall harvesting, and plant protection strategies that help farmers grow more with limited water. The goal is to help farmers adapt to water challenges using proven, affordable methods that increase resilience and farm productivity.

Keywords: Drought Management; Water Conservation; Soil Health; Sustainable Agriculture; Climate Resilience

Facing the Reality of Drought

For farmers, water is life. But today, many agricultural regions are facing increasingly erratic rainfall and prolonged dry spells. Reduced water availability affects germination, plant growth, and final crop yield. In many areas, farmers watch as their crops struggle under the harsh sun, soil cracks under drought stress, and harvests shrink year by year. These conditions are not just a one-time challenge — they represent a new climate reality that requires innovative thinking and smart farming strategies.

Understanding the nature of drought and its impact on crops is the first step toward adaptation. Drought does not affect plants suddenly; its effects begin in the soil long before the leaves show signs. When soil moisture drops, root development slows, nutrient uptake declines, and water stress accelerates plant aging. It becomes essential for farmers to adopt practices that conserve every drop of water and help crops endure dry conditions.

Improving Soil Moisture: The First Step

Healthy soil is the foundation of drought-resilient farming. Soil acts like a sponge — it stores water and makes it available to crops during dry spells. Farmers can improve soil moisture through regular addition of organic matter such as compost, farmyard manure, and crop residues. Organic matter increases the soil's ability to hold water, reduces evaporation, and improves soil structure.

Practices like mulching covering the soil surface with straw, leaves, or crop residue help in reducing water loss. Mulch acts as a protective blanket, keeping the soil cool and moist even

under hot sun. Farmers who use mulching often notice that soil feels moist longer after irrigation or rain, and crops show better growth during dry periods.

Conservation tillage is another important technique. Instead of deep plowing that exposes soil to sun and wind, reduced tillage leaves crop residues on the surface. This protects the soil from evaporation, minimizes erosion, and helps retain moisture for longer periods. By managing soil wisely, farmers lay the groundwork for crops that can better withstand water stress.

Choosing the Right Crops and Varieties

The choice of crop and crop variety plays a crucial role in drought resilience. Certain crops are naturally more tolerant of dry conditions. Pulses, millets, sorghum, and cowpea are good examples of crops that perform well under limited water supply. These crops have evolved to survive in tough environments and can yield even when rainfall is scarce.

Within each crop species, selecting drought-tolerant varieties enhances success. Improved varieties developed through plant breeding often have deeper roots, efficient water use, and stable yields under stress. Farmers are encouraged to choose such varieties from agricultural research centers or extension agencies. Combining drought-tolerant genetics with good management practices makes a strong defense against water scarcity.

Efficient Water Use on the Farm

Once the soil and crop choice are optimized, efficient water application becomes the next priority. Traditional flood irrigation may result in wasted water due to runoff and evaporation. Techniques like drip irrigation and sprinkler systems apply water directly to the plant root zone in measured amounts. This reduces waste and ensures that most of the applied water is available for crop use.

If modern irrigation systems are not available, even simple practices such as irrigating at cooler times of the day (early morning or late evening) can reduce evaporation losses significantly. Farmers can also improve water distribution by leveling their fields to prevent uneven water flow and pooling.

Rainwater harvesting capturing and storing rainfall for later use is another effective approach. Simple farm ponds, trenches, or contour bunds help collect rainwater and reduce runoff. Stored water can be used during dry periods to sustain crops when rainfall fails.

Protecting Crops During Stress

Even with good soil, crop choice, and water management, extreme drought can still stress plants. Farmers can help crops by maintaining adequate nutrition and protecting them from pests and diseases. Balanced fertilization strengthens plant health and improves drought tolerance. For example, adequate phosphorus helps in early root development, while potassium strengthens water regulation in plants.

Pest and disease outbreaks are common during stress conditions because weakened plants become more susceptible. Regular field monitoring and early intervention using sustainable pest-management measures help protect crops during tough environmental periods.

Agroforestry integrating trees with crops can also reduce wind speed, shade soil, and improve microclimate conditions. Trees act as natural windbreaks, reduce evaporation, and enhance biodiversity on farms.

Sharing Knowledge in the Community

Farmers do not face drought alone. Sharing knowledge within the community strengthens collective resilience. Farmer groups, cooperatives, and local extension services play a vital role in spreading awareness about drought-adapted practices. Participating in field demonstrations, group visits to research stations, and farmer workshops helps exchange practical experiences.

Local governments and agricultural organizations often provide resources such as drought-tolerant seeds, soil testing facilities, and irrigation subsidies. By staying informed and connected, farmers can benefit from science-based recommendations that improve their farming success.

Hope for a Water-Scarce Future

Water scarcity may be a growing challenge, but it does not have to be a barrier to productive farming. By improving soil health, choosing smart crop varieties, using water efficiently, and protecting crops under stress, farmers can adapt and thrive even in dry conditions. These practices do not require heavy investment they are based on knowledge, observation, and determination.

Agriculture has always adapted to change, and today's challenges call for a blend of tradition and innovation. With patience and smart planning, farmers can grow more with less water, secure stable yields, and safeguard their livelihoods for the future.

References

- El-Beltagi, H. S., Basit, A., Mohamed, H. I., Ali, I., Ullah, S., Kamel, E. A., ... & Ghazzawy, H. S. (2022). Mulching as a sustainable water and soil saving practice in agriculture: A review. *Agronomy*, 12(8), 1881.
- Soujanya, B., & Gurjar, D. S. (2024). Water-efficient crop production: Agronomic strategies for drought-prone areas. *Int. J. Res. Agron*, 7(12), 187-196.
- Zhang, W., Dong, A., Liu, F., Niu, W., & Siddique, K. H. (2022). Effect of film mulching on crop yield and water use efficiency in drip irrigation systems: A meta-analysis. *Soil and tillage Research*, 221, 105392.
- El-Beltagi, H. S., Basit, A., Mohamed, H. I., Ali, I., Ullah, S., Kamel, E. A., ... & Ghazzawy, H. S. (2022). Mulching as a sustainable water and soil saving practice in agriculture: A review. *Agronomy*, 12(8), 1881.

CAN PLANTS FIGHT CLIMATE CHANGE? THE HIDDEN POWER OF ROOTS

Yogesh V. Wayal¹, Deshmukh Sarita Babarao² and Choudhari Balaji Keshavrao³

¹Ph.D. Scholar, Department of Genetics and Plant Breeding College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram, Kerala 695522

^{2&3}Ph.D. Scholar, Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram – 695522, Kerala, India.

*Corresponding Email: hushalmuradi2361998@gmail.com

Abstract

Climate change is increasingly threatening global agriculture through rising temperatures, erratic rainfall, frequent droughts, and declining soil health. While most climate-smart solutions focus on visible plant parts such as leaves and shoots, an equally powerful but often overlooked ally lies beneath the soil—plant roots. Roots play a central role in water and nutrient uptake, soil stabilization, microbial interactions, and carbon storage. This article explores how root systems contribute to crop survival under climate stress, enhance soil resilience, and support carbon sequestration. By highlighting the hidden power of roots, it emphasizes the importance of root-focused research and breeding strategies in developing climate-resilient agriculture and ensuring future food security.

Keywords: Climate change, Plant roots, Root architecture, Drought tolerance, Soil health, Carbon sequestration, Climate-resilient agriculture.

Introduction

Climate change has emerged as one of the greatest challenges to modern agriculture. Across the world, farmers are facing rising temperatures, unpredictable rainfall patterns, extended droughts, and increasing soil degradation. These changes are not only reducing crop productivity but are also threatening food security, rural livelihoods, and environmental sustainability. Traditional agricultural practices and even high-yielding varieties are often unable to cope with these rapidly changing conditions.

When climate solutions are discussed, attention usually turns to irrigation systems, weather-based advisories, fertilizers, or improved crop varieties. However, one of the most powerful natural tools for climate resilience remains largely unnoticed because it lies hidden underground—the root system. Roots form the foundation of plant health. They anchor crops in the soil, absorb water and nutrients, interact with beneficial microorganisms, and store carbon in the soil.

Understanding and strengthening root systems offers a promising pathway to help crops withstand climate stress while also improving soil health and environmental sustainability. This article explores how roots contribute to drought tolerance, soil resilience, and climate change mitigation, revealing how the fight against climate change may begin beneath our feet.

Climate Change and the Silent Crisis in the Soil

Soil is not just dirt it is a living system. Climate change is disturbing this system through erosion, nutrient loss, reduced organic matter, and water scarcity. When rainfall becomes erratic, the

upper soil layers dry quickly, making it harder for plants to survive. Even if a plant has healthy leaves, weak or shallow roots cannot supply enough water and nutrients under stress.

Roots are the plant's first line of defense against climate extremes. They anchor the plant, absorb water and minerals, interact with billions of beneficial microorganisms, and store large amounts of carbon underground. Without strong and functional roots, crops become highly vulnerable to heat and drought.

The Hidden Power of Roots

Roots are far more intelligent and dynamic than they appear. Different crops develop different types of root systems depending on their genetics and environment. Some produce deep taproots that penetrate several feet into the soil, while others form dense, fibrous networks near the surface.

These underground structures allow plants to:

- Search for deep or scattered water sources
- Absorb nutrients efficiently
- Stabilize soil and reduce erosion
- Communicate chemically with beneficial microbes
- Store energy and carbon

Roots can also change their growth pattern when conditions become harsh. Under drought, many plants redirect their energy downward, extending roots deeper to reach moisture. This adaptability is one reason why roots are now at the center of climate-resilient agriculture.

Roots vs Drought: Nature's Survival Strategy

Drought is one of the most destructive outcomes of climate change. Shallow-rooted plants suffer quickly when surface moisture disappears. In contrast, crops with deep, thick, and well-branched roots can continue to absorb water stored in deeper soil layers long after rainfall stops.

This is why scientists are increasingly focusing on root architecture the depth, angle, thickness, and spread of roots. By identifying and breeding plants with superior root systems, researchers are developing crop varieties that use water more efficiently, survive longer dry spells, and maintain yield stability under stress.

For farmers, this means crops that are not only productive in good years, but also reliable in bad ones.

Roots and Soil: A Powerful Partnership

Roots do not work alone. They live in close partnership with soil organisms such as bacteria and fungi. Through root exudates—natural chemical secretions—plants feed beneficial microbes that, in return, help release nutrients, improve soil structure, and protect against some diseases.

Healthy root systems create healthy soils. They increase organic matter, improve water infiltration, and reduce nutrient losses. Over time, this leads to soils that can better withstand floods, droughts, and temperature extremes—making agriculture more climate-resilient from the ground up.

Roots as Climate Warriors: Storing Carbon Underground

One of the most remarkable roles of roots is their contribution to carbon sequestration. Plants absorb carbon dioxide from the atmosphere during photosynthesis. While some of this carbon is used above ground, a large portion is transferred below ground through roots.

Dead roots, root secretions, and microbial interactions help lock carbon into the soil as organic matter. Deep-rooted crops are especially valuable because carbon stored deeper in the soil remains there longer. In this way, plants are not only adapting to climate change they are actively helping to slow it.

Digging Deeper: Science Goes Underground

For a long time, roots were difficult to study. Digging them up destroyed their natural structure. Today, new technologies such as underground imaging, transparent growth systems, sensor-based monitoring, and molecular tools allow scientists to observe root growth without harming the plant.

Plant breeders are using this knowledge to develop varieties with:

- Improved drought and heat tolerance
- Better nutrient-use efficiency
- Stronger soil-binding capacity
- Greater adaptability to changing climates

This underground revolution is transforming crop improvement from a surface-focused science into a whole-plant approach.

What Stronger Roots Mean for Farmers and the Future

For farmers, root-focused crops can mean:

- More stable yields under stress
- Reduced dependence on irrigation
- Better fertilizer efficiency
- Healthier soils year after year

For society, it means stronger food security, improved environmental protection, and a more sustainable agricultural system.

A Future That Begins Below the Surface

We may not see roots, but they are quietly shaping the future of agriculture. As climate change intensifies, survival will depend not only on what grows above the ground, but on what grows below it. The next major breakthrough in climate-smart farming may not be taller plants or bigger leaves—but deeper, smarter, and stronger roots.

Because sometimes, the greatest solutions grow in the darkest places.

Conclusion

Climate change is forcing agriculture to rethink how crops are grown and improved. While leaves and grains receive most of the attention, it is the root system that often determines whether a plant survives or fails under stress. Strong, deep, and efficient roots help crops withstand drought, improve soil health, and store carbon in the ground.

By focusing on the hidden half of plants, scientists and farmers can develop more resilient cropping systems that protect food security and the environment. The future of climate-smart agriculture may not be visible above the surface—but it is already growing below it.

References

- Kalra, A., Goel, S. and Elias, A.A., 2024. Understanding role of roots in plant response to drought: Way forward to climate-resilient crops. *The plant genome*, 17(1), p.e20395.
- Singh, P.K., Singh, S., Manzoor, U. and Dubey, A., 2025. Enhancing Crop Sustainability through Climate-Resilient Agronomic Practices. *International Journal of Environment and Climate Change*, 15(6), pp.75-85.
- Dhawi, F. and Aleidan, M.M., 2024. Oasis agriculture revitalization and carbon sequestration for climate-resilient communities. *Frontiers in Agronomy*, 6, p.1386671.
- Ullah, F., Ali, S., Siraj, M., Akhtar, M.S. and Zaman, W., 2025. Plant Microbiomes Alleviate Abiotic Stress-Associated Damage in Crops and Enhance Climate-Resilient Agriculture. *Plants*, 14(12), p.1890.
- Sargar, P., Jwala, P., Thakur, N., Mehtre, S., Kalpande, H., Pawar, G., Chavan, S. and Habyarimana, E., 2025. Decoding Sorghum Root System Architecture for Resource Use Efficiency and Climate Resilience Under Multifactorial Stress Conditions. *Physiologia Plantarum*, 177(6), p.e70672.

EDIBLE FLOWERS IN MODERN CUISINE

Vibin Sankar¹, Deshmukh Sarita Babarao² and Choudhari Balaji Keshavrao³

¹Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

^{2&3} Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram -695522, Kerala, India.

*Corresponding Email: vibinsankar2016@gmail.com

Abstract

Edible flowers are emerging as a vibrant and innovative component of modern cuisine, transforming food beyond mere nourishment into a multisensory experience. Once confined to traditional dishes and royal feasts, flowers such as rose, marigold, hibiscus, pansy, nasturtium, and jasmine are now gaining renewed attention for their aesthetic appeal, unique flavours, and nutritional value. This popular article explores the role of edible flowers in contemporary gastronomy, highlighting their culinary versatility, sensory attributes, and growing importance as functional foods rich in antioxidants, vitamins, minerals, and bioactive phytochemicals. The article also discusses the contribution of edible flowers to dietary diversification, malnutrition alleviation, and sustainable agriculture, particularly through low-input cultivation systems suitable for small and marginal farmers. With increasing consumer interest driven by curiosity, novelty, health awareness, and social media influence, edible flowers are becoming valuable natural ingredients in beverages, desserts, salads, and savoury dishes. At the same time, the article emphasizes the importance of correct identification, safe cultivation, and responsible consumption. Overall, edible flowers represent a promising bridge between horticulture and gastronomy, offering opportunities for nutritional enhancement, culinary innovation, and alternative income generation within sustainable food systems.

Introduction

Once used mainly as garnishes in royal feasts and traditional cuisines, edible flowers are now making a vibrant comeback on modern plates. From fine-dining restaurants to home kitchens, flowers like nasturtium, pansy, marigold, and rose are transforming dishes into multisensory experiences, adding color, aroma, texture, and even subtle Flavors. What was once seen as decorative is now being rediscovered as nutritious and functional.

This renewed interest in edible flowers is driven by today's consumers who seek natural, aesthetic, and health-promoting foods. Many edible blooms are rich in antioxidants, vitamins, and bioactive compounds, linking beauty with wellness. Chefs value them for their ability to elevate presentation, while nutritionists and horticulturists recognize their untapped dietary and commercial potential. Beyond their visual appeal, edible flowers are becoming symbols of a broader food movement that celebrates diversity, locality, and sustainability. Farm-to-table dining has encouraged chefs to source fresh, locally grown blooms, often from small-scale floriculture farms or even their own kitchen gardens. This not only ensures freshness and safety but also connects consumers more closely to the origins of their food.

Edible flowers also bring unique sensory elements to cuisine. Some offer peppery or citrus-like notes, others a mild sweetness or herbal hint. For example, nasturtiums provide a spicy kick

similar to watercress, while rose petals lend a delicate floral sweetness to desserts and beverages. These subtle Flavors allow chefs to experiment creatively, turning ordinary recipes into memorable culinary experiences.

At the same time, social media and food photography have played a major role in popularizing edible flowers. A beautifully garnished dish can quickly capture attention online, inspiring home cooks to explore floral ingredients themselves. This visual appeal has helped edible flowers move from niche gourmet spaces into mainstream culinary culture. However, with this growing popularity comes the need for awareness. Not all flowers are edible, and safe consumption depends on correct identification, pesticide-free cultivation, and proper handling. This is where the role of floriculture experts and researchers becomes important, ensuring that edible flowers are not only attractive and flavourful but also safe and sustainably produced.

In many ways, the rise of edible flowers represents a reunion between horticulture and gastronomy. It reminds us that flowers are more than ornamental, they can be flavourful, functional, and culturally meaningful. As modern cuisine continues to evolve, edible flowers are likely to remain a blooming trend that delights both the eye and the palate.

Varieties of Edible Flowers

Edible flowers include nearly 180 species, ranging from fruit flowers such as banana and citrus blossoms to ornamental flowers like hibiscus, begonia, and calendula. Some commonly eaten vegetables—such as broccoli, cauliflower, and artichoke—are also flower parts. However, this article focuses only on ornamental edible flowers. Ornamental edible flowers are widely valued for their color, flavor, and culinary versatility. Many are used in beverages, herbal infusions, salads, soups, desserts, and garnishes. Flowers such as chive (*Allium schoenoprasum*) add a mild onion-garlic flavor, while begonia, hibiscus, and geranium offer refreshing citrus-like notes. Some flowers, including chrysanthemum, marigold, dandelion, nasturtium, and pansy, have a slightly bitter taste and are popular in both sweet and savory dishes, especially in Asian cuisines. Others like jasmine, lavender, chamomile, bougainvillea, tulip, and mallow have sweet or floral flavors and are commonly used in desserts, syrups, and drinks.

Most edible flowers have a delicate, pleasant taste, and some resemble familiar foods, making them more acceptable to consumers. Sensory studies show that certain flowers taste like fruits or vegetables, for example, begonia resembles lemon, borage tastes like cucumber, and nasturtium resembles radish. Beyond flavor, edible flowers are gaining attention in the food industry as natural additives. Flowers such as bougainvillea, butterfly pea, and hibiscus act as natural colorants, while hibiscus and mallow, rich in mucilage, function as natural thickeners. Consumer surveys indicate a high acceptance level, highlighting the strong potential of edible flowers in modern diets.

Nutritional Composition of Edible Flowers

Edible flowers are gaining attention not only for their beauty and flavor but also for their nutritional and health benefits. They contain a range of essential nutrients and bioactive compounds that support a balanced diet. Fresh edible flowers are made up mostly of water (70–90%), which means their dry matter content is low. As a result, a large quantity of fresh flowers is needed to obtain a small amount of dried product. Although their nutritional composition varies among species, some common patterns are observed. Edible flowers are a good source of protein

and dietary fiber, with protein levels ranging roughly from 2% to 23%. Their fat content is generally low (usually below 10%), while natural sugars are often present in higher amounts, contributing to their mild sweetness and pleasant taste.

Edible flowers are particularly rich in dietary fiber, including non-digestible components such as cellulose, pectin, mucilage, and gums, which are beneficial for digestion and provide very few calories. They also contain notable amounts of minerals, reflected by their ash content.

In addition to basic nutrients, edible flowers provide valuable phenolic compounds, vitamins, flavonoids, and carotenoids, which are known for their antioxidant and health-promoting properties. These components make edible flowers not just decorative ingredients, but also functional foods with promising nutritional value.

Nutraceutical properties of edible flowers:

1. **Phytochemicals** are biologically active, non-nutritive, naturally occurring chemical compounds found in plants, which impart human health benefits as medicinal constituents. The most common phytochemicals found in edible flowers are phenolic acids, carotenoids, flavonoids, including anthocyanins. Flower colour is attributed due to the presence of carotenoids and flavonoids, which also impart antioxidant power to the flowers. Phytochemicals of marigold particularly lutein and flavonoids are reported to have anti-inflammatory, free radical scavenging and cytotoxic effects against various cancerous cells.



Marigold – *Tagetes* spp

2. **Anthocyanin** compounds have a high free radical scavenging capacity and play an important role in the prevention of cancer, cardiovascular disease, obesity, diabetes and other diseases. Rose, chrysanthemum, hibiscus, pelargonium, petunia and pansy are the rich source of anthocyanin pigment.
3. **Carotenoids** play vital role in human/animal nutrition since new carotenoids cannot be synthesized; therefore, they must be absorbed from natural foods and supplements. Researches have shown that carotenoids can reduce peril of vitamin A deficiency, age-related macular degeneration (AMD), cataracts, photoprotection, cancer, and cardiovascular diseases. Various studies revealed that marigold flowers are potential

source of lutein and its derivatives which group of phytochemicals found in edible flowers for instance, honeysuckle.



Rose – *Rosa* spp



Hibiscus – *Hibiscus rosa-sinensis*



**Chrysanthemum -
Chrysanthemum ×
*morifolium***



Honeysuckle - *Lonicera*

These phytochemicals present in edible flowers are responsible for their health promoting properties like antioxidant, hypoglycemic, anticancer, anti-diabetic, anti-obesity, neuroprotective, hepatoprotective and anti-microbial.

Many scientists found out that edible flowers like *Catharanthus roseus*, *Butea monosperma*, *Bauhinia variegata*, Honey suckle, etc have potential to lower the elevated glucose levels in blood. Edible flowers exerted strong activities against various types of cancers. *Bauhinia tomentosa*, *Tagetes* identify the flower exactly before its consumption because; some flowers may have toxic effect on humans. Very limited information is available on anti-nutritional/ toxic factors found in edible flowers. Allergies occur in wind pollinated species characterized blossoms to develop functional foods is increasing day by day in global food and pharma industry which has opened immense opportunity for the rise of edible flower market.



Conclusion

Edible flowers are no longer just visual garnishes on a plate; they represent a vibrant intersection of nutrition, creativity, and sustainability in modern cuisine. Their inclusion in daily diets opens new possibilities for alleviating malnutrition through the provision of micronutrients, antioxidants, and bioactive compounds, while also encouraging agricultural diversification and the use of underexplored plant resources. Unlike conventional crops, many edible flowers require minimal inputs and can even serve as safer, plant-based alternatives to pollen sources that are highly prone to aero-dispersion and allergenic effects.

Driven by curiosity, novelty, and innovation, the global food market is increasingly embracing edible flowers, not only for their decorative appeal and nutraceutical potential, but also for the exciting new flavours and textures they introduce to gastronomy. From home kitchens to fine dining, edible flowers inspire chefs and consumers alike to reimagine food as an experience that is both aesthetic and functional. Moreover, their cultivation offers an additional, sustainable source of income for small and marginal farmers, linking culinary innovation with rural livelihood enhancement. Thus, edible flowers stand as a promising component of future food systems, blending health, heritage, and creativity on a single plate.

References

ManojKumar, K., Nadaradjan, S., Adhimoolam, P., Ilakkia, K., & Vaishnavi, M. (2023). Kerala Karshakan.

- Newman, M., & Kirker, C. L. (2016). *Edible flowers: a global history*. Reaktion Books.
- Nicolau, A. I., & Gostin, A. I. (2016). Safety of edible flowers. In *Regulating safety of traditional and ethnic foods* (pp. 395-419). Academic Press.
- PF Guiné, R., Florença, S. G., Villalobos Moya, K., & Anjos, O. (2020). Edible flowers, old tradition or new gastronomic trend: A first look at consumption in Portugal versus Costa Rica. *Foods*, 9(8), 977.
- Santos, I. C. D., & Reis, S. N. (2021). Edible flowers: Traditional and current use. *Ornamental Horticulture*, 27(4), 438-445.

WHY TREES ARE THE BACKBONE OF LANDSCAPING?

Vibin Sankar^{1*}, Khushal B. Muradi² and K. Bhrundha³

¹Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur -680656, Kerala, India.

²Department of Vegetable Science, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: vibinsankar2016@gmail.com

Abstract

Trees are the foundation of sustainable, functional, and visually appealing landscapes, offering a unique combination of aesthetic, environmental, and economic benefits. They enhance beauty through graceful forms, seasonal blooms, and natural focal points, while also improving property value and creating inviting outdoor spaces. Beyond their visual appeal, trees regulate microclimates by providing shade, reducing heat in summer, acting as windbreaks in winter, and lowering energy costs. They support ecosystem health by sequestering carbon, improving air quality, conserving water, stabilizing soil, and providing habitats for wildlife and pollinators. Native trees, in particular, play a crucial role in resilient landscaping due to their adaptability, low maintenance needs, and ecological contributions. While managing trees presents challenges such as pruning, root control, and pest management, adopting sustainable landscaping practices, including water-efficient irrigation, organic pest control, mulching, and composting, ensures long-term tree health and environmental benefits. By thoughtfully incorporating both native and well-suited tree species, homeowners and planners can create landscapes that are not only beautiful and functional but also environmentally responsible, climate-smart, and capable of supporting biodiversity for generations to come.

Introduction

Trees form the backbone of any thoughtfully designed landscape, seamlessly combining beauty, utility, and environmental benefits. Their elegant shapes, lush foliage, and seasonal flowers add visual interest and create a sense of harmony, whether used as striking focal points, privacy screens, or shade providers. Beyond their aesthetic appeal, trees play a vital role in moderating temperatures, offering cool shade during hot summer months and acting as natural windbreaks in winter, which can reduce energy costs. They also improve air quality by absorbing carbon dioxide, releasing oxygen, and filtering harmful pollutants such as dust, ozone, and sulphur dioxide.

The extensive root systems of trees help stabilize soil, prevent erosion, enhance water absorption, and enrich the soil with essential nutrients, supporting overall landscape health. In urban environments, trees serve as natural noise buffers, dampening traffic sounds and creating more peaceful surroundings. Moreover, they provide crucial habitats for wildlife, including birds, insects, and small mammals, thereby supporting biodiversity. Finally, well-maintained trees increase property value, adding curb appeal, character, and a sense of permanence to outdoor

spaces. By offering a combination of functional and aesthetic benefits, trees truly form the foundation of sustainable, vibrant, and resilient landscapes.



Trees in landscaping

Environmental Benefits of Trees in Landscaping

Carbon Sequestration: One of the most significant environmental contributions of trees is their ability to capture and store carbon dioxide, a major greenhouse gas responsible for climate change. Through the process of photosynthesis, trees convert carbon dioxide into biomass—trunks, branches, leaves, and roots, effectively acting as natural carbon sinks. Over time, mature trees can store substantial amounts of carbon, helping to mitigate the impacts of global warming while contributing to a healthier ecosystem.

Improving Air Quality: Trees play a critical role in purifying the air we breathe. By absorbing carbon dioxide and releasing oxygen, they maintain a balanced and breathable atmosphere. In addition, trees filter harmful pollutants such as ozone, sulphur dioxide, nitrogen oxides, and particulate matter, reducing respiratory risks for humans and wildlife alike. Urban landscapes with abundant tree cover have been shown to exhibit cleaner, fresher air, improving overall public health.

Water Conservation and Soil Health: Trees are vital for maintaining soil structure and promoting water conservation. Their extensive root systems anchor the soil, preventing erosion during heavy rainfall, while simultaneously increasing water infiltration and retention in the ground. This reduces surface runoff and minimizes water loss, making gardens and landscapes more resilient to drought. Fallen leaves also decompose to enrich the soil with organic matter, further enhancing soil fertility and moisture-holding capacity.

Biodiversity Support: Trees create habitats for a wide array of wildlife, from birds and insects to small mammals. Flowering and fruit-bearing trees attract pollinators such as bees and butterflies,

while dense foliage offers nesting and shelter sites. By supporting diverse ecosystems, trees contribute to ecological balance, helping maintain healthy populations of beneficial species while encouraging natural pest control within gardens.

Energy Efficiency: Strategically planted trees can significantly reduce energy consumption in buildings. During hot summer months, trees provide shade that lowers ambient temperatures and reduces reliance on air conditioning. In winter, trees act as windbreaks, protecting homes from cold winds and decreasing heating needs. This not only helps homeowners save on energy costs but also reduces the carbon footprint associated with artificial heating and cooling.

Incorporating trees into landscaping designs is not only visually appealing but also provides lasting environmental benefits. From mitigating climate change and improving air quality to conserving water, supporting wildlife, and enhancing energy efficiency, trees are indispensable components of sustainable and functional landscapes.

Trees as Your Natural Climate Control

Trees aren't just beautiful additions to a landscape; they are also natural climate regulators that can significantly improve the comfort and energy efficiency of your home. By carefully positioning trees around your property, you can create shaded areas that reduce direct sunlight exposure on your walls and roof during hot summer months. This natural shading helps lower indoor temperatures, reducing the reliance on air conditioning and cutting energy costs, while simultaneously minimizing your household's carbon footprint.

In addition to providing shade, trees act as effective windbreaks during the colder months. Strategically placed evergreen or dense-foliage trees can shield your home from chilly winds, reducing heat loss and lowering heating expenses. This dual function of cooling in summer and protection in winter makes trees an invaluable tool for passive energy management.

Beyond energy savings, trees help establish a more comfortable microclimate around your property. Through the process of evapotranspiration, trees release moisture into the air, which cools the surrounding environment and improves humidity levels. This not only makes outdoor spaces more enjoyable but also enhances the overall viability of your home environment. By moderating temperature extremes and improving air circulation, trees contribute to both human comfort and environmental sustainability.

In short, planting trees is a natural, cost-effective, and eco-friendly strategy to regulate temperature, conserve energy, and create a healthier, more comfortable living space—benefiting your home, your wallet, and the planet.

Enhance Your Home's Beauty and Value

Trees do more than provide environmental benefits, they are powerful tools for elevating the aesthetic appeal and market value of your property. A strategically placed tree can serve as a natural focal point, adding structure, texture, colour, and depth to your landscape. Whether it's the vibrant blossoms of a flowering tree in spring, the lush green canopy of summer, or the fiery hues of autumn foliage, trees create visual interest year-round and transform ordinary outdoor spaces into inviting, picturesque environments.

Beyond their beauty, trees contribute significantly to a home's financial value. Properties featuring mature, healthy trees and well-designed landscapes are often appraised higher than

those without. Numerous studies indicate that homes with attractive, tree-lined yards tend to sell faster and at premium prices, making trees not just a decorative element but a smart investment. The presence of trees also signals care and attention to landscaping, which can positively influence potential buyers' perceptions and enhance the overall appeal of your property.

Additionally, trees provide functional benefits that complement their visual appeal. Shade trees reduce energy costs by cooling homes in the summer, while windbreaks can minimize heating expenses in winter. These practical advantages, combined with their aesthetic impact, make trees a valuable asset that improves both the liability and the marketability of a property. Whether you aim to boost curb appeal, create outdoor spaces for relaxation, or increase resale value, incorporating trees into your landscape is a simple yet highly effective strategy that pays dividends over time.

Challenges in Managing Trees: Growing Pains for Homeowners

While trees provide numerous benefits to landscapes, they also come with responsibilities that homeowners should not overlook. One of the main challenges is maintaining tree health. Regular pruning is essential to control overgrowth, remove dead or damaged branches, and reduce the risk of disease. Proper pruning not only keeps trees looking their best but also ensures safety, as falling limbs from large or mature trees can pose hazards. Incorrect pruning techniques, however, can weaken a tree and make it more susceptible to pests, diseases, or structural failure.

Root management is another critical concern. Tree roots naturally spread to support healthy growth, but they can interfere with underground utilities, sidewalks, driveways, and foundations if not planned carefully. When planting trees, it is important to consider the mature root spread and provide adequate space to prevent costly property damage in the future.

Pests and diseases also pose ongoing challenges. Insects, fungal infections, and other pathogens can compromise tree health if not detected and treated early. Regular monitoring and timely intervention are key to preventing small issues from becoming major problems. Collaborating with professional arborists or tree care services can help homeowners maintain healthy trees, manage potential risks, and ensure that their trees continue to thrive safely and attractively within the landscape.

Sustainable Landscaping Practices

Sustainable landscaping goes beyond simply selecting the right plants, it involves managing your trees and outdoor spaces in ways that support long-term environmental health. Implementing eco-friendly practices such as mulching, composting, and minimizing the use of chemical fertilizers and pesticides can improve soil structure, conserve water, and create a safer habitat for local wildlife. These practices not only benefit the environment but also promote healthier, more resilient trees and landscapes.

A key component of sustainable landscaping is planting native tree species. Native trees are naturally adapted to local soil, climate, and rainfall patterns, making them hardier and less dependent on supplemental irrigation or fertilizers. They also provide vital habitats for native birds, insects, and other wildlife, enhancing biodiversity and supporting the overall ecological balance of your garden.

In addition, integrating water-efficient irrigation systems, such as drip or soaker hoses, and using organic or biological pest control methods can reduce your environmental footprint while keeping your trees healthy and thriving. Sustainable landscaping also emphasizes proper soil management,

seasonal pruning, and responsible maintenance, all of which reduce resource waste and enhance the long-term beauty and productivity of your landscape.

By adopting these practices, homeowners can create outdoor spaces that are not only visually appealing but also environmentally responsible, low-maintenance, and resilient. Sustainable landscaping ensures that your trees and garden flourish today while preserving the natural resources and ecosystem health for future generations.

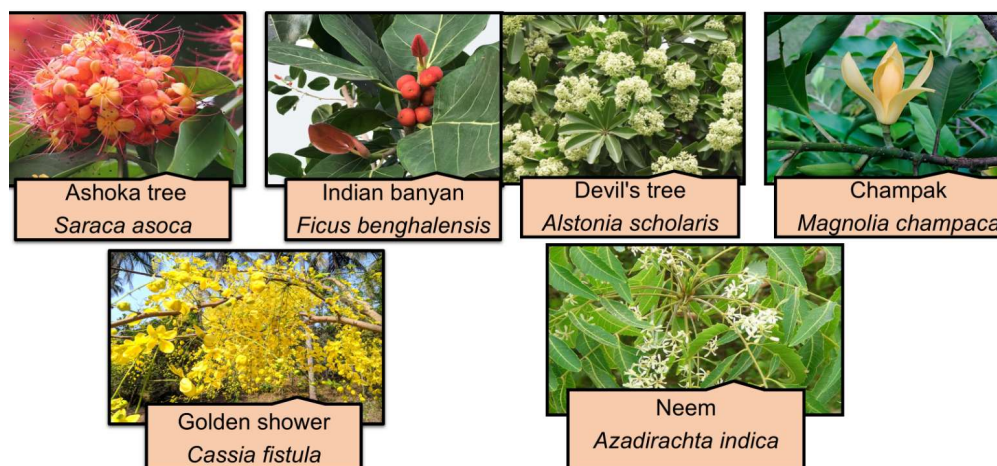
Role of Native Trees in Landscaping

Native trees are the cornerstone of sustainable and resilient landscaping because they are naturally adapted to local climates, soils, and water availability. This inherent adaptability makes them low-maintenance, drought-tolerant, and less dependent on fertilizers or chemical inputs, reducing both cost and environmental impact. Unlike exotic species, native trees are more resistant to local pests and diseases, which contributes to healthier landscapes over the long term.

Species such as *Hopea ponga*, *Crateva magna*, and *Cassia fistula* offer multiple benefits in a landscaped environment. They provide much-needed shade, cooling surrounding areas during hot seasons, and some bear edible fruits or seeds, supporting human nutrition and wildlife alike. Many native trees also have medicinal properties that have been used traditionally, adding cultural and practical value to landscapes.

Beyond their functional uses, native trees play a critical ecological role by supporting local wildlife and pollinators. Birds, bees, butterflies, and other beneficial insects rely on these trees for food, nesting, and shelter. Incorporating native trees into gardens, parks, and urban green spaces helps restore ecological balance, encourages biodiversity, and creates vibrant, self-sustaining ecosystems.

Aesthetically, native trees bring a sense of place and natural harmony to landscapes. Their seasonal changes, flowering patterns, and unique forms enrich the visual appeal of gardens and public spaces, creating environments that are not only beautiful but also ecologically meaningful. By prioritizing native species in landscaping design, homeowners and planners can create greener, healthier, and more resilient spaces that benefit people, wildlife, and the environment alike.



Native trees used for landscaping

Conclusion

Trees are far more than decorative elements, they are vital components of healthy, sustainable, and resilient landscapes. From enhancing aesthetic appeal and boosting property value to regulating microclimates, improving air quality, conserving water, and supporting biodiversity, their contributions are multifaceted and long lasting. Native trees, in particular, offer added benefits by thriving naturally in local conditions, requiring minimal maintenance, and providing essential habitats for wildlife.

While managing trees requires attention to pruning, root control, and pest prevention, adopting sustainable landscaping practices ensures their long-term health and maximizes their ecological and functional benefits. By thoughtfully incorporating trees into gardens, parks, and urban spaces, homeowners and planners can create environments that are visually stunning, environmentally responsible, and resilient to climate challenges. Ultimately, trees form the backbone of every well-designed landscape, offering a harmonious balance between beauty, utility, and sustainability for present and future generations.

References

- Clouston, B. (Ed.). (2013). *Landscape design with plants*. Newnes.
- Kakkar, P., & Lal, S. LANDSCAPING AND ORNAMENTAL HORTICULTURE. *New Horizons and Advancements in Horticulture Volume*, 117.
- Laverne, R. J., & Winson-Geideman, K. (2003). The influence of trees and landscaping on rental rates at office buildings. *Arboriculture & Urban Forestry (AUF)*, 29(5), 281-290.
- Tallamy, D. W. (2017). Creating living landscapes: Why we need to increase plant/insect linkages in designed landscapes. *HortTechnology*, 27(4), 446-452.
- Velmurugan, M., Anand, M., Davamani, V., Rajamani, K., & Pugalendhi, L. (2020). Landscape value of trees. *Biotica Research Today*, 2(7), 693-695.

BURLAPPING: GIVING TREES A NEW HOME

Vibin Sankar^{1*}, Athira S² and Laxmi P. S³

^{1&2}Department of Floriculture and Landscaping, College of Agriculture,
Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Laxmi P. S., Ph.D. Scholar, Department of Postharvest Management,
College of Agriculture, Vellanikkara, Kerala Agricultural University,
Thrissur - 680656, Kerala, India.

*Corresponding Email: vibinsankar2016@gmail.com

Abstract

Rapid urbanization and infrastructure development pose significant threats to mature trees, often resulting in their removal and loss of valuable ecosystem services. Tree transplantation through burlapping has emerged as a practical conservation-oriented strategy to preserve established trees while accommodating developmental pressures. Burlapping, particularly the balled-and-burlapped (B&B) technique, involves relocating trees along with an intact soil-root ball, thereby minimizing transplant shock and enhancing post-transplant survival. This review critically examines the historical evolution, principles, and practical applications of burlapping in tree transplantation, with emphasis on its relevance in contemporary urban landscaping and green infrastructure projects. Various transplanting methods including bare-root, packed stock, containerized plants, field-potted stock, and mechanized tree spade transplants are discussed in relation to their suitability, advantages, and limitations. The paper further explains key planting guidelines, excavation techniques, site preparation, and post-transplant management practices such as root pruning, mulching, fertilization, and staking, which collectively determine transplant success. Special attention is given to species-specific responses, physiological considerations of root-shoot balance, and factors influencing survival under tropical conditions, particularly in the Indian context. By synthesizing traditional horticultural knowledge with modern mechanized approaches, this review highlights burlapping as an effective tool for conserving mature trees, maintaining urban green cover, and promoting sustainable landscape development. The adoption of scientifically informed burlapping practices can significantly contribute to climate-resilient urban landscapes and long-term ecological sustainability.

Introduction

Burlapping is the process of carefully moving an established tree from one location to another. It's a major task, and trees need time to recover afterward. Because a tree's roots spread widely, transplanting often involves digging up a significant portion of the root system. This age-old practice is used to save, preserve, or relocate trees that might otherwise be cut down or damaged. Nowadays, moving mature trees while keeping them upright and maintaining their full canopy is becoming more common, especially in upscale landscaping and projects with commercial or heritage value. Remarkably, trees ranging from as little as 50 kilograms to massive 50-ton giants have been successfully relocated.



Burlapping of trees in Malappuram district, Kerala

Metropolitan cities like Delhi, Hyderabad, Chandigarh, and Noida are increasingly using tree transplantation to quickly create lush green spaces. In Karnataka, cities like Gadag, Hubballi, Bangalore, and Mysore have launched campaigns to relocate mature trees, while Tamil Nadu has started similar efforts along the roads of Salem. Hyderabad's Ramachandra Appari has successfully transplanted over 35,000 trees near roads and construction sites (Green Morning Horticulture Pvt. Ltd.), and in Andhra Pradesh, Kadiyam nurseries specialize in tree relocation (Satyadeva Nurseries).

Although transplanting trees is far more expensive than planting saplings, it preserves mature trees with high aesthetic and ecological value. However, some extraordinary trees are simply too delicate or large to move.



Burlapping in landscaping

History of transplantation

The practice of moving trees isn't new; it dates back thousands of years. Ancient Egyptians were transporting large trees by ship as early as 2000 B.C. In the 18th century, landscape designer

Lancelot “Capability” Brown revolutionized tree relocation, using specially designed machines to move trees as tall as 36 feet. During this period, large-scale landscaping projects often involved manually relocating entire hills and mature trees.

Kew Gardens in England began major tree planting campaigns in 1761 and again in 1846. By the mid-1800s, mechanization started to replace manual labor. The Barron tree transplanter enabled the movement of mature trees at estates like Elvaston Castle, while the late 1930s saw large-scale projects in the U.S., such as the transplantation of 500 pine trees at California’s Hearst Estate.

The 1950s introduced hydraulic tree diggers, transforming nursery operations, and the late 1970s brought techniques to preserve topsoil during transplantation with mechanized loaders. By the 1980s, tree spades became commercially available, making tree relocation faster, more efficient, and more affordable.

In India, tree transplantation is guided by laws aimed at protecting green cover. Acts such as the Karnataka Preservation of Trees Act (1976), Delhi Preservation of Trees Act (1994), and Goa, Daman and Diu Preservation of Trees Act (1984) provide regulations for relocating trees safely. Interestingly, even before these laws, the Delhi Government relocated 25 trees in 1972, highlighting an early commitment to urban greenery.

Types of Tree Transplanting: From Bare Roots to Modern Machinery

1. Bare-Root Transplanting

This is the oldest method used in nurseries and orchards. Trees and shrubs are moved without soil around their roots, making it especially suitable for deciduous plants during dormancy. Bare-root plants are cost-effective and commonly used in municipal projects, highways, and orchards. However, they need very high humidity during storage and careful coverage during transport. Overwatering must be avoided to prevent root or stem rot.

2. Balled and Burlapped (B&B)

B&B is the most traditional and widely recognized method. Trees are dug up with a ball of soil around their roots and wrapped in burlap. This allows the root ball’s soil to match the planting site, reducing water stress. The downside is that over 95% of the original roots may be lost during digging, so careful aftercare, root pruning, and smaller container-grown trees can improve survival. Timing is critical: the best results occur when water loss is minimal and roots are ready to regrow. Moving large B&B trees also requires special equipment and trained workers.



Balled and burlapped

3. Packed Stock

Packed stock is like bare-root plants but with roots wrapped in a moist material such as peat moss. These plants are best planted early in spring and stored in cool, dark, and moist conditions until planting.

4. Containerized Plants

These start as bare-root specimens but are transplanted into containers with a prepared growing medium. Containerized plants are convenient for sale and easy planting.

5. Field-Potted Plants

Nursery-grown trees initially grown in the field are transferred into pots, keeping the soil ball intact. They should ideally be planted in spring, and extra care must be taken to avoid disturbing the roots during potting or planting.

6. Tree Spade Transplants

Tree spades are specialized machines that dig out trees with a mound of soil and part of their roots. Available in different sizes for evergreens or deciduous trees, tree spades allow the relocation of larger plants that would be difficult to move by hand.

Planting Guidelines for Different Types of Nursery Stock**1. Bare-Root and Packaged Plants**

Start by inspecting the plant and trimming any damaged or diseased roots or branches. Dig a hole slightly deeper than needed and position the plant a bit higher than it grew in the nursery. Spread the roots evenly and straighten them. As you fill the hole with soil, gently lift and lower the plant to remove air pockets, and avoid clumps, rocks, or debris. Once three-quarters filled, tamp the soil lightly, water deeply to remove remaining air pockets, then fill the rest and water thoroughly. Position the largest branches facing southwest for best growth.

2. Balled and Burlapped (B&B) Plants

Place the tree in the hole so it sits at or slightly above its original nursery depth, using the root flare and top of the soil ball as a guide. Handle carefully to avoid breaking the soil ball. Fill the hole three-quarters, tamp to remove air pockets, then cut away all twine and pull back burlap from the trunk and top. Water slowly to saturate the root ball and surrounding soil, then fill the rest of the hole. Make sure no burlap is exposed above ground, as it can draw moisture away from roots. For evergreens, plant before October to allow proper root establishment.

3. Container-Grown and Containerized Plants

Remove the container completely at the planting site, including biodegradable pots. If roots are circling inside (root-bound), gently loosen them with shallow vertical cuts on the sides and a crisscross cut at the bottom. Plant using the same steps as B&B stock. As with other types, avoid planting evergreens after October to ensure they establish roots before winter.

Planting Techniques for Successful Tree Transplantation**1. Pre-Transplant Care**

Handle the root ball carefully to avoid damage, especially for B&B trees or those in soft fabric containers. Never lift a tree by the trunk. Water the trees thoroughly before transport, cover them to prevent water loss, and plant them immediately upon arrival. If planting must be delayed, keep them in a sheltered area away from sun and wind, and continue regular watering.

2. Plant and Site Selection

Choose species suited to the site's soil, drainage, and light conditions. Test drainage by filling a hole with water; slow drainage may require berms or water-tolerant species. Dig holes that are shallow but 2–3 times wider than the root ball to allow roots to spread naturally. In heavy clay soil, make the hole slightly shallower than the root ball. Mulch around the root ball after planting to protect it. Avoid placing loose soil beneath roots or digging too deep, as this can cause the tree to settle too low.

3. Excavation

Ensure the hole is large enough to accommodate roots without bending or damage. B&B and container-grown plants should have holes matching their root-ball depth, while bare-root plants need slightly deeper holes.

4. Soil Filling

Use the excavated soil as backfill. Keep topsoil and subsoil separate, adding subsoil first and topsoil on top, with light watering between layers. Gently tamp soil to stabilize the tree, but avoid over-compacting.

5. Plant Placement

Place the tree upright, ideally oriented like it was at the donor site.

6. Removal of Wrapping and Support Materials

Before final backfilling, remove burlap, gunny bags, or any other materials used to support the root ball.

7. Pruning Damaged Branches

Trim any branches damaged during transport, making cuts at the nearest branch bark ridge.

8. Root Ball Positioning

Ensure the top of the root ball is level with or slightly above the surrounding soil, with the trunk flare at or above final grade.

9. Final Backfilling and Watering

Compact soil around the base for stability and gently tamp the remaining soil. Water thoroughly to hydrate both the root ball and the surrounding soil.

6. Post-Transplant Care

Root Pruning

Trees that are regularly root-pruned in nurseries adapt better to transplantation, as their absorbing roots stay close to the trunk, reducing damage during lifting. Root pruning also encourages root branching and the formation of fine roots, enhancing water absorption. In contrast, large trees from open fields or forests often develop long, sparse roots, many of which are far from the trunk, making them prone to significant root loss when dug up. To increase transplant success, such trees should undergo root pruning at least two years before moving. This involves digging a trench around the tree, with the trench's distance from the trunk depending on the tree's size approximately 5 inches of trench radius per inch of trunk diameter. The excavated soil should be mixed with organic matter like compost or manure, or with fertilizer, and returned to the trench. This method restricts top growth while promoting new roots near the cuts, resulting in a dense, fibrous root system with excellent water absorption and reduced transpiration. It is

especially useful for trees with tap roots and container-grown specimens that have outgrown their pots.

Mulching

Apply a 2–3-inch-thick layer of mulch around the tree, forming a circle about 6 feet in diameter. Keep the mulch at least 4 inches away from the trunk to protect the bark.

Fertilization

Avoid applying nitrogen in late summer, as it may promote new growth that is vulnerable to winter damage unless the plant is nutrient-deficient. Phosphorus (P) and potassium (K) should be applied in autumn to support winter hardening. Root growth stimulants can also be beneficial during this period.

Staking

Young trees generally develop stronger, more resilient trunks when left unstaked, as natural movement strengthens the crown. Staking should only be done if the tree is unstable due to wind or has toppled. To prevent girdling, use soft materials such as nylon webbing or carpet strips, rather than tight wire ties, which can severely damage or even kill the tree. The timing of transplanting significantly affects survival; for example, *Eldarica* pine planted in late spring, with average temperatures between 10°C and 20°C, shows the highest survival rates. Palms subjected to prolonged nutrient or water stress often exhibit trunk narrowing, indicating periods of stress.

Treatment at the Transplant Site

Choose a site similar to the tree's original location. Begin site preparation 5–7 days before transplanting. Dig a pit measuring 2–3 meters, leaving at least 2 feet of extra space around the root ball. Ensure proper drainage, daily watering, and treat the area with antifungal or antibacterial solutions. Fill the pit with a mixture of compost, farmyard manure (FYM), and native soil to support root establishment.

General Procedure for Transplanting

Step 1 : Irrigate the soil one day prior to transplanting to maintain the integrity of the root ball and minimize root stress. Prepare a planting pit that is two to three times wider than the root ball and lightly moisten the soil.

Step 2 : Carefully remove the surface soil around the roots. Extend excavation 4–6 inches beyond the existing trench to include newly formed roots, and prune these roots cleanly.

Step 3 : Secure the lower branches to prevent obstruction during digging. Make precise cuts around the plant perimeter before excavating beneath the root ball.

Step 4 : Place a tarp or burlap adjacent to the root ball before completely severing the roots. Dig underneath to cut the remaining roots safely.

Step 5 : Lift the plant from beneath the root ball, never by the trunk. Immediately protect the roots from direct sunlight and keep them moist after removal.

Step 6 : During transportation, cover the plant to prevent desiccation. Avoid transporting plants in open vehicles such as uncovered trucks.

Step 7 : Planting depth is critical: shallow planting exposes roots to temperature stress, while deep planting increases the risk of rot. Position the tree 2–3 inches above the original soil level to allow for natural settling.

Step 8 : Provide staking immediately after transplanting to stabilize the plant and support root establishment. Apply mulch around the base to conserve moisture and reduce weed competition.

Step 9 : Avoid pruning after transplanting, as the plant requires its full foliage to sustain physiological functions during establishment.

Step 10 : Refrain from fertilizing newly transplanted trees, as nutrient application may stimulate excessive shoot growth before adequate root establishment. Fertilization should be delayed until one year after transplanting.

Trees Suitable for Burlapping

Several tree species respond well to burlapping during transplanting, as this technique helps maintain root ball integrity and reduces transplant shock. Commonly burlapped trees include *Ficus religiosa*, *Ficus benghalensis*, *Ficus carica*, *Saraca asoca*, *Ziziphus jujuba*, *Terminalia arjuna*, *Dalbergia sissoo*, *Peltophorum* spp., *Madhuca longifolia*, *Phyllanthus emblica*, *Bombax ceiba*, *Tectona grandis*, *Betula pendula*, *Delonix regia*, *Mangifera indica*, *Pongamia pinnata*, *Oreodoxa regia*, *Phoenix sylvestris*, *Woodeya bifurcata*, *Artocarpus heterophyllus*, *Tamarindus indica*, *Syzygium cumini*, *Celtis occidentalis*, *Quercus* spp., *Morus* spp., and *Pinus* spp.

Conclusion

Tree transplantation, although not suitable for all situations, is a vital practice for conserving mature trees in areas facing ecological sensitivity and developmental pressures. The success of this technique is influenced by several factors, including species selection, root system characteristics, trunk girth, site suitability, and appropriate planting practices. Effective pre transplant preparation, careful excavation, and post-transplant management, such as adequate watering, mulching, and minimal pruning are crucial for improving survival rates. Adherence to established horticultural principles further enhances transplant success.

Despite requiring skilled labor, specialized equipment, and meticulous planning, tree transplantation provides a practical approach to reconciling urban development with environmental protection. Treating trees as dynamic living systems and adapting transplanting strategies to their biological needs can facilitate the sustainable integration of green infrastructure within rapidly urbanizing landscapes.

References

- Buckstrup, M. J., & Bassuk, N. L. (2000). Transplanting success of balled-and-burlapped versus bare-root trees in the urban landscape. *Arboriculture & Urban Forestry (AUF)*, 26(6), 298-308.
- Grabosky, J. (2000). Trees in urban construction. *Construction in Cities*, 157.
- Katisat, N., Srisuwan, N., Thammanoonkul, P., Warit, S., & Meunpong, P. (2025). Pulling tests for tree support systems: evaluating strength on artificial balled and burlapped trees. *Arboricultural Journal*, 1-17.

- Koeser, A. K., Stewart, J. R., Bollero, G. A., Bullock, D. G., & Struve, D. K. (2009). Impacts of handling and transport on the growth and survival of balled-and-burlapped trees. *HortScience*, 44(1), 53-58.
- Maleike, R., & Hummel, R. L. (1992). Planting landscape plants. *Arboricultural Journal*, 16(3), 217-226.
- Parthiban, K. T., Fernandaz, C. C., & Selvanayaki, S. (2022). Agroforestry Business Incubator—an innovative institution for leveraging technology-based business opportunities in forestry. *Journal of Global Entrepreneurship Research*, 12(1), 97-105.
- Pease, R. W. (1959). *The Balled-and-burlapped Pack for Ornamental Shrubs and Trees*. West Virginia University Agricultural Experiment Station.

CARBON SEQUESTRATION POTENTIAL OF URBAN ORNAMENTAL LANDSCAPES

Athira S^{1*}, K. Bhrendha² and Chaithra B. S³

¹Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

²Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Assistant Professor, Kadiri Baburao College of Agriculture, C. S. Puram - 523112, Andhra Pradesh, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Urbanization is rapidly transforming natural ecosystems into built environments, leading to increased atmospheric carbon dioxide (CO₂) concentrations and intensified urban heat island effects. In this context, urban ornamental landscapes including parks, residential gardens, institutional campuses, roadside plantings, and green roofs are increasingly recognized not only for their aesthetic and recreational value but also for their ecological functions. These designed green spaces can act as localized carbon sinks by capturing atmospheric CO₂ through photosynthesis and storing it in plant biomass and soils.

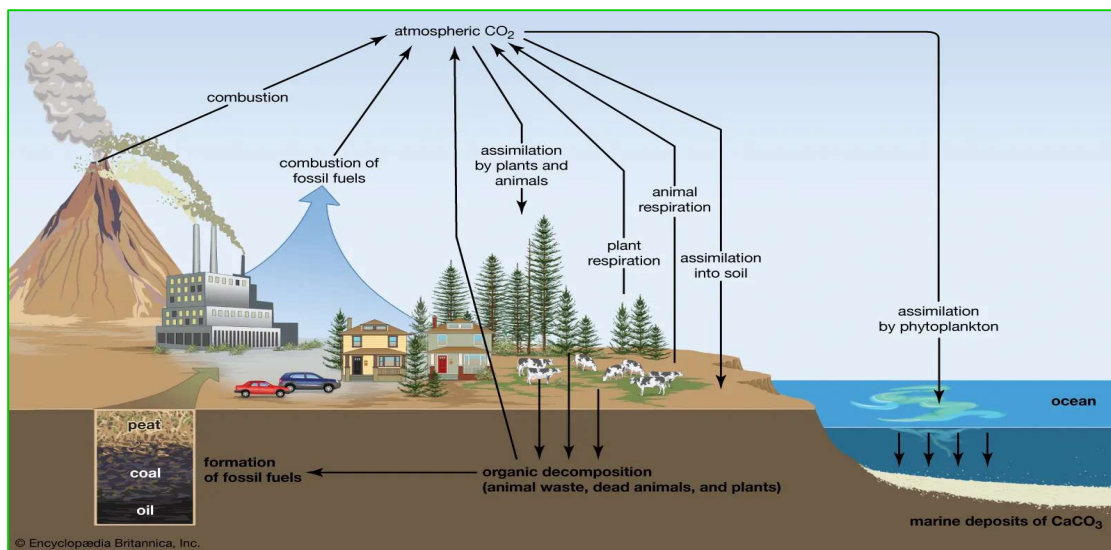
The carbon sequestration potential of urban ornamental landscapes depends on multiple factors such as plant species composition, growth rate, canopy structure, management intensity, soil characteristics, and landscape design. Trees and shrubs with high biomass accumulation capacity contribute significantly to above-ground carbon storage, while turfgrass systems and ornamental groundcovers influence below-ground carbon dynamics through root turnover and soil organic carbon buildup. Compared to natural forests, ornamental landscapes are intensively managed; therefore, maintenance practices such as mowing, pruning, irrigation, and fertilization may either enhance or offset their net carbon sequestration capacity.

Understanding the role of ornamental landscapes in urban carbon budgets is essential for developing climate-resilient cities. Quantifying their carbon storage and fluxes provides scientific evidence to guide species selection, sustainable design strategies, and low-carbon management practices. Integrating carbon-focused planning into urban landscape architecture can strengthen the contribution of ornamental green spaces toward climate change mitigation and sustainable urban development.

What is carbon sequestration?

Carbon sequestration is the process of capturing atmospheric carbon dioxide (CO₂) and storing it for long periods in natural or artificial reservoirs to reduce the concentration of greenhouse gases in the atmosphere. In natural systems, carbon sequestration occurs primarily through photosynthesis, where plants absorb CO₂ and convert it into organic carbon compounds that are stored in plant biomass (leaves, stems, roots) and eventually in soils. Major natural carbon sinks include forests, grasslands, wetlands, oceans, and soils. In terrestrial ecosystems, a significant portion of sequestered carbon is stored as soil organic carbon, which can remain stable for decades to centuries depending on environmental conditions and management practices.

Carbon sequestration can also be enhanced through anthropogenic interventions such as afforestation, reforestation, improved land management, and engineered technologies like carbon capture and storage (CCS). In the context of urban ecosystems, green spaces including ornamental landscapes, parks, and turfgrass systems contribute to carbon sequestration by accumulating biomass and improving soil carbon storage, thereby playing a supportive role in climate change mitigation.



Pictorial representation of carbon cycle

Carbon sequestration potential of urban ornamental landscapes

Carbon sequestration potential of urban ornamental landscapes refers to the capacity of designed urban green spaces such as parks, residential gardens, avenue plantations, institutional campuses, turfgrass lawns, and green roofs to capture atmospheric carbon dioxide (CO₂) and store it in plant biomass and soils over time. In these landscapes, carbon is sequestered primarily through photosynthesis, where ornamental trees, shrubs, turfgrass, and groundcovers absorb CO₂ and convert it into organic carbon. This carbon is stored in above-ground biomass (trunks, branches, leaves), below ground biomass (roots), and soil organic matter. The magnitude of sequestration depends on factors such as species selection, plant density, age structure, canopy cover, growth rate, soil properties, climatic conditions, and management practices (e.g., mowing, pruning, irrigation, and fertilization).

Although urban ornamental landscapes typically store less carbon per unit area than natural forests, their cumulative contribution can be significant due to their widespread distribution across cities. When properly designed and sustainably managed, these landscapes can function as decentralized carbon sinks, contribute to urban carbon budgeting, and support climate change mitigation strategies while simultaneously providing aesthetic, ecological, and social benefits.

Examples of ornamental plants commonly used in urban landscaping that also have good carbon sequestration potential include *Azadirachta indica* (Neem), *Delonix regia* (Gulmohar), *Polyalthia longifolia* (False Ashoka), *Ficus benghalensis* (Banyan), and *Alstonia scholaris* (Saptaparni) among trees. Among shrubs and woody ornamentals, *Hibiscus rosa-sinensis* (Hibiscus), *Bougainvillea*

glabra (Bougainvillea), and *Nerium oleander* (Oleander) are widely planted and contribute to biomass carbon storage. For turf and groundcover systems, *Cynodon dactylon* (Bermuda grass) and *Zoysia japonica* (Zoysia grass) play an important role in below-ground carbon sequestration through extensive root systems and soil organic carbon accumulation.

Large, long-lived trees store the greatest amount of carbon because of their substantial woody biomass and extended lifespan, allowing continuous carbon accumulation over decades. Shrubs and climbers contribute moderately to carbon storage; however, when planted densely and managed effectively, they significantly enhance the overall carbon stock of ornamental landscapes. Turfgrass systems play a particularly important role in below-ground carbon sequestration by increasing soil organic carbon through extensive root biomass and rhizodeposition, especially under reduced-disturbance and low-input management practices. Furthermore, the selection of native and fast-growing species adapted to local climatic conditions generally ensures higher survival rates, sustained biomass production, and improved long-term carbon sequestration benefits in urban ornamental landscapes.

Factors influencing carbon sequestration in urban green spaces

The carbon sequestration potential of urban green spaces is determined by a complex interaction of biological, environmental, and management-related factors. One of the most important determinants is plant species composition and structural diversity. Large, long-lived trees with high wood density and rapid growth rates generally store more carbon in above-ground biomass compared to small ornamental species. Canopy cover, planting density, age distribution, and vertical stratification also influence the overall carbon storage capacity of a landscape. Diverse plant assemblages often enhance productivity and resilience, thereby supporting sustained carbon accumulation over time.

Soil characteristics play a critical role in below-ground carbon sequestration. Soil texture, organic matter content, microbial activity, moisture availability, and nutrient status directly affect the stabilization and turnover of soil organic carbon. Urban soils are often compacted or disturbed, which can limit root growth and carbon storage. Practices that improve soil structure such as mulching, organic amendments, and reduced soil disturbance can significantly enhance soil carbon retention. In addition, management practices and climatic conditions strongly influence net carbon balance. Frequent mowing, excessive pruning, irrigation using energy-intensive systems, and synthetic fertilizer application may offset carbon gains through associated greenhouse gas emissions. Conversely, low-input, sustainable management strategies can improve sequestration efficiency. Climate factors such as temperature, rainfall patterns, and atmospheric CO₂ concentration also regulate photosynthetic rates and biomass accumulation. Therefore, the carbon sequestration performance of urban green spaces depends not only on plant selection but also on integrated, climate-adaptive landscape planning and maintenance approaches.

Challenges and limitations in quantifying urban landscape carbon

Quantifying carbon storage and sequestration in urban landscapes is challenging due to their highly heterogeneous nature. Unlike natural forests, urban green spaces consist of mixed ornamental species, irregular planting designs, fragmented patches, and varying levels of management intensity, making the application of standard forest-based allometric equations less

reliable. Many ornamental species lack species-specific biomass and carbon estimation models, forcing researchers to rely on generalized coefficients that may reduce accuracy. Additionally, the diversity in plant age, size, and spatial distribution further complicates precise carbon stock assessment.

Another significant limitation involves measuring soil organic carbon and evaluating the net carbon balance. Urban soils are often disturbed, compacted, or modified by construction activities, which alters natural carbon dynamics and makes soil sampling complex and variable. Moreover, maintenance practices such as mowing, pruning, irrigation, fertilization, and plant replacement generate associated greenhouse gas emissions that must be accounted for when estimating net sequestration. The absence of standardized methodologies, limited long-term monitoring data, and inadequate integration of life-cycle assessments restrict comprehensive carbon budgeting in urban ornamental landscapes.

Conclusion

In conclusion, urban ornamental landscapes represent an underutilized yet strategically important component of urban carbon management. Although their carbon sequestration capacity per unit area may be lower than that of natural forests, their extensive distribution across residential, institutional, and public spaces enables a meaningful cumulative impact on urban carbon budgets. The sequestration potential of these landscapes is strongly influenced by species composition, structural diversity, soil health, and maintenance regimes, highlighting the importance of science-based design and sustainable management practices. By integrating carbon-conscious plant selection, enhancing soil organic carbon, and minimizing emission intensive maintenance, urban ornamental landscapes can function as effective, multifunctional green infrastructure systems that contribute to climate change mitigation while simultaneously enhancing biodiversity, microclimate regulation, and urban livability.

References

- Kumari, S., Patel, M., Choudhury, A. G., & Kumari, A. (2022). Adverse effect of lawn on carbon sequestration vis-à-vis climate change and mitigation strategies. In C. Baskar, S. Ramakrishna, S. Baskar, R. Sharma, A. Chinnappan, & R. Sehrawat (Eds.), *Handbook of solid waste management: Sustainability through circular economy* (pp. 2229–2254). Springer. https://doi.org/10.1007/978-981-15-7525-9_89-1
- Wang, R., Mattox, C. M., Phillips, C. L., & Kowalewski, A. R. (2022). Carbon sequestration in turfgrass–soil systems. *Plants*, 11(19), 2478. <https://doi.org/10.3390/plants11192478>

NANOTECHNOLOGY-DRIVEN INNOVATIONS FOR ENHANCING THE POSTHARVEST LONGEVITY OF FLOWERS

Athira S^{1*}, Laxmi P. S² and Deshmukh Sarita Babarao³

¹Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur -680656, Kerala, India.

²Department of Postharvest Management, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Nanotechnology-driven innovations for enhancing the postharvest longevity of flowers have emerged as a promising advancement in modern floriculture science. Cut flowers are highly perishable due to rapid physiological and biochemical changes after harvest, including microbial blockage of xylem vessels, ethylene-induced senescence, water imbalance, and oxidative stress. These factors significantly reduce vase life, aesthetic appeal, and market value. Traditional postharvest treatments such as chemical preservatives, pulsing solutions, and refrigeration provide only temporary solutions and may pose environmental or health concerns. Therefore, there is a growing need for safer, more efficient, and sustainable technologies to improve postharvest management. Nanotechnology offers innovative solutions through the application of nanoparticles, nano-emulsions, and nano-coatings with antimicrobial, antioxidant, and controlled-release properties. Metallic nanoparticles such as silver and zinc oxide nanoparticles effectively suppress microbial growth in vase solutions, thereby preventing vascular blockage and improving water uptake. Nano-encapsulation techniques also enable the slow and targeted release of growth regulators and preservatives, enhancing their efficiency while minimizing chemical usage. By maintaining cellular integrity, reducing oxidative damage, and delaying senescence, nanotechnology significantly extends the freshness, colour retention, and overall quality of cut flowers, ultimately contributing to improved shelf life, economic returns, and sustainability in the floriculture industry.

What is a nanotechnology

Nanotechnology is the branch of science and technology that deals with the design, manipulation, and application of materials and structures at the nanoscale, typically between 1 and 100 nanometers (nm). At this extremely small scale, materials exhibit unique physical, chemical, and biological properties that differ significantly from their bulk counterparts due to their increased surface area and quantum effects.

By controlling matter at the atomic and molecular level, nanotechnology enables the development of advanced materials, devices, and systems with enhanced strength, reactivity, conductivity, and antimicrobial properties. It has wide applications in agriculture, medicine, electronics, environmental science, and postharvest technology, where nano-sized particles are used to improve efficiency, sustainability, and performance.

Properties of nanoparticles

1) Nano-scale materials show unusual physical, chemical, and optical properties

Materials at the nanoscale (1-100 nm) behave differently from their bulk form because of quantum effects and extremely small size. At this scale, the arrangement of atoms and electrons changes, leading to unique properties such as altered colour, improved conductivity, enhanced catalytic activity, and increased strength. For example, gold nanoparticles appear red or purple instead of metallic yellow due to changes in light interaction.

2) Higher charge density and higher reactivity due to small size (high surface-to-volume ratio)

Nanoparticles have a very large surface area compared to their volume. This means more atoms are present on the surface rather than inside the material. Since chemical reactions occur on surfaces, nanoparticles show higher charge density and increased reactivity. This makes them more effective in antimicrobial activity, catalysis, and controlled release applications in agriculture and medicine.

3) Higher hardness, breaking strength, and toughness at low temperature

At the nanoscale, materials often have fewer structural defects such as cracks or dislocations. This leads to improved mechanical properties like increased hardness, tensile strength, and resistance to breaking. Even at low temperatures, nanoparticles can maintain strength because their small grain size strengthens atomic bonding interactions.

4) Superplasticity at high temperature

Superplasticity refers to the ability of a material to undergo very large deformation without breaking. Nanomaterials, especially nanocrystalline materials, can stretch or deform significantly at high temperatures due to easier movement of grain boundaries. This makes them useful in advanced engineering and manufacturing processes.

5) High mobility in the human body, plants, and environment

Due to their extremely small size, nanoparticles can easily move through biological membranes, plant tissues, soil pores, and even bloodstream systems. This high mobility allows them to be efficiently transported within organisms. However, this also raises concerns regarding environmental safety and toxicity, making proper regulation and risk assessment essential.

Advantages of nanomaterials over bulk-scale materials

1) Higher surface area

Nanomaterials have a much larger surface area-to-volume ratio compared to bulk materials. This increases their reactivity, making them more effective in catalysis, antimicrobial activity, adsorption, and chemical reactions.

2) Enhanced mechanical strength

Nanomaterials often exhibit greater hardness, tensile strength, and toughness due to their small grain size and fewer structural defects. This improves durability and resistance to wear and fracture.

3) Improved chemical reactivity

Because more atoms are exposed on the surface, nanomaterials show higher chemical activity and faster reaction rates, making them efficient in industrial and agricultural applications.

4) Unique optical properties

Nanomaterials interact with light differently than bulk materials due to quantum effects. This results in special properties such as colour changes, enhanced fluorescence, and improved light absorption.

5) Better electrical and thermal properties

At the nanoscale, materials can show improved electrical conductivity or insulation properties, and enhanced heat transfer efficiency, depending on their structure.

6) Controlled and targeted delivery

In biological and agricultural systems, nanomaterials can be designed for controlled release and targeted delivery of nutrients, pesticides, or drugs, reducing wastage and improving efficiency.

7) Reduced material usage

Because of their high efficiency, smaller quantities of nanomaterials are often required to achieve the same or better performance compared to bulk materials.

8) Improved functional performance

Nanomaterials can combine multiple properties (e.g., antimicrobial + antioxidant), making them multifunctional and more versatile than conventional bulk materials.

Factors affecting post-harvest life of cut flowers

The postharvest life of cut flowers is significantly reduced by several physiological and microbial factors. Stem blockage is one of the primary causes, mainly resulting from vascular occlusion, physiological injury, and bacterial infection at the cut end of the stem. These conditions obstruct water uptake, leading to reduced hydration and early wilting, thereby shortening vase life. In addition, increased ethylene biosynthesis, water imbalance, and depletion of stored carbohydrates further accelerate deterioration. Postharvest longevity and overall quality are also influenced by floral senescence and petal abscission, which are closely associated with ethylene production and microbial proliferation within the xylem vessels. The growth of microorganisms inside the stem restricts water movement and enhances senescence processes, ultimately reducing the decorative value and shelf life of cut flowers.

Methods to improve post-harvest life

Several approaches have been developed to enhance the postharvest life of cut flowers, particularly those that are sensitive to ethylene. One of the most effective strategies involves the use of ethylene inhibitors such as **1-methylcyclopropene (1-MCP)** and silver-based compounds. These substances function by blocking ethylene receptors in plant tissues, thereby preventing the hormone from triggering senescence-related processes such as petal wilting and abscission. In ethylene-sensitive flowers like carnations, 1-MCP significantly delays aging and maintains floral freshness. Interestingly, it has also been reported to reduce senescence in certain ethylene-insensitive species, such as roses, by improving overall physiological stability.

In addition to conventional inhibitors, nanotechnology-based interventions have gained importance in recent years. Nano-silver (NS) particles are widely used due to their strong antimicrobial and ethylene-inhibiting properties. When incorporated into packaging materials or vase solutions, nano-silver suppresses bacterial growth in the xylem vessels, thereby preventing stem blockage and improving water uptake. This helps maintain turgidity, colour retention, and overall flower quality. Furthermore, placing cut stems in preservative solutions containing sugars, biocides, and growth regulators under optimal environmental conditions (appropriate

temperature, humidity, and light) further enhances vase life. Together, these chemical and nano-enabled strategies offer promising solutions for improving the longevity and market value of horticultural products.

Application of nanoparticles in post-harvest life of cut flowers

The application of nanoparticles has emerged as an effective strategy for extending the postharvest life of cut flowers due to their strong antimicrobial properties. Metals and metal oxides in nanoparticle form exhibit remarkable germicidal efficiency, often eliminating up to 99% of microbial populations. For example, silver nanoparticles have been reported to effectively destroy more than 650 species of bacteria in water. Their extremely small size and large surface area enhance their contact with microbial cells and increase their mobility within plant tissues and vase solutions, making them highly efficient antimicrobial agents.

The antimicrobial mechanism of nanoparticles is primarily associated with the release of metal ions, which interact with sulfhydryl (–SH) or thiol groups present on bacterial cell membrane proteins. This interaction disrupts membrane integrity, reduces permeability, and interferes with essential cellular functions, ultimately leading to cell death. In postharvest management of cut flowers, commonly used nanoparticles include nanosilver, nanocopper, nanozinc oxide, and nanosilicon, all of which help suppress microbial growth, prevent vascular blockage, and improve water uptake, thereby enhancing vase life and maintaining flower quality.

Studies showed that calcium oxide nanoparticles improve stem strength, reduce bending, minimize weight loss, and help maintain flower diameter and chlorophyll content, thereby preserving the overall visual quality of gerbera. Graphene oxide, with its large surface area and abundant oxygen-containing functional groups, is highly hydrophilic and enhances water transport within plant tissues. It also exhibits strong antimicrobial activity by damaging microbial cell membranes and reducing their survival. Copper nanoparticles contribute to longer vase life by inhibiting chlorophyll-degrading enzymes, thereby preventing leaf yellowing and maintaining freshness in flowers such as chrysanthemum. Capped zinc nanoparticles act as effective hydrating agents and help prevent microbial infection at the cut end of stems by increasing bacterial membrane permeability. Silicon nanoparticles play multiple roles, including reducing ethylene production, strengthening cell walls, protecting cells from oxidative damage, decreasing transpiration and evaporation rates, and enhancing photosynthesis, which collectively improve water uptake and maintain fresh weight in flowers like lisianthus and rose. Additionally, carbon nanotubes enhance vase solution uptake, thereby contributing to improved hydration and extended vase life. Together, these nanoparticles improve postharvest quality through antimicrobial action, enhanced water relations, and strengthened cellular protection mechanisms.

Conclusion

In conclusion, nanotechnology-driven innovations offer a highly promising and sustainable approach for enhancing the postharvest longevity of cut flowers. By utilizing nanoparticles with antimicrobial, antioxidant, and ethylene-regulating properties, it is possible to effectively control microbial stem blockage, reduce oxidative stress, maintain water balance, and delay senescence. Various nanomaterials such as silver, copper, zinc, silicon, graphene oxide, and carbon-based nanostructures have demonstrated significant potential in improving vase life, preserving visual quality, and maintaining physiological stability. Compared to conventional postharvest

treatments, nano-enabled strategies provide targeted action, improved efficiency, and reduced chemical usage. Therefore, the integration of nanotechnology into floriculture practices can contribute to extended shelf life, enhanced market value, and greater sustainability in the ornamental flower industry.

References

- Bashir, M., Manzoor, A., & Hashmi, M. (2020). Nanoparticles as a preservative solution can enhance postharvest attributes of cut flowers. *Italus Hortus*, 27, 1–14.
- Gupta, D., Verma, A., & Monika, T. (2018). Application of ZnO nanoparticles in enhancing shelf life of cut flowers with special reference to *Gerbera jamesonii*. *Research Journal of Chemistry and Environment*, 22, 1–8.
- Hatami, M., Hatamzadeh, A., Ghasemnezhad, M., & Ghorbanpour, M. (2013). The comparison of antimicrobial effects of silver nanoparticles (SNP) and silver nitrate (AgNO₃) to extend the vase life of 'Red Ribbon' cut rose flowers. *Trakia Journal of Sciences*, 11.
- Langroudi, M. E., Hashemabadi, D., Kalatejari, S., & Asadpour, L. (2019). Effect of silver nanoparticles, spermine, salicylic acid and essential oils on vase life of *Alstroemeria*. *Journal of Neotropical Agriculture*, 6(2), 108–115.

BIOMIMETIC LANDSCAPING: DESIGNING GARDENS INSPIRED BY NATURAL ECOSYSTEMS

Athira S^{1*}, Choudhari Balaji Keshavrao² and Khushal B. Muradi³

¹ Athira S., Ph.D. Scholar, Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

². Scholar, Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

³ Department of Vegetable Science, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Biomimetic landscaping is an innovative approach to garden and landscape design that draws inspiration from the structure, processes, and resilience of natural ecosystems. In contrast to conventional ornamental landscaping, which often emphasizes symmetry, monoculture plantings, and high external inputs, biomimetic design studies how forests, wetlands, grasslands, and other ecosystems function efficiently and sustainably. By observing how nature manages water, cycles nutrients, supports biodiversity, and adapts to environmental changes, designers can create gardens that are not only aesthetically pleasing but also ecologically balanced and self-sustaining.

Natural ecosystems thrive through diversity, layered vegetation, symbiotic relationships, and efficient resource use. Biomimetic landscaping translates these principles into practical horticultural strategies such as multi-layered planting, use of native and climate-adapted species, soil regeneration through organic matter recycling, and water-sensitive design. These landscapes reduce dependency on chemical fertilizers, pesticides, and excessive irrigation while enhancing soil health, pollinator activity, and overall ecosystem stability. As cities face challenges like climate change, urban heat islands, and biodiversity loss, biomimetic gardens offer a sustainable alternative that aligns beauty with environmental responsibility.

Beyond ecological benefits, biomimetic landscaping fosters a deeper connection between people and nature by creating dynamic, living spaces that reflect natural patterns and seasonal rhythms. Such landscapes are more resilient to drought, flooding, and temperature extremes, making them suitable for long-term sustainable urban development. By learning from nature rather than attempting to dominate it, biomimetic landscaping redefines garden design as a regenerative practice - one that harmonizes horticulture, floriculture, and ecological stewardship for the future.

Why biomimetic landscaping is important?

Biomimetic landscaping is important because it promotes ecological sustainability by designing gardens that function like natural ecosystems. Unlike conventional landscapes that depend heavily on fertilizers, pesticides, and excessive irrigation, biomimetic systems mimic natural nutrient cycling, water infiltration, and plant diversity. This reduces maintenance costs, conserves water, improves soil fertility, and minimizes environmental pollution. By working with nature rather than against it, these landscapes become more self-regulating and resource-efficient.

It also plays a crucial role in addressing climate change and urban environmental challenges. Landscapes inspired by forests, wetlands, and grasslands can reduce urban heat island effects, increase carbon sequestration, manage stormwater naturally, and enhance drought resilience.

Diverse plant communities improve biodiversity by providing habitat and food sources for pollinators, birds, and beneficial insects. In rapidly urbanizing areas, biomimetic landscaping helps restore ecological balance and supports climate-resilient cities. Furthermore, it enhances human well-being and environmental awareness. Gardens designed to reflect natural ecosystems create calming, restorative spaces that improve mental health and strengthen people's connection to nature. They also serve as living educational models, demonstrating sustainable practices in horticulture and floriculture. Overall, biomimetic landscaping is important because it integrates beauty, functionality, and environmental responsibility into a single, regenerative design approach.

Steps involved in biomimetic landscaping**1) Site analysis and observation**

The first step is to carefully study the site conditions, climate, soil type, rainfall pattern, sunlight exposure, slope, and existing vegetation. Observe how natural ecosystems function in that region. Understanding local ecology helps in selecting plant species and designing systems that align with natural processes rather than opposing them.

2) Study of natural ecosystems

Identify a natural ecosystem similar to your site, such as a forest, grassland, wetland, or coastal system. Analyze how it manages:

- Water movement and retention
- Nutrient cycling
- Plant layering (canopy, understory, shrubs, groundcover)
- Biodiversity interactions

3) Design based on ecological principles

Translate natural patterns into landscape design by:

- Using **layered planting systems**
- Selecting **native and climate-adapted species**
- Encouraging plant diversity instead of monoculture
- Designing natural water harvesting and drainage systems
- Creating pollinator-friendly zones

4) Soil regeneration and preparation

Enhance soil health through organic compost, mulching, and microbial enrichment. Avoid excessive chemical inputs. Healthy soil is the foundation of a self-sustaining landscape.

5) Water-sensitive planning

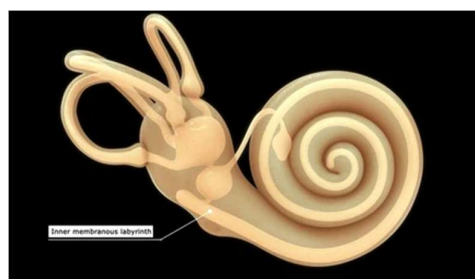
Incorporate rain gardens, swales, permeable surfaces, and natural drainage systems to imitate how ecosystems manage water. This reduces runoff and improves groundwater recharge.

6) Implementation and planting

Plant according to ecological grouping species that naturally grow together should be planted together. Ensure proper spacing to allow natural growth and succession.

7) Monitoring and adaptive management

Observe how the landscape evolves over time. Nature changes seasonally and gradually stabilizes. Make minimal but necessary adjustments to maintain ecological balance without disrupting natural processes.



Photographs of butterfly shaped and labyrinth shaped gardens

Environmental significance

Biomimetic landscaping holds immense environmental significance as it strengthens climate resilience through nature-inspired design. By mimicking the structure and function of natural ecosystems such as forests and grasslands, these landscapes become better adapted to withstand drought, heavy rainfall, and temperature fluctuations. Deep-rooted native plants enhance water infiltration and soil stability, while diverse plant communities reduce the risk of pest outbreaks and system failure. Such ecological gardens play a vital role in biodiversity conservation in urban landscapes by creating habitats and food sources for pollinators, birds, and beneficial insects. Instead of isolated ornamental plantings, biomimetic landscapes function as interconnected living systems that restore ecological balance within cities.

Moreover, biomimetic landscaping contributes significantly to carbon sequestration potential in ecological gardens. Healthy soils enriched with organic matter, combined with dense and diverse vegetation, capture and store atmospheric carbon dioxide, thereby supporting climate change mitigation efforts. Another major benefit is urban heat island mitigation. Multi-layered planting, tree canopies, and groundcovers reduce surface temperatures by providing shade and promoting evapotranspiration, which cools surrounding air. By integrating climate resilience, biodiversity support, carbon storage, and temperature regulation, biomimetic landscaping emerges as a sustainable solution for environmentally responsible urban development.

Conclusion

In conclusion, biomimetic landscaping represents a transformative approach to garden and landscape design that aligns human creativity with the wisdom of nature. By studying and

emulating the structure, functions, and resilience of natural ecosystems, this method creates landscapes that are sustainable, climate-responsive, and ecologically balanced. It reduces dependency on external inputs, enhances biodiversity, improves soil and water management, and strengthens environmental resilience in urban and rural settings alike. More than a design trend, biomimetic landscaping is a regenerative philosophy that redefines horticulture and floriculture as practices that coexist harmoniously with nature, ensuring healthier environments and sustainable landscapes for future generations.

References

- Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature* (Vol. 688136915). New York: Morrow.
- Jović, B. S., & Mitić, A. D. (2020). Exploration of nature-based biomimetic approach in landscape architectural design: parametric study of candelabra model design. *Visual Computing for Industry, Biomedicine, and Art*, 3(1), 25.

BIOFERTILIZERS AND MICROBIOME MANIPULATION: REVOLUTIONIZING SUSTAINABLE AGRICULTURE

Choudhari Balaji Keshavrao¹, Chaithra B. S² and Yogesh V. Wayal³

¹Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

²Assistant Professor, Kadiri Baburao College of Agriculture, C. S. Puram - 523112, Andhra Pradesh, India.

³Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram - 695522, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Abstract

Biofertilizers have gained increasing attention as sustainable agricultural inputs capable of improving crop productivity through strategic manipulation of soil and plant-associated microbiomes. As global food demand rises alongside environmental challenges such as climate change, soil degradation, and biodiversity loss, the use of beneficial microorganisms offers an eco-friendly alternative to chemical fertilizers. Biofertilizers enhance nutrient availability through biological nitrogen fixation, solubilization of phosphorus and potassium, and production of plant growth-promoting substances including phytohormones and siderophores. Additionally, microbial inoculants improve plant tolerance to biotic and abiotic stresses by modulating plant physiological responses and rhizosphere interactions. Despite their potential, challenges such as inconsistent field performance, storage limitations, and strain specificity hinder large-scale adoption. Advances in multi-omics technologies, genetic engineering, and nano-biofertilizer development are expected to improve efficiency and reliability. Overall, microbiome-based biofertilizers represent a promising approach for achieving sustainable crop production while reducing dependence on synthetic fertilizers and minimizing environmental impacts.

Keywords: Biofertilizers, Microbiome manipulation, Plant growth-promoting rhizobacteria, Sustainable agriculture, Nutrient mobilization, Arbuscular mycorrhizal fungi, Soil health, Biological nitrogen fixation.

Introduction

The increasing global population and environmental concerns have intensified the need for sustainable agricultural practices that enhance crop productivity while preserving natural resources. Biofertilizers, containing beneficial microorganisms, offer an eco-friendly approach to improve nutrient availability and plant growth through microbiome manipulation in the rhizosphere. As global population approaches 10 billion by 2050, agriculture faces unprecedented challenges including ecosystem degradation, climate change, and biodiversity loss (Mitter et al., 2021). Biofertilizers have emerged as a promising solution, harnessing beneficial microorganisms to manipulate soil and plant-associated microbiomes for enhanced crop productivity.

Understanding Biofertilizers and Microbiome Manipulation

Biofertilizers are preparations containing living microbial cells that enhance plant nutrition through rhizosphere interactions (Okur et al., 2018; Rana et al., 2013). These microbial inoculants

represent sophisticated microbiome manipulation, where specific microorganisms modify existing soil microbial community structure and function (Maćik et al., 2020).

This approach strategically manages soil and plant-associated microorganisms to enhance nutrient availability and plant health (Mitter et al., 2021). The process accelerates microbial processes in soil, increasing nutrient availability in forms easily assimilated by plants (Chakraborty et al., 2021).

Mechanisms of Microbial Action

Biofertilizers manipulate microbiomes through several key mechanisms. Nitrogen-fixing bacteria including *Rhizobium*, *Azotobacter*, and *Azospirillum* establish symbiotic relationships, converting atmospheric nitrogen into plant-available forms (Chakraborty et al., 2021) (Itelima J.U. et al., 2018). Phosphorus and potassium solubilizing microorganisms, particularly *Bacillus* and *Pseudomonas* species, transform insoluble soil nutrients into bioavailable forms (Nosheen et al., 2021).

Beyond nutrient mobilization, these microorganisms produce plant growth-promoting substances including phytohormones, siderophores, antibiotics, and antifungal compounds (Maćik et al., 2020)(Chakraborty et al., 2021). This biochemical arsenal enhances plant growth while providing protection against biotic and abiotic stresses, effectively reprogramming plant physiological responses through microbiome modulation.

Diverse Microbial Components

The microbiome manipulation toolkit includes diverse microorganisms. Bacterial components encompass nitrogen-fixers like *Cyanobacteria* and *Paenibacillus*, phosphate solubilizers, and plant growth-promoting rhizobacteria (PGPRs) (Itelima et al., 2018). Fungal partners, particularly arbuscular mycorrhizal fungi (AMF), form extensive hyphal networks that dramatically expand plant root surface area and nutrient uptake capacity (Chakraborty et al., 2021). Modern biofertilizer development increasingly focuses on co-inoculation strategies, combining multiple microbial species for synergistic effects. These approaches pair bacteria with other bacteria, rhizobia with rhizobacteria, or bacteria with fungi to optimize microbiome manipulation outcomes (Chakraborty et al., 2021).

Benefits and Applications

Strategic microbiome manipulation through biofertilizers offers numerous advantages for sustainable agriculture. These eco-friendly alternatives reduce chemical fertilizer dependency while maintaining or improving crop yields (Nosheen et al., 2021). Biofertilizers enhance soil fertility, improve water and nutrient uptake, and increase plant tolerance to environmental stresses (Itelima J. U. et al., 2018).

Environmentally, biofertilizers protect air, water, and soil quality while preventing eutrophication associated with chemical fertilizer runoff (Chakraborty et al., 2021). Their cost-effectiveness and renewable nature make them particularly attractive for sustainable farming systems (Rana et al., 2013).

Challenges and Future Directions

Despite their potential, biofertilizers face significant challenges in replacing conventional fertilizers commercially (Mitter et al., 2021). Key limitations include inconsistent field performance, specific storage requirements, and limited shelf life of living microbial preparations.

Future developments focus on creating genetically engineered microbes with enhanced capabilities, developing nano-biofertilizers, and utilizing advanced technologies like bioinformatics and genome sequencing to optimize microbial strains (Chakraborty *et al.*, 2021). Multi-omics studies promise to deepen microbiome function understanding and improve translation of this knowledge into practical agricultural applications.

Conclusion

Biofertilizers represent a paradigm shift toward microbiome-based agriculture, offering sustainable pathways to meet global food security challenges. As microbial ecology understanding advances, strategic manipulation of soil and plant microbiomes through biofertilizers will become increasingly sophisticated and effective, transforming modern agricultural practices toward greater sustainability and productivity while reducing environmental impact.

References

- Chakraborty, T. and Akhtar, N., 2021. Biofertilizers: Characteristic features and applications. *Biofertilizers: study and impact*, pp.429-489.
- Itelima, J.U., Bang, W.J., Onyimba, I.A. and Oj, E., 2018. A review: biofertilizer; a key player in enhancing soil fertility and crop productivity. *J Microbiol Biotechnol Rep*, 2(1), pp.22-28.
- Mıcık, M., Gryta, A. and Frąc, M., 2020. Biofertilizers in agriculture: An overview on concepts, strategies and effects on soil microorganisms. *Advances in agronomy*, 162, pp.31-87.
- Mitter, E.K., Tosi, M., Obregón, D., Dunfield, K.E. and Germida, J.J., 2021. Rethinking crop nutrition in times of modern microbiology: innovative biofertilizer technologies. *Frontiers in Sustainable Food Systems*, 5, p.606815.
- Nosheen, S., Ajmal, I. and Song, Y., 2021. Microbes as biofertilizers, a potential approach for sustainable crop production. *Sustainability*, 13(4), p.1868.
- Okur, N., 2018. A review-bio-fertilizers-power of beneficial microorganisms in soils. *Biomed. J. Sci. Tech. Res*, 4(4), pp.4028-4029.
- Rana, M., Chandra, R. and Pareek, N., 2015. Co-inoculation effect of endophytic bacteria with *Mesorhizobium* sp. in chickpea (*Cicer arietinum* L.) on nodulation, yields, nutrient uptake and soil biological properties. *Journal of the Indian Society of Soil Science*, 63(4), pp.429-435.

ADVANCES IN NUTRIENT USE EFFICIENCY IN AGRONOMIC CROPS: MECHANISMS, CHALLENGES, AND FUTURE PROSPECTS

Choudhari Balaji Keshavrao^{1*}, V. Kishanth Kanna² and R. Jeevanraj³

¹Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

²Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Abstract

Nutrient use efficiency (NUE) is a key component of sustainable agriculture, aiming to enhance crop productivity while reducing environmental impacts associated with fertilizer use. Despite increased fertilizer consumption globally, crop recovery of applied nutrients remains low due to losses through leaching, volatilization, fixation, and runoff. NUE is governed by complex interactions among plant physiological processes, root architecture, genetic regulation, and soil–environment dynamics. Recent advances in enhanced efficiency fertilizers, molecular breeding, and improved agronomic management practices such as integrated and site-specific nutrient management offer promising opportunities to improve nutrient utilization. An integrated approach combining genetic, agronomic, and technological innovations is essential to achieve higher NUE, ensuring sustainable crop production and environmental protection under changing climatic conditions.

Keywords: Nutrient use efficiency; Sustainable agriculture; Integrated nutrient management; Enhanced efficiency fertilizers; Precision agriculture; Crop productivity; Soil fertility.

Introduction

Nutrient use efficiency (NUE) has emerged as a critical concept in modern agriculture, representing the cornerstone of sustainable crop production systems. As global population continues to increase, fertilizer use has risen by 21% in the last two decades (Singh *et al.*, 2025). However, the fundamental challenge remains: crops utilize only a fraction of applied nutrients effectively, creating both economic and environmental concerns that demand innovative solutions.

Current State and Challenges

The current state of nutrient efficiency in agriculture presents sobering statistics. Research indicates that overall efficiency of applied fertilizers remains disappointingly low: approximately 50% or lower for nitrogen, less than 10% for phosphorus, and about 40% for potassium (Baligar *et al.*, 2001). These inefficiencies stem from multiple pathways including surface runoff, leaching, volatilization, denitrification, and fixation of micronutrients in soil due to high pH conditions (Singh *et al.*, 2019).

The implications extend beyond mere economic losses. Low NUE directly correlates with excess nutrient stability in ecosystems, causing environmental pollution through eutrophication, soil

acidification, and air pollution (Chen *et al.*, 2017). Furthermore, at least 60% of the world's arable lands suffer from mineral deficiencies or elemental toxicity problems, making fertilizer inputs essential yet environmentally problematic (Fageria *et al.*, 2008).

Mechanisms of Nutrient Efficiency

Understanding the biological mechanisms underlying NUE is crucial for developing effective improvement strategies. Nutrient efficiency encompasses two primary components: acquisition efficiency and utilization efficiency (Chen *et al.*, 2017). Root system architecture plays a fundamental role in improving nutrient acquisition efficiency, while mineral translocation, remobilization, and metabolic efficiency contribute significantly to nutrient utilization efficiency.

Recent molecular research has revealed that NUE is under genetic and physiological control, modified by plant interactions with environmental variables (Baligar *et al.*, 2001). The regulatory mechanisms controlling plant nitrogen economy involve complex gene, protein, and metabolite interactions that govern nitrogen uptake, assimilation, and recycling from vegetative organs to storage organs (Hirel *et al.*, 2007).

Recent Advances and Solutions

Several promising approaches have emerged to address NUE challenges. Enhanced efficiency fertilizers (EEFs) represent a significant technological advancement, designed to couple nutrient release with crop nutrient uptake patterns (Singh *et al.*, 2025). These fertilizers utilize sophisticated coating materials and release mechanisms that can potentially increase NUE while mitigating environmental risks. Breeding strategies have also evolved considerably. Modern approaches combine conventional breeding with molecular genetics, focusing on identifying traits such as nutrient absorption, transport, utilization, and mobilization in plant cultivars (Fageria *et al.*, 2008). Quantitative genetics, forward and reverse genetics approaches, and emerging systems biology techniques are being integrated to develop comprehensive understanding of nutrient efficiency mechanisms (Hirel *et al.*, 2007).

Agronomic management practices offer immediate implementation opportunities. Best management practices that apply nutrients at the right rate, time, and place, accompanied by appropriate agronomic techniques, can significantly optimize NUE (Singh *et al.*, 2019). Alternative farming techniques, including no-till continuous cover cropping and organic nitrogen nutrition, show promise for sustainable nutrient management (B. Hirel *et al.*, 2011).

Future Prospects

The future of NUE improvement lies in integrated approaches that harmonize agronomic, genetic, and biotechnological tools (Govindasamy *et al.*, 2023). Climate change adds urgency to these efforts, as enhanced NUE becomes critical for maintaining crop productivity under changing environmental conditions.

Long-term sustainability may require gradual transition from synthetic nitrogen inputs to legume-based crop rotations, including continuous cover cropping systems where climatically feasible (Hirel *et al.*, 2007). The development of nutrient-efficient crops coupled with best management practices will contribute to sustainable agricultural systems that protect soil, water, and air quality (Baligar *et al.*, 2001).

Conclusion

While significant challenges remain in improving NUE, recent advances in understanding mechanisms, developing enhanced fertilizers, and implementing integrated management approaches offer promising pathways forward. Success will require continued collaboration between breeders, soil scientists, physiologists, and agronomists to address this complex challenge holistically (Fageria *et al.*, 2008). The ultimate goal remains clear: achieving optimal balance between nutrient use efficiency and crop productivity for sustainable agricultural systems.

References

- Baligar, V.C., Fageria, N.K. and He, Z.L., 2001. Nutrient use efficiency in plants. *Communications in soil science and plant analysis*, 32(7-8), pp.921-950.
- Chen, L. and Liao, H., 2017. Engineering crop nutrient efficiency for sustainable agriculture. *Journal of Integrative Plant Biology*, 59(10), pp.710-735.
- Fageria, N.K., Baligar, V.C. and Li, Y.C., 2008. The role of nutrient efficient plants in improving crop yields in the twenty first century. *Journal of plant nutrition*, 31(6), pp.1121-1157.
- Govindasamy, P., Muthusamy, S.K., Bagavathiannan, M., Mowrer, J., Jagannadham, P.T.K., Maity, A., Halli, H.M., GK, S., Vadivel, R., TK, D. and Raj, R., 2023. Nitrogen use efficiency—a key to enhance crop productivity under a changing climate. *Frontiers in Plant Science*, 14, p.1121073.
- Hirel, B., Le Gouis, J., Ney, B. and Gallais, A., 2007. The challenge of improving nitrogen use efficiency in crop plants: towards a more central role for genetic variability and quantitative genetics within integrated approaches. *Journal of experimental botany*, 58(9), pp.2369-2387.
- Singh, A., Jaswal, A. and Singh, M., 2019. Enhancing nutrients use efficiency in crops by different approaches-A review. *Agricultural Reviews*, 40(1).
- Singh, K., Singh, R., Nwosu, N.J., Omara, P., Sharma, L., Dunn, B.L. and Singh, H., 2025. Optimizing nutrient delivery in agronomic crops: a review of enhanced efficiency fertilizers. *Journal of Plant Nutrition and Soil Science*, 188(4), pp.570-584.

BIOSTIMULANTS IN CEREAL CROPS: ENHANCING GROWTH, YIELD, AND SUSTAINABILITY

Choudhari Balaji Keshavrao¹, Khushal B. Muradi² and K. Bhrundha³

¹Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

²Department of Vegetable Science, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Introduction

Cereals including wheat (*Triticum aestivum*), rice (*Oryza sativa*), maize (*Zea mays*), and barley (*Hordeum vulgare*) form the backbone of global food security, collectively contributing to more than 50% of humanity's caloric intake. However, mounting pressures from climate change, soil degradation, and the environmental costs of synthetic fertilizer overuse are threatening cereal productivity worldwide. In this context, biostimulants have emerged as a scientifically validated, eco-friendly strategy to sustainably boost cereal production. Biostimulants are defined under the European Union Fertilizing Products Regulation 2019 as substances or microorganisms that, when applied to plants or the rhizosphere, stimulate natural nutrition processes, enhance nutrient use efficiency, abiotic stress tolerance, crop quality traits, or the availability of confined nutrients in the soil regardless of their nutrient content. This article reviews the types, mechanisms, field-based evidence, and future prospects of biostimulants in cereal crops, drawing on recent peer-reviewed literature.

Types of Biostimulants

Biostimulants are broadly categorized into microbial and non-microbial types. Microbial biostimulants include plant growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF), and beneficial fungi such as *Trichoderma* spp. Non-microbial biostimulants encompass humic and fulvic acids, seaweed extracts, protein hydrolysates, amino acids, and chitosan-based compounds. Both categories operate through distinct but often complementary mechanisms to improve cereal growth and productivity. Biostimulants including humic substances, seaweed extracts, PGPR, and mycorrhizal fungi have been consistently investigated for their effects on seed germination, root growth, leaf development, and grain yield across major wheat-growing regions (Sellami *et al.*, 2025).

Mechanisms of Action in Cereals

Biostimulants exert their effects through multiple physiological and biochemical pathways. They increase nutrient use efficiency (NUE) by enhancing root architecture, improving ion uptake, and modulating phytohormone signaling. Humic acids, for example, exhibit hormone-like activity that activates stress-dependent signaling pathways and improves grain yield under drought. A study reported in *New Phytologist* (2025) found that foliar application of humic acids improved drought resistance in wheat by increasing antioxidant responses, while humic acid application improved

grain yield by 16% in two maize genotypes exposed to drought stress (Chen *et al.*, 2021). Also, result with 100% RDF + 20 kg humic acid recorded significantly highest grain yield of maize (Deshmukh *et al.*, 2023) Microbial biostimulants further enhance root colonization, phosphate solubilization, nitrogen fixation, and the secretion of siderophores and phytohormones such as indole-3-acetic acid (auxin) and cytokinin all of which stimulate cereal growth directly. AMF, one of the most widely studied microbial biostimulants, promote efficient mineral absorption, rapid water uptake, and alterations in stress-responsive gene expression, thereby providing protection against drought, salinity, and heavy metal stress (PMC, 2023).

Key Biostimulants and Their Roles in Cereals

Microbial Biostimulants (PGPR and AMF)

PGPR consortia have shown notable results in improving cereal performance under stress. Research published in *ScienceDirect* (2024) demonstrated that PGPR consortia significantly increased root and shoot biomass, relative water content, and grain yield in barley under severe drought stress, while decreasing oxidative stress indicators compared to uninoculated controls (Ferioun *et al.*, 2024). In wheat, PGPR inoculation was similarly documented to increase root growth and nitrogen accumulation, affirming the potential of rhizobacteria in enhancing cereal NUE (Dal Cortivo *et al.*, 2017).

Seaweed Extracts

Seaweed extracts, particularly those derived from brown macroalgae such as *Ascophyllum nodosum*, are among the fastest-growing biostimulant products globally. They contain polysaccharides, polyphenols, betaines, and natural phytohormones that enhance germination, tillering, and stress tolerance in cereals. A field experiment published in *Scientific Reports* (2025) on rainfed wheat in Iran found that foliar application of seaweed extracts combined with amino acids improved plant performance, root growth, physiological attributes, and grain quality compared to chemical fertilizer-only treatments (Moradi *et al.*, 2025). Seaweed extracts activate antioxidant defenses, modulate stress-responsive gene expression, and maintain cellular hydration under abiotic stress (Deolu-Ajayi *et al.*, 2022).

Humic and Fulvic Acids

Humic and fulvic acids, derived from decomposed organic matter, improve soil structure, enhance micronutrient mobility, and stimulate microbial activity in the rhizosphere. Research published in *BMC Plant Biology* (2025) on bread wheat demonstrated that combining humic-based biostimulants with reduced chemical fertilizer inputs can maintain high grain yield while enriching cationic nutrients such as calcium, magnesium, and potassium in the grain (Ferrari *et al.*, 2025). The stress-protective effects of humic acids are attributed to their hormone-like activity, which regulates osmotic pressure and maintains cell turgor under water stress conditions.

Amino Acids and Protein Hydrolysates

Amino acid-based biostimulants improve grain protein content and facilitate stress recovery in cereals. A study in *Molecules* found that amino acid-based biostimulants significantly improved yield and grain quality of winter wheat (Popko *et al.*, 2018). Proline, histidine, and tryptophan in particular contribute to reactive oxygen species (ROS) scavenging, providing biochemical protection during heat, drought, and salinity episodes that are increasingly common under climate change.

Documented Benefits: Field Evidence

A landmark meta-analysis of 107 biostimulant treatments across European field trials found an average crop growth and yield increase of 9.3%, with maize outperforming wheat in responsiveness (Nkebiwe *et al.*, 2024). A broader meta-analysis by Li *et al.* (2022) focusing on non-microbial biostimulants reported an overall yield increase of 17.9%. The sole and combined application of biostimulants significantly improved maize grain yield, protein content, and oil content across multiple agro-climatic regions (Ocwa *et al.*, 2024). Microbial biostimulant inoculation in durum wheat under drought and salinity stress also improved protein, sugar, and lipid content in the grain, pointing to quality improvements beyond mere yield gains (Li *et al.*, 2026).

Challenges and Limitations

Despite promising results, biostimulant adoption in cereal farming faces several hurdles. Performance is highly variable between controlled greenhouse trials and open-field conditions, largely because effective root colonization by microbial inoculants is difficult to guarantee under diverse soil and climatic conditions (Nkebiwe *et al.*, 2024). Regulatory frameworks remain fragmented across countries, and there is limited farmer awareness of product selection and application protocols. Moreover, the absence of crop- and region-specific formulations means that generic products often deliver inconsistent results. Researchers increasingly advocate for long-term, multi-site field trials under diverse agro-ecological conditions to establish robust evidence bases.

Future Outlook

The field of biostimulants is rapidly advancing into what researchers have termed "Biostimulants 4.0" a new paradigm integrating multi-omics data, artificial intelligence-driven discovery, nanotechnology, and IoT-enabled precision application systems. Synthetic biology is enabling the engineering of microbial strains with enhanced phytohormone production and phosphate solubilization capabilities, promising more predictable and targeted outcomes in cereals. At the policy level, the European Green Deal and FAO's global sustainable plant production frameworks are actively encouraging research and adoption of biostimulants as part of a broader agro-ecological transition. Scaling these innovations from laboratory to large-scale cereal farms, particularly in climate-vulnerable regions of Asia, Africa, and South America, will be essential to meet future food security targets.

Conclusion

Biostimulants represent a scientifically robust and environmentally responsible approach to enhancing cereal crop productivity and resilience. From PGPR and AMF to seaweed extracts, humic acids, and amino acid formulations, each category offers distinct and often complementary benefits from improved root architecture and NUE to enhanced stress tolerance and grain quality. Field-based evidence consistently demonstrates measurable yield gains and reduced dependency on synthetic inputs. As research transitions into the next generation of precision bioformulations powered by omics and digital technologies, biostimulants are poised to become a cornerstone of sustainable cereal production systems worldwide. Bridging the gap between research and farmer practice through targeted education, policy support, and region-specific product development will be key to unlocking their full potential.

References

- Chen, Q., Qu, Z., Li, Z., Zhang, Z., Ma, G., Liu, Z., Wang, Y., Wu, L., Fang, F., Wei, Z. and Zhang, M., 2021. Coated diammonium phosphate combined with humic acid improves soil phosphorus availability and photosynthesis and the yield of maize. *Frontiers in Plant Science*, 12, p.759929.
- Dal Cortivo, C., Barion, G., Visioli, G., Mattarozzi, M., Mosca, G. and Vamerali, T., 2017. Increased root growth and nitrogen accumulation in common wheat following PGPR inoculation: Assessment of plant-microbe interactions by ESEM. *Agriculture, Ecosystems & Environment*, 247, pp.396-408.
- Deolu-Ajayi, A.O., van der Meer, I.M., Van der Werf, A. and Karlova, R., 2022. The power of seaweeds as plant biostimulants to boost crop production under abiotic stress. *Plant, Cell & Environment*, 45(9), pp.2537-2553.
- Deshmukh, S.B., Karanjikar, P.N., Patil, P.D., Sabne, K.S. and Mamdi, S.J., 2023. Effect of humic acid and fertilizer on growth and yield of maize (*Zea mays* L.).
- Ferionun, M., Bouhraoua, S., Belahcen, D., Zouitane, I., Srhiaouar, N., Louahlia, S. and El Ghachtouli, N., 2024. PGPR consortia enhance growth and yield in barley cultivars subjected to severe drought stress and subsequent recovery. *Rhizosphere*, 31, p.100926.
- Li, J., Forghieri, G., Geelen, D., Du Jardin, P. and Brown, P.H., 2026. The optimization of crop response to climatic stress through modulation of plant stress response mechanisms. Opportunities for biostimulants and plant hormones to meet climate challenges. *New Phytologist*, 249(1), pp.130-151.
- Li, J., Van Gerrewey, T. and Geelen, D., 2022. A meta-analysis of biostimulant yield effectiveness in field trials. *Frontiers in Plant Science*, 13, p.836702.
- Moradi, L. and Siosemardeh, A., 2025. Bio and chemical fertilizers integration supplemented by biostimulants a sustainable way to reduce chemical inputs in rainfed wheat systems. *Scientific Reports*.
- Nkebiwe, P.M., Stevens Lekfeldt, J.D., Symanczik, S., Thonar, C., Mäder, P., Bar-Tal, A., Halpern, M., Biró, B., Bradáčová, K., Caniullan, P.C. and Choudhary, K.K., 2024. Effectiveness of bio-effectors on maize, wheat and tomato performance and phosphorus acquisition from greenhouse to field scales in Europe and Israel: a meta-analysis. *Frontiers in Plant Science*, 15, p.1333249.
- Ocwa, A., Mohammed, S., Mousavi, S.M.N., Illés, Á., Bojtor, C., Ragán, P., Rátonyi, T. and Harsányi, E., 2024. Maize grain yield and quality improvement through biostimulant application: a systematic review. *Journal of Soil Science and Plant Nutrition*, 24(2), pp.1609-1649.
- Popko, M., Michalak, I., Wilk, R., Gramza, M., Chojnacka, K. and Górecki, H., 2018. Effect of the new plant growth biostimulants based on amino acids on yield and grain quality of winter wheat. *Molecules*, 23(2), p.470.
- Sellami, M.H., Di Mola, I. and Mori, M., 2025. Evaluating wheat response to biostimulants: a 25-year review of field-based research (2000–2024). *Frontiers in Sustainable Food Systems*, 9, p.1543981.

INTEGRATED NUTRIENT MANAGEMENT IN PULSES

Deshmukh Sarita Babarao^{1*}, K. Bhrundha² and V. Kishanth Kanna³

¹Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

^{2&3}Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Abstract

Pulses play a crucial role in global food and nutritional security by providing high-quality protein, essential amino acids, and micronutrients, while also contributing to sustainable agriculture through biological nitrogen fixation and soil fertility improvement. Despite their importance, pulse productivity remains low due to nutrient imbalances, soil fertility constraints, climate stress, and limited adoption of improved management practices. Integrated Nutrient Management (INM), which combines chemical fertilizers, organic manures, and biofertilizers, offers a holistic and sustainable solution to these challenges. INM ensures balanced nutrient supply, enhances nutrient use efficiency, improves biological nitrogen fixation, and sustains soil health through increased organic carbon and microbial activity. Studies demonstrate that INM significantly improves growth, yield, and yield stability of pulse crops compared to sole fertilizer use, while reducing environmental impacts and production costs. By enhancing soil resilience and supporting climate-smart agriculture, INM represents a viable strategy for sustainable and climate-resilient pulse production. Wider adoption through research, extension, and policy support is essential for achieving long-term food and nutritional security.

Keywords: Integrated Nutrient Management, Pulses; Soil Health, Biological Nitrogen Fixation, Nutrient Use Efficiency, Biofertilizers, Organic Manures, Sustainable Agriculture, Climate-Resilient Farming

Introduction

Pulses are a vital component of global food and nutritional security, particularly for vegetarian populations, as they provide high-quality protein, essential amino acids, vitamins, and minerals. With a protein content of 22–24%, pulses contain nearly double the protein of wheat and three times that of rice (Gowda *et al.*, 2013). Regular consumption of pulses has been associated with reduced risks of non-communicable diseases such as cardiovascular disorders and colon cancer, highlighting their importance in addressing malnutrition and hidden hunger (Gowda *et al.*, 2013). Despite these benefits, per capita pulse availability declined from 60 g to 42 g per day between 1951 and 2013, posing serious nutritional concerns, especially for women and children in rural areas (Pathak *et al.*, 2017).

Beyond nutrition, pulses play a significant role in sustainable agriculture due to their ability to fix atmospheric nitrogen through symbiotic association with *Rhizobium*. This reduces dependence on synthetic nitrogen fertilizers and associated greenhouse gas emissions (Kumar *et al.*, 2023). Pulse residues enrich soil organic matter, improve nutrient cycling, and contribute to carbon sequestration (Alekhya *et al.*, 2024). Pulses also enhance phosphorus availability and soil fertility

when integrated into crop rotations, intercropping, and mixed cropping systems (Gowda *et al.*, 2013).

However, pulse productivity has remained low over the past several decades due to cultivation on marginal lands, rainfed conditions, limited access to quality seeds, imbalanced fertilizer use, and poor adoption of improved management practices (Pooniya *et al.*, 2015). Climate change, rising temperatures, and widespread phosphorus deficiency in Indian soils further constrain yields, resulting in demand–supply gaps, increased imports, and price instability (Pathak *et al.*, 2017, Patel *et al.*, 2025).

Integrated Nutrient Management (INM) offers a holistic solution to these challenges by combining chemical fertilizers, organic manures, and biofertilizers to ensure balanced nutrition while maintaining soil and environmental health (Puneeth *et al.*, 2023). Studies indicate that INM can increase crop yields by 8–150% compared to conventional practices, improve water-use efficiency, enhance grain quality, and increase economic returns (Patel *et al.*, 2025). Thus, INM represents an eco-friendly and climate-resilient strategy for sustainable pulse production.

Nutrient Requirements of Pulse Crops

Pulses meet a major portion of their nitrogen requirement through biological nitrogen fixation, which can supply up to 80% of crop nitrogen demand (Pooniya *et al.*, 2015). However, a small starter dose of nitrogen is beneficial during early growth. Phosphorus is critical for root development, nodulation, and energy transfer, with optimal requirements around 60–70 kg P₂O₅ ha⁻¹ for crops like chickpea. Potassium also plays an important role in physiological processes, and positive responses have been observed with 15 kg K₂O ha⁻¹ application in chickpea (Pooniya *et al.*, 2015).

Secondary nutrients, particularly sulfur, are essential for protein synthesis. Long-duration pulses such as pigeonpea respond to sulfur application up to 40 kg ha⁻¹, while short-duration pulses show optimal responses around 20 kg ha⁻¹, resulting in improved yield and protein content. Micronutrients such as zinc, iron, molybdenum, and boron are crucial for enzymatic activities and nitrogen fixation. Combined application of Zn, Mo, and B has been shown to significantly enhance pulse yields, with ZnSO₄ at 25 kg ha⁻¹ proving economically beneficial in pigeonpea (Pooniya *et al.*, 2015).

Principles of Integrated Nutrient Management

INM is based on balanced nutrient supply, synchronization of nutrient release with crop demand, improved nutrient use efficiency, and long-term soil fertility maintenance. The combined use of organic, inorganic, and biological sources corrects nutrient imbalances and prevents soil degradation while minimizing environmental pollution (Singh *et al.*, 2020).

Organic components release nutrients slowly, ensuring better synchronization with crop requirements and reducing losses through leaching and denitrification (Aulakh *et al.*, 2010). Improved soil structure and microbial activity under INM enhance nutrient uptake and apparent recovery efficiency. Over time, INM builds soil organic carbon, sustains productivity, and supports environmentally sustainable farming systems (Selim *et al.*, 2020).

Components of INM in Pulses

Chemical fertilizers remain essential for meeting immediate nutrient demands but should be applied judiciously within an integrated framework to avoid environmental and economic drawbacks (Pandey *et al.*, 2017). Organic sources such as farmyard manure, compost, and

vermicompost supply nutrients gradually, improve soil physical properties, and enhance microbial activity (Chejara *et al.*, 2021). Green manures, crop residues, and alternative organic amendments like poultry and piggery manure further contribute to nutrient recycling and soil fertility buildup (Aulakh *et al.*, 2010).

Biofertilizers are a key component of INM. *Rhizobium* inoculation enhances nitrogen fixation, growth, and yield in pulses such as chickpea, cowpea, and field pea (Puneeth *et al.*, 2023). Phosphate-solubilizing bacteria improve phosphorus availability, while arbuscular mycorrhizal fungi enhance nutrient and water uptake. Plant growth-promoting rhizobacteria contribute to improved plant vigor and soil health (Singh *et al.*, 2020).

Role of INM in Biological Nitrogen Fixation

INM creates a favorable rhizosphere environment that enhances *Rhizobium* establishment, nodulation, and nitrogen fixation through improved soil conditions and energy supply from organic matter decomposition (Chejara *et al.*, 2021). Balanced nutrient availability, particularly phosphorus and micronutrients, supports efficient nodulation and reduces reliance on external nitrogen inputs (Pandey *et al.*, 2017).

Impact of INM on Growth, Yield, and Soil Health

INM significantly improves growth parameters, yield attributes, and grain yield of pulses compared to sole fertilizer use (Aulakh *et al.*, 2010). Enhanced nutrient synchronization and improved soil conditions lead to higher productivity and yield stability (Puneeth *et al.*, 2023) (Choudhari *et al.*, 2023). Long-term INM increases soil organic carbon, microbial biomass, enzyme activity, nutrient availability, and soil structure, thereby sustaining soil health and productivity (Srivastava *et al.*, 2009; Singh *et al.*, 2020).

INM under Climate Stress and Adoption Constraints

By improving soil organic matter and water-holding capacity, INM enhances soil resilience and may improve tolerance to drought and heat stress (Chejara *et al.*, 2021). INM also supports climate-smart agriculture through reduced dependence on synthetic fertilizers and enhanced carbon sequestration (Selim *et al.*, 2020).

However, adoption of INM is constrained by limited availability of organic inputs, high transportation costs, lack of farmer awareness, and technical complexity (Menon *et al.*, 2020). Strengthening extension services and policy support is essential to overcome these barriers.

Conclusion

Integrated Nutrient Management is a scientifically proven, sustainable strategy for enhancing pulse productivity, soil health, and environmental quality. By combining organic, inorganic, and biological nutrient sources, INM ensures balanced nutrition, improves nutrient use efficiency, sustains yields, and supports climate-resilient pulse production. Wider adoption of INM through research, extension, and policy support is crucial for achieving sustainable food and nutritional security.

References

Alekhy, G., Darjee, S., Rajareddy, G., Reddy, K.S., Kumar, A.A. and Reddy, A.J. 2024. Integrating Pulses into Conservation Agriculture for Sustainable Soil Health and Productivity in the Indo-Gangetic Plains. *Journal of Scientific Research and Reports*, 30(9), pp.560-570.

- Aulakh, M.S. 2010. Integrated nutrient management for sustainable crop production, improving crop quality and soil health, and minimizing environmental pollution. In *19th world congress of soil science, soil solutions for a changing world* (pp. 1-6).
- Chejara, S., Malik, K., Rani, M. and Bhardwaj, A.K. 2021. Integrated nutrient management: Concept, constraints, and advantages for a sustainable agriculture. *Journal of Natural Resource Conservation and Management*, 2(2), pp.85-94.
- Choudhari, B.K., Aglave, B.N., Bhosle, N.U., Deshmukh, S.B. and Sharma, P., 2023. Effect of integrated nutrient management on economics of niger (*Guizotia abyssinica* L.).
- Gowda, C.L., Samineni, S., Gaur, P.M. and Saxena, K.B. 2013. Enhancing the productivity and production of pulses in India.
- Kumar, S., Gopinath, K. A., Sheoran, S., Meena, R. Srinivasarao, C., Bedwal, S., Kumar J, Mrunalini, K. Jat, R. and Praharaj. C. 2023. Pulse-based cropping systems for soil health restoration, resources conservation, and nutritional and environmental security in rainfed agroecosystems
- Menon, S., 2020. A review on integrated nutrient management an approach to sustainability. *International Journal of Chemical Studies*.
- Pandey, V., Dahiya, O.S., Mor, V.S., Yadav, R., Jitender, P.O. and Brar, A. 2017. Impact of integrated nutrient management on seed yield and its attributes in field pea (*Pisum sativum* L.). *Chemical science review and letters*, 6(23), pp.1428-1431.
- Patel, V.K., Singh, S.V., Patel, C., Ingle, S.N., Das, S.P., Singh, A.K. and Kumar V. 2025. Importance of Integrated Nutrient Management for Pulse Crops Amidst Climate Change in India: A Review *Agricultural Reviews*•<https://doi.org/10.18805/ag.r-2747>
- Pathak, A.R., Pithia, M.S., Javia, R.M. and Mehta, D.R. 2017. Challenges and options for meeting the needs of pulses-A review. *Agricultural Reviews*, 38(2).
- Pooniya, V., Choudhary, A.K., Dass, A., Bana, R.S., Rana, K.S., Rana, D.S., Tyagi, V.K. and Puniya, M.M. 2015. Improved crop management practices for sustainable pulse production: An Indian perspective. *Indian Journal of Agricultural Sciences*, 85(6), pp.747-758.
- Puneeth Raj, M. S., Narender, Pavitra B. V. 2023. Review on Effect of Integrated Nutrient Management on Seed Yield and Quality of Pulses *International Journal of Plant & Soil Science*• <https://doi.org/10.9734/ijpss/2023/v35i183303>
- Selim, M.M., 2020. Introduction to the integrated nutrient management strategies and their contribution to yield and soil properties. *International Journal of Agronomy*, 2020(1), p.2821678.
- Singh, B.R., 2020. Integrated nutrient management. In *Managing Soils and Terrestrial Systems* (pp. 419-433). CRC Press
- Srivastava, A.K. and Ngullie, E. 2009. Integrated nutrient management: Theory and practice. *Dynamic Soil, Dynamic Plant*, 3(1), pp.1-30.

ROLE OF BIOFERTILIZERS IN SUSTAINABLE AGRICULTURAL PRODUCTION

Deshmukh Sarita Babarao^{1*}, Choudhari Balaji Keshavrao² and Khushal B. Muradi³

^{1&2}Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

³Department of Vegetable Science, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Abstract

Biofertilizers have emerged as a promising and sustainable alternative to synthetic fertilizers by harnessing beneficial microorganisms to enhance soil fertility, nutrient availability, and crop productivity. Conventional agricultural systems rely heavily on chemical fertilizers, resulting in severe environmental and human health concerns such as soil acidification, nutrient depletion, reduced soil fertility, and low nutrient use efficiency, with only 10–40% of applied nutrients being absorbed by crops. Biofertilizers, including nitrogen-fixing microorganisms, phosphate- and potassium-solubilizing microbes, plant growth-promoting rhizobacteria (PGPR), and mycorrhizal fungi, offer eco-friendly solutions by improving nutrient cycling, stimulating plant growth, and restoring soil health. These microorganisms operate through multiple mechanisms such as biological nitrogen fixation, solubilization of macro- and micronutrients, production of phytohormones, suppression of phytopathogens, and enhancement of root morphology and nutrient uptake efficiency. The application of biofertilizers has demonstrated significant improvements in crop growth, yield, and nutrient use efficiency across cereals, pulses, oilseeds, and horticultural crops, particularly when integrated with chemical fertilizers and organic manures. Beyond productivity gains, biofertilizers play a crucial role in improving soil microbial diversity, enzyme activity, soil structure, organic matter accumulation, and carbon sequestration, thereby contributing to climate-smart agriculture. Despite these benefits, large-scale adoption is constrained by issues related to quality control, shelf life, inconsistent field performance, limited farmer awareness, and inadequate regulatory frameworks. Recent advances in microbial consortia development, metagenomics, CRISPR-based strain improvement, and advanced formulation technologies offer new opportunities to overcome these challenges. Strengthening research, policy support, standardization, and extension services will be essential to fully realize the potential of biofertilizers in achieving sustainable agricultural production, environmental protection, and long-term food security.

Keywords: Biofertilizers, Sustainable agriculture, Nutrient use efficiency, Plant growth-promoting rhizobacteria (PGPR), Biological nitrogen fixation, Phosphate solubilization, Soil health, Climate-smart agriculture, Microbial consortia, Carbon sequestration.

Introduction and Concept

Biofertilizers represent a revolutionary approach to sustainable agriculture, containing beneficial microorganisms that naturally enhance soil fertility and crop productivity. (Bhardwaj *et al.*, 2014) explains that conventional agriculture's heavy dependence on chemical fertilizers has led to

serious threats to human health and environmental degradation, including soil acidification, nutrient depletion, and reduced fertility. The historical development of biofertilizers stems from growing recognition that exploiting beneficial microbes has become paramount in agriculture for their potential role in food safety and sustainable crop production. Sustainable Agriculture Development emphasizes that these formulations offer natural alternatives to chemical fertilizers, improving nutrient availability while reducing environmental impacts associated with synthetic inputs. The importance of this transition is underscored by the fact that 60-90% of applied chemical fertilizers are lost, with only 10-40% taken up by plants, highlighting the urgent need for more efficient biological alternatives.

Types of Biofertilizers

The classification of biofertilizers encompasses several distinct categories based on their functional mechanisms. (Shahzad *et al.*, 2025) categorizes them into nitrogen-fixing biofertilizers (Rhizobium for symbiotic relationships, Azotobacter/Azospirillum for free-living nitrogen fixation), phosphate-solubilizing biofertilizers (bacteria and fungi), compost accelerators, and plant growth-promoting rhizobacteria (PGPR). Nitrogen-fixing bacteria are particularly crucial, with (Bhardwaj *et al.*, 2014) detailing how Azotobacter species produce vitamins like thiamine and riboflavin, plant hormones including indole acetic acid (IAA), gibberellins, and cytokinins. Phosphorus-solubilizing microorganisms include bacteria like Pseudomonas, Bacillus, and Micrococcus, along with fungi such as Aspergillus and Penicillium. (Nosheen *et al.*, 2021) notes that these microorganisms render naturally insoluble nutrients like nitrogen, phosphorous, potassium, zinc, and silica available to plants. Potassium-solubilizing bacteria and micronutrient solubilizers further expand the biofertilizer arsenal, with mycorrhizal fungi establishing crucial symbiotic relationships that enhance nutrient uptake and overall plant health.

Mechanisms of Action

Biofertilizers operate through multiple sophisticated biological processes that collectively enhance plant nutrition and growth. (Kour *et al.*, 2020) describes how these mechanisms include biological nitrogen fixation, production of plant growth hormones, siderophores, HCN, various hydrolytic enzymes, and solubilization of potassium, zinc, and phosphorus. (Mącik *et al.*, 2020) elaborates that various mechanisms are used by microbial strains to enhance nutrient uptake, improve soil fertility, and increase crop yields, including excretion of phytohormones, production of substances suppressing phytopathogens, and detoxification of belowground pollutants. The nitrogen fixation process involves the conversion of atmospheric N₂ into ammonia through the nitrogenase enzyme complex, which consists of MoFe protein and Fe protein. (Shahzad *et al.*, 2025) explains that phosphorus solubilization occurs through the production of organic acids that lower soil pH and convert insoluble phosphate compounds into plant-available forms. Additionally, these microorganisms enhance root growth and nutrient uptake efficiency while improving overall plant health through the production of growth regulators and stress-mitigating compounds.

Role in Crop Production

Biofertilizers demonstrate significant positive impacts on crop growth and yield across diverse agricultural systems. (Wahane *et al.*, 2020) indicates that biofertilizers help maintain long-term soil fertility and sustainability by fixing atmospheric nitrogen, mobilizing fixed macro and micronutrients, and converting insoluble phosphorus into forms available to plants. The effects vary among different crop types, with cereals, pulses, oilseeds, and horticultural crops showing

distinct responses to biofertilizer applications. (Bhardwaj *et al.*, 2014) provides specific examples, noting that efficient strains of *Azotobacter*, *Azospirillum*, *Phosphobacter*, and *Rhizobacter* can provide significant amounts of nitrogen to crops like *Helianthus annuus*, increasing plant height, number of leaves, stem diameter, percentage of seed filling, and seed dry weight. In rice, the addition of these bacteria promotes physiology and improves root morphology. The integration of biofertilizers with chemical fertilizers and organic manures creates synergistic effects, allowing for reduced chemical inputs while maintaining or improving productivity levels. This integrated approach supports sustainable intensification of agriculture by optimizing nutrient use efficiency and reducing environmental impacts.

Impact on Soil Health

The application of biofertilizers creates profound positive changes in soil ecosystem functioning and long-term fertility. Biofertilizers play a critical role in improving soil microbial diversity, enhancing soil structure, increasing organic matter content, and contributing to carbon sequestration. These beneficial microorganisms enhance soil enzyme activity and nutrient cycling, creating more dynamic and resilient soil ecosystems. (Bhardwaj *et al.*, 2014) explains that the rhizosphere, which can comprise up to 10^{11} microbial cells per gram of root and above 30,000 prokaryotic species, improves plant productivity through organic matter decomposition, nutrient acquisition, water absorption, nutrient recycling, weed control, and biocontrol. The collective genome of rhizosphere microbial communities is larger than that of plants and provides numerous services to crop plants. Biofertilizers contribute to soil structure improvement through the production of polysaccharides and other binding agents that enhance aggregate stability. The increased microbial activity also promotes the formation of soil organic matter, which improves water retention capacity, nutrient holding capacity, and overall soil fertility.

Nutrient Use Efficiency

Biofertilizers significantly enhance the efficiency of nutrient utilization in agricultural systems, addressing the major problem of nutrient losses in conventional farming. (Singh *et al.*, 2025) highlights that biofertilizers improve nutrient availability and promote plant growth through strategies such as nitrogen fixation, phosphate solubilization, and the enlargement of soil microbial diversity. (Shahzad *et al.*, 2025) notes that more than 50-65% of nitrogen fertilizer is lost to the environment in traditional agriculture, leading to water and air pollution, but biofertilizers provide a viable solution by improving nutrient uptake and utilization. The enhanced nutrient recovery efficiency results from multiple mechanisms: improved root development increases the surface area for nutrient absorption, microbial solubilization makes nutrients more bioavailable, and the production of chelating compounds facilitates nutrient transport. (Bhardwaj *et al.*, 2014) demonstrates that synergistic interactions of PGPR and arbuscular mycorrhizal fungi (AMF) can make 70-90% fertilizer plus inoculants significantly comparable to 100% chemical fertilizer application. This improved efficiency translates to reduced input costs for farmers while maintaining or improving crop yields, supporting the economic viability of sustainable farming practices.

Climate-Smart Agriculture

Biofertilizers play increasingly important roles in climate change mitigation and adaptation strategies within agricultural systems. (Shahzad *et al.*, 2025) emphasizes their capacity to mitigate greenhouse gas emissions while improving carbon sequestration and nutrient-use efficiency in major cropping systems. Biofertilizers help crops withstand various biotic and abiotic stresses, addressing global agricultural challenges like soil degradation, salinity, drought, and plant

diseases. The climate-smart benefits extend beyond direct plant effects to ecosystem-level impacts. Soil bacteria contribute to carbon sequestration through various processes, including the formation of stable organic matter, interactions with clay minerals, and production of decomposition-resistant fungal products. (Shahzad *et al.*, 2025) explains that arbuscular mycorrhizal fungi enhance carbon assimilation, release carbon into soil, and strengthen aggregate stability through glomalin production. Under abiotic stress conditions such as drought, salinity, and heat, biofertilizers help plants maintain physiological functions through the production of osmoprotectants, stress-responsive proteins, and antioxidant compounds. Advanced biotechnological tools have identified microbial strains capable of synthesizing trehalose and glycine betaine, which enhance plant tolerance to multiple environmental stresses.

Constraints and Challenges

Despite their numerous benefits, biofertilizers face significant adoption barriers that limit their widespread implementation. (Shahzad *et al.*, 2025) identifies major constraints including field performance variability, challenges in microbial survival, and insufficient regulatory frameworks. Limited awareness, inconsistent performance under field conditions, and inadequate regulatory frameworks are significant barriers. Quality control and shelf-life issues represent persistent technical challenges, as maintaining microbial viability during storage and transport remains difficult. The variability in biofertilizer effectiveness due to environmental factors, carrier material selection, and poor formulation techniques creates uncertainty for farmers and limits adoption. Compatibility with existing agrochemicals and management practices poses additional challenges, as some chemical inputs can negatively affect beneficial microorganisms. Economic constraints include high production costs, limited availability of quality inoculants, and lack of awareness among farmers about proper application methods. The absence of standardized protocols for production, quality control, and field application further hampers consistent performance and farmer confidence in these biological products.

Future Perspectives and Research Gaps

The future of biofertilizers lies in addressing current limitations through advanced biotechnological approaches and integrated management strategies. Recent advancements in biofertilizer technology, including the development of multi-functional biofertilizers, genetic engineering, and microbial consortia, have shown promising results in improving efficacy. (Shahzad *et al.*, 2025) highlights that recent advances have uncovered nitrogen-fixing bacterial strains isolated via metagenomic approaches from extreme environments, with CRISPR-based modifications employed to enhance nitrogenase activity under aerobic conditions. The development of consortium biofertilizers that combine multiple beneficial strains shows promise for enhanced effectiveness compared to single-strain products. Advances in formulation and delivery systems, including nano-encapsulation techniques and controlled-release formulations, are improving field performance and survival rates. Integration with precision agriculture and digital tools offers opportunities for site-specific application and monitoring of biofertilizer effectiveness. Effective policy support, training programs, and public awareness initiatives are essential for promoting biofertilizer usage among farmers. Future research should focus on enhancing formulation techniques, conducting long-term impact studies on soil health, and establishing standardized guidelines for quality control.

Conclusion and Way Forward

Biofertilizers represent a crucial component of sustainable agricultural systems, offering substantial benefits for environmental protection while enhancing productivity. (Shahzad *et al.*, 2025) concludes that biofertilizers are sustainable alternatives to synthetic fertilizers that enhance nutrient availability, stimulate plant growth, and improve soil quality through key processes including nitrogen fixation, phosphorus and potassium solubilization, and phytohormone synthesis. These interventions reduce greenhouse gas emissions and promote carbon sequestration to mitigate climate change challenges. The integration of biotechnology with sustainable farming systems can reduce reliance on synthetic inputs, increase crop resilience to abiotic stress, and restore ecological balance. However, successful large-scale adoption requires coordinated efforts in standardization, policy development, and farmer education to realize the full potential of biofertilizers for ensuring food security and environmental protection. Addressing current challenges through enhanced formulation techniques, long-term impact studies, and standardized quality control guidelines will ensure successful implementation of biofertilizer technology, contributing to agricultural sustainability and environmental protection. The way forward involves continued research and development, supportive policy frameworks, and collaborative efforts among researchers, extension services, and policymakers to promote widespread adoption of these environmentally friendly agricultural inputs.

References

- Bhardwaj, D., Ansari, M.W., Sahoo, R.K. and Tuteja, N., 2014. Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial cell factories*, 13(1), p.66.
- Kour, D., Rana, K.L., Yadav, A.N., Yadav, N., Kumar, M., Kumar, V., Vyas, P., Dhaliwal, H.S. and Saxena, A.K., 2020. Microbial biofertilizers: Bioresources and eco-friendly technologies for agricultural and environmental sustainability. *Biocatalysis and Agricultural Biotechnology*, 23, p.101487.
- Măcic, M., Gryta, A. and Frăc, M., 2020. Biofertilizers in agriculture: An overview on concepts, strategies and effects on soil microorganisms. *Advances in agronomy*, 162, pp.31-87.
- Nosheen, S., Ajmal, I. and Song, Y., 2021. Microbes as biofertilizers, a potential approach for sustainable crop production. *Sustainability*, 13(4), p.1868.
- Shahzad, M., Hayat, R., Mujtaba, G., Rehman, W.U. and Nadeem, M., 2025. Biofertilizers in sustainable agriculture: mechanisms, applications, and future prospects. *Discover Agriculture*, 3(1), p.224.
- Singh, S.K., Pachauri, R.K., Khatoon, H., Katiyar, D. and Agnihotri, G., 2025. The Role of Biofertilizers in enhancing soil and Productivity-A Review. *Int. J. Plant Soil Sci*, 37(3), pp.141-161.
- Wahane, M.R., Meshram, N.A., More, S.S. and Khobragade, N.H., 2020. Biofertilizer and their role in sustainable agriculture-A. *Pharma Innovation J*, 9(7), pp.127-30.

INTEGRATED NUTRIENT MANAGEMENT (INM) IN OILSEED CROPS

Deshmukh Sarita Babarao^{1*}, R. Jeevanraj² and Chaithra B. S³

¹Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

²Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Assistant Professor, Kadiri Baburao College of Agriculture, C. S. Puram - 523112, Andhra Pradesh, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Abstract

Integrated Nutrient Management (INM) involves the balanced and judicious use of chemical fertilizers, organic manures, and biofertilizers to supply crop nutrients efficiently while sustaining soil health and long-term productivity. In oilseed crops such as soybean, groundnut, mustard/rapeseed, sunflower, sesame, linseed, and niger, INM plays a crucial role due to their high nutrient demand associated with oil and protein synthesis. Despite their agronomic and economic importance, oilseed yields in many regions remain below potential owing to imbalanced fertilization, declining soil organic matter, and widespread micronutrient deficiencies. Excessive reliance on chemical fertilizers has further aggravated soil degradation and environmental pollution, underscoring the need for integrated nutrient approaches. Oilseed crops require an optimal balance of macronutrients, particularly nitrogen, phosphorus, potassium, and sulphur, along with critical micronutrients such as zinc and boron during key growth stages including flowering and seed development. INM integrates site-specific fertilizer application with organic inputs like farmyard manure, compost, vermicompost, and green manures to improve soil structure, water-holding capacity, and microbial activity. Biofertilizers such as *Rhizobium*, *Azotobacter*, *Azospirillum*, phosphate-solubilizing bacteria, and vesicular arbuscular mycorrhiza enhance nutrient availability, biological nitrogen fixation, and nutrient use efficiency. Crop-specific INM practices, guided by soil testing and nutrient diagnostics, have been shown to increase oilseed yields by 10–25%, improve oil content and seed quality, and reduce fertilizer costs while minimizing environmental impacts. Although challenges such as inconsistent biofertilizer quality and labor-intensive organic inputs persist, recent advances including nano-fertilizers and climate-smart INM strategies offer promising solutions. Overall, INM represents a sustainable pathway for enhancing productivity, profitability, and environmental resilience in oilseed-based cropping systems.

Keywords : Integrated Nutrient Management; Oilseed crops; Soil health; Biofertilizers; Nutrient use efficiency; Sulphur nutrition; Micronutrients; Sustainable agriculture; Climate-smart farming

Introduction

Integrated Nutrient Management (INM) refers to the judicious and balanced use of chemical fertilizers, organic manures, and biofertilizers to meet the nutrient requirements of crops while maintaining soil health for long-term productivity. In oilseed crops which include soybean,

groundnut, mustard/rapeseed, sunflower, sesame, and linseed INM is especially critical because these crops have high nutrient demands linked to oil and protein synthesis.

Oilseed crops are of immense agronomic and economic importance. They serve as the primary source of edible vegetable oils, raw material for biodiesel, and a rich source of protein for humans and livestock. Despite their significance, yields remain below potential in many regions, largely due to imbalanced or inadequate nutrient supply. Sole dependence on chemical fertilizers has led to soil degradation, declining organic matter, and environmental pollution making INM an essential strategy for sustainable oilseed production.

Nutrient Requirements of Oilseed Crops

Macronutrients

Oilseed crops demand a precise balance of primary nutrients:

- Nitrogen (N): Essential for protein synthesis, chlorophyll formation, and vegetative growth. Leguminous oilseeds like soybean and groundnut can partially fix atmospheric N through Rhizobium.
- Phosphorus (P): Promotes strong root development, energy transfer, and seed filling critical during the reproductive stage.
- Potassium (K): Regulates water use, stomatal function, and influences oil quality and grain weight.
- Sulphur (S): Often called the '4th major nutrient' for oilseeds. It is indispensable for amino acid formation and directly influences oil content and protein quality particularly in mustard, soybean, and groundnut.

Micronutrients

Zinc (Zn), Boron (B), Iron (Fe), and Manganese (Mn) are frequently deficient in oilseed-growing soils. Boron is especially vital for pollen viability and pod setting in mustard and sunflower. Zinc deficiency is widespread and reduces both yield and oil content.

Critical Nutrient Uptake Stages

Germination & seedling establishment, vegetative growth, flowering and pod/seed development, and grain filling are the four stages when timely nutrient availability is essential. Deficiency during flowering or seed filling causes the greatest yield reduction.

Components of INM

Chemical Fertilizers

Chemical fertilizers provide readily available, precise doses of NPK and are indispensable for meeting peak nutrient demands. The key principle is split application applying nitrogen in two or more doses reduces losses and improves uptake. For mustard, sulphur is commonly supplied via single super phosphate (SSP) or gypsum.

Organic Manures

Farmyard manure (FYM), compost, vermicompost, and green manures form the backbone of organic inputs in INM. Their benefits go beyond nutrient supply they improve soil structure, water-holding capacity, aeration, and microbial activity. Green manuring before an oilseed crop can add 60–80 kg N/ha equivalents. Neem cake additionally acts as a nitrification inhibitor, slowing nitrogen loss from the soil.

3. Biofertilizers

Biofertilizers are low-cost, eco-friendly inputs that harness microbial activity to enhance nutrient availability:

- Rhizobium: Seed inoculation fixes 50–200 kg atmospheric N/ha in soybean and groundnut, significantly reducing the need for chemical N.
- Azospirillum / Azotobacter: Free-living N-fixing bacteria beneficial for non-leguminous oilseeds like sunflower and sesame.
- Phosphate-Solubilizing Bacteria (PSB): Convert insoluble soil phosphates into plant-available forms, improving P use efficiency.
- Vesicular Arbuscular Mycorrhiza (VAM): Fungal associations that dramatically expand root surface area for phosphorus uptake.

Combining Rhizobium + PSB + VAM as a seed treatment package gives synergistic benefits.

Crop-Specific INM Recommendations

- Soybean: Rhizobium seed treatment + reduced N dose + 60–80 kg P_2O_5 + sulphur @ 20 kg/ha.
- Groundnut: Rhizobium + PSB seed treatment, gypsum @ 500 kg/ha (supplies Ca and S), FYM @ 5 t/ha.
- Mustard/Rapeseed: N @ 80–120 kg/ha in splits; sulphur @ 30–40 kg/ha; boron @ 1 kg/ha foliar spray for pod set.
- Sunflower: K @ 60 kg/ha for head development; boron foliar spray at bud initiation; FYM + NPK combination.
- Sesame and Linseed: Responsive to 40–50 kg P_2O_5 and S; organic manure improves yield on light soils.
- Niger : 75% RDF + Vermicompost + Azotobacter + PSB recorded significantly highest seed yield

Soil Testing and Nutrient Diagnostics

Soil Health Cards (SHC) provide site-specific nutrient status and guide balanced fertilizer recommendations. Site-Specific Nutrient Management (SSNM) avoids both over-application and deficiency. Plant tissue analysis allows early identification of deficiencies and corrective foliar sprays (boron, zinc, sulphur) before yield losses occur.

Benefits of INM

Agronomic and Soil Health Benefits

INM consistently improves yield (10–25% over sole chemical fertilization), oil content, and seed quality. Long-term use builds soil organic matter, improves microbial biomass carbon, enhances soil structure, and prevents nutrient depletion.

Environmental and Economic Benefits

Reduced chemical inputs mean less nitrate leaching, lower greenhouse gas emissions, and reduced ecological damage. Economically, INM reduces fertilizer cost burden by 20–40% while maintaining or improving yields.

Challenges and Recent Advances

Challenges

Key constraints include inconsistent quality and limited availability of biofertilizers, high labor requirements for organic manure management, and policy environments that heavily subsidize chemical fertilizers.

Recent Advances and Future Directions

Nano-fertilizers and nano-biofertilizers offer precision delivery with reduced doses and improved nutrient use efficiency. Climate-smart INM strategies incorporate stress-tolerant bioinoculants and carbon-sequestering organic amendments for resilience under changing climates.

Conclusion

Integrated Nutrient Management is the cornerstone of sustainable, productive, and profitable oilseed farming. By combining chemical fertilizers, organic manures, and biofertilizers tailored to specific crops and soils INM optimizes yield, improves oil and seed quality, maintains long-term soil health, and reduces environmental impact.

References

- Ahmad, G., Jan, A., Arif, M., Jan, M.T. and Khattak, R.A., 2007. Influence of nitrogen and sulfur fertilization on quality of canola (*Brassica napus* L.) under rainfed conditions. *Journal of Zhejiang University Science B*, 8(10), pp.731-737. <https://pmc.ncbi.nlm.nih.gov/articles/PMC1997227/>
- Ali, A., Niu, G., Masabni, J., Ferrante, A. and Cocetta, G., 2024. Integrated nutrient management of fruits, vegetables, and crops through the use of biostimulants, soilless cultivation, and traditional and modern approaches—A mini review. *Agriculture*, 14(8), p.1330. <https://www.mdpi.com/2077-0472/14/8/1330>
- Amanullah, Khan, J.A. and Yasir, M., 2025. Improving soybean yield and oil productivity: an integrated nutrient management approach for sustainable soybean production. *BMC Plant Biology*, 25(1), p.293. <https://link.springer.com/article/10.1186/s12870-025-06245-y>
- Choudhari, B.K., Aglave, B.N., Bhosle, N.U., Deshmukh, S.B. and Sharma, P., 2023. Effect of integrated nutrient management on economics of niger (*Guizotia abyssinica* L.).
- Hegde, D. (2000). Nutrient management in oilseed crops. *Semantic Scholar*. CorpusID: 127879101. <https://www.semanticscholar.org/paper/Nutrient-management-in-oilseed-crops.-Hegde/cd8af11effe409960384f04d6a8843d4afed71fb>
- Maurya, M.K., Sarma, A., Behera, P., Karan, N., Shukla, V.K., Kumar, A., Kumar, G. and Kumar, A., 2023. A critical review on sulphur application in rapeseed-mustard to enhancing productivity and oil quality. *International Journal of Plant & Soil Science*, 35(21), pp.661-671. <https://journalijpss.com/index.php/IJPSS/article/view/4026>
- Meena, M. and Vishnuvardhan, R.K., 2021. A review on Integrated nutrient management for sustainable agriculture. *The International journal of analytical and experimental modal analysis*, 8(5), pp.541-551. <https://www.researchgate.net/publication/351457955>
- Paramasivan, M., Kumar, N.S., Rajkumar, A., Nallakurumban, B., Rajasekar, M., Rajkumar, J. and Jeyasrinivas, R., 2025. Effect of Integrated Nutrient Management Practices on Growth and Yield of Groundnut (*Arachis hypogaea* L.) in an Alfisols of Tamiraparani Tract. *Legume Research-An International Journal*, 1, p.7. <https://arccjournals.com/journal/legume-research-an-international-journal/LR-5095>
- Paramesh, V., Mohan Kumar, R., Rajanna, G.A., Gowda, S., Nath, A.J., Madival, Y., Jinger, D., Bhat, S. and Toraskar, S., 2023. Integrated nutrient management for improving crop yields, soil properties, and reducing greenhouse gas emissions. *Frontiers in Sustainable Food Systems*, 7, p.1173258.

- Verma, S., Singh, A., Swayamprabha Pradhan, S., Kumar, V. and Kumar, V., 2022. Effect of sulphur nutrition on the production potential of Brassica spp.: A review. International Journal of Plant & Soil Science, 34(24), pp.880-887.
<https://www.researchgate.net/publication/368233623>
- Walker, K. C., and Booth, E. J. 2003. Sulphur Nutrition and Oilseed Quality. In Sulphur in Plants (pp. 323–339). Springer. DOI: 10.1007/978-94-017-0289-8_18
https://link.springer.com/chapter/10.1007/978-94-017-0289-8_18
- Wu, W. and Ma, B., 2015. Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. Science of the Total Environment, 512, pp.415-427.. <https://pubmed.ncbi.nlm.nih.gov/25644838/>

AI IN THE COLD ROOM: HOW SMART TECHNOLOGY IS REVOLUTIONIZING POSTHARVEST STORAGE

Laxmi P. S¹, Deshmukh Sarita Babarao² and Choudhari Balaji Keshavrao³

¹Department of Postharvest Management, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

^{2&3}Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Introduction

Postharvest management is one of the most critical components of horticultural production systems because it directly determines the quantity, quality, safety, and market value of produce after harvest. In countries such as India, where fruits and vegetables contribute substantially to agricultural GDP, employment, and nutritional security, postharvest losses represent not only an economic setback but also a serious social and food security concern. A considerable proportion of perishable commodities is lost between harvest and final consumption due to inadequate storage infrastructure, improper harvesting methods, mechanical injuries during handling, lack of pre-cooling facilities, temperature abuse during transportation, and gaps in cold chain integration. These losses reduce farmers' profitability, increase price volatility in markets, and limit consumer access to affordable and nutritious food. Unlike cereal grains, fruits and vegetables are living biological materials even after harvest. They remain physiologically active, continuing processes such as respiration, transpiration, enzymatic activity, and hormonal regulation. Respiration leads to the breakdown of stored carbohydrates into energy, resulting in weight loss and depletion of nutritional reserves. Transpiration causes moisture loss, leading to wilting, shriveling, and reduction in visual appeal. The production of ethylene, particularly in climacteric fruits such as mango and banana, accelerates ripening and senescence when not properly controlled. In addition, cell wall degradation enzymes soften tissues, while oxidation reactions may cause browning and nutrient loss. When storage conditions such as temperature, relative humidity, and atmospheric composition are not carefully maintained, these physiological and biochemical processes intensify. Elevated temperatures increase respiration rates exponentially, shortening shelf life. Low humidity promotes excessive moisture loss, while high humidity may encourage fungal and bacterial growth. Mechanical injuries sustained during harvesting and transport create entry points for pathogens, further accelerating decay. Inadequate sanitation and packaging also contribute to cross-contamination and spoilage. As a result, produce may suffer from shriveling, softening, discoloration, off-flavor development, vitamin degradation, and microbial decay before reaching consumers.

Beyond direct quantitative losses, qualitative deterioration also has significant economic implications. Reduced firmness, poor appearance, and diminished nutritional value lower market prices and consumer acceptance. Farmers often resort to distress sales due to limited storage options, especially during peak harvest seasons when supply exceeds immediate demand. This not only reduces income but also discourages investment in high-value horticultural crops. Furthermore, postharvest losses contribute to resource wastage, as water, fertilizers, labor, and

energy invested in crop production are effectively lost when produce deteriorates before consumption. Therefore, strengthening postharvest storage technologies and cold chain infrastructure is essential for minimizing waste, stabilizing markets, improving food availability, and enhancing farmer income. Efficient postharvest management bridges the gap between production and consumption, ensuring that the nutritional and economic value created in the field is preserved throughout the supply chain. In the context of growing population, climate variability, and increasing demand for fresh produce, improving postharvest systems is not merely a technical improvement but a strategic priority for sustainable horticultural development.

Limitations of Traditional Cold Storage

Conventional cold storage systems are primarily designed to maintain fixed temperature and relative humidity levels. While refrigeration significantly slows down metabolic activities and microbial proliferation, these systems lack adaptability. Fruits and vegetables differ widely in their optimal storage requirements. For instance, bananas are highly sensitive to chilling injury if stored below their threshold temperature, whereas apples require near-freezing conditions for long-term storage. Traditional cold rooms cannot dynamically adjust conditions based on commodity type, load variation, or environmental fluctuations. Additionally, mixed storage of incompatible commodities often results in cross-effects such as ethylene-induced ripening. Static systems also fail to respond to external weather changes, door openings, fluctuating produce loads, and uneven air circulation. As a result, temperature gradients may develop within storage chambers, leading to uneven ripening, condensation, fungal growth, and moisture loss. The absence of real-time monitoring and predictive control further limits the efficiency of conventional cold storage, making it insufficient for modern supply chain demands.

Integration of Artificial Intelligence and Smart Technologies

The integration of Artificial Intelligence (AI) with Internet of Things (IoT) technology has revolutionised cold storage management by transforming conventional refrigeration units into intelligent, self-regulating systems. Smart cold rooms are equipped with advanced sensors that continuously monitor critical environmental parameters, including temperature, relative humidity, carbon dioxide concentration, oxygen levels, and ethylene accumulation. Some systems also include weight sensors, door activity trackers, and energy consumption monitors to capture a complete operational profile. These sensors transmit real-time data to centralised cloud-based platforms, where machine learning algorithms analyse patterns related to respiration rate, ripening behaviour, moisture loss, and spoilage trends. Unlike traditional static systems that operate on fixed settings, AI-driven platforms dynamically adapt to changing internal and external conditions. By processing both historical and real-time datasets, these systems can predict optimal storage conditions for specific commodities, accounting for factors such as maturity stage, storage duration, and load variation. For instance, the respiration rate of freshly harvested produce differs from that of produce stored for several days; AI models recognise such variations and automatically recalibrate environmental controls. The system can regulate refrigeration compressor cycles, adjust airflow distribution, modify controlled atmosphere gas composition, and activate ventilation mechanisms when ethylene concentrations exceed threshold levels.

In the case of climacteric fruits such as mango and banana, early detection of rising ethylene levels allows timely intervention to delay the climacteric peak and slow ripening. Similarly, AI systems can detect microclimate variations within different zones of a cold room, preventing

uneven cooling or localized condensation that may promote microbial growth. Predictive analytics also help forecast potential equipment failures by analyzing compressor vibration patterns, refrigerant pressure changes, or abnormal energy consumption trends. This enables preventive maintenance before breakdowns occur, thereby reducing unexpected losses and downtime. Moreover, AI-integrated cold storage enhances traceability and decision-making across the supply chain. Data collected from storage facilities can be shared with logistics providers and retailers to optimize dispatch timing and distribution routes. Energy optimization algorithms reduce electricity consumption by adjusting cooling intensity according to actual demand rather than continuous operation at maximum capacity. Remote monitoring through mobile applications allows operators to supervise multiple storage units from a centralized location, improving operational control and reducing dependency on manual supervision. This predictive, automated, and data-driven approach ensures commodity-specific storage management, minimizes human error, enhances energy efficiency, and significantly improves the reliability of cold chain systems. By combining real-time sensing, intelligent analytics, and automated control, AI-enabled cold rooms represent a major advancement toward precision postharvest management and sustainable horticultural supply chains.

Shelf Life Extension and Quality Preservation

One of the most significant advantages of AI-powered cold storage is its ability to extend shelf life while consistently preserving key quality attributes. Precise environmental regulation prevents abrupt temperature fluctuations that commonly lead to condensation, surface wetness, and subsequent microbial proliferation. Stable temperature maintenance is especially critical because even minor deviations can accelerate respiration rates and shorten storage duration. By maintaining optimal relative humidity, smart systems reduce physiological weight loss, prevent excessive transpiration, and minimize shriveling, thereby preserving fresh appearance and market value. In addition to temperature and humidity control, AI-integrated systems manage atmospheric composition through controlled atmosphere (CA) and modified atmosphere (MA) technologies. By carefully regulating oxygen and carbon dioxide concentrations, these systems slow metabolic activity, reduce oxidative stress, and delay enzymatic degradation processes responsible for softening, discoloration, and nutrient breakdown. For instance, lower oxygen levels suppress respiration intensity, while controlled carbon dioxide levels inhibit certain spoilage microorganisms and enzymatic browning reactions. In climacteric fruits, automated ventilation and ethylene scrubbers play a crucial role in managing ripening. AI algorithms detect early increases in ethylene concentration and activate corrective measures such as ventilation, ethylene absorption filters, or atmospheric adjustments. This prevents the rapid onset of the climacteric peak and ensures uniform ripening when desired. In non-climacteric produce such as leafy vegetables, AI helps maintain crispness and chlorophyll stability by optimizing humidity and airflow, reducing wilting and yellowing.

Another important benefit is the reduction of postharvest physiological disorders such as chilling injury, internal browning, superficial scald, and uneven ripening. By continuously analyzing storage data, AI systems can identify conditions that predispose commodities to such disorders and adjust settings proactively. This not only enhances visual and sensory quality but also maintains biochemical integrity, including retention of vitamins, antioxidants, sugars, and organic acids. Extended storage stability provides greater flexibility in supply chain management. Farmers

can avoid immediate distress sales during periods of glut and instead target favorable market windows. Traders and exporters gain the ability to ship produce over longer distances without compromising quality, expanding access to domestic and international markets. Retailers benefit from reduced shrinkage and improved shelf display life, while consumers receive fresher, safer, and more nutritious products.

Energy Efficiency and Sustainability

Cold storage facilities are energy-intensive operations that significantly contribute to operational costs and carbon emissions. AI-driven systems enhance energy efficiency by optimizing compressor cycles and cooling loads according to real-time storage requirements rather than operating continuously at maximum capacity. Machine learning algorithms forecast cooling demand based on produce load, ambient weather conditions, and storage duration. Predictive maintenance modules identify mechanical anomalies before breakdowns occur, reducing downtime and preventing product loss. Several technologically advanced countries, including United States, Netherlands, and Japan, are increasingly adopting smart cold chain technologies to enhance sustainability and operational efficiency. By minimizing energy wastage and reducing greenhouse gas emissions, AI-integrated cold storage systems contribute to climate-resilient agriculture and sustainable food supply chains.

Economic and Supply Chain Impact

The adoption of AI-powered cold storage systems has far-reaching economic implications across the horticultural supply chain. Farmers benefit from reduced quantitative and qualitative losses, leading to improved price realization and income stability. Traders and wholesalers gain enhanced inventory control and lower spoilage risks, while retailers receive consistent quality produce with longer shelf life. Consumers ultimately benefit from improved food safety, better nutritional quality, and price stability. Additionally, digital monitoring systems improve traceability by recording environmental data throughout storage duration. This transparency strengthens food safety standards and builds consumer confidence. Smart storage systems thus create a more efficient, resilient, and profitable supply chain ecosystem.

Conclusion

In conclusion, postharvest losses remain a major challenge in horticulture, particularly in developing economies where cold chain infrastructure is still evolving. Traditional cold storage systems, though beneficial, lack adaptability and predictive capability to manage diverse commodities effectively. The integration of Artificial Intelligence and IoT technologies transforms conventional cold rooms into intelligent storage environments capable of real-time monitoring, predictive analysis, and automated control. These advancements significantly extend shelf life, preserve quality, enhance energy efficiency, and improve supply chain coordination. As digital agriculture continues to expand, AI-enabled cold storage systems are poised to become essential components of modern horticulture. With sustained technological investment and policy support, smart cold chains can play a transformative role in reducing food losses, strengthening food security, promoting sustainability, and improving farmer livelihoods.

TURNING POSTHARVEST WASTE INTO PROFIT: VALUE ADDITION FROM PEELS AND POMACE

Laxmi P. S^{1*}, V. Kishanth Kanna² and R. Jeevanraj³

¹Department of Postharvest Management, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

²Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Introduction

Postharvest management has traditionally concentrated on minimising losses of fresh fruits and vegetables during harvesting, grading, storage, transportation, and marketing. While considerable attention is given to preserving quality in the fresh supply chain, relatively less focus has been placed on the substantial volume of by-products generated during processing. As agro-processing industries expand to meet the growing demand for juices, pulps, ready-to-serve beverages, jams, wines, dehydrated products, and minimally processed foods, the quantity of organic residues such as peels, pomace, seeds, stones, and trimmings has increased dramatically. In a horticulturally vibrant nation like India, which is one of the largest producers of fruits and vegetables globally, processing activities generate millions of tonnes of such residues annually. These by-products are often seasonal and concentrated around processing clusters, creating logistical and environmental challenges. When not managed properly, accumulated waste undergoes rapid microbial decomposition due to its high moisture and sugar content. This leads to unpleasant odour, attraction of pests, contamination of nearby water sources, and emission of greenhouse gases such as methane. Disposal costs also add a financial burden to processors. Therefore, postharvest waste management is not merely a technical issue, but an environmental and economic concern linked to sustainability and resource efficiency.

Importantly, peels and pomace are not inert materials devoid of value. They are biologically active plant tissues that contain significant quantities of fibre, phenolic compounds, vitamins, minerals, essential oils, and pigments. In many fruits, the concentration of antioxidants and protective phytochemicals is higher in the outer layers than in the pulp because these compounds serve as natural defence mechanisms against environmental stress. This means that the so-called “waste” often contains more concentrated functional components than the portion consumed directly. Recognising this hidden potential marks a fundamental shift in perspective from a disposal-oriented approach to a value-creation model. Globally, the concept of circular economy and zero-waste agriculture has gained momentum, encouraging industries to maximize utilization of raw materials. Advanced agro-processing systems in countries such as the United States and the Netherlands have already begun integrating by-product recovery units within fruit processing plants. These integrated systems aim to extract valuable compounds, produce secondary products, and ensure that nearly every fraction of the harvested crop contributes to economic output. For developing economies, adopting similar strategies can significantly improve

profitability, reduce environmental impact, and create additional employment opportunities in rural areas.

Furthermore, increasing consumer awareness regarding natural ingredients, plant-based products, and sustainable sourcing has opened new markets for bioactive extracts and functional ingredients derived from fruit residues. Food, pharmaceutical, cosmetic, and nutraceutical industries are actively seeking natural antioxidants, dietary fibres, and essential oils. Thus, the growing intersection between sustainability, health consciousness, and technological innovation has positioned postharvest waste valorisation as a promising frontier in modern horticulture. In this context, transforming peels and pomace from environmental liabilities into high-value commodities represents not only an economic opportunity but also a strategic pathway toward sustainable agro-industrial development.

Scientific and Nutritional Potential of Peels and Pomace

Fruit and vegetable by-products are biochemically rich materials with immense nutritional and therapeutic potential. Research has consistently shown that peels often contain higher concentrations of phenolic compounds, flavonoids, tannins, carotenoids, anthocyanins, vitamins, and minerals than the edible pulp because these outer tissues function as protective barriers against environmental stress. For instance, citrus peels are rich in pectin, limonene, hesperidin, and essential oils; apple pomace contains polyphenols and insoluble dietary fiber; mango peel is abundant in carotenoids and antioxidant compounds; and pomegranate peel exhibits strong antimicrobial and free radical scavenging properties due to its high tannin content. Similarly, grape pomace contains resveratrol and anthocyanins, while banana peels are rich in potassium, dopamine, and bioactive phenolics.

These bioactive compounds have scientifically recognized health benefits, including antioxidant, anti-inflammatory, antidiabetic, antihypertensive, antimicrobial, and cardioprotective effects. Phenolic compounds help neutralize free radicals, thereby reducing oxidative stress associated with chronic diseases such as diabetes, cardiovascular disorders, and certain cancers. Flavonoids and carotenoids contribute to immune modulation and improved metabolic health. Tannins and other polyphenols exhibit antimicrobial activity, making them useful as natural preservatives in food systems.

Dietary fibre extracted from pomace plays a critical role in digestive health by improving bowel movement, promoting beneficial gut microbiota, and reducing the risk of gastrointestinal disorders. Soluble fibres such as pectin help regulate blood glucose levels and lower serum cholesterol, while insoluble fibres enhance satiety and support weight management. Because of these properties, pomace-derived fibre is increasingly incorporated into functional foods, nutraceutical formulations, and dietary supplements.

Natural pigments derived from grape skin, berry pomace, beet peel, or pomegranate rind can serve as safe and sustainable alternatives to synthetic colourants, which are increasingly scrutinised due to potential health concerns. These natural pigments not only enhance visual appeal but also provide antioxidant benefits, adding functional value to food products. Moreover, essential oils extracted from peels possess antimicrobial and aromatic properties, making them valuable in food preservation, cosmetics, and pharmaceutical applications.

The growing global demand for clean-label, plant-based, minimally processed, and naturally sourced ingredients has significantly expanded the commercial potential of fruit and vegetable by-products. Consumers are increasingly aware of the health benefits associated with phytochemicals and prefer products free from synthetic additives. As a result, industries are exploring innovative ways to incorporate peel and pomace extracts into beverages, bakery items, dairy products, meat alternatives, and health supplements. This shift in consumer preference, combined with scientific validation of bioactive compounds, has positioned fruit and vegetable by-products as valuable raw materials in the rapidly expanding functional food and nutraceutical markets.

Technologies for Value Addition

Advances in food science and biotechnology have enabled efficient recovery of valuable constituents from postharvest residues, transforming what was once discarded into high-value industrial inputs. Mechanical drying and milling can convert pomace into stable, fibre-rich powder suitable for incorporation into bakery products, extruded snacks, breakfast cereals, and health supplements. Enzymatic treatments using pectinases, cellulases, and hemicelluloses enhance the extraction efficiency of pectin, dietary fibre, and phenolic compounds by breaking down complex plant cell wall structures. Spray drying and freeze-drying technologies help preserve heat-sensitive bioactive compounds such as anthocyanins, flavonoids, and vitamins, while also extending product shelf life and improving handling stability. Supercritical fluid extraction using carbon dioxide provides high-purity recovery of essential oils, carotenoids, and nutraceutical compounds without leaving harmful solvent residues, making it suitable for food-grade and pharmaceutical applications. In addition to these techniques, emerging green extraction methods such as ultrasound-assisted extraction, microwave-assisted extraction, pulsed electric field treatment, and pressurized liquid extraction further improve yield, reduce solvent usage, and shorten processing time. Membrane filtration and nano-filtration technologies are increasingly applied for selective separation and concentration of bioactive molecules. Microencapsulation techniques are also being used to protect sensitive phytochemicals from oxidation and degradation, enabling their incorporation into functional foods and beverages without compromising stability or sensory quality.

Fermentation technologies play a crucial role in waste valorisation by converting pomace into bioethanol, organic acids such as lactic and citric acid, industrial enzymes, single-cell protein, and probiotic beverages. Solid-state fermentation can enhance the nutritional profile of residues by increasing protein content and bioavailability of nutrients. Additionally, lignocellulosic fractions of fruit residues can be processed into biodegradable films, moulded packaging trays, edible coatings, and biochar, contributing to sustainable packaging innovation and soil health improvement. Anaerobic digestion of processing waste can generate biogas, providing renewable energy for processing plants and reducing dependence on fossil fuels. Integrated biorefinery models are now being developed to utilise multiple fractions of postharvest residues in a single processing chain, ensuring maximum resource recovery. Countries such as the United States and Netherlands have successfully integrated advanced waste utilisation strategies into their agro-processing industries, demonstrating the economic viability and environmental sustainability of circular bioeconomy systems. These innovations highlight how scientific advancement, when combined with sustainable industrial practices, can convert postharvest residues into diverse value-added products while minimising environmental impact and enhancing overall profitability.

Economic and Environmental Impact

Value addition from peels and pomace offers multiple economic advantages. First, it reduces waste disposal costs and environmental compliance burdens for processing industries. Second, it creates new revenue streams through the production of functional ingredients, natural additives, and nutraceutical extracts. Third, it generates employment opportunities in rural areas through small-scale extraction units and start-ups focused on by-product processing. From an environmental perspective, converting organic waste into useful products reduces methane emissions from decomposition and minimises landfill accumulation. It supports sustainable production systems by maximising resource utilisation and reducing the overall carbon footprint of horticultural industries. Integrating by-product valorisation into supply chains also strengthens food system resilience by diversifying product portfolios and increasing overall profitability.

Challenges and Future Prospects

Despite its potential, large-scale adoption of waste valorisation faces challenges such as high initial investment, need for standardised extraction protocols, quality control requirements, and regulatory approvals for food and nutraceutical applications. Ensuring a consistent raw material supply and maintaining hygienic processing conditions are also essential. However, with increasing research support, government incentives, and industry collaboration, these challenges can be addressed effectively. In the future, integrated biorefineries may become common in fruit processing hubs, where every component of raw produce is utilised efficiently. Digital technologies, automation, and green extraction methods will further enhance sustainability and profitability.

Conclusion

The transformation of peels and pomace from disposal burdens into valuable commodities represents a paradigm shift in postharvest management. Rather than viewing by-products as waste, modern horticultural systems recognise them as reservoirs of nutrients, bioactive compounds, and industrial raw materials. Through scientific innovation, technological advancement, and circular economy approaches, postharvest residues can generate significant economic returns while reducing environmental impact. For countries with large horticultural production systems, embracing value addition from peels and pomace is not merely an option, it is a strategic necessity for sustainable growth, enhanced profitability, and long-term agricultural resilience.

POSTHARVEST LOSSES AND CLIMATE CHANGE: THE HIDDEN CONNECTION

Laxmi P. S^{1*}, Khushal B. Muradi² and K. Bhrundha³

¹ Department of Postharvest Management, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

² Department of Vegetable Science, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³ Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Introduction

Postharvest losses and climate change are two major global challenges that are deeply interconnected, yet their relationship is often overlooked. Postharvest losses refer to the quantitative and qualitative reduction in agricultural produce between harvest and final consumption. These losses are especially high in perishable commodities such as fruits and vegetables. At the same time, climate change—characterised by rising temperatures, erratic rainfall patterns, and increased frequency of extreme weather events—is affecting agricultural productivity and supply chains worldwide. In countries like India, where horticulture plays a vital role in nutritional security and farmer livelihoods, the interaction between climate stress and postharvest management is becoming increasingly significant. Understanding this hidden connection is essential for developing climate-resilient food systems. Climate change not only influences crop production in the field but also significantly affects the postharvest phase. Elevated temperatures increase the respiration rate of harvested produce, accelerating metabolic activity and shortening shelf life. Heat stress during harvesting or transportation can lead to rapid softening, moisture loss, and higher susceptibility to microbial infection. Similarly, irregular rainfall and high humidity levels create favorable conditions for fungal growth, resulting in greater decay during storage and transit. Extreme weather events such as floods and cyclones can damage storage facilities, disrupt transportation networks, and delay market access, thereby increasing spoilage. These climate-induced stresses amplify the already existing weaknesses in postharvest infrastructure, particularly in developing countries where cold chain systems are limited or unevenly distributed. The relationship is also reciprocal. When agricultural produce is lost after harvest, all the inputs used in its production—water, fertilizers, pesticides, labor, and energy—are wasted. This inefficiency contributes indirectly to greenhouse gas emissions. Moreover, decomposing organic waste in landfills releases methane, a potent greenhouse gas with high global warming potential. According to assessments by the Intergovernmental Panel on Climate Change, food loss and waste are significant contributors to global emissions. Therefore, reducing postharvest losses is not merely a matter of improving supply chain efficiency; it is also a climate mitigation strategy.

In addition, climate variability complicates storage planning and inventory management. Higher ambient temperatures increase cooling demand in cold storage facilities, leading to greater energy consumption and carbon emissions, especially when powered by fossil fuels. Fluctuating

environmental conditions can cause condensation inside storage units, resulting in microbial growth and physiological disorders. Farmers and traders often face uncertainty in determining optimal harvest time, as unpredictable weather can alter maturity indices and quality parameters. These factors collectively highlight the need for integrating climate adaptation measures into postharvest management systems. Addressing this hidden connection requires a multi-dimensional approach. Investments in climate-resilient cold chain infrastructure, renewable energy-powered storage units, improved packaging technologies, and real-time monitoring systems can significantly reduce vulnerability. Strengthening farmer awareness about proper harvesting time, grading, and handling practices under changing climatic conditions is equally important. By linking postharvest management with climate-smart agricultural strategies, countries can reduce food losses, lower greenhouse gas emissions, and enhance food security simultaneously. Recognizing this interconnected challenge is a crucial step toward building sustainable and resilient horticultural systems for the future.

Climate Change Intensifies Postharvest Losses

Climate change directly influences postharvest losses by altering environmental conditions during and after harvest. Higher ambient temperatures accelerate respiration rates in fruits and vegetables, leading to rapid ripening and senescence. Elevated temperatures also promote microbial growth, increasing the risk of fungal and bacterial spoilage during storage and transport. For example, heatwaves during harvest seasons can drastically reduce the shelf life of perishable crops. Irregular rainfall and humidity fluctuations further complicate storage management by increasing moisture-related disorders such as decay and sprouting. In tropical countries, inadequate cold chain infrastructure makes produce highly vulnerable to these climatic variations. As global temperatures continue to rise, the physiological stability of harvested produce becomes more difficult to maintain, thereby increasing postharvest losses.

Postharvest Losses Contribute to Climate Change

The connection between postharvest losses and climate change is bidirectional. When fruits and vegetables are wasted, all the resources used in their production—water, fertilizers, energy, fuel, and labor—are also wasted. This represents a loss of embedded natural and economic resources. Additionally, decomposing organic matter in landfills releases methane, a potent greenhouse gas with a much higher global warming potential than carbon dioxide. According to assessments by the Intergovernmental Panel on Climate Change, food loss and waste account for a significant share of global greenhouse gas emissions. Beyond landfill emissions, postharvest inefficiencies increase the overall carbon footprint of the food system. Energy-intensive storage, refrigeration, packaging, and long-distance transportation contribute further to emissions, particularly when powered by fossil fuels. When produce is lost at later stages of the supply chain—such as during retail or storage—the cumulative environmental cost is even higher because emissions from cultivation, harvesting, processing, and distribution have already been incurred. Moreover, continuous production to compensate for losses places additional pressure on land, water, and energy resources, accelerating deforestation, groundwater depletion, and soil degradation. This creates a feedback loop: climate change increases postharvest losses, and increased losses intensify climate change through higher emissions and resource exploitation. Therefore, reducing postharvest losses is not only an economic necessity for improving farmer income and supply

chain efficiency, but also an environmental imperative for mitigating climate change and promoting sustainable resource use.

Impact on Food Security and Farmer Livelihoods

Climate-induced postharvest losses have serious implications for food security. As extreme weather events become more frequent, production variability increases. When a significant portion of harvested produce is lost before reaching consumers, market supply becomes unstable, leading to price volatility. Smallholder farmers are especially vulnerable, as they often lack access to advanced storage facilities and climate-resilient technologies. In developing economies such as India, reduced marketable yield directly affects farmer income, rural employment, and overall economic stability. Thus, the combined pressure of climate change and postharvest inefficiency can exacerbate poverty and malnutrition, particularly in regions heavily dependent on horticulture. Beyond economic losses, the nutritional dimension of food security is also affected. Fruits and vegetables are primary sources of essential vitamins, minerals, antioxidants, and dietary fiber. When these perishable commodities are lost due to climate-related deterioration, the availability of nutrient-rich foods declines, especially for low-income populations. This can contribute to hidden hunger and micronutrient deficiencies.

Climate-induced disruptions in transportation and storage systems may also reduce food accessibility in remote or disaster-affected areas. Supply chain interruptions caused by floods, cyclones, or heatwaves can delay distribution, resulting in temporary shortages and higher consumer prices. Urban populations, which rely heavily on continuous supply from rural production zones, are particularly sensitive to such disruptions. Furthermore, persistent losses discourage farmers from investing in high-value horticultural crops due to increased risk and uncertainty. This may shift production toward less perishable but lower-nutrient crops, affecting dietary diversity at the national level. Therefore, addressing climate-related postharvest losses is essential not only for stabilising markets and protecting farmer livelihoods but also for ensuring consistent availability, accessibility, and nutritional adequacy of food in a changing climate.

Need for Climate-Resilient Postharvest Systems

To address this hidden connection, investment in climate-resilient postharvest infrastructure is essential. Modern cold chain systems with energy-efficient refrigeration, renewable energy integration (such as solar-powered cold rooms), and real-time environmental monitoring can significantly reduce quantitative and qualitative losses. Improved packaging technologies, controlled atmosphere (CA) storage, and modified atmosphere packaging (MAP) enhance shelf life under variable climatic conditions by regulating oxygen, carbon dioxide, and humidity levels. Digital tools, remote sensing, and predictive analytics further help optimise harvest timing, grading, storage allocation, and transportation scheduling, reducing exposure to adverse environmental conditions. In advanced agricultural economies such as the Netherlands and Japan, integrated cold chain networks, automated warehouses, and precision storage systems have successfully minimised postharvest losses while reducing energy consumption and carbon emissions. These systems combine advanced sensors, data-driven decision-making, and efficient logistics coordination to maintain consistent quality throughout the supply chain.

For developing regions, adapting such models requires context-specific strategies. Establishing decentralised pack houses, mobile pre-cooling units, and community-based cold storage facilities

can benefit smallholder farmers. Capacity-building programs to train farmers in proper harvesting, grading, and handling techniques under changing climatic conditions are equally important. Public-private partnerships and supportive government policies can facilitate infrastructure development and technology adoption. Integrating renewable energy sources into rural cold storage systems not only reduces operational costs but also lowers greenhouse gas emissions. Furthermore, promoting research on climate-resilient varieties with improved storage potential, along with strengthening rural roads and transport networks, enhances overall supply chain efficiency. By combining technological innovation, policy support, and farmer participation, climate-resilient postharvest systems can significantly reduce losses, stabilise markets, and contribute to sustainable food security in a warming world.

Policy and Sustainable Development Perspective

Reducing postharvest losses aligns closely with global sustainability goals. Strengthening infrastructure, promoting renewable energy in cold storage, encouraging farmer cooperatives, and investing in research on climate-smart technologies are critical policy measures. Public-private partnerships can facilitate the expansion of cold chains in rural areas. Capacity building and awareness programs also play a key role in improving handling practices at the farm level. By linking postharvest management with climate adaptation strategies, governments can simultaneously reduce greenhouse gas emissions and improve food availability.

Conclusion

The relationship between postharvest losses and climate change represents a hidden but powerful connection within the global food system. Climate change accelerates deterioration and increases vulnerability of perishable commodities, while postharvest waste contributes to greenhouse gas emissions and resource depletion. Addressing this dual challenge requires integrated solutions that combine climate-smart agriculture, efficient cold chain infrastructure, renewable energy use, and improved handling practices. By reducing postharvest losses, nations can strengthen food security, protect farmer incomes, and contribute meaningfully to climate mitigation efforts. Recognizing and acting upon this interconnection is essential for building a sustainable and resilient agricultural future.

PHYSIOLOGY OF NUTRIENT USE EFFICIENCY IN VEGETABLES

Khushal B. Muradi¹, K. Bhrendha² and V. Kishanth Kanna³

¹Ph.D. Scholar, Department of Vegetable Science, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

^{2&3}Ph.D. Scholar, Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Abstract

Nutrient use efficiency (NUE) is a critical physiological trait determining the productivity, quality, and sustainability of vegetable crops. NUE represents the ability of a plant to absorb nutrients from the soil, translocate them efficiently, and convert them into biomass or marketable yield. Low nutrient efficiency leads to excessive fertilizer use, increased production costs, and environmental pollution, whereas improved NUE supports sustainable vegetable production. The physiological basis of NUE involves complex interactions between root architecture, nutrient transporters, metabolic assimilation pathways, internal nutrient allocation, and adaptive responses to environmental conditions. Understanding these physiological mechanisms provides a foundation for developing nutrient-efficient vegetable varieties, optimizing fertilizer management, and enhancing crop resilience under nutrient-limiting conditions. This article provides an in-depth overview of the physiological aspects influencing nutrient use efficiency in vegetable crops, emphasizing root function, nutrient transport, metabolic pathways, and internal allocation mechanisms.

Keywords: Nutrient Use Efficiency, Vegetables, Physiology, Root Architecture, Nutrient Uptake, Metabolic Assimilation, Internal Allocation, Sustainable Production

Physiology of Nutrient Use Efficiency in Vegetables

Nutrient Uptake and Root Architecture

The root system is the primary interface for nutrient acquisition. Root morphology, including length, branching pattern, root hair density, and surface area, plays a central role in nutrient absorption. Fine roots and root hairs enhance contact with the soil matrix, facilitating efficient uptake of macro- and micronutrients. Vegetables with fibrous root systems, such as lettuce and cabbage, often display greater surface area for nutrient absorption compared to taproot systems like carrots, which penetrate deeper soil layers for nutrient access.

Root exudates, including organic acids and enzymes, improve nutrient solubility in the rhizosphere. Organic acids such as citrate and malate mobilize phosphate and micronutrients, making them available for root absorption. Root growth is highly dynamic and responds to nutrient availability; under low nutrient conditions, roots elongate and increase branching to maximize soil exploration.

Table 1. Root and physiological traits in selected vegetable crops that influence nutrient use efficiency

Vegetable Crop	Root Type	Key Trait for NUE
Lettuce	Fibrous	High root density, efficient N uptake
Tomato	Fibrous	Balanced N, P, K absorption
Carrot	Taproot	Deep soil nutrient access
Cabbage	Fibrous	Enhanced phosphate uptake

Nutrient Transport and Internal Allocation

After uptake, nutrients are transported via xylem and phloem to active growth sites, including leaves, fruits, and storage organs. Efficient nutrient translocation is essential for sustaining metabolic activities and maximizing yield per unit nutrient absorbed.

- **Nitrogen:** Absorbed as nitrate or ammonium and transported as amino acids to developing leaves and fruits. Efficient nitrogen transport and remobilization from older tissues support continuous growth under limiting conditions.
- **Phosphorus:** Moves primarily through xylem to growing tissues, where it is incorporated into energy molecules like ATP and nucleic acids. Phosphorus allocation to reproductive organs is crucial for flower and fruit development.
- **Potassium:** Regulates osmotic balance, stomatal activity, and enzyme activation. Potassium is mobile within the plant, allowing redistribution to active growth zones during stress or nutrient limitation.

Internal allocation of nutrients is influenced by physiological demand, developmental stage, and hormonal regulation. Plants optimize allocation to ensure that critical tissues receive nutrients first during periods of deficiency, maintaining metabolic activity and reproductive success.

Nutrient Assimilation and Metabolic Efficiency

Nutrient assimilation converts inorganic nutrients into organic molecules required for growth and metabolism.

Nitrogen assimilation: Nitrate is reduced to ammonium and incorporated into amino acids through enzymatic pathways involving nitrate reductase and glutamine synthetase. Efficient nitrogen assimilation supports protein synthesis and photosynthetic activity.

Phosphorus assimilation: Phosphate is incorporated into ATP, nucleic acids, and phospholipids, providing energy for cellular processes and supporting structural functions.

Potassium function: Although not assimilated into organic molecules, potassium regulates enzyme activity, turgor pressure, and photosynthate translocation, indirectly enhancing nutrient utilisation efficiency.

Metabolic efficiency also depends on interactions between nutrients. Balanced nutrition ensures optimal photosynthetic performance, biomass accumulation, and yield formation.

Adaptive Physiological Responses

Vegetable crops adapt to varying nutrient availability through physiological adjustments:

- **Root plasticity:** Enhanced root growth and proliferation under nutrient-limiting conditions.

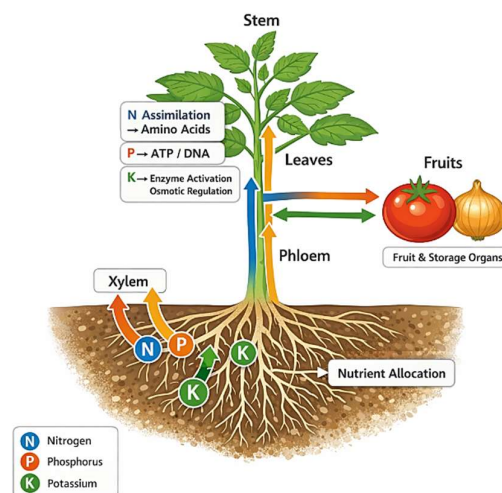


Figure 1. Physiological pathways of nutrient uptake, transport, assimilation, and allocation in vegetable crops.

- **Transporter regulation:** Upregulation of high-affinity nutrient transporters during deficiency.
- **Remobilization:** Redistribution of nutrients from older to younger tissues to support growth and development.
- **Metabolic adjustments:** Optimization of nitrogen and carbon metabolism under nutrient stress to maintain photosynthesis and growth.

These adaptive responses are crucial for maintaining nutrient efficiency under sub-optimal soil conditions and reducing dependency on external fertilizer inputs.

Table 2. Physiological mechanisms that enable vegetables to maintain high nutrient use efficiency under nutrient-limiting conditions.

Response	Mechanism	Effect on NUE
Root plasticity	Increased branching and elongation	Improves nutrient uptake
Transporter regulation	High-affinity nutrient transporters	Enhances nutrient absorption
Nutrient remobilization	From older to younger tissues	Supports growth under deficiency
Metabolic adjustment	Optimized N and C metabolism	Maintains biomass and photosynthesis

Integrative Physiology for High NUE

NUE is determined by the coordinated functioning of nutrient uptake, transport, assimilation, and allocation processes. Efficient root systems, active nutrient transport, and effective metabolic conversion collectively ensure that vegetables utilize available nutrients optimally. Physiological monitoring, including leaf nutrient content, chlorophyll concentration, and enzyme activity, can provide insights into the nutrient status and efficiency of vegetable crops.

A comprehensive understanding of these physiological mechanisms is essential for developing nutrient-efficient varieties, implementing precision nutrient management, and sustaining high productivity under limited nutrient availability.

Genotypic and Species Variation in NUE

Vegetables display considerable genetic and species-specific variability in nutrient use efficiency. Traits associated with higher NUE include:

- Enhanced root surface area and branching patterns.
- Efficient expression and regulation of nutrient transporters.
- High metabolic capacity for nutrient assimilation.
- Effective remobilization of nutrients between organs.

Genotypic differences allow selection of nutrient-efficient varieties adapted to low-input conditions. Breeding programs can target root architecture, transporter gene regulation, and metabolic traits to improve NUE in commercial vegetable cultivars.

Environmental Influences on Physiological NUE

Soil Factors

Soil characteristics, including pH, texture, organic matter content, and moisture, influence nutrient availability and uptake. For instance, phosphorus becomes less available in high pH soils

due to fixation with calcium, while micronutrients may be limited in alkaline conditions. Soil fertility management directly affects physiological nutrient efficiency.

Climate and Abiotic Stress

Temperature extremes, drought, and salinity can reduce nutrient uptake and internal allocation. Abiotic stresses impair membrane transport, enzymatic activity, and root growth, thereby lowering NUE. Vegetables respond through adaptive mechanisms, including increased root proliferation, altered transporter activity, and remobilization of nutrients to essential tissues.

Agronomic Practices to Enhance NUE

Precision Nutrient Management

Applying fertilizers in synchronization with crop demand improves nutrient efficiency. Techniques include split applications, fertigation, and controlled-release fertilizers to reduce losses and improve uptake.

Integrated Nutrient Management

Combining organic amendments, inorganic fertilizers, and biofertilizers improves soil health, nutrient availability, and plant physiological performance. Crop rotations and intercropping can enhance soil nutrient cycling and NUE.

Use of Biostimulants

Humic substances, fulvic acids, and beneficial microbes improve root growth, nutrient uptake, and assimilation efficiency. These practices enhance NUE and promote sustainable vegetable production.

Measurement and Evaluation of NUE

NUE can be evaluated using agronomic and physiological indicators:

- Agronomic efficiency: Yield per unit nutrient applied.
 - Recovery efficiency: Fraction of applied nutrient absorbed by the crop.
 - Physiological efficiency: Yield per unit nutrient uptake.
 - Physiological markers: Leaf nutrient content, chlorophyll concentration, enzyme activity.
 - Isotopic tracing: Techniques like ^{15}N labeling allow precise evaluation of nutrient uptake and allocation.

Future Directions

- a) Genomic approaches: Identification of genes regulating nutrient transport and metabolism.
- b) Root phenotyping: High-throughput analysis of root traits under field conditions.
- c) Sensor-based management: Real-time monitoring for precision nutrient application.
- d) Multi-nutrient optimization: Understanding interactions among macro- and micronutrients for maximum efficiency.

These innovations can drive sustainable vegetable production with reduced fertilizer dependence and environmental impact.

Conclusion

Nutrient use efficiency in vegetables is governed by coordinated physiological processes including root uptake, transport, assimilation, and internal allocation. Genotypic traits, environmental

factors, and management practices collectively influence NUE. Understanding these mechanisms provides a foundation for breeding nutrient-efficient varieties, implementing precision nutrient management, and promoting sustainable vegetable production systems globally.

References

- Li, X., Zeng, R. and Liao, H., 2016. Improving crop nutrient efficiency through root architecture modifications. *Journal of integrative plant biology*, 58(3), pp.193-202.
- Romera, F.J., Lucena, C., García, M.J., Alcántara, E., Angulo, M., Aparicio, M.Á. and Pérez-Vicente, R., 2021. Plant hormones and nutrient deficiency responses. In *Hormones and plant response* (pp. 29-65). Cham: Springer International Publishing.
- Valenzuela, H., 2024. Optimizing the nitrogen use efficiency in vegetable crops. *Nitrogen*, 5(1), pp.106-143.
- Weih, M., Hamnér, K. and Pourazari, F., 2018. Analyzing plant nutrient uptake and utilization efficiencies: comparison between crops and approaches. *Plant and Soil*, 430(1), pp.7-21.

RESPIRATION AND RIPENING PHYSIOLOGY IN VEGETABLES: MECHANISMS AND POSTHARVEST IMPLICATIONS

Khushal B. Muradi¹, R. Jeevanraj² and Chaithra B. S.³

¹Department of Vegetable Science, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

²Ph.D. Scholar, Department of Plant Physiology, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Assistant Professor, Kadiri Baburao College of Agriculture, C. S. Puram - 523112, Andhra Pradesh, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Abstract

Respiration and ripening are fundamental physiological processes that regulate postharvest quality, shelf life, and marketability of vegetables. These processes influence energy metabolism, biochemical transformations, and structural modifications occurring during maturation and senescence. Respiration determines the rate of substrate utilization, while ripening is primarily regulated by ethylene and associated molecular pathways. Excessive respiratory activity and uncontrolled ripening accelerate deterioration, resulting in significant postharvest losses. This article reviews the biochemical pathways of respiration, physiological and molecular mechanisms of ripening, and their interaction during postharvest storage. The influence of environmental factors, storage conditions, and preharvest management on these processes is also discussed. Emphasis is given to practical postharvest technologies such as cold storage, controlled atmosphere, and ethylene inhibitors. Understanding respiration–ripening relationships provides a scientific basis for improving storage efficiency and maintaining vegetable quality in global supply chains.

Keywords: Respiration, Ripening, Ethylene, Climacteric, Shelf Life, Postharvest Physiology, Storage

Introduction

Vegetables are essential components of human nutrition, providing vitamins, minerals, dietary fiber, and bioactive compounds. However, a considerable proportion of harvested vegetables is lost due to rapid physiological deterioration during storage and transportation. Respiration and ripening are the primary biological processes responsible for postharvest quality changes.

The oxidation of organic substrates during respiration generates the energy needed for cellular upkeep. A key component of this process is the tricarboxylic acid cycle, which was initially explained by Hans Krebs. In contrast, ripening is a well-coordinated series of structural and biochemical alterations that result in taste development, color development, and softening. Uncontrolled ripening and high respiration rates limit shelf life, decrease nutritional value, and hasten senescence. Therefore, creating effective postharvest management plans requires a knowledge of these processes. The purpose of this article is to examine the ripening and respiration processes and their applications to the marketing and storage of vegetables.

Classification of Vegetables Based on Ripening Pattern

Vegetables are classified into climacteric and non-climacteric groups based on changes in respiration rate and ethylene production during ripening. This classification is used to determine harvesting stage, storage conditions, and postharvest handling requirements.

Climacteric vegetables exhibit a distinct increase in respiration rate and ethylene synthesis during ripening and continue to ripen after harvest. Non-climacteric vegetables do not show a respiratory peak, produce low levels of ethylene, and show limited ripening after harvest.

Table 1. Comparison Between Climacteric and Non-Climacteric Vegetables

Feature	Climacteric Vegetables	Non-Climacteric Vegetables
Respiration Rate	Sharp increase during ripening (respiratory climacteric)	No distinct increase
Ethylene Production	High during ripening	Low
Ripening Pattern	Continues after harvest	Limited after harvest
Response to Ethylene	Strong	Weak or absent
Storage Behavior	Sensitive to ethylene	Less sensitive
Examples	Tomato, Muskmelon, Chili	Cucumber, Lettuce, Spinach
Post-Harvest Handling	Harvest at mature-green stage possible	Harvest at full maturity required

Biochemistry of Respiration in Vegetables

Respiration is a central metabolic process responsible for energy production and substrate utilization in harvested vegetables. It involves the oxidative breakdown of carbohydrates, organic acids, and other reserves to generate adenosine triphosphate (ATP) required for cellular maintenance.

Glycolysis

Glycolysis occurs in the cytoplasm and involves the conversion of glucose into pyruvate through a series of enzymatic reactions. This pathway produces a limited amount of ATP and reducing equivalents in the form of NADH. Glycolysis supplies substrates for mitochondrial respiration and serves as the primary entry point of carbohydrates into energy metabolism.

Tricarboxylic Acid (TCA) Cycle

The TCA cycle operates in mitochondria and oxidizes acetyl-CoA derived from pyruvate. It releases carbon dioxide and generates NADH and FADH₂. The cycle, originally described by **Hans Krebs**, is the major source of reducing power for ATP synthesis in plant tissues.

Electron Transport Chain

The electron transport chain is located in the inner mitochondrial membrane. Electrons from NADH and FADH₂ are transferred through a series of carriers to molecular oxygen. This process drives proton transport and ATP formation through oxidative phosphorylation. Oxygen availability directly influences the efficiency of this system.

Alternative Respiratory Pathway

Vegetables possess an alternative oxidase pathway that bypasses part of the electron transport chain. This pathway reduces ATP production but limits excessive reactive oxygen species formation. It is activated under stress conditions such as chilling, wounding, and pathogen attack.

Regulation of Respiratory Activity

Respiratory activity in vegetables is regulated by environmental conditions and physiological status. These factors determine the rate of substrate oxidation and energy production during storage and transportation.

Temperature

Temperature is the primary factor influencing respiration rate. An increase in temperature accelerates enzymatic reactions and enhances metabolic activity. The Q_{10} coefficient describes the change in respiration rate with a 10°C temperature increase. Low temperatures reduce respiration but may cause chilling injury in sensitive vegetables, while high temperatures promote rapid senescence.

Oxygen and Carbon Dioxide Concentration

Oxygen availability controls aerobic respiration. Reduced oxygen levels suppress oxidative metabolism and decrease respiration rate. Elevated carbon dioxide concentrations inhibit key respiratory enzymes. These effects are utilized in controlled atmosphere and modified atmosphere storage systems.

Substrate Availability

Respiration depends on the availability of carbohydrates, organic acids, and other substrates. Depletion of reserves during storage leads to reduced metabolic activity and accelerated senescence. Vegetables with higher initial carbohydrate content generally exhibit better storage performance.

Mechanical and Biotic Stress

Mechanical injury during harvesting and handling increases respiration due to activation of wound-healing processes. Pathogen infection stimulates defense-related metabolism, resulting in elevated respiratory activity and increased deterioration.

Physiology and Biochemistry of Ripening

Ripening is a genetically regulated and hormonally controlled process involving coordinated biochemical, structural, and physiological changes that lead to improved edibility and market quality of vegetables. In most climacteric vegetables, ripening is primarily regulated by ethylene, whose biological role was first demonstrated by **Dimitry Neljubov**.

Ethylene Biosynthesis

Ethylene is synthesized from the amino acid methionine through the Yang cycle. Methionine is converted to S-adenosyl methionine (SAM), which is then transformed into 1-aminocyclopropane-1-carboxylic acid (ACC) by ACC synthase. ACC is oxidized to ethylene by ACC oxidase. The activity of these enzymes determines the rate of ethylene production during ripening.

Ethylene Perception and Signal Transduction

Ethylene is perceived by specific receptors located in the endoplasmic reticulum membrane. Binding of ethylene activates signal transduction pathways that regulate transcription factors and induce expression of ripening-related genes. This signaling system controls multiple physiological responses, including softening, color development, and aroma formation.

Cell Wall Modification and Softening

Softening is caused by enzymatic degradation of cell wall components. Polygalacturonase, pectin methylesterase, and cellulase hydrolyze pectin and cellulose, resulting in reduced tissue firmness. These structural changes contribute to increased susceptibility to mechanical damage and microbial infection.

Pigment Metabolism and Color Development

Ripening involves degradation of chlorophyll and synthesis of carotenoids and anthocyanins. Chlorophyll breakdown leads to loss of green color, while carotenoid accumulation produces red, orange, or yellow pigmentation. These changes enhance visual appeal and consumer acceptance.

Flavor and Aroma Formation

Ripening is associated with accumulation of soluble sugars and reduction of organic acids, leading to improved sweetness and palatability. Volatile compounds such as esters, aldehydes, and alcohols are synthesized, contributing to characteristic aroma and flavor.

Molecular Control of Ripening

Ripening is regulated at the molecular level through coordinated expression of specific genes and regulatory networks. These mechanisms control ethylene synthesis, signal transduction, and downstream metabolic processes.

Ripening-Related Genes

Several genes play key roles in regulating ripening, particularly in climacteric vegetables. Important regulatory genes include RIN (Ripening Inhibitor), NOR (Non-Ripening), and CNR (Colorless Non-Ripening). These genes encode transcription factors that activate or repress the expression of enzymes involved in cell wall modification, pigment synthesis, and aroma production.

Transcriptional Regulation

Transcription factors belonging to MADS-box, NAC, and AP2/ERF families regulate ripening-associated gene expression. These proteins bind to promoter regions of target genes and coordinate temporal and spatial patterns of ripening-related metabolism.

Epigenetic Regulation

Epigenetic mechanisms such as DNA methylation and histone modification influence gene expression during ripening. Changes in methylation status affect chromatin structure and accessibility of transcriptional machinery, thereby regulating ripening progression.

Omics-Based Approaches

High-throughput techniques, including transcriptomics, proteomics, and metabolomics, are used to analyze global changes in gene expression, protein abundance, and metabolite profiles during ripening. These approaches provide integrated insights into regulatory networks and metabolic pathways.

Interaction Between Respiration and Ripening

Respiration and ripening are physiologically interconnected processes that regulate energy metabolism and quality development in vegetables. During climacteric ripening, an increase in ethylene production stimulates respiratory activity, resulting in a characteristic respiratory climacteric.

Elevated respiration supplies ATP and metabolic intermediates required for biosynthetic reactions associated with cell wall modification, pigment synthesis, and aroma formation. Increased oxidative metabolism also accelerates the consumption of carbohydrate and organic acid reserves. Ethylene enhances the expression of genes involved in respiratory pathways, while high respiratory activity promotes further ethylene synthesis. This positive feedback mechanism regulates the rate of ripening and senescence.

Excessive respiratory activity leads to rapid substrate depletion, membrane degradation, and oxidative stress, thereby shortening shelf life. Regulation of respiration is therefore essential for controlling ripening and maintaining postharvest quality.

Postharvest Applications

Knowledge of respiration and ripening physiology is essential for developing effective postharvest management practices aimed at extending shelf life and preserving quality.

Cold Storage

Low-temperature storage reduces enzymatic activity and metabolic rate, thereby slowing respiration and delaying ripening. Optimal storage temperature varies among vegetable species. Improper temperature management may result in chilling injury or accelerated senescence.

Controlled and Modified Atmosphere Storage

Controlled atmosphere (CA) and modified atmosphere packaging (MAP) regulate oxygen and carbon dioxide concentrations around stored vegetables. Reduced oxygen levels and elevated carbon dioxide suppress respiration and ethylene action, leading to delayed ripening and reduced deterioration.

Ethylene Management

Ethylene accumulation during storage accelerates ripening and senescence in climacteric vegetables. Application of ethylene inhibitors such as 1-methylcyclopropene (1-MCP) blocks ethylene receptors and delays ripening. Ethylene absorbers and ventilation are also used to control ethylene concentration.

Handling and Transportation Practices

Proper harvesting, grading, packaging, and transportation minimize mechanical damage and physiological stress. Maintenance of cold chain systems and appropriate humidity levels reduces water loss and metabolic activity during transit.

Sanitation and Disease Control

Clean storage environments and appropriate fungicidal treatments reduce microbial infection. Lower pathogen incidence prevents stress-induced respiration and quality deterioration.

Influence of Preharvest Factors

Preharvest growing conditions significantly influence postharvest respiration rate, ripening behavior, and storage performance of vegetables. Balanced mineral nutrition improves carbohydrate accumulation, membrane stability, and enzyme activity. Adequate nitrogen promotes vegetative growth and yield, while excessive nitrogen increases respiration rate and reduces shelf life. Potassium enhances translocation of assimilates and improves tissue firmness. Micronutrients such as calcium and boron strengthen cell walls and reduce physiological disorders. Irrigation management affects cellular hydration and metabolic activity. Water stress before harvest increases respiration and accelerates senescence. Excessive irrigation reduces dry matter content and storage quality. Climatic conditions, including temperature and light intensity, influence photosynthetic efficiency and reserve accumulation. Vegetables produced under moderate temperatures and optimal radiation generally exhibit superior postharvest performance.

Harvest maturity is a critical determinant of storage life. Immature vegetables show poor flavor development, while over-mature produce exhibits rapid senescence and higher susceptibility to mechanical damage and pathogens.

Future Perspectives

Advances in molecular biology, postharvest technology, and digital monitoring provide opportunities to improve vegetable storage, quality, and shelf life.

- **Gene Editing for Ripening Control:** CRISPR/Cas-based modification of ripening-related genes such as RIN and NOR can delay ethylene-induced ripening, enhance shelf life and reducing postharvest losses.
- **Smart Packaging and Biosensors:** Intelligent packaging systems with ethylene absorbers, moisture control, and embedded sensors can monitor real-time quality changes and maintain optimal storage conditions.
- **Artificial Intelligence-Based Storage Models:** AI and machine learning tools can predict shelf life based on preharvest conditions, respiration rates, and environmental parameters, enabling precise postharvest management.
- Integration of these technologies with conventional storage practices can optimize energy use, reduce food waste, and improve global vegetable supply chain efficiency.

Conclusion

Respiration and ripening are central physiological processes that determine postharvest quality, shelf life, and marketability of vegetables. Respiratory metabolism provides energy for maintenance and ripening-related biosynthetic reactions, while ethylene regulates ripening through molecular and biochemical pathways. Climacteric and non-climacteric vegetables exhibit distinct physiological behaviors, which dictate harvesting stage, storage conditions, and postharvest handling strategies. Effective management of respiration and ripening through temperature control, atmospheric modification, ethylene regulation, and proper preharvest practices can significantly reduce losses and maintain quality. Emerging technologies, including gene editing, smart packaging, and AI-based monitoring, offer additional opportunities to enhance storage performance and supply chain efficiency. Understanding and integrating the mechanisms of respiration and ripening into practical postharvest strategies are essential for improving vegetable quality and sustainability in global agriculture.

References

- Irtiza, S.A.B., Wani, A.B., Khan, F.A., Murtaza, I. and Wani, M.Y., 2019. Physiological and biochemical interactions for extending the shelf life of fruits and vegetables: A review. *Int. J. Chem. Stud.* 7(1), pp.2153-2166.
- Oke, M.O., Sobratee, N. and Workneh, T.S., 2013. Integrated pre-and postharvest management processes affecting fruit and vegetable quality. *Stewart Postharvest Review*, 9(3), pp.1-8.
- Umeohia, U.E. and Olapade, A.A., 2024. Physiological processes affecting postharvest quality of fresh fruits and vegetables. *Asian Food Sci. J.* 23(4), p.115915.
- Wang, C., Cao, J., Hao, N. and Wu, T., 2022. Genetic and molecular regulation mechanisms in the formation and development of vegetable fruit shape. *Applied Sciences*, 12(3), p.1514.

HOW PLANT BREEDING HELPS FARMERS GROW BETTER CROP

Khushal B. Muradi^{1*}, Yogesh V. Wayal² and Banka Vaishnavi³

¹Department of Vegetable Science, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

^{2&3}Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram - 695522, Kerala, India.

*Corresponding Email: khushalmuradi2361998@gmail.com

Abstract

Plant breeding is a fundamental tool for enhancing crop productivity, quality, and resilience under changing environmental conditions. Improved cultivars with higher production potential, disease resistance, and stress tolerance are created by harnessing genetic variety through traditional and contemporary breeding techniques. Breeding has quickened and trait selection has become more precise because to developments in genome editing and molecular breeding. These developments assist farmers in lowering production risks, making the most use of available resources, and increasing financial gains. Additionally, by encouraging climate-resilient and productive agricultural systems, plant breeding supports sustainable agriculture and food security. The importance of plant breeding in helping farmers produce superior harvests and guaranteeing long-term agricultural sustainability is emphasized in this article.

Keywords: Plant breeding, crop improvement, genetic variation, molecular breeding, hybridization, stress tolerance, sustainable agriculture, food security.

Introduction

Agriculture plays a crucial role in ensuring food and nutritional security and supporting the livelihoods of farming communities. The need for increased and more consistent agricultural output has grown significantly as a result of the world's population expansion and mounting strain on natural resources. However, poor yield potential, insect and disease outbreaks, soil degradation, and shifting climatic conditions including heat, drought, and erratic rainfall frequently limit agricultural output. These limitations lower agricultural profitability and raise production hazards. Agriculture plays a crucial role in ensuring food and nutritional security and supporting the livelihoods of farming communities. The need for increased and more consistent agricultural output has grown significantly as a result of the world's population expansion and mounting strain on natural resources. However, poor yield potential, insect and disease outbreaks, soil degradation, and shifting climatic conditions including heat, drought, and erratic rainfall frequently limit agricultural output. These limitations lower agricultural profitability and raise production hazards.

Concept of Plant Breeding

The science and practice of developing agricultural plants by altering their genetic composition to create better types is known as plant breeding. Desired features including high yield, disease resistance, stress tolerance, and enhanced quality are identified, selected, and recombined. The procedure is founded on the laws of heredity and genetics, which control how qualities are passed down from one generation to the next. Breeders develop new plant varieties that are more suited

to particular agricultural and environmental circumstances by taking use of both natural and artificial genetic diversity.

Plant breeding has historically depended on techniques like hybridization and selection to accumulate advantageous features over many generations. Modern breeding today incorporates molecular and biotechnological methods to improve accuracy and efficiency due to scientific advancements. Breeding programs and the preservation of rich plant genetic resources have benefited greatly from the efforts of international research networks like the Consultative Group on International Agricultural Research. Plant breeding is therefore a methodical and ongoing process that aims to create better crop varieties that satisfy the changing demands of farmers and consumers.

Objectives of Plant Breeding

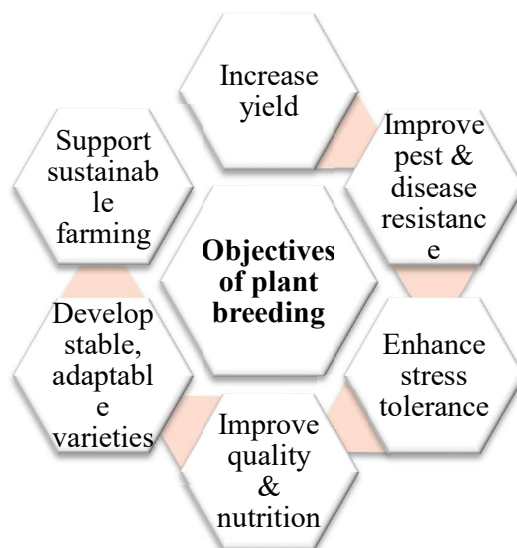


Figure 1 - Objectives of Plant Breeding

The main goals of plant breeding in agricultural development are depicted in this picture. By improving genetic potential and resource efficiency, plant breeding seeks to raise agricultural output. To minimize crop losses and lessen reliance on chemical control methods, it focuses on enhancing resistance to pests and diseases. Improving resistance to abiotic stressors like heat, salt, and drought aids in maintaining production stability in the face of shifting weather patterns. To suit market needs and combat hunger, breeding programs also place a strong emphasis on enhancing crop quality and nutritional content. Additionally, constant performance in a variety of conditions is ensured by the production of stable and highly adaptable types. When taken as a whole, these goals promote environmentally friendly farming methods, long-term agricultural output, and environmental preservation.

Genetic Basis of Crop Improvement

Genetic heterogeneity within and across plant populations is the foundation for crop improvement through plant breeding. Breeders may find individuals with desired features like high yield, disease resistance, and stress tolerance thanks to genetic variety, which serves as the

basis for selection. This variety is preserved in germplasm collections for later use and emerges spontaneously through mutation, recombination, and hybridisation.

Genes and their alleles, which are passed down from parents to children in accordance with accepted genetic principles, control the inheritance of characteristics. Effective selection and breeding techniques need an understanding of quantitative trait inheritance, gene interactions, and patterns of heredity. Numerous genes regulate key agronomic features, including yield and stress tolerance, and environmental variables also have an impact.

Landraces, wild relatives, and modified varieties are examples of germplasm resources that are important sources of beneficial genes. Utilising and maintaining plant genetic resources is greatly aided by national and international organizations like the Consultative Group on International Agricultural Research. Breeders may create better crop varieties with increased performance and adaptability by making effective use of genetic variation and understanding inheritance mechanisms.

Conventional and Modern Plant Breeding Methods

Plant breeding employs both traditional and advanced techniques to develop improved crop varieties with superior yield, quality, and adaptability. The integration of conventional and modern methods enables efficient utilisation of genetic resources and accelerates the breeding process.

Selection

Selection is the process of identifying superior plants from a genetically variable population and using them for further multiplication. It helps in accumulating favourable genes over successive generations.

a) Mass Selection

Mass selection involves choosing a large number of desirable plants based on their phenotypic performance and harvesting their seeds collectively. This method improves population performance and is mainly used in cross-pollinated crops such as maize and pearl millet.

b) Pure Line Selection

Pure line selection is practiced in self-pollinated crops like wheat and rice. Individual plants are selected and advanced through several generations to obtain genetically uniform and stable lines with superior traits.

c) Clonal Selection

Clonal selection is applied in vegetatively propagated crops such as potato, sugarcane, and banana. Superior plants are identified and multiplied through vegetative parts to maintain genetic uniformity and desirable characteristics.

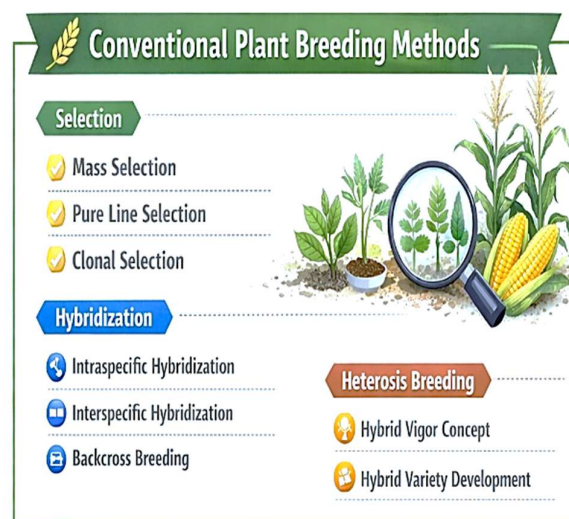


Figure 2 - Conventional and Modern Plant Breeding Methods

Hybridization

Hybridization refers to the crossing of genetically different parents to create new genetic combinations and improve crop performance.

a) Intraspecific Hybridization

This method involves crossing plants within the same species to combine favorable traits such as high yield, early maturity, and disease resistance.

b) Interspecific Hybridization

Interspecific hybridization is carried out between related species to transfer valuable traits such as pest resistance, drought tolerance, and salinity tolerance into cultivated crops.

c) Backcross Breeding

Backcross breeding is used to incorporate specific desirable genes from a donor parent into a high-yielding variety by repeated crossing with the recurrent parent. It is widely applied in disease resistance breeding.

Heterosis Breeding

Heterosis breeding exploits hybrid vigor, where the first-generation hybrid exhibits superior performance compared to its parents. Hybrids often show increased yield, better growth, improved resistance, and uniform maturity. This method is extensively used in commercial hybrid development of cereals and vegetables.

Modern Breeding Techniques

Modern breeding techniques integrate molecular biology, genomics, and biotechnology to enhance the accuracy, speed, and efficiency of crop improvement programs.

Mutation Breeding - Mutation breeding creates new genetic variation by inducing mutations artificially.

a) Induced Mutations- Induced mutations generate novel traits that may not exist in natural populations, such as altered plant architecture or enhanced resistance.

b) Physical and Chemical Mutagens- Physical mutagens (gamma rays, X-rays) and chemical mutagens (EMS, sodium azide) are used to induce genetic changes in seeds, pollen, or tissues.

Molecular Breeding

Molecular breeding uses DNA-based tools to assist in selection and breeding.

a) Marker-Assisted Selection (MAS) : MAS uses molecular markers linked to target genes for early and accurate selection of superior genotypes, reducing time and cost.

b) QTL Mapping : QTL mapping identifies genomic regions associated with complex traits such as yield, drought tolerance, and nutrient efficiency, facilitating targeted breeding.

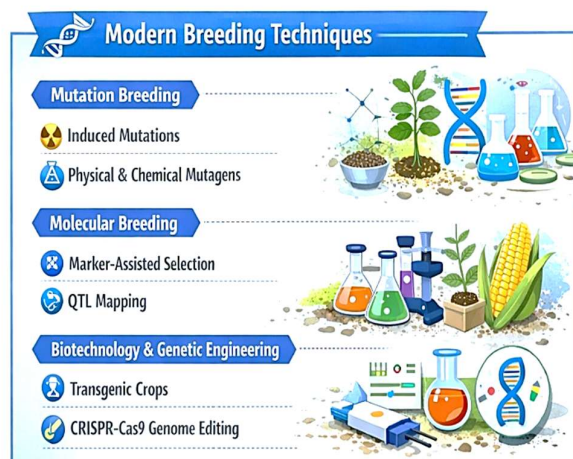


Figure 3 - Conventional and Modern Plant Breeding Methods

Biotechnology and Genetic Engineering

Biotechnology allows direct manipulation of plant genetic material for precise improvement.

- a) **Transgenic Crops** -Transgenic technology introduces foreign genes to confer specific traits such as insect resistance, herbicide tolerance, and improved nutritional quality.
- b) **Genome Editing (CRISPR-Cas9)**- CRISPR-Cas9 enables precise modification of specific genes without introducing foreign DNA, making it a powerful tool for crop improvement.
- c) **Trait Improvement** -These technologies are used to enhance productivity, nutritional value, shelf life, stress tolerance, and resistance to pests and diseases.

Development of Improved Crop Varieties

The development of improved crop varieties is a systematic and multi-stage process that ensures the release of high-performing, stable, and farmer-friendly cultivars. This process integrates breeding, evaluation, and validation under diverse environmental conditions to meet the needs of farmers, consumers, and industry.

Selection of Parental Material

The first step in variety development involves the identification and selection of suitable parental lines possessing desirable traits such as high yield, disease resistance, stress tolerance, and good quality. Germplasm collections, landraces, and advanced breeding lines serve as valuable sources of genetic diversity for this purpose.

Hybridization and Population Development

Selected parents are crossed to create breeding populations with wide genetic variability. The resulting progenies are advanced through successive generations using appropriate breeding methods such as pedigree selection, bulk method, or single-seed descent. This stage aims to combine favorable traits and eliminate undesirable characteristics.

Selection and Evaluation of Progenies

Segregating populations are subjected to rigorous selection based on morphological, physiological, and agronomic traits. Promising lines are evaluated under controlled and field conditions for yield potential, resistance to pests and diseases, and tolerance to environmental stresses.

Multi-Location Testing

Advanced breeding lines are tested across different agro-climatic regions through multi-location trials to assess their adaptability, stability, and performance. This step helps in identifying varieties that perform consistently under diverse environmental conditions.

Quality Assessment and Farmer Participation

Selected lines are evaluated for quality parameters such as nutritional value, processing suitability, and shelf life. Participatory varietal selection involving farmers is increasingly adopted to ensure that new varieties meet local preferences and farming practices.

Variety Release and Commercialization

After successful evaluation, superior lines are submitted to national variety release committees for approval. Released varieties are multiplied and distributed through seed production systems and extension networks to ensure timely availability to farmers.

Overall, the systematic development of improved crop varieties ensures that only high-performing, stable, and farmer-acceptable cultivars are promoted for large-scale cultivation, thereby enhancing agricultural productivity and sustainability.

Benefits of Plant Breeding to Farmers

Plant breeding enhances crop productivity, stability, and profitability by developing high-yielding, stress-tolerant, and disease-resistant varieties. Improved cultivars utilize resources more efficiently, enabling farmers to obtain better returns from limited land and inputs. Resistant varieties reduce dependence on chemical pesticides, thereby lowering production costs and environmental risks. In addition, improved quality, uniform maturity, and better market value contribute to higher income and livelihood security.

Impact on Sustainable Agriculture

Plant breeding supports sustainable agriculture by improving resource-use efficiency and reducing environmental degradation. Pest- and disease-resistant varieties minimize pesticide use, while stress-tolerant cultivars ensure stable production under changing climatic conditions. Biofortified crops further contribute to nutritional security. Overall, improved varieties promote environmentally friendly and climate-resilient farming systems.

Challenges in Plant Breeding

Major challenges in plant breeding include climate variability, narrowing genetic diversity, long breeding cycles, and high research costs. Limited infrastructure, regulatory constraints, and weak seed distribution systems also restrict the adoption of improved varieties. Addressing these issues requires strengthened research capacity and effective extension services.

Future Prospects of Plant Breeding

Future breeding programs will integrate genomics, precision breeding, and digital tools to accelerate variety development. Emphasis will be placed on climate-smart and farmer-oriented breeding approaches. Advances in genome editing and international collaboration will further enhance crop improvement and food security.

Conclusion

Plant breeding plays a vital role in improving crop productivity, quality, and resilience. Through the integration of conventional and modern techniques, superior varieties have been developed to support farmers and ensure food security. Continuous innovation and institutional support are essential for sustaining agricultural growth and environmental stability.

References

- Gillespie, S. and van den Bold, M., 2017. Agriculture, food systems, and nutrition: meeting the challenge. *Global Challenges*, 1(3), p.1600002.
- Moose, S.P. and Mumm, R.H., 2008. Molecular plant breeding as the foundation for 21st century crop improvement. *Plant physiology*, 147(3), pp.969-977.
- Rashid, B., Tariq, M., Khalid, A., Shams, F., Ali, Q., Ashraf, F., Ghaffar, I., Khan, M.I., Rehman, R. and Husnain, T., 2017. Crop improvement: new approaches and modern techniques. *Plant Gene Trait*, 8(3), pp.18-30.
- Shaniware, Y.A., Pandey, P., Dash, A.P. and Haokip, S.W., 2023. The Role of Genetics and Plant Breeding for Crop Improvement: Current Progress and Future Prospects. *Int. J. Plant Soil Sci*, 35(20), pp.190-202.

Varshney, R.K. and Dubey, A., 2009. Novel genomic tools and modern genetic and breeding approaches for crop improvement. *Journal of Plant Biochemistry and Biotechnology*, 18(2), pp.127-138.

PHYTOREMEDIATION: NATURE'S CLEANUP CREW - HOW PLANTS DETOXYFY POLLUTED SOIL AND WATER

Banka Vaishnavi¹, Laxmi P. S² and Deshmukh Sarita Babarao³

¹Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram - 695522, Kerala, India.

²Department of Postharvest Management, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

³Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

*Corresponding Email: vaishnavinetha1999@gmail.com

Abstract

Phytoremediation is an eco-friendly, plant-based approach for mitigating environmental contamination in soil and water systems. This article highlights the fundamental mechanisms of phytoremediation, including phytoextraction, phytostabilization, rhizofiltration, phytodegradation, and phytovolatilization. The role of plant-microbe interactions in enhancing contaminant uptake and transformation is discussed, along with key factors influencing remediation efficiency such as soil properties, pollutant bioavailability, and plant selection. Recent advancements aimed at improving phytoremediation performance — including genetic improvement of hyperaccumulator species, microbial inoculation, and soil amendments — are examined. Emerging concepts like phytomining and biomass valorization are also explored. Despite limitations such as slower remediation rates and biomass management challenges, phytoremediation offers a cost-effective and sustainable solution for long-term environmental restoration and land reclamation.

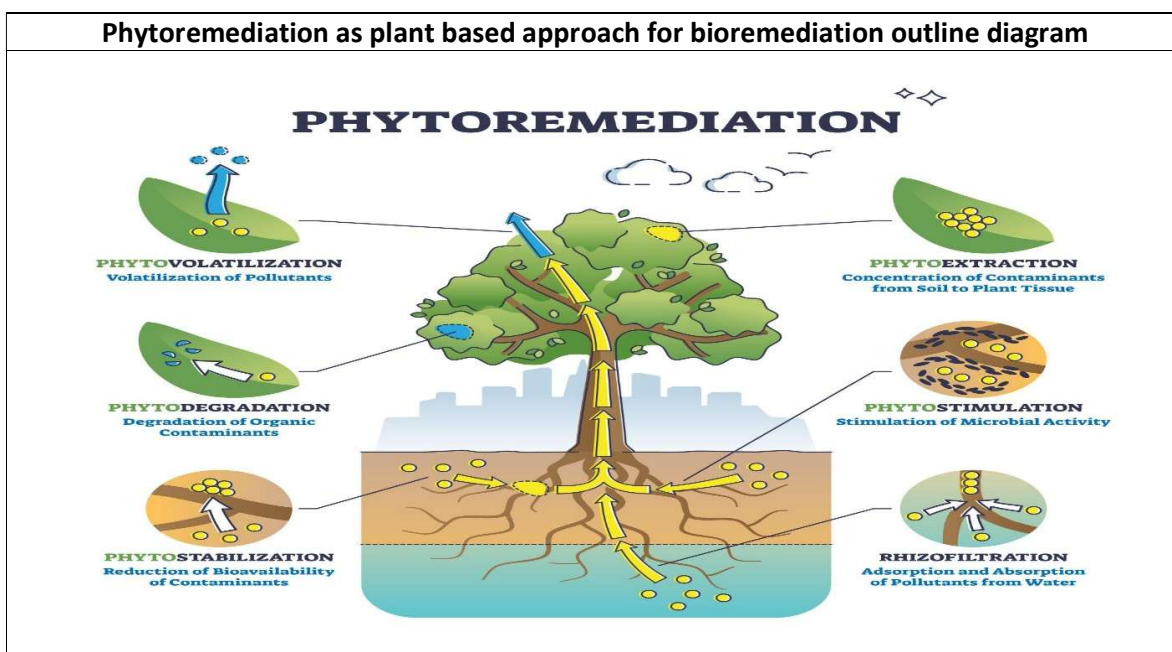
Introduction

Phytoremediation uses living plants and their associated microbes to remove, stabilize, or transform contaminants in soil, water and air. It's a low-cost, low-impact remediation strategy that can turn polluted land into productive or at least safe green space. Compared to mechanical or chemical remediation, phytoremediation is often cheaper and less disruptive — but it's also slower and limited by plant root depth and contaminant type. Modern research aims to speed it up, manage contaminated plant biomass responsibly, and even recover valuable metals from plants ("phytomining").

How plants clean the main mechanisms

1. **Phytoextraction (phytoaccumulation).** Plants take up contaminants (typically metals) through roots and translocate them to above-ground tissues. Harvesting the shoots removes the stored contaminants from the site; repeated harvests can reduce soil metal concentrations over seasons. Hyperaccumulator species (e.g., some *Brassica*, *Thlaspi*, *Pteris* spp.) are of special interest because they concentrate metals to unusually high levels.
2. **Phytostabilization.** Plants immobilize contaminants in the rhizosphere or root zone, reducing erosion and leaching. They're useful where removal isn't feasible or necessary, turning contaminated soils into covered, less mobile systems.

3. **Rhizofiltration.** Roots or harvested root mats remove contaminants from water — valuable for treating industrial wastewater or polluted runoff. Aquatic macrophytes (e.g., *Phragmites*, *Typha*) are commonly used.
4. **Phytodegradation and phytovolatilization.** Plants and their rhizosphere microbes break down organic pollutants (petroleum hydrocarbons, some pesticides), or transform compounds into volatile forms that plants release into the atmosphere (sometimes less toxic). Microbial partnerships in the rhizosphere are critical for degradation.
5. **Assessing sites and choosing species**
6. A successful project begins with a complete site assessment: pollutant identity and concentrations, soil texture, pH, organic matter, hydrology, and depth of contamination. These factors determine whether removal, stabilization, or a mixed strategy makes the most sense. Plant choice depends on pollutant tolerance, biomass productivity, rooting depth, translocation behavior (for extraction), and local climate. In many cases, fast-growing woody species (poplars, willows) are used for organic contamination and shallow metal issues, while herbaceous hyperaccumulators are used for metal phytoextraction.



Speeding up the process: breeding, microbes, amendments

Phytoremediation is often criticized for being slow. Researchers address this by:

- **Selecting or breeding plants** with higher biomass and metal uptake or enhanced rhizosphere activity.
- **Using microbial inoculants** (plant growth-promoting rhizobacteria, mycorrhizae) that increase bioavailability of contaminants or improve plant tolerance.
- **Soil amendments** (chelators, organic matter) that temporarily increase metal solubility for better uptake — used carefully because of leaching risks. Combining approaches (plant + microbe + amendment + agronomic practice) tends to give the best results.

Phytomining and biomass valorization

A powerful idea is converting phytoremediation from a cost center into a revenue stream. **Phytomining** (or agromining) uses hyperaccumulators to concentrate valuable metals (nickel, cobalt) and then recovers them from biomass through combustion/ash processing or other extraction methods. Similarly, contaminated biomass can be processed via controlled combustion with subsequent ash recovery, gasification, or pyrolysis to produce energy and recover metals — but these pathways must manage air emissions and residues carefully. New reviews emphasize lifecycle analyses and integrated approaches to make phytoremediation sustainable at scale.

Risks and “end-of-life”

Phytoremediation moves contaminants into plants — that biomass becomes hazardous and must be handled. Options include:

- Incineration with ash stabilization and metal recovery.
- Thermal conversion (gasification/pyrolysis) with residues processed for metals.
- Secure disposal in hazardous-waste landfills (least desirable). Additionally, food-chain transfer risk requires preventing grazing or crop use on remediated sites until contaminant levels are safe. These management steps are essential for regulatory compliance and community acceptance.

Table 1. Mechanisms of Phytoremediation

Mechanism	Description	Target Pollutants	Typical Plant Types	Key Advantage
Phytoextraction	Uptake & accumulation in shoots	Heavy metals (Cd, Pb, Ni, As)	Hyperaccumulators (<i>Brassica</i> , <i>Pteris</i>)	Removes contaminants
Phytostabilization	Immobilization in soil/root zone	Metals, metalloids	Grasses, tolerant shrubs	Prevents leaching
Rhizofiltration	Root adsorption from water	Metals, radionuclides	Aquatic plants (<i>Typha</i> , <i>Phragmites</i>)	Good for wastewater
Phytodegradation	Breakdown via plant/microbes	Organic pollutants	Poplar, willow	Detoxifies organics
Phytovolatilization	Conversion → volatile release	Hg, Se, some organics	Engineered/tolerant plants	Reduces soil burden

Real-world examples & research frontiers

Constructed wetlands treating municipal and industrial wastewater, poplar/willow plantations remediating petroleum-contaminated soils, and small phytomining trials on mining tailings illustrate real applications. Current research priorities include: improving plant and microbe performance via omics and breeding; developing safe biomass valorization workflows; economic assessments for phytoremediation vs. conventional methods; and predictive modelling to guide site-scale decisions.

Bottom line

Phytoremediation is a versatile, green approach for many contamination problems — especially where low cost, ecosystem benefits, and aesthetics matter. It's not universal: success needs the right plant, proper site matching, and a plan for contaminated biomass. However, with integrated

strategies (microbes, breeding, biomass valorization), phytoremediation is moving from niche to an increasingly practical remediation option.

References

- Acharya, A., Bellaloui, N., Pilipovic, A., Perez, E., Maddox-Mandolini, M., & de la Fuente, H. (2025). *Current assessment and future perspectives on phytoremediation of heavy metals*. *Plants*, 14(18), 2847. <https://doi.org/10.3390/plants14182847>.
- Kumar, A. (2024). *Phytoremediation: Sustainable Approach for Heavy Metal Pollution*. *Journal* (Open Access). <https://onlinelibrary.wiley.com/doi/10.1155/2024/3909400>.
- Mukherjee, S. (2025). *Sustainable management of post-phytoremediation biomass*. *Environmental Technology Reviews*. Springer. <https://link.springer.com/article/10.1007/s40974-025-00364-w>.
- Oubohssaine, M., & Dahmani, I. (2024). *Phytoremediation: Harnessing plant power and innovative technologies for effective soil remediation*. *Plant Stress*, 10, 100578. <https://doi.org/10.1016/j.stress.2024.100578>

AI IN PLANT BREEDING: FROM DATA TO BETTER CROPS

Banka Vaishnavi^{1*}, Vibin Sankar² and Athira S³

¹ Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram 695522, Kerala, India.

^{2 & 3} Department of Floriculture and Landscaping, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: vaishnavinetha1999@gmail.com

Abstract

Artificial intelligence (AI) and machine learning (ML) are transforming plant breeding by enabling efficient analysis of large genomic and phenotypic datasets. This article reviews major AI applications, including genomic selection, high-throughput phenotyping, computer vision-based trait analysis, multi-omics integration, and decision-support systems. AI-driven prediction models improve selection accuracy and reduce breeding cycle duration, particularly for complex traits such as yield and stress tolerance. The integration of AI with breeding pipelines facilitates optimized parent selection, resource allocation, and variety deployment. Challenges related to data quality, model interpretability, computational infrastructure, and accessibility are discussed. Emerging trends such as explainable AI, transfer learning, and real-time analytics indicate strong future potential. AI is presented as a complementary technology that enhances breeding efficiency, precision, and sustainability.

Introduction

AI and machine learning (ML) are transforming plant breeding by turning massive, complex datasets into actionable predictions. These tools help breeders identify which crosses and selection candidates are most likely to deliver improved varieties faster and with fewer field trials. AI is complementary to classical breeding — not a replacement — and its impact depends on data quality, experimental design, and interpretability.

Why AI matters now

Breeders now have access to genome-wide marker data, high-throughput phenotyping (drones, sensors, automated platforms), environmental records (soil, weather), and management metadata. AI handles heterogeneous, high-dimensional data and finds patterns hard for humans to detect. For complex traits (yield, drought tolerance), genomic selection powered by ML increases selection gains per unit time by improving prediction accuracy.

Key AI applications in breeding

1. **Genomic selection (GS) with ML.** GS uses genome-wide markers to predict breeding values; ML models (random forests, gradient boosting, deep neural nets) often outperform linear models for certain traits and datasets. These models reduce the need for multi-year field trials by reliably predicting performance from genotypes and prior phenotypes.
2. **High-throughput phenotyping (HTP) and computer vision.** Deep learning applied to drone and field imagery quantifies canopy structure, disease symptoms, senescence, and biomass proxies at scale and speed. This provides richer training data for genomic models and helps detect genotype × environment interactions.

3. **Multi-omics integration.** AI can merge genomics, transcriptomics, metabolomics, and phenomics to prioritize candidate genes and pathways for breeding or editing. These multi-modal approaches improve biological interpretability and target selection.
4. **Designing crosses and managing genebanks.** AI helps select parents to maximize genetic gain while preserving diversity, and mines genebanks for useful alleles by predicting trait expression in untested accessions.

Challenges & practical limits

- **Data quality and representativeness:** Poor or biased training data leads to poor predictions in new environments or germplasm. Underrepresented smallholder environments are a particular concern.
- **Model interpretability:** Breeders often need explanations (which markers or regions drive predictions) for trust and actionable decisions; explainable AI methods are an active research area.
- **Infrastructure and capacity:** Computational resources, data standards, and skilled personnel are required; equitable access is necessary for broad benefit.

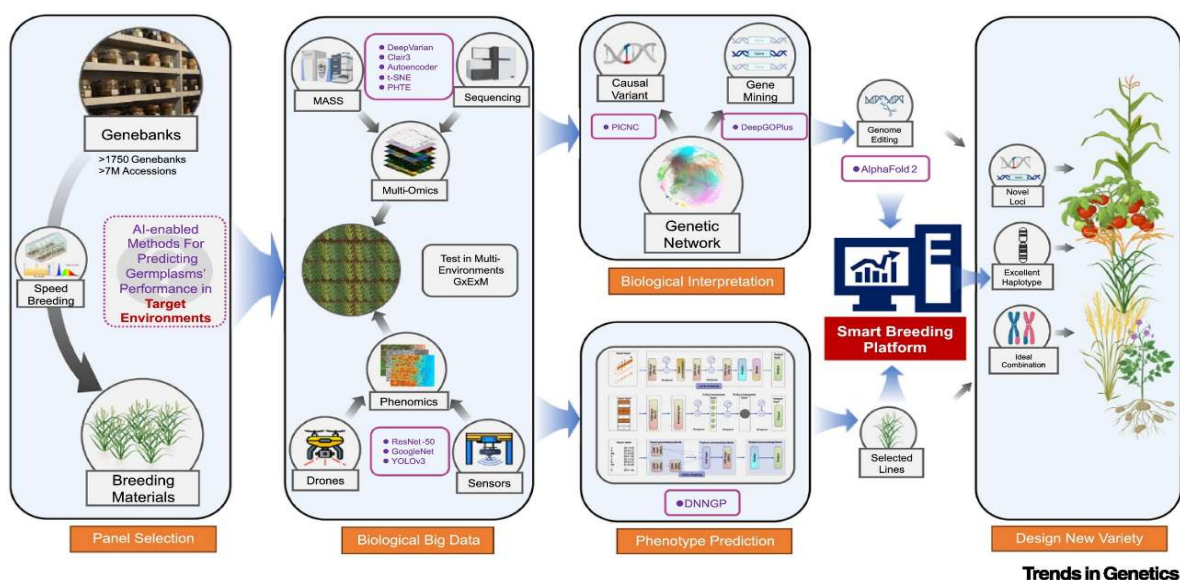


Fig 1. AI in plant breeding

Emerging trends

- **Transfer learning and data augmentation** that allow models trained in one crop or environment to be adapted to others.
- **Explainable AI (XAI)** methods to reveal which features drive predictions, making recommendations more actionable.
- **Automated pipelines** that integrate field sensors, cloud analytics, and breeder dashboards for real-time decision support.
- **Large language models (LLMs) and foundation models** adapted to biological data for hypothesis generation (early but growing area).

Table 1 Major AI Applications

AI Application	Role in Breeding	Benefit
Genomic Selection	Predict breeding values	Faster selection
Computer Vision	Image-based phenotyping	Cheap, rapid traits
ML Prediction Models	Yield/stress prediction	Higher accuracy
Decision Support Systems	Variety recommendation	Better deployment
Gene Discovery AI	Identify candidate genes	Targeted breeding

Case studies & impact

Practical examples include disease detection apps that let extension workers rapidly diagnose crop diseases from smartphone images, ML-assisted genomic selection programs in major cereals that shortened selection cycles, and genotype $\times$ environment models that guide variety deployment to specific agro-ecological zones. These examples show AI's potential when coupled to good breeding design and validation trials.

Bottom line

AI is a force multiplier for modern breeding: when breeders invest in high-quality data collection, validation trials, and interpretability, AI increases genetic gain and accelerates variety development. The real challenge now is democratizing access and building trustworthy workflows that deliver benefits to farmers especially smallholders.

References

- Bhuiyan, M. M. R., Islam, M. T., Hossain, M. M., Rahman, M. A., Rahman, M. S., & Kabir, M. H. (2025). *Transformation of plant breeding using data analytics and artificial intelligence*. *Frontiers in Bioengineering and Biotechnology*, 17, FBE27936. <https://doi.org/10.31083/FBE27936>
- Farooq, M. A., Azad, M. A., Islam, A., Jahan, T., Rumana, S., & Hasan, M. M. (2024). *Artificial intelligence in plant breeding*. *Trends in Plant Science*. <https://www.sciencedirect.com/science/article/pii/S0168952524001677>
- Shai Prasanna, G. S., Joshi, J. L., Ganesan, S., Shoba, D., Muralidharan, A., & Pavithra, P. (2025). *Advances in genetics and plant breeding with AI, data science and machine learning*. *International Journal of Agriculture and Food Science*, 7(9), 399–403. <https://doi.org/10.33545/2664844X.2025.v7.i9e.772>

MOLECULAR BIOTECHNOLOGY IN BREEDING: TOOLS THAT CHANGED THE GAME

Banka Vaishnavi¹, Choudhari Balaji Keshavrao² and Khushal B. Muradi³

¹Ph.D. Scholar, Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram - 695522, Kerala, India.

²Ph.D. Scholar, Department of Agronomy, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram - 695522, Kerala, India.

³Ph.D. Scholar, Department of Vegetable Science, College of Agriculture, Vellanikkara, Kerala Agricultural University, Thrissur - 680656, Kerala, India.

*Corresponding Email: vaishnavinetha1999@gmail.com

Abstract

Molecular biotechnology has significantly advanced plant breeding by introducing precise, predictive, and accelerated improvement strategies. This article summarizes the contributions of molecular markers, marker-assisted selection (MAS), genomic selection (GS), genome editing, and transgenic and cisgenic technologies. MAS enables early selection of major-gene traits, while GS improves prediction accuracy for complex quantitative traits. CRISPR/Cas-based genome editing and its derivatives provide rapid and targeted genetic modifications, enhancing trait development efficiency. The integration of molecular tools with high-throughput genotyping, phenotyping, and AI-based analytics is discussed. Regulatory, ethical, and socio-economic considerations surrounding gene-edited crops are examined alongside technical challenges such as off-target effects. Molecular biotechnology is ultimately portrayed as a cornerstone of modern crop improvement for food security and climate resilience.

Introduction

Molecular biotechnology molecular markers, genomic selection, and genome editing has transformed plant breeding from a time-consuming art into a precision-driven discipline. These technologies increase selection accuracy, shorten breeding cycles, and enable trait improvements that were previously difficult or impossible. But the science is entwined with regulation, IP, and social acceptance questions that shape how quickly tools are adopted.

The toolbox what each method does

1. **Molecular markers & marker-assisted selection (MAS).** Markers linked to desirable alleles let breeders select seedlings that carry the trait without waiting for phenotypic expression. MAS is especially valuable for simple, major-gene traits such as many disease resistances or quality traits.
2. **Genomic selection (GS).** GS uses genome-wide marker information to predict breeding values for complex traits. Instead of tracking a few markers, GS leverages all marker information and statistical/ML models to accelerate selection for traits influenced by many loci.
3. **Genome editing (CRISPR/Cas and derivatives).** CRISPR/Cas systems, base editors and prime editors enable precise edits: knocking out genes, altering regulatory sequences, or making specific base changes. These edits can create disease resistance, modify flowering

these decisions shape innovation pathways and investment. Transparent risk assessment and stakeholder engagement are crucial for public trust.

Limitations and risk management

- Off-target edits and mosaicism: improved enzymes and delivery methods reduce, but do not eliminate, these risks; empirical validation and field testing remain essential.
- Genetic background dependency: edits that work in one genotype may behave differently in others; breeders must test across germplasm and environments.
- Socioeconomic impacts: IP, seed systems and regulatory costs can bias benefits toward large companies unless public-interest models and open-access tools are strengthened.

Bottom line

Molecular biotechnology gives breeders unprecedented precision and speed. The science is mature and developing rapidly (new editors, delivery systems, AI-guided target selection). The near-term success of these tools depends as much on governance, equitable access, and robust field evaluation as on laboratory innovation.

References

- Aziz, M. A., Khan, F. A., Mahmood, Q., Ahmad, M., Ali, A., Ullah, F., & Khan, M. (2025). *Molecular breakthroughs in modern plant breeding*. Heliyon Plant Journal, HPJ.2024.01.004. <https://www.sciopen.com/article/10.1016/j.hpj.2024.01.004>
- Wu, Y., Huang, J., Ming, L., Deng, P., Wang, M., & Zhang, Z. (2025). *DeepPlantCRE: Transformer-CNN hybrid framework for plant gene expression modeling and cross-species generalization*. arXiv preprint arXiv:2505.09883.
- Deng, P., Liu, K., Zhou, M., Li, M., Yang, R., Cao, C., Wang, M., & Zhang, Z. (2025). *DPCformer: An interpretable deep learning model for genomic prediction in crops*. arXiv preprint arXiv:2510.08662.
- Financial Times (2024). *Proposed EU ban on gene-edited crop patents prompts dispute*. FT.com (reporting on EU policy debates influencing regulation and IP). <https://www.ft.com/content/5e3cc871-1377-4c65-88e5-e9096fb4db1f>.

A NEW FRONTIER: CULTIVATING BUFFALO GOURD IN INDIA'S ARID ZONES

Udham Singh*, Jayshree Singh, Manish Kumar Singh,
Shweta Soni and Ajeet Singh

Department of Vegetable Science, College of Horticulture, Banda University of Agriculture and Technology, Banda , Uttar Pradesh- 210001, India.

*Corresponding Email: 26us0202@gmail.com

Abstract

Cucurbita foetidissima, commonly known as the buffalo gourd, is a resilient, drought-deciduous perennial native to the arid regions of North America, now gaining global attention as a candidate for sustainable agriculture in marginal lands. This study explores the plant's unique morphology, characterized by a massive starchy taproot and its nutrient-dense seeds. The species' high adaptability to extreme environments makes it particularly suitable for the arid and semi-arid zones of India, supported by the plant's preference for sandy loam soils with excellent drainage and its high tolerance for alkaline conditions (achieving 90% germination at pH 8.0). Climatologically, the buffalo gourd requires a long, warm growing season of five to eight months, with optimal germination occurring at 25°C. Beyond its role as a hardy food and oil source, the high starch content (47–56%) of its root system positions the buffalo gourd as a strategic feedstock for biofuel production and industrial starch extraction in water-stressed environments.

Introduction

Native to northern Mexico and the central-southwestern United States, *Cucurbita foetidissima* (frequently referred to as the buffalo gourd), is a drought-resistant plant characterized by its large, starchy taproot. First documented by explorers Alexander von Humboldt and Aime Bonpland in the early 19th century, the species earned its Latin name from its notably pungent odor. Because it thrives in harsh, arid climates and produces seeds rich in protein and oil, it has become a subject of interest for sustainable agriculture. Furthermore, the significant carbohydrate reserves found in its roots have positioned the plant as a potential candidate for biofuel production. The buffalo gourd serves as a food source for wildlife and people alike, reaching its final "gourd" phase only after the vine and fruit have fully dried out.



Plant Morphology

Buffalo gourd is a resilient plant characterized by its large, heart-shaped leaves that generally measure about 10 to 13 cm at the base and up to 25 cm in length. Its reproductive cycle involves the growth of individual flowers at vine nodes once the plant has established sufficient seasonal foliage. The plant is notably productive; it yields gourds roughly 7 to 10 cm in diameter that contain upwards of 300 seeds each. These seeds are small but hardy, protected by a thick coat that allows them to remain fertile for long periods if the fruit stays intact. Perhaps the most

remarkable feature of the species is its massive, fleshy tap root, which serves as a vital energy reservoir for overwintering. These roots can reach extraordinary proportions; a cultivated plant may develop a root system weighing around 45 kg and extending 2.5 meters deep within just four years.



Botanical Classification

The botanical classification of *Cucurbita foetidissima*, commonly known as the buffalo gourd or calabazilla, reveals its evolutionary journey from simple green organisms to complex flowering plants. As a member of the kingdom Plantae, it belongs to the Tracheophyte clade, signifying it is a vascular plant equipped with specialized tissues for transporting water and nutrients. Furthermore, it is categorized within the Angiosperms, the vast group of plants that produce seeds within protective fruits, and the Eudicots, which are characterized by having two embryonic seed leaves. Moving deeper into its lineage, this species sits within the Rosid clade and the order Cucurbitales, a group often recognized for their climbing or prostrate growth habits. It is a prominent member of the Cucurbitaceae family, the same family that hosts melons, cucumbers, and squashes. Specifically, it belongs to the genus *Cucurbita*, which encompasses various pumpkins and gourds. The specific epithet, *foetidissima*, refers to the pungent, “foetid” odor released by its crushed leaves, distinguishing this hardy, drought-resistant perennial from its more pleasant-smelling cousins.

Cultivation

The Buffalo Gourd (*Cucurbita foetidissima*) is a remarkably hardy perennial plant designed by nature to thrive where most crops would fail. It is a specialist of “marginal” lands areas with poor soil quality and minimal rainfall making it a subject of interest for sustainable agriculture in desert regions.

Porpogation

- **Seed Propagation (Sexual):** This is the most common method for establishing new fields. In this method a whole dried seeds (usually 4g per 100 seeds) are used for sowing. Roughly 2.5 to 5 kg of seed per hectare depending on desired density. Spacing of about 2 to 2.5 meters apart, with 45 to 60 cm between plants within the row. Soaking seeds in water for 24 hours prior to planting is highly recommended to soften the seed coat and accelerate the germination process.
- **Nodal Root & Vine Cuttings (Asexual):** The Buffalo Gourd naturally “clones” itself as its vines sprawl. Where a node (the point where a leaf meets the stem) touches moist soil, it can

develop adventitious roots. Mature vine segments or “nodal cuttings”. For commercial-scale vegetative propagation, you generally need 6,000–7,000 cuttings per hectare. Each cutting should be 60 to 90 cm long and contain at least 7 to 10 nodes to ensure a high survival rate. Cuttings are typically taken in late autumn (October/November), rooted in a nursery over winter, and transplanted in early spring. Alternatively, fresh 1 meter “coiled” cuttings can be buried directly in 20 cm deep furrows.

- **Tuber Division (Asexual):** Because the plant develops a massive taproot (which can weigh up to 45 to 70 kg in mature plants), the crown can be divided. Sections of the tuberous rootstock (crown) usually 4,500 to 5,000 root divisions per hectare if used as the primary propagation method. This must be done during the plant’s dormant period (winter) to avoid transplant shock. Each piece must have at least one “eye” or bud to successfully sprout.

Germination & Soil Requirements

The success of a Buffalo Gourd crop starts with precise seed placement and soil chemistry. The plant shows a wide range of tolerance but has a very clear “sweet spot” for optimal yields.

- **Optimal Temperature:** While the seeds are resilient enough to sprout anywhere between 15°C and 37°C, the highest success rate occurs at a steady 25°C.
- **Planting Depth:** Seeds should be sown no deeper than 12 cm. Exceeding this depth prevents the seedling from reaching the surface before its stored energy reserves are depleted.
- **pH Flexibility:** This species is incredibly acid-tolerant but prefers alkaline environments. At a highly acidic pH of 2.2, the germination rate is a low 15%. At an alkaline pH of 8.0, the germination rate climbs significantly to 90%.

Growth Requirements

For the Buffalo Gourd to flourish, it requires a specific set of environmental conditions that mimic its native high-desert habitats:

- **Climate & Duration:** The plant demands a long, warm growing season lasting between five and eight months. It is highly drought-tolerant and specifically adapted to arid and semiarid zones.
- **Soil Composition:** It prefers sandy loam soils. The most critical factor for the root system is drainage; the plant will not tolerate “wet feet” or waterlogged earth.
- **Water Usage:** Its water requirements are exceptionally low, allowing it to maintain biomass in regions that receive very little annual precipitation.

Nutritional Composition

The nutritional value of the buffalo gourd is primarily concentrated within its seeds and massive taproot, making it a significant resource in arid environments. The seeds are remarkably dense in macronutrients, boasting a crude protein content ranging from 29% to 35%, which can increase significantly once the oil is extracted. These seeds are also a rich source of edible fats, containing between 25% and 50% crude oil dominated by linoleic acid, an essential omega-6 fatty acid. Additionally, the seeds provide a substantial amount of dietary fiber, roughly 26%, mostly located within the seed coats. The plant's enormous roots serve as a primary energy reservoir, consisting of 47% to 56% starch when dried. While the flowers and young vines contain various vitamins and minerals common to the squash family, the mature fruit pulp remains largely inedible. This is due to the presence of cucurbitacins, which are bitter biochemical compounds that can be toxic, necessitating careful separation of the nutritious seeds from the surrounding flesh.

Use of Buffalo Gourd

- Similar to pumpkin seeds, the seeds can be washed, salted, and roasted. They have a nutty, rich flavor once the bitterness of the pulp is removed.
- Indigenous groups historically ground the parched seeds into a meal or flour. This was used to thicken stews or mixed with water to make a high-protein porridge.
- Seeds are so rich in linoleic acid that they can be pressed for edible cooking oil, though this is more common in experimental agriculture than in home kitchens.
- The root is too fibrous and bitter to eat like a carrot, it is packed with starch. It can be processed to extract a fine, white starch (similar to cornstarch or arrowroot) used for thickening sauces or baking. This requires heavy processing grating, soaking, and multiple rinses to wash away the bitter compounds.
- When the gourds are very young (about the size of a marble), the bitterness is less intense. Some cultures have used them boiled or fried like summer squash, but even then, a “bitter gene” can make them unpalatable or cause stomach upset. Once yellow and hard, the flesh is virtually inedible. It’s dry, fibrous, and soapy.
- The bitterness comes from cucurbitacins, which can be toxic in high concentrations. If a gourd tastes extremely bitter, can cause “Toxic Squash Syndrome”, leading to severe gastrointestinal distress.

Conclusion

The Buffalo Gourd (*Cucurbita foetidissima*) is a high-potential crop for India’s arid regions, due to its extreme drought resistance and preference for alkaline, sandy soils. It is a resilient, drought-tolerant perennial native to arid North American regions. Distinguished by its pungent odor and massive, starchy taproot, it thrives in poor soils with minimal water. The plant is a botanical powerhouse, offering seeds rich in protein (up to 35%) and linoleic oil, alongside roots viable for starch or biofuel. While its bitter cucurbitacins render mature fruit inedible, careful processing allows for diverse applications in sustainable agriculture, traditional cooking, and industrial production.

Reference

- Thompson, M. N., Russavage, E. M., Garces, J. G., Bradford, B. J., Merrell, D., Suh, C. P. C., & Helms, A. M. (2025). Cucurbit plant defenses against aboveground or belowground insect herbivores are distinct and shaped by eco-evolutionary factors. *Basic and Applied Ecology*, 86, 21-31.
- Hernández-Centeno, F., Hernández-González, M., Tirado-Gallegos, J. M., Rodríguez-González, C., Rios-Velasco, C., Rodríguez-Hernández, A. M. & Zamudio-Flores, P. B. (2022). Effect of oregano essential oil (*Lippia berlandieri* Schauer) inclusion on physicochemical properties of buffalo gourd (*Cucurbita foetidissima* Kunth) root starch films.

ADVANCES IN REMOTE SENSING AND GIS FOR AGRO-METEOROLOGICAL ADVISORY AND CLIMATE-SMART AGRICULTURE

**Ekanshi Shreshtha¹, Shubham Pandey^{2*}, Sita Ram Mishra³,
Shivani Pandey¹ and Anamika Rajput¹**

Department of Agricultural Meteorology,

Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya

*Corresponding Email: pandeyshubham0121@gmail.com

Abstract

Agriculture is increasingly challenged by climate variability, resource limitations, and the need for sustainable intensification. In this context, advances in Remote Sensing (RS) and Geographic Information Systems (GIS) have become pivotal for strengthening agro-meteorological advisory services and promoting climate-smart agriculture. RS provides precise and timely data that can detect early signs of drought, floods, or pest outbreaks, supporting proactive decision-making. GIS complements RS by integrating meteorological variables with agricultural datasets, allowing spatial analysis and visualization of complex interactions between climate and farming systems. Through mapping and modeling, GIS transforms raw data into actionable insights, guiding farmers on crop selection, planting schedules, and resource allocation. Together, RS and GIS form a powerful synergy that underpins precision agriculture, enhances resilience to climate variability, and reduces environmental impacts.

Introduction

In the rapidly evolving landscape of modern agriculture, the twin pressures of a growing global population and an increasingly volatile climate have necessitated a shift from traditional practices toward data-driven, resilient strategies. Central to this transformation are the advancements in remote sensing (RS) and Geographic information systems (GIS), which together serve as the nervous system of Climate-Smart Agriculture (CSA). Remote Sensing, through its ability to capture high-resolution spectral data from satellites, drones, and aircraft, provides a “bird’s-eye view” of crop health, soil moisture, and pest dynamics without physical contact. When these datasets are integrated into GIS, they are transformed from raw images into actionable spatial maps, allowing for the precise layering of topographical, meteorological, and biological information.

The Role Of Agro-Meteorological Advisory

One of the most critical breakthroughs in this field is the development of Agro-meteorological Advisory Services (AAS). By blending real-time weather forecasting with geospatial crop monitoring, these services provide farmers with site-specific recommendations- such as the optimal timing for sowing, irrigation, and fertilization- thereby minimizing weather-related risks.

Core objective of integration -RS and GIS facilitate the three main pillars of Climate-smart Agriculture:

- Sustainability: Increasing agricultural productivity and incomes in a sustainable manner.

- **Adaptation:** Building and enhancing resilience to climate change through predictive modelling.
- **Mitigation:** Reducing or removing greenhouse gas emissions where possible, such as through precision nitrogen application.

Importance Of RS And GIS For Agro-Met Advisory And Climate-Smart Agriculture

Agriculture today faces unprecedented challenges due to climate variability, resource constraints, and the need to feed a growing population sustainably. Agro-meteorological advisory services, which provide farmers with weather-based guidance, have become vital in helping communities adapt to changing conditions. High-resolution imagery allows detection of early stress in crops, whether due to drought, pests, or nutrient deficiencies. This information feeds into advisory systems, enabling farmers to take preventive measures before losses escalate. Remote Sensing also supports early warning systems for extreme events such as floods, cyclones, or heatwaves, giving farmers crucial time to prepare.

While RS supplies raw observational data, GIS provides the analytical framework to interpret and apply it. Advances in GIS allow integration of meteorological variables—rainfall, temperature, humidity—with agricultural datasets such as soil type, crop distribution, and irrigation networks. This spatial analysis helps identify susceptible zones, forecast yields, and design site-specific management practices.

Broader Impacts

Advances in RS and GIS also strengthen policy and planning. Governments can use these tools to design crop insurance schemes, manage water resources, and plan disaster response strategies. At the community level, they empower farmers with knowledge, reducing dependence on guesswork and increasing confidence in decision-making.

Geographic Information System (GIS) And Remote Sensing In Agro-Meteorology

In the field of Agro-meteorology, the integration of Remote Sensing (RS) and Geographic Information System (GIS) has transmogrified how we understand the relationship between weather patterns and agricultural productivity. Instead of relying on isolated weather stations, scientists and farmers now use a “spatial lens” to monitor the atmosphere and the field contemporaneously. Agro-meteorology combines weather and climate science with agriculture to improve crop productivity and sustainability. Within this field, Geographic Information Systems (GIS) and Remote Sensing (RS) are essential tools that provide spatial and temporal insights into farming systems and their interaction with the atmosphere.

Key Applications

- **Weather and Climate Monitoring:** Satellite-derived data on temperature, rainfall, and drought patterns are integrated with local weather forecasts to guide sowing dates and irrigation scheduling.
- **Crop Stress Detection:** NDVI (Normalized Difference Vegetation Index) detect plant stress due to heat, water shortage, or nutrient deficiencies before symptoms appear.
- **Pest and Disease Risk Mapping:** Multispectral imagery coupled with machine learning models can anticipate pest infestation zones by identifying abnormal spectral signatures.
- **Real-Time Advisory Delivery:** GIS platforms enable extension services to send location-specific advisories directly to farmers via mobile apps, SMS, or community dashboards.

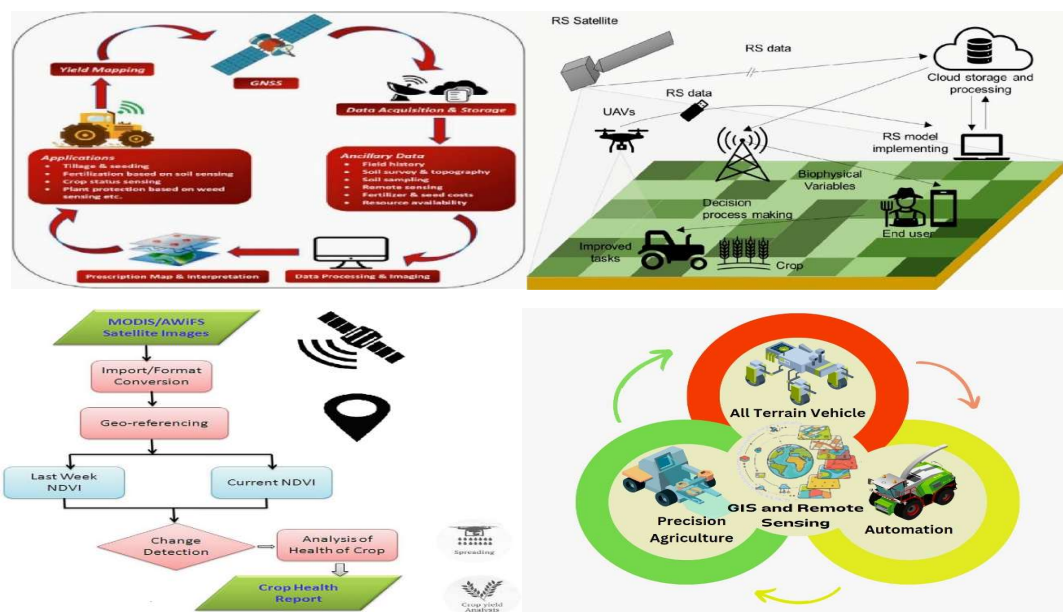


Figure: Flowchart of working Principles of RS and GIS in Climate Agriculture

Challenges and Future Outlook

While RS and GIS unlock powerful insights, challenges remain:

- **Technical Capacity:** Smallholder adoption may be limited by lack of training and digital literacy.
- **Data Accessibility:** High-resolution imagery and analysis tools can be costly without supportive policies or open-data initiatives.
- **Infrastructure Gaps:** Reliable internet and mobile connectivity are essential for real-time advisory dissemination.

Conclusion

Advances in Remote Sensing and GIS have revolutionized agro-meteorological advisory services, making them more precise, timely, and farmer-friendly. Their integration into climate-smart agriculture ensures higher productivity, better adaptation to climate variability, and reduced environmental impact. By bridging the gap between observation and decision, these technologies are not just tools but essential pillars of sustainable agriculture in the 21st century.

References

- Nandeha, N., Trivedi, A., Adawadkar, M., Subhasish, B., & Sonowal, S. (2025). Review on IoT, Remote Sensing, GIS and AI for Climate Smart Agriculture. *Journal of Experimental Agriculture International*, 47(6), 784–793.
- Sangeetha, C., Moond, V., Rajesh G. M., Damor, J. S., Pandey, S. K., Kumar, P., & Singh, B. (2024). Remote Sensing and Geographic Information Systems for Precision Agriculture: A Review. *International Journal of Environment and Climate Change*, 14(2), 287–309.
- Haque, S. J., Hossain, S., & Billah, M. M. (2025). Precision Agriculture through Remote Sensing and GIS: Advancing Sustainable Farming and Climate Resilience. *American Journal of Smart Technology and Solutions*, 4(1), 30-36.

WHAT BUDGET 2026 MEANS FOR INDIAN FARMERS AND FOOD SECURITY

K. N. Tiwari

Ex. Director, International Plant Nutrition Institute, India Programme,
4/B861, Hanumat Kripa, Gomati Nagar Extension, Lucknow 226010

*Corresponding Email: kashinathtiwari730@gmail.com

Abstract

The Union Budget 2026 occupies a critical position in shaping the future trajectory of Indian agriculture at a time when the sector faces mounting pressures from climate change, soil degradation, rising input costs, and persistent income uncertainty among farmers. While agriculture continues to support nearly half of India's population and remains central to food and nutritional security, structural challenges have constrained productivity growth and sustainability. This paper critically examines the agricultural provisions of Union Budget 2026, with a focus on budgetary allocations, fertilizer subsidy policy, soil health implications, and gaps in farmer income and risk management. The analysis highlights that although the budget provides short-term relief through enhanced allocations and subsidy support, it largely avoids deeper reforms in fertilizer pricing, nutrient management, and market risk mitigation. Continued reliance on subsidy expansion, particularly in fertilizers, perpetuates nutrient imbalances and undermines long-term soil health and productivity. The paper argues that without phased structural reforms aligned with efficiency, sustainability, and resilience, incremental measures will yield limited outcomes. It concludes by outlining a reform-oriented pathway that balances political economy constraints with the need for climate-smart, income-secure, and resource-efficient agricultural growth.

Introduction

Agriculture continues to occupy a pivotal place in India's economic and social landscape, underpinning national food security, rural livelihoods, and nutritional well-being. Nearly half of India's population depends directly or indirectly on agriculture for employment and income, while the sector also supplies raw materials to agro-based industries and contributes to export earnings. Beyond its economic role, agriculture remains central to poverty reduction, regional balance, and the sustainability of natural resources, particularly land and water. In this broader context, the Union Budget 2026 assumes heightened significance, as it is expected to respond to long-standing structural challenges confronting the sector, including declining farm profitability, deteriorating soil health, increasing climate-induced risks, and persistent market and price volatility.

The Budget 2026 has generated mixed reactions among farmers, researchers, policymakers, and agri-industry stakeholders. While the enhanced allocations and targeted interventions signal the government's continued commitment to agricultural growth and farmer welfare, the overall approach reflects continuity and caution rather than a transformative policy shift. The emphasis remains on managing immediate risks and maintaining input affordability within fiscal constraints. However, the budget stops short of initiating deeper structural reforms needed to improve productivity, resilience, and resource-use efficiency. Consequently, it prioritizes short-term stability and fiscal prudence over long-term systemic correction required to place Indian agriculture on a sustainable and growth-oriented trajectory.

Key Budgetary Allocations and Strategic Focus

The Union Budget 2026 allocates ₹1.62 lakh crore to the agriculture sector, representing a 7 per cent increase over the previous year. This enhanced allocation reflects continued commitment to the sector, particularly in the context of rising input costs, climate-related risks, and global market volatility. The budget emphasizes crop diversification and export-oriented growth, with a specific focus on high-value horticultural and plantation crops such as coconut, cashew, walnut, and cocoa. These crops are expected to contribute to higher farm incomes, improved export earnings, and value chain development.

In addition, the reduction of Goods and Services Tax (GST) on bio-pesticides from 12 per cent to 5 per cent is a positive step toward promoting environmentally sustainable and climate-smart agriculture. Investments in allied sectors, including animal husbandry, fisheries, water management, cold chain infrastructure, and the development of 500 water bodies, aim to strengthen rural livelihoods, reduce post-harvest losses, and enhance resource-use efficiency. Post-harvest losses, currently estimated at 15–20 per cent, continue to impose a significant economic burden on farmers and the national food system.

Table 1. Key Budgetary Allocations and Strategic Focus in Union Budget 2026 (Agriculture & Allied Sectors)

Budget Component / Focus Area	Budget 2026 Provision	Strategic Objective	Expected Outcomes / Implications
Overall Agriculture Allocation	₹1.62 lakh crore (7% increase over previous year)	Sustain public investment in agriculture amid rising input costs, climate risks, and global volatility	Short-term sectoral stability; enhanced fiscal support to farmers and allied activities
Crop Diversification & Export Orientation	Policy emphasis on diversification and export-led growth	Shift from cereal dominance to high-value agriculture	Improved farm incomes, reduced market risk, and enhanced export earnings
High-Value Horticultural & Plantation Crops	Focus on coconut, cashew, walnut, cocoa	Promote income-rich, export-friendly crops with strong value-chain potential	Higher profitability, employment generation, and regional diversification
GST Reduction on Bio-pesticides	GST reduced from 12% to 5%	Encourage adoption of eco-friendly and climate-smart inputs	Lower cost of sustainable inputs; reduced chemical load on soils and ecosystems
Animal Husbandry & Dairy	Increased investment	Strengthen allied sectors as income stabilizers	Diversified livelihoods, regular cash flow, and resilience for smallholders
Fisheries & Aquaculture	Enhanced allocation	Expand high-growth allied sectors	Employment generation, nutrition security, and export potential
Water Management & 500 Water Bodies	Investment in irrigation and water infrastructure	Improve water-use efficiency and climate resilience	Reduced production risk, improved resource sustainability
Cold Chain & Post-Harvest Infrastructure	Increased funding	Address post-harvest losses (15–20%)	Reduced economic losses, better price realization, and value addition

Budget Component / Focus Area	Budget 2026 Provision	Strategic Objective	Expected Outcomes / Implications
Rural Employment Generation	Embedded across agriculture and allied investments	Strengthen rural economy	Job creation, reduced distress migration, and inclusive growth

The allocation pattern of **Budget 2026 prioritizes stability, diversification, and allied sectors**, with a strong emphasis on **fertilizer subsidy and infrastructure support**. However, allocations remain **scheme-driven rather than reform-driven**, with limited direct linkage to soil health correction, nutrient-use efficiency, and farmer risk mitigation. Aligning future allocations with **outcome-based indicators** will be critical for improving impact. While the enhanced allocation under Budget 2026 reflects continued commitment to agriculture, the effectiveness of these investments will depend on timely implementation, convergence with state-level programs, and integration with structural reforms aimed at productivity, sustainability, and income security.

State-Level Dimensions and Implementation Challenges

The diversification thrust of Union Budget 2026, although strongly oriented toward horticulture, plantation crops, and allied activities, can complement existing production systems in agriculturally dominant states such as Uttar Pradesh, Punjab, Haryana, and Maharashtra, even where plantation crops are limited. The intent of diversification lies not in replacing dominant crops, but in widening income avenues, improving system efficiency, and reducing risk within established agro-ecological settings.

In Punjab and Haryana, where rice–wheat monoculture prevails, diversification can occur through non-plantation alternatives such as vegetables, fodder, pulses, oilseeds, and seed production, supported by investments in cold chains, logistics, and post-harvest infrastructure. Allied activities including dairy, fisheries, and custom hiring centres can further augment incomes while easing pressure on groundwater and soil health. In Uttar Pradesh, sugarcane-based systems can benefit from vertical diversification through ethanol blending, livestock integration, fisheries, and water body development, alongside limited horticultural diversification through boundary planting and peri-urban vegetable production. Maharashtra's diverse agro-climatic regions can leverage export-oriented value chains, water management, and allied sectors to stabilize rainfed systems and buffer climate risks.

However, the effectiveness of these measures hinges on strong Centre–State coordination, convergence with state budgets, and efficient last-mile implementation. Weak institutional capacity and governance fragmentation risk underutilization and uneven outcomes without robust monitoring and alignment mechanisms.

Fertilizer Subsidy Reform Altogether Missing

A key policy decision in Union Budget 2026 is the increase in the fertilizer subsidy to ₹1.7 lakh crore, reflecting the government's effort to shield farmers from global volatility in fertilizer and energy prices. In the short term, this measure ensures the affordability and availability of critical inputs, providing essential relief to small and marginal farmers, who constitute nearly 85 per cent of agricultural households—and helping maintain cropping intensity during periods of market uncertainty.

However, the continued expansion of fertilizer subsidies highlights an unresolved structural challenge. India's fertilizer policy remains heavily dependent on price controls and fiscal support, with limited movement toward efficiency or outcome-based reform. Despite repeated expert recommendations, urea remains outside the Nutrient-Based Subsidy (NBS) framework, sustaining price distortions between nitrogen, phosphorus, and potassium. This skewed pricing encourages excessive urea use, discourages balanced nutrient application, and contributes to declining fertilizer response ratios. As a result, while higher subsidies offer short-term stability, they also reinforce inefficiencies that degrade soil health, constrain productivity growth, and weaken the long-term sustainability of India's agricultural systems.

Deferred Reforms in Input Policy

Several long-standing industry and policy recommendations have been deferred once again in Budget 2026. These include rationalization of customs duties on critical raw materials such as ammonia, phosphoric acid, and rock phosphate; correction of the inverted GST duty structure affecting fertilizers; restoration of weighted tax deductions for research and development; and promotion of energy-efficient and low-carbon fertilizer manufacturing.

These reforms could have strengthened domestic fertilizer production, reduced import dependence, improved nutrient-use efficiency, and supported innovation in soil health management. Their continued postponement reflects the government's preference for incremental adjustments over structural transformation.

Political Economy and Fiscal Constraints

The hesitation to undertake meaningful fertilizer reform in Budget 2026 is largely shaped by entrenched political economy considerations and fiscal limitations. Bringing urea under the Nutrient-Based Subsidy (NBS) regime would require partial or full deregulation of its maximum retail price, raising concerns about an immediate increase in fertilizer prices faced by farmers. Such price adjustments are politically sensitive, particularly in a context where farm incomes remain under stress and food price inflation carries significant electoral and macroeconomic implications. Consequently, governments have historically preferred price controls and subsidies over market-linked pricing mechanisms.

From a fiscal standpoint, reducing customs duties on key fertilizer inputs such as ammonia, phosphoric acid, and rock phosphate would entail short-term revenue losses at a time when fiscal consolidation and deficit management remain high priorities. These trade-offs limit the policy space for reform-oriented interventions. In addition, the *Atma Nirbhar Bharat* framework places strong emphasis on import substitution and domestic manufacturing, complicating decisions related to duty rationalization and input cost reduction. Within these constraints, the government has opted for the politically safer and administratively simpler route of expanding subsidies, even though this approach postpones structural correction and perpetuates inefficiencies in the fertilizer sector.

Soil Health and Productivity Implications

The continued distortion in fertilizer pricing has serious implications for soil health and long-term productivity. Excessive and imbalanced use of urea encourages over-application of nitrogen relative to phosphorus and potassium, leading to nutrient imbalance. The consequences are increasingly visible in the form of declining soil organic carbon, widespread micronutrient

deficiencies, reduced fertilizer response ratios, and stagnating yields despite rising input use. Without corrective reforms that promote balanced nutrient management, integrated soil fertility practices, and site-specific nutrient application, these trends threaten the sustainability of India's production systems and long-term food security. Table 2 highlights political economy constraints in fertilizer policy and their implications for soil health and productivity.

Table 2: Political Economy Constraints in Fertilizer Policy and Their Implications for Soil Health and Productivity

Policy Dimension	Current Policy Position	Underlying Political / Fiscal Constraint	Immediate Outcome	Soil Health & Productivity Implications
Urea Pricing Policy	Urea kept outside Nutrient-Based Subsidy (NBS); MRP controlled	Fear of politically sensitive price increases if deregulated	Continued price distortion favouring urea	Excessive nitrogen use; imbalance in N: P: K application
Fertilizer Subsidy Approach	Subsidies expanded to absorb global price shocks	Preference for politically safer short-term relief	Rising fiscal burden without efficiency gains	Low fertilizer-use efficiency; declining response ratios
Customs Duty on Fertilizer Inputs	No reduction in duties on ammonia, phosphoric acid, rock phosphate	Concern over revenue loss during fiscal consolidation	High cost of domestic fertilizer production	Limited innovation; inefficient nutrient formulations
Atma Nirbhar Bharat Framework	Focus on import substitution and domestic manufacturing	Duty rationalization seen as conflicting with self-reliance goals	Policy rigidity in input trade reforms	Slower adoption of balanced and specialty fertilizers
Nutrient Use Regulation	Weak incentives for balanced nutrient application	Avoidance of regulatory enforcement that may raise costs	Farmers continue skewed fertilizer practices	Soil organic carbon decline; micronutrient deficiencies
Reform versus Subsidy Choice	Higher subsidies preferred over structural reform	Political risk aversion and fiscal caution	Delayed systemic correction	Long-term threat to productivity and sustainability
Soil Health Management Integration	Soil Health Card Scheme operates in isolation	Lack of linkage with subsidy and pricing reforms	Limited behavioural change among farmers	Continued soil degradation and yield stagnation

As mentioned in Table 2 **political and fiscal constraints have directly shaped fertilizer policy choices**, resulting in short-term stability but long-term degradation of soil health and productivity. Without aligning fertilizer pricing reforms with soil health objectives, subsidy expansion risks reinforcing inefficiencies and undermining India's agricultural sustainability and food security.

Evidence from ICAR studies and long-term fertilizer experiments indicates that excessive nitrogen use, combined with inadequate phosphorus, potassium, and micronutrient application, has resulted in:

- Declining soil organic carbon

- Widespread Sulphur and micronutrient deficiencies (Zn, Fe, B)
- Reduced fertilizer response ratio
- Increased greenhouse gas emissions and nutrient leaching

Without reform, fertilizer subsidies risk reinforcing *input-intensive, low-efficiency production systems*, undermining the sustainability of Indian agriculture. Table 3 highlights integrated assessment of subsidy, soil health and reform pathway.

Table 3. Integrated Assessment: Subsidy, Soil Health and Reform Pathway

Policy Dimension	Current Status (Budget 2026)	Soil Health Implications	Way Forward (Phased Reform)
Subsidy Design	Price-based, blanket subsidy	Overuse of nitrogen	Phase I: Improve targeting via DBT
Urea Policy	Outside NBS	Nutrient imbalance	Phase II: Partial inclusion under NBS
NPK Balance	No corrective incentives	Declining productivity	Phase III: Full nutrient-based pricing
Soil Organic Carbon	No incentives	Soil degradation	Incentivize carbon-building practices
Micronutrients	Neglected	Hidden hunger in soils	Promote fortified fertilizers
SHC Integration	Weak linkage	Poor adoption	Digital advisory-driven fertilization
Environmental Costs	Not internalized	Emissions, leaching	Incentivize low-emission inputs

Policy Recommendations

Short-Term (1–2 Years): Stabilization and Protection

- Maintain fertilizer price stability for small and marginal farmers
- Improve subsidy targeting using *Direct Benefit Transfer (DBT)*
- Cap excessive per-hectare urea subsidy
- Promote customized and micronutrient-enriched fertilizers

Medium-Term (3–5 Years): Efficiency and Convergence

- Gradually bring urea under the *Nutrient-Based Subsidy (NBS)* framework
- Link fertilizer access to *Soil Health Card recommendations*
- Introduce pilot outcome-based subsidy models in select states
- Incentivize composting, crop residue management, and organic inputs

Long-Term (5+ Years): Sustainability and Resilience

- Transition to performance and outcome-linked support systems
- Mainstream *precision nutrient management* and digital advisory platforms
- Internalize environmental externalities through incentive-based mechanisms
- Align fertilizer policy with *climate-smart and regenerative agriculture goals*.

Policy Takeaway

Fertilizer subsidy reform must move beyond short-term price relief toward a phased, evidence-based transformation that balances farmer welfare, soil health restoration, fiscal prudence, and

environmental sustainability. A calibrated transition—anchored in ICAR science and field-level validation—can ensure resilient and productive agriculture for the future.

Farmer Income and Risk Management Gaps

Equally concerning is the absence of decisive action on broader farmer demands. Budget 2026 does not address legal guarantees for minimum support prices, restoration of agricultural futures trading, or the establishment of comprehensive risk management frameworks. Climate-induced shocks, price volatility, and rising indebtedness continue to expose farmers to significant income instability.

For small and marginal farmers, who have limited access to formal credit, insurance, and markets, the lack of robust safety nets remains a critical vulnerability. Incremental income support measures, without systemic risk mitigation, are insufficient to ensure income security (**Table 4**).

Table 4: Farmer Income and Risk Management Gaps in Union Budget 2026

Policy Area	Current Status in Budget 2026	Key Gaps	Implications for Farmers	Policy Direction Needed
Minimum Support Price (MSP)	No legal guarantee or expansion of MSP framework	Absence of income floor for farmers	Continued exposure to price crashes	Introduce price deficiency payment or graded MSP assurance mechanisms
Agricultural Futures Trading	Futures trading remains suspended / restricted	Farmers lack price discovery and hedging tools	Higher price volatility and market uncertainty	Restore regulated futures markets with farmer safeguards
Comprehensive Risk Management Framework	Fragmented schemes addressing isolated risks	No integrated approach to price, climate, and credit risks	Inadequate protection against multiple shocks	Develop a unified farmer risk management framework
Climate Risk Mitigation	Limited focus through existing insurance schemes	Climate shocks not fully covered or timely compensated	Crop losses and income instability	Strengthen climate-linked insurance, early warning, and adaptive extension
Access to Formal Credit	Credit expansion uneven across farmer categories	Small and marginal farmers face exclusion	Dependence on informal credit and rising indebtedness	Expand collateral-free credit and digital inclusion
Crop and Income Insurance	Insurance coverage remains partial and uneven	Low penetration and delayed claim settlement	Weak safety nets during crop failure	Improve insurance design, coverage, and claim settlement efficiency
Market Access for Small Farmers	Limited integration with formal markets	Weak bargaining power and price realization	Low and unstable farm incomes	Strengthen FPOs, aggregation models, and market linkages
Income Support Measures	Incremental direct income support continues	Support not linked to risk exposure or productivity	Temporary relief without income security	Align income support with risk profiles and productivity incentives

It is revealed from Table 4 that **Budget 2026 prioritizes incremental income support but does not address systemic risks** faced by farmers. Without reforms in price assurance, market instruments, and climate risk management, small and marginal farmers remain vulnerable to income shocks. Sustainable income security requires **integrated, forward-looking risk mitigation frameworks**, not stand-alone support measures.

Overall Policy Assessment

Union Budget 2026 may best be described as pragmatic yet cautious in its approach to agricultural policy. The budget clearly acknowledges the importance of agriculture in ensuring food security, rural livelihoods, and economic stability, and it reflects this concern through enhanced allocations and targeted interventions. Measures aimed at input affordability, diversification, and allied sector development indicate an effort to maintain growth momentum while addressing immediate vulnerabilities faced by farmers. At the same time, the budget signals a strong preference for fiscal prudence and political stability.

However, this caution comes at the cost of deeper structural reform. By postponing decisive changes in fertilizer pricing, nutrient management, soil health restoration, and comprehensive market risk mitigation, the budget confines itself to incremental adjustments rather than transformative outcomes. The continued reliance on subsidies over efficiency-oriented reforms risks perpetuating input distortions, environmental stress, and fiscal pressure. While such an approach may deliver short-term stability and prevent disruption, it falls short of laying the foundation for a resilient, climate-smart, and income-secure agricultural system. As a result, Budget 2026 manages risks effectively in the near term but leaves unresolved the systemic challenges that will determine the long-term sustainability of Indian agriculture.

Policy Recommendations and Way Forward

To transform Indian agriculture into a resilient, climate-smart, and income-secure sector, future budgets must move beyond expanding input subsidies toward efficiency and outcome-oriented reforms. A critical step in this transition is the gradual integration of urea into the Nutrient-Based Subsidy (NBS) framework to correct price distortions and promote balanced use of nitrogen, phosphorus, and potassium. Complementary measures such as customized and fortified fertilizers, site-specific nutrient application, and integrated nutrient management are essential for restoring soil health, improving fertilizer response, and sustaining productivity.

Strengthening domestic input manufacturing should also be a policy priority through rationalization of duties on key raw materials, correction of tax distortions, and incentives for energy-efficient and low-carbon fertilizer production. Equally important are sustained investments in agricultural research, extension, digital advisory systems, and soil diagnostics to drive behavioural change at the farm level. In parallel, robust climate and market risk management mechanisms including improved insurance, price stabilization, and market reforms are essential for income stability. While short-term relief offers temporary stability, only well-sequenced structural reforms can deliver lasting resilience and sustainability.

Table 5. Policy Matrix: Key Issues, Gaps, and Recommendations (Union Budget 2026)

Policy Issue	Current Status (Budget 2026)	Key Gaps / Limitations	Policy Recommendations
Agriculture Budget Allocation	₹1.62 lakh crore allocated to agriculture (7% increase); focus on	Allocation increases without commensurate institutional and	Link higher allocations with outcome-based monitoring, convergence across schemes,

Policy Issue	Current Status (Budget 2026)	Key Gaps / Limitations	Policy Recommendations
	diversification and exports	structural reform; risk of fragmented impact	and state-level performance incentives
Crop Diversification & High-Value Agriculture	Emphasis on high-value crops (coconut, cashew, walnut, cocoa) and export orientation confined to south Indian states	Limited support for market linkages, value addition, and farmer aggregation	Strengthen FPOs, processing infrastructure, and export logistics; integrate diversification with nutrition and climate goals
Sustainable Farming Inputs	GST on bio-pesticides reduced from 12% to 5%	Adoption remains limited due to weak extension and price competitiveness	Expand extension services, provide adoption incentives, and integrate bio-inputs into soil health programs
Post-Harvest Management	Investments in cold chains, water bodies, animal husbandry, and fisheries	High post-harvest losses (15–20%) persist due to weak last-mile infrastructure	Promote decentralized storage, village-level cold rooms, and PPP-based logistics solutions
Fertilizer Subsidy	Subsidy increased to ₹1.7 lakh crore to cushion global price shocks	Rising fiscal burden; continued price distortion and inefficient nutrient use	Gradually shift from price-based to nutrient-use efficiency-based support; incentivize balanced fertilization
Urea under NBS	Urea remains outside Nutrient-Based Subsidy regime	Overuse of nitrogen; imbalance in NPK application	Phased inclusion of urea under NBS with direct benefit transfers and farmer awareness programs
Customs Duty on Fertilizer Inputs	No change in customs duties on ammonia, phosphoric acid, and rock phosphate	High production costs and import dependence	Rationalize duties to support domestic manufacturing and reduce import vulnerability
GST Structure on Fertilizers	Inverted GST duty structure continues	Discourages domestic production and investment	Correct GST inversion to align input and output tax rates
R&D and Innovation in Inputs	No restoration of weighted tax deduction for R&D	Weak private investment in innovation and efficiency	Reinstate R&D tax incentives and support public–private research partnerships
Soil Health Management	Soil Health Card scheme continues	Limited impact on farmer behaviour and nutrient balancing	Link soil health data with input subsidies, advisories, and precision nutrient application
Farmer Income Security	Income support through subsidies and schemes	No legal MSP guarantee; weak income stabilization	Develop price deficiency payment systems and income stabilization funds
Market Risk Management	No revival of futures trading or price risk tools	Farmers exposed to price volatility	Restore regulated futures markets and expand price risk management instruments
Climate Risk	Incremental focus	No comprehensive	Integrate climate insurance,

Policy Issue	Current Status (Budget 2026)	Key Gaps / Limitations	Policy Recommendations
Management	through allied sector investments	climate-risk framework	early warning systems, and adaptive extension services
Centre–State Coordination	Central allocations enhanced	Weak convergence with state budgets and programs	Institutionalize joint planning, co-financing, and real-time monitoring mechanisms

This matrix highlights that **Budget 2026 prioritizes fiscal stability and short-term farmer relief, but defers critical reforms** required for long-term sustainability, soil health restoration, and income security. Addressing these gaps through phased, politically feasible reforms can significantly enhance the effectiveness of future agricultural budgets.

10. Executive Summary: The Road Ahead

- Shift from Subsidy Expansion to Reform**
Gradually transition from blanket input subsidies to efficiency- and outcome-based support that rewards balanced nutrient use, productivity gains, and sustainability.
- Integrate Urea under NBS**
Phase the inclusion of urea into the Nutrient-Based Subsidy framework to correct price distortions and promote balanced application of nitrogen, phosphorus, and potassium.
- Restore Soil Health as a Core Objective**
Mainstream integrated nutrient management, customized fertilizers, organic amendments, and site-specific nutrient application linked with Soil Health Cards.
- Strengthen Domestic Input Manufacturing**
Rationalize customs duties on key fertilizer inputs, correct tax distortions, and incentivize energy-efficient and low-carbon fertilizer production to reduce import dependence.
- Promote Innovation and R&D**
Restore weighted tax incentives for agricultural R&D and support innovation in bio-fertilizers, micronutrients, and climate-smart inputs.
- Invest in Extension and Digital Advisory Systems**
Scale up data-driven extension services, digital platforms, and precision advisory tools to translate policy reforms into on-field behavioural change.
- Enhance Climate Risk Management**
Strengthen crop insurance, early warning systems, and climate-resilient farming practices to mitigate weather-induced production risks.
- Improve Market and Price Risk Management**
Reinforce price stabilization mechanisms, restore futures trading, and enhance market transparency to improve price discovery and reduce volatility.
- Strengthen Farmer Income Security**
Complement input support with income diversification, value-chain development, and allied sector integration to ensure more stable farm incomes.
- Ensure Centre–State Convergence**
Align central policies with state-level priorities and budgets, supported by strong monitoring, evaluation, and accountability mechanisms.

11. Adopt a Phased Reform Strategy

Pilot reforms in select regions, build political consensus, and scale up gradually to ensure acceptability and smooth implementation.

12. Institutionalize Evidence-Based Policymaking

Use real-time data, impact evaluations, and stakeholder feedback to continuously refine agricultural policies and ensure long-term sustainability.

Summary and Conclusion

Union Budget 2026 reflects a pragmatic yet cautious approach toward India's agricultural sector. With an allocation of ₹1.62 lakh crore, a 7 per cent increase over the previous year, the budget emphasizes diversification, export-oriented growth, and support for high-value crops, along with investments in allied sectors such as animal husbandry, fisheries, water management, and cold chain infrastructure. The reduction in GST on bio-pesticides signals a positive intent toward sustainable agriculture.

However, the budget stops short of addressing long-standing structural challenges. The increase in fertilizer subsidy to ₹1.7 lakh crore provides short-term relief to farmers but reinforces reliance on subsidies rather than reform. Key measures such as inclusion of urea under the Nutrient-Based Subsidy framework, correction of input tax distortions, and strengthening of domestic input manufacturing remain deferred. The absence of decisive action on soil health restoration, market risk management, and farmer income security limits the transformative potential of the budget. Future policy must move beyond incremental support toward efficiency-driven, climate-resilient, and income-secure agricultural reforms.

APOMIXIS AND ITS ROLE IN FIXING HETEROSIS

Boddu Aruna^{1*} and Koyya Unnathi Madhuri²

¹PhD scholar, Department of Plant Breeding and Genetics,
Kerala Agricultural University, Vellanikkara, Kerala

²PhD scholar, Department of Fruit Science, Dr. YSR Horticultural University,
Anantharaju peta, Andhra Pradesh

*Corresponding Email: arunab.phd@gmail.com

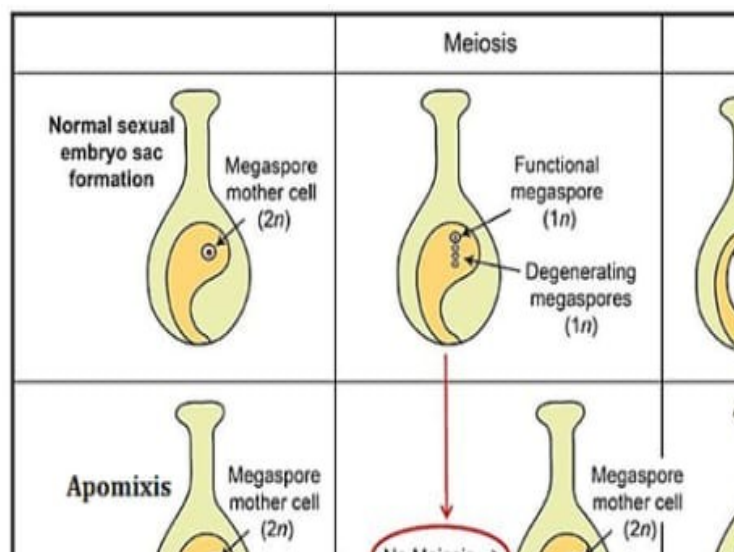
Abstract

Apomixis is a unique form of asexual reproduction that enables seed formation without fertilisation. First defined by Winkler (1940) and later refined by Richards (1997), apomixis encompasses mechanisms such as diplospory, apospory, and adventitious embryony, which bypass sexual processes to produce genetically uniform progeny. Classification of apomixis can be based on the cell involved, occurrence, or frequency, ranging from obligate to facultative systems. Its agricultural significance lies in the fixation of heterosis, as apomictic reproduction preserves the genetic constitution of F₁ hybrids across generations, ensuring stable hybrid vigour. This phenomenon has been successfully exploited in crops such as citrus, buffel grass, and Kentucky bluegrass. An ideal apomictic system should be obligate, dominant over sexuality, environmentally stable, and capable of producing clonal seeds with uniformity. Thus, apomixis represents a powerful tool for crop improvement, offering both genetic stability and enhanced productivity.

Keywords: Apomixis, Diplospory, Apospory, Heterosis, Fertilisation

Apomixis

Apomixis is derived from the Greek words “apo” (meaning “away from”) and “mixis” (meaning “mixing”). The term was first coined by botanist Hans Winkler. Apomixis is also a form of asexual reproduction. This offers a mechanism to propagate genotypes asexually through development of seeds in the absence of fertilization. Apomixis was described by Winkler (1940) as the replacement of sexual reproduction without any form of fusion, either nuclear or cellular. Similarly, Fagerlind (1940) defined apomixis as a type of reproduction that does not require fertilization and does not involve alternation of nuclear phases. Later, Richards (1997) proposed the most widely accepted definition, equating apomixis with agamospermy, in which the megaspore mother cell (MMC) directly develops into an embryo sac without undergoing the typical sexual processes.

**Types of apomixis**

Apomixis can be classified based on:

1. Cell involved
2. Occurrence
3. Frequency

Based on Cell involved**Diplospory**

In diplospory, the embryo sac is derived from the megaspore mother cell either directly by mitotic division or by interrupting meiosis. In the mitotic diplospory, the megaspore mother cell divides mitotically thrice to form 8 nuclei. The embryo sac is unreduced and have same number of chromosomes and genetic material.

Apospory:

In apospory, the nucellar cells give rise to the apomictic embryo sac. It is the most common type of apomixis in higher plants. Aposporous initial cells differentiate and undergo mitosis to produce an embryo sac. Sometimes multiple embryo sacs may be found. The initiation of the apospory embryo sac and the sexual one can occur simultaneously or it can displace or interrupt sexual embryo sac formation.

Adventitious Embryony:

It is a type of sporophytic apomixis, where embryos are produced directly from the nucellus or the integument of the ovule. The embryo develops by mitotic division and forms a bud-like structure. Simultaneous fertilization in the adjoining sexual embryo sac is required to form viable seeds. The developing embryos grow towards it to obtain nutrients and signals from the embryo sac.

Based on Occurrence**Recurrent Apomixis:**

In recurrent apomixis, both the egg cell and embryo are diploid and the embryo sac is developed from the megaspore mother cell.

Non-recurrent Apomixis:

In non-recurrent apomixis, both the egg cell and embryo are haploid and the embryo is developed directly from an egg cell without fertilization.

Vegetative Apomixis:

In this apomixis type, vegetative bulbils or buds are produced in the inflorescence instead of flowers. They are easily reproducible and are seen in certain plants like *Fragaria*, *Agave* etc.

Based on Frequency

Obligate Apomixis: The reproduction takes place by apomictic means only.

Facultative apomixis: The process of reproduction is carried out by both apomictic and sexual means.

Fixation of heterosis:

There are four principal ways of fixation of heterosis in crop plants:

1. Asexual reproduction
2. Apomixis
3. Balanced lethal system
4. polyploidy

Apomixis in fixing heterosis

Apomixis plays a significant role in fixing heterosis because it enables the production of clonal seeds that maintain the exact genetic constitution of the F_1 hybrid. When an F_1 plant and its progeny produce only apomictic seeds with diploid ($2n$) embryos, the F_2 and subsequent generations remain genetically identical to the F_1 , thereby preserving hybrid vigor without segregation. For hybrid seed production, one parental inbred should reproduce sexually (usually the female), while the other parent is preferably an obligate apomict (male). Moreover, apomixis must be dominant over sexuality so that the F_1 and later generations produce only apomictic seeds, ensuring stable transmission of heterosis. This phenomenon is observed in several crops and ornamentals such as citrus, blackberries, roses, and bluegrasses. Complete fixation of heterosis occurs in cases of obligate apomixis, as demonstrated in Bahia grass (*Paspalum notatum*) and buffel grass (*Pennisetum ciliare*). In contrast, when apomixis is facultative, heterosis can be fixed only partially; however, highly apomictic hybrids can still be selected and utilized, as seen in Kentucky bluegrass and Guinea grass.

Ideal Apomictic System

An ideal apomictic system should produce only apomictic progeny ($2n+0$) so that all offspring are genetically identical to the maternal parent, ensuring uniformity and stable fixation of desirable traits. Mechanisms such as obligate adventitious embryony, somatic embryony, apospory, and diplospory meet this requirement. The apomictic genotype should be male fertile, preferably self-incompatible, and reproduce via pseudogamy to enable transfer of apomixis genes. Apomixis should be dominant over sexuality, usually governed by simple qualitative inheritance, and its expression should be stable across environments. Minimal or no recombination during meiosis (in diplospory) helps maintain genetic uniformity.

Conclusion

Apomixis provides a natural mechanism for clonal seed production, bypassing fertilisation and maintaining genetic uniformity across generations. Its ability to fix heterosis makes it invaluable

for crop breeding, as it ensures the perpetuation of hybrid vigour without segregation. While obligate apomixis offers complete fixation of heterosis, facultative systems still provide partial but useful stability in hybrid populations. The development of an ideal apomictic system—dominant, obligate, and environmentally stable—would revolutionise plant breeding by reducing the need for repeated hybridisation and enabling cost-effective, large-scale production of superior cultivars. Harnessing apomixis thus holds immense promise for sustainable agriculture and long-term genetic improvement of crops.

References

- Bicknell, R. A., & Koltunow, A. M. (2004). Understanding apomixis: Recent advances and remaining conundrums. *The Plant Cell*, 16(Suppl), S228–S245.
- Fagerlind, F. (1940). *Die Erscheinung der Apomixis bei den Angiospermen*. Svensk Botanisk Tidskrift, 34, 1–16.
- Hanna, W. W., & Bashaw, E. C. (1987). Apomixis: Its identification and use in plant breeding. *Crop Science*, 27(6), 1136–1139.
- Koltunow, A. M., & Grossniklaus, U. (2003). Apomixis: A developmental perspective. *Annual Review of Plant Biology*, 54, 547–574.
- Richards, A. J. (1997). *Plant Breeding Systems*. 2nd Edition. Chapman & Hall, London.
- Winkler, H. (1940). *Apomixis in plants*. Berlin: Gebrüder Borntraeger.

APPLICATION OF SIMPLE RANDOM SAMPLING TECHNIQUES WITH AND WITHOUT REPLACEMENT USING MS-EXCEL

Nathina P^{1*}, Surulivel L² and Aanand S³

¹Ph.D. scholar, Department of Aquaculture, TNJFU- Dr. M.G.R. Fisheries College and Research Institute, Ponneri, Tamil Nadu - 601 204, India

²Assistant Professor, Department of Fisheries Extension, Economics and Statistics, Dr. MGR. Fisheries College and Research Institute, Ponneri, Tamil Nadu -601 204, India

³Associate Professor, Department of Aquaculture, Dr. MGR. Fisheries College and Research Institute, Ponneri, Tamil Nadu -601 204, India

*Corresponding Email: nathinapalanivel01@gmail.com

Abstract

Simple random sampling is one of the most common techniques in research for selecting unbiased and representative samples from a population. This study explains how to use Simple Random Sampling with Replacement (SRSWR) and Simple Random Sampling without Replacement (SRSWOR) with Microsoft Excel as a practical statistical tool. The main goal was to show how Excel functions can generate random samples without needing advanced software. In the with-replacement method, random selection allows the same unit to appear more than once. In the without-replacement method, each unit is selected only once after sorting random numbers. We provided step-by-step procedures to help students and researchers understand the process clearly, especially for analyzing fisheries and aquaculture data. The study shows that Microsoft Excel is a useful and accessible platform for learning sampling techniques and doing basic statistical analysis in academic research.

Keywords: Simple Random Sampling, SRSWR, SRSWOR, Microsoft Excel

Introduction

Simple random sampling is one of the most basic and commonly used sampling techniques in scientific research, especially when the study population is fairly uniform (Bhardwaj, 2019). This method works on the idea that every unit in a population has the same chance of being chosen, which reduces selection bias and improves how well the sample represents the population (Acharya, 2013). Due to its straightforwardness and fairness, simple random sampling is often seen as the most fundamental approach for selecting research participants. In this method, units are picked one at a time, each with an equal chance every time (Singh, 2003). In practical applications, researchers typically construct a complete sampling frame by assigning numerical identifiers to all members of the population. For studies involving large datasets, computer-based tools and statistical software are frequently used to generate random numbers and facilitate the selection process efficiently (Rahi, 2017; Omair, 2014). The reliance on probability ensures that the resulting sample reflects the natural variation present within the population, including differences in demographic and physical characteristics (Cohen et al., 2018). Therefore, it is essential for researchers to clearly define the eligibility criteria and common characteristics of participants before implementing simple random sampling, ensuring that the selected sample aligns with the objectives and scope of the research.

Simple random sampling can be performed in two ways.

1. Simple random sampling with replacement (SRSWR)

2. Simple random sampling without replacement (SRSWOR)

Simple Random Sampling with Replacement

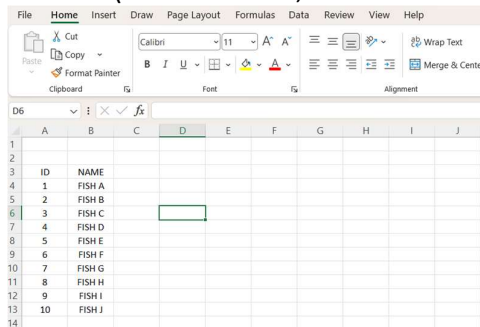
In SRSWR, once a unit is selected, it is placed back into the population before the next selection takes place. Because the same unit can be chosen again, every draw remains completely independent of the previous one. Sampling with replacement is often useful in statistical simulations, experimental studies, or situations where maintaining constant probability is important. It simplifies calculations and ensures that each selection does not influence the next.

Simple Random Sampling without Replacement

Simple random sampling without replacement does not return the selected unit to the population. Once an individual is chosen, it cannot appear again in the sample. As a result, each draw slightly changes the remaining population, and the probability of selection is influenced by previous choices. This creates a level of dependence between selections. Sampling without replacement is commonly used in real-world surveys, classroom experiments, and field studies because it avoids duplication and ensures a wider representation of participants.

Procedure Simple Random Sampling with replacement using

1. Enter the population data in Excel (Column A = ID, Column B = Name).

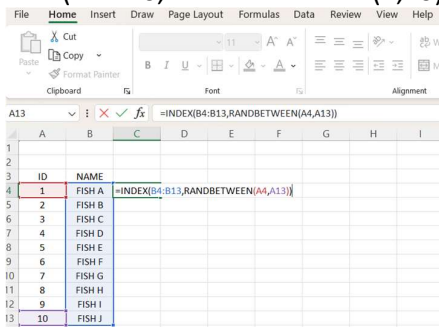


The screenshot shows an Excel spreadsheet with the following data:

ID	NAME
1	FISH A
2	FISH B
3	FISH C
4	FISH D
5	FISH E
6	FISH F
7	FISH G
8	FISH H
9	FISH I
10	FISH J

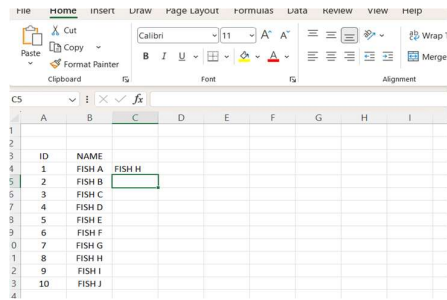
2. In the first sample cell, type the formula:

= INDEX (B1:B10, RANDBETWEEN (1,10))



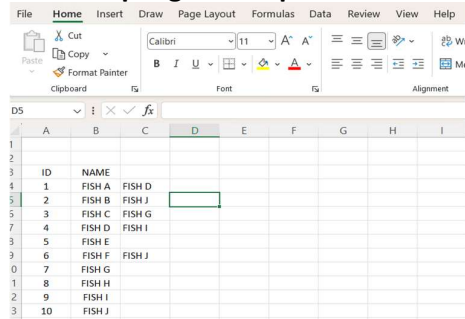
The screenshot shows the same Excel spreadsheet as before, but with the formula =INDEX(B1:B10,RANDBETWEEN(A4,A13)) entered in cell C4. The formula bar shows the formula. The cell C4 is highlighted, and the formula is visible in the formula bar.

3. Press **Enter** to generate one random sample.



ID	NAME	
1	FISH A	
2	FISH B	
3	FISH C	
4	FISH D	
5	FISH E	
6	FISH F	
7	FISH G	
8	FISH H	
9	FISH I	
10	FISH J	

4. Drag the formula down to obtain the required number of samples (e.g., 5 rows).
5. The same item may appear more than once because each selection is random and independent. This indicates **sampling with replacement**.



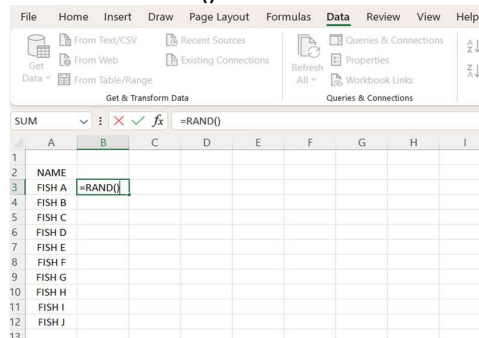
ID	NAME	
1	FISH A	
2	FISH B	
3	FISH C	
4	FISH D	
5	FISH B	
6	FISH C	
7	FISH D	
8	FISH H	
9	FISH I	
10	FISH J	

6. Copy the sample column and use **Paste Special → Values** to fix the final sample.

Procedure for Simple Random Sampling without Replacement

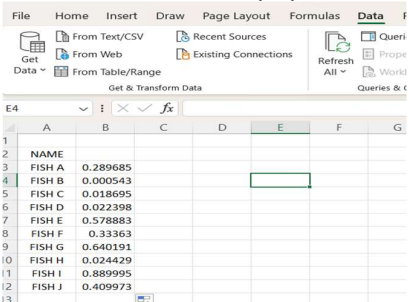
1. Enter the population data in Excel (Column A = ID, Column B = Name).
2. In the first cell of the random column, type:

= RAND ()



ID	NAME	
1	FISH A	
2	FISH B	
3	FISH C	
4	FISH D	
5	FISH E	
6	FISH F	
7	FISH G	
8	FISH H	
9	FISH I	
10	FISH J	

3. Press **Enter** and drag the formula down for all population rows.



ID	NAME	
1	FISH A	0.289685
2	FISH B	0.000543
3	FISH C	0.018695
4	FISH D	0.022398
5	FISH E	0.578883
6	FISH F	0.33363
7	FISH G	0.640191
8	FISH H	0.024429
9	FISH I	0.889995
10	FISH J	0.409973

4. Select the entire data table (ID, Name, Random Number).

	A	B	C	D	E	F	G	H	I	J
1										
2	NAME									
3	FISH A	0.289685								
4	FISH B	0.000543								
5	FISH C	0.018695								
6	FISH D	0.022398								
7	FISH E	0.578883								
8	FISH F	0.33363								
9	FISH G	0.640191								
10	FISH H	0.024429								
11	FISH I	0.889995								
12	FISH J	0.409973								

5. Go to **Data → Sort** and sort by the Random Number column in **Ascending (Smallest to Largest)** order.
6. After sorting, select the first 5 rows as the sample.
7. Since each item appears only once and no duplicates occur, it represents **simple random sampling without replacement**.

Advantage and Disadvantage of Simple Random Sampling

Simple random sampling is a widely utilized sampling method in studies with large number of participants. Since in simple random sampling data selection depends on luck, it is possible that the data obtained from the research may lead to precise generalizable results. According to Best and Kahn (2016), simple random sampling is a cumbersome and rarely used procedure in research design. In addition, random selection can easily result in subsets that do not adequately cover the data in more complicated (non-uniformly distributed) datasets, which will result in a high variance in the estimation of the model error (Reitermanova 2010). Furthermore, when the population's size in a particular demographic is not defined, then this method cannot run properly. And for this, different areas such as research on animals are in the field area; this method is not that useful (Rahman et al., 2022). On the other hand, ideally, such randomization techniques give every individual in the population the same chance to be selected in the sample (Stockemer, 2019). It is also an unbiased and impartial selection method (Sharma, 2017; Fink, 2003); when cautiously designed, the sample can be representative of the whole population.

Conclusion

Simple random sampling generation in Microsoft Excel offers a practical and accessible way to simulate variability and perform unbiased sampling across a wide range of fields. In fisheries research, it can be used to randomly select fish tanks, sample fish populations or populations ensuring objectivity. Other fields like education, healthcare, and business also use it for unbiased testing and simulations. It's a simple yet powerful tool for adding randomness to real-world tasks.

References

- Acharya, A. S., Prakash, A., Saxena, P., & Nigam, A. (2013). Sampling: Why and how of it. *Indian Journal of Medical Specialties*, 4(2), 330-333. DOI: 10.7713/ijms.2013.0032
- Ansar, L. A., Arifin, D. Y., & Dengo, Y. J. (2017). The influence of school culture on the performance of high school English teachers in Gorontalo province. *Int J Educ Res*, 5(10), 35-47. <https://www.ijern.com/journal/2017/October-2017/04.pdf>
- Best, J. W., & Kahn, J. V. (2016). *Research in education*. Pearson Education India.
- Bhardwaj P. (2019). Types of sampling in research. *Journal of the Practice of Cardiovascular Sciences*, 5(3), 157. DOI: 10.4103/jpcs.jpcs_62_19

- Omair, A. (2014). Sample size estimation and sampling techniques for selecting a representative sample. *Journal of Health specialties*, 2(4), 142. DOI: 10.4103/1658-600X.142783
- Rahi, S. (2017). Research design and methods: A systematic review of research paradigms, sampling issues and instruments development. *International Journal of Economics & Management Sciences*, 6(2), 1-5. DOI: 10.4172/2162-6359.1000403
- Rahman, M. M., Tabash, M. I., Salamzadeh, A., Abduli, S., & Rahaman, M. S. (2022). Sampling techniques (probability) for quantitative social science researchers: conceptual guidelines with examples. *Seeu Review*, 17(1), 42-51. DOI: 10.2478/seeur-2022-0023
- Reitermanova, Z. (2010, June). Data splitting. In *WDS* (Vol. 10, pp. 31-36). Prague:Matfyzpress.
- Sharma, G. (2017). Pros and cons of different sampling techniques. *International journal of applied research*, 3(7), 749-752. <https://www.allresearchjournal.com/archives/2017/vol3issue7/PartK/3-7-69-542.pdf>
- Singh, S. (2003). Simple random sampling. In *advanced sampling theory with applications* (pp. 71-136). Springer, Dordrecht.
- Stockemer, D., Stockemer, G., & Glaeser. (2019). Quantitative methods for the social sciences (Vol. 50, p. 185). *Quantitative methods for the social sciences*: Springer International Publishing.
- West, P. W. (2016). Simple random sampling of individual items in the absence of a sampling frame that lists the individuals. *New Zealand journal of forestry science*, 46(1), 1-7. DOI: 10.1186/s40490-016-0071-1

AQUACULTURE AND VIKSIT BHARAT 2047: HOW FISH FARMING CAN POWER INDIA'S GROWTH STORY

Md Meraj*, Indulata Tekam, Pravesh Kumar and Roshan Kumar Ram

College of Fisheries, Dholi, Muzaffarpur- 843121, Bihar

*Corresponding Email: mdmeraj8858@gmail.com

Abstract

Aquaculture has become a vital driver of India's development agenda for Viksit Bharat 2047. With fish production rising to 175.45 lakh tonnes in 2022-23 and aquaculture contributing nearly 70 percent of national output, the sector is central to food security, rural livelihoods, and economic growth. It supports over 28 million people and provides highly nutritious, affordable animal protein essential for combating malnutrition. Advances in hatchery technologies, digital tools, and smart farming systems are further accelerating productivity. Coupled with record seafood exports and rising domestic demand, aquaculture is strengthening India's blue economy. Ensuring long-term sustainability through climate-resilient and eco-friendly practices will be key to unlocking aquaculture's full potential for a prosperous Viksit Bharat by 2047.

Keywords: Aquaculture, Viksit Bharat 2047, Blue Economy, Fish Production, Sustainable Aquaculture.

Introduction: Aquaculture in India's Development Vision

India's vision for Viksit Bharat 2047 focuses on inclusive growth, good nutrition, better rural livelihoods, and sustainable use of natural resources. In this journey, fisheries and aquaculture play a vital role, especially for communities that depend on fish for food and income. Aquaculture has become one of India's fastest-growing food sectors, growing at nearly 8% per year. Fish is an important source of high-quality protein, healthy fats, and essential vitamins and minerals, making it especially valuable for children and nutritionally vulnerable populations as demand for affordable animal protein continues to rise (Golden *et al.*, 2017; Gephart *et al.*, 2020).

Beyond nutrition, aquaculture supports the livelihoods of more than 28 million people across India, from fish farmers and workers to traders and exporters. It is a major source of employment in states such as Andhra Pradesh, West Bengal, and Uttar Pradesh. India is also a global leader in seafood exports, earning over ₹57,000 crore in 2022-23, largely from farmed shrimp (Handbook on Fisheries Statistics, 2023). Together, these contributions show how aquaculture links food security, jobs, and economic growth, making sustainable aquaculture a key pillar of India's path toward Viksit Bharat 2047.

Aquaculture's Growing Importance in India

A Key Driver of India's Fish Production

Over the past two decades, aquaculture has transformed India into a global leader in fish production. India now ranks among the top fish-producing countries in the world and stands second globally in aquaculture output (FAO, 2022). Fish farming contributes nearly 70% of the country's total fish production, clearly overtaking capture fisheries. With steady growth of around 8% per year, aquaculture has become a major pillar of India's food system rather than a supporting activity.

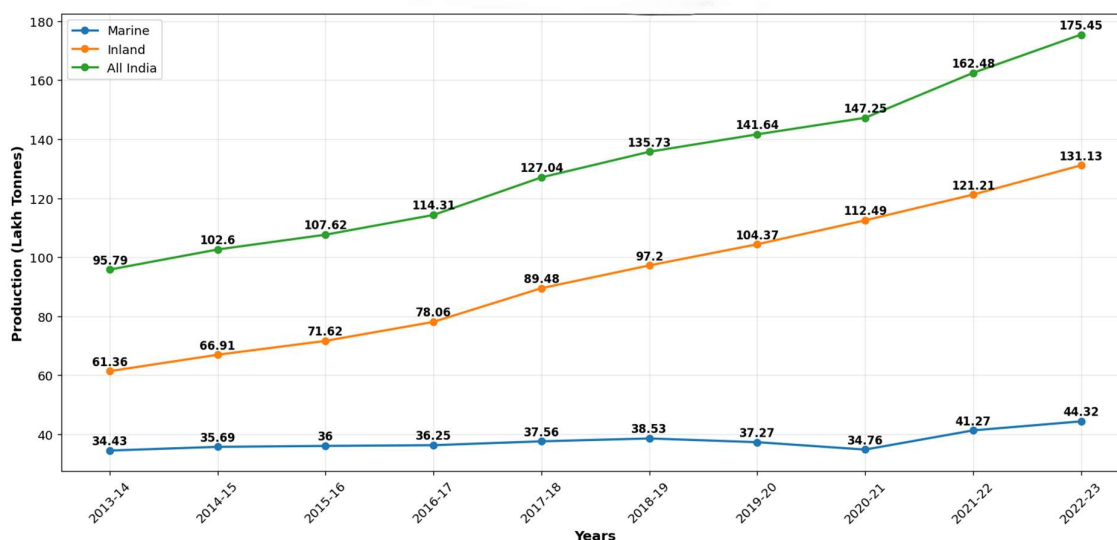


Figure 1: Trend in All India Fish Production (Handbook on Fisheries Statistics 2023)

Supporting Jobs, Incomes, and Rural Economies

Aquaculture plays a vital role in strengthening India's rural economy. The sector supports the livelihoods of more than 28 million people, including fish farmers, hatchery workers, traders, processors, transporters, and many women-led self-help groups and contributes around 1.1% to national GDP and nearly 6.72% to agricultural GDP (Handbook on Fisheries Statistics, 2023). In rural and semi-rural areas, where ponds, wetlands, and reservoirs are widely available, fish farming provides an important source of income diversification. For many farming families, aquaculture has improved financial security and reduced dependence on traditional crops.

Rapid expansion of Aquaculture

Several factors are driving the rapid expansion of aquaculture in India. Fish farming offers high productivity even on small plots of land, making it attractive to small and marginal farmers (Kumaran *et al.*, 2020). At the same time, rising health awareness and changing food habits have increased demand for fish as a nutritious and affordable source of protein (Gephart *et al.*, 2020; Vijayan *et al.*, 2025). Advances in technology, such as better-quality fish seed, improved feeds, aeration systems, and digital advisory services, have reduced risks and increased profitability (Bunting *et al.*, 2023). Strong government support through schemes like the Pradhan Mantri Matsya Sampada Yojana has further encouraged investment and innovation (Suresh *et al.*, 2025). Together, these factors highlight why aquaculture is becoming central to India's development vision and its journey toward **Viksit Bharat 2047**.

Aquaculture's Strategic Role in Achieving Viksit Bharat 2047

Creating Jobs and Rural Entrepreneurs

One of the most powerful ways aquaculture can support *Viksit Bharat 2047* is by generating large-scale rural employment and encouraging entrepreneurship. Fish farming is relatively easy to start and can provide good returns even on small landholdings, making it especially suitable for small and marginal farmers (Kumaran *et al.*, 2020). In many cases, aquaculture offers more stable incomes than traditional crop farming, helping rural households improve financial security.

Beyond fish ponds, aquaculture supports a wide range of jobs across its value chain hatcheries, nurseries, feed production, seed rearing, processing, cold storage, transport, and local markets (Bunting *et al.*, 2023). The sector has also become attractive to educated rural youth, who are adopting modern business models such as biofloc farming, recirculatory systems, ornamental fish breeding, and export-oriented enterprises. Women are playing an increasingly important role through self-help groups involved in seed rearing, feeding, harvesting, value addition, and fish vending. These activities strengthen household incomes while promoting women's empowerment and inclusive growth.

Powering Growth Through Smart and Digital Technologies

The future of aquaculture lies in smarter and more efficient farming practices. Today, many fish farmers are using digital tools such as water-quality sensors to monitor oxygen levels, temperature, and water health in real time. These technologies help farmers respond quickly to problems, reduce losses, and improve productivity (Chouhan & Choudhary, 2025). Automatic feeders, mobile advisory apps, and digital platforms now guide farmers on feeding, disease management, and overall farm performance. Emerging systems such as digital traceability and blockchain are also gaining importance, especially for exports, as they help ensure food safety and build consumer trust. Together, these innovations are making aquaculture more predictable, profitable, and attractive as a modern enterprise (Suresh *et al.*, 2023).

Strengthening Nutrition and Public Health

Aquaculture plays a key role in building a healthier India, which is central to the vision of *Viksit Bharat 2047*. Fish is one of the most affordable and nutritious animal foods available, rich in high-quality protein, healthy fats, vitamins, and essential minerals (Gephart *et al.*, 2020; Vijayan *et al.*, 2025). Increasing fish availability can help address malnutrition, anemia, and micronutrient deficiencies, particularly among women and children. There is growing interest in including fish in public nutrition programs such as school meals, Anganwadi services, and community nutrition initiatives (Dubey *et al.*, 2024).



Figure 2: Aquaculture Pathways for Growth.

Special attention is being given to small indigenous fish species, which are rich in micronutrients and can be eaten whole. Promoting these species through community ponds and household-level fish farming offers a low-cost and effective way to improve dietary diversity and nutrition.

Driving Exports and the Blue Economy

Aquaculture is a major contributor to India's export growth and blue economy. India recorded its highest-ever seafood exports at 1.73 million metric tonnes valued at USD 8.09 billion, with farmed shrimp emerging as the leading export commodity and contributing the largest share of total export earnings (Department of Fisheries 2023), making fisheries one of India's top foreign exchange earning agricultural sectors.

Beyond shrimp, there is strong potential to expand exports of tilapia, pangasius, ornamental fish, and value-added products such as fillets and ready-to-cook items. Global demand is increasingly shifting toward sustainably produced and traceable seafood, creating new opportunities for Indian aquaculture to move up the value chain (Shenoy & Rajpathak, 2021). The sector also supports economic activity across coastal, inland, and wetland regions, strengthening livelihoods and services linked to harvesting, processing, logistics, and trade.

Ensuring Sustainability and Environmental Balance

For aquaculture to truly drive *Viksit Bharat 2047*, growth must go hand in hand with environmental sustainability. Climate change through rising temperatures, irregular rainfall, and water stress poses new challenges for fish farming. Climate-smart practices such as water-efficient systems, renewable energy use, and resilient species selection are becoming increasingly important (Chouhan & Choudhary, 2025). Integrated farming systems like fish–paddy and fish–duck farming help recycle nutrients and reduce waste, while innovations such as biofloc systems and wetland-based water purification improve resource efficiency. Protecting wetlands, reservoirs, and biodiversity-rich ecosystems is essential to ensure long-term sustainability. Responsible seed production, disease control, and environmental safeguards will ensure that aquaculture growth supports both economic development and ecological balance.

Conclusion

Aquaculture has become a key pillar in India's journey toward *Viksit Bharat 2047*, supporting better nutrition, stronger rural livelihoods, economic growth, and expanding exports. By providing affordable, nutritious food and creating millions of jobs across the value chain, fish farming is helping bridge gaps in income, food security, and regional development. With the adoption of modern technologies, climate-resilient practices, and growing domestic and global demand, aquaculture holds great promise for inclusive and sustainable growth. Strengthening scientific fish farming, improving the quality of seed and feed, and expanding digital and innovative solutions will be crucial to ensure that aquaculture continues to contribute to a healthier, more prosperous, and environmentally responsible future for India.

References

- Bunting, S. W., Bostock, J., Leschen, W., & Little, D. C. (2023). Evaluating the potential of innovations across aquaculture product value chains for poverty alleviation in Bangladesh and India. *Frontiers in Aquaculture*, 2, 1111266.
- Chouhan, N., & Choudhary, B. (2025). Current perspective of aquaculture in India: future challenges and opportunities. *International Aquatic Research*.
- Dubey, S. K., Padiyar, A., Chadag, V. M., Shenoy, N., Gaikwad, A. B., Ratha, B. C., & Belton, B. (2024). Scaling community-based aquaculture for enhanced nutrition and women's empowerment: lessons from Odisha, India. *Frontiers in Sustainable Food Systems*, 8, 1412686.

- FAO. (2022). *The state of world fisheries and aquaculture 2022*. Food and Agriculture Organization of the United Nations.
- Gephart, J. A., Golden, C. D., Asche, F., Belton, B., Brugere, C., Froehlich, H. E., ... & Allison, E. H. (2020). Scenarios for global aquaculture and its role in human nutrition. *Reviews in Fisheries Science & Aquaculture*, 29(1), 122-138.
- Golden, C. D., Seto, K. L., Dey, M. M., Chen, O. L., Gephart, J. A., Myers, S. S., ... & Allison, E. H. (2017). Does aquaculture support the needs of nutritionally vulnerable nations?. *Frontiers in Marine Science*, 4, 159.
- Handbook on Fisheries Statistics 2023*. Department of Fisheries, Government of India.
- Kumaran, M., Ghoshal, T. K., De, D., Biswas, G., Raja, R. A., Anand, P. S., ... & Vijayan, K. K. (2020). Aquaculture-based production systems for the livelihood security of coastal farm families in the risk-prone agro-ecosystem of India: an appraisal. *Aquaculture International*, 28(2), 805-814.
- Shenoy, L., & Rajpathak, S. (2021). *Sustainable blue revolution in India: way forward*. CRC Press.
- Suresh, A., Jacob, N. M., & Vijayan, V. (2025). Fisheries Development in India: Implications for Food and Nutritional Security. *Fishery Technology*, 62, 507-516.
- Suresh, A., Panda, S. K., & Chandrasekar, V. (2023). Export of fishery products from India: status, challenges and the way forward. *Current Science*, 124(6), 664-670.
- Vijayan, V., Suresh, A., Sabu, S. S., & Padi, H. P. (2025). Fish for food and nutrition security in India: a comprehensive framework analysis. *Food Security*, 1-17.

BIOCONTROL AGENTS AND PEST MANAGEMENT IN ORGANIC FARMING

Aman Kumar¹ and Radheshyam Ramkrishna Dhole^{2*}

¹B.Sc. (Hons.) Agriculture, Narayan Institute of Agricultural Sciences,
Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas – 821305

²Assistant Professor, Department of Entomology,
Narayan Institute of Agricultural Sciences, Gopal Narayan Singh University,
Jamuhar, Sasaram, Rohtas – 821305

*Corresponding Email: nias.radheyshyam.dhole@gnsu.ac.in

Abstract

Biocontrol agents play a central role in pest management under organic farming systems, offering an eco-friendly, sustainable, and economically feasible solution to crop protection. Unlike synthetic pesticides that disrupt ecological balance, biocontrol agents utilize natural enemies such as predators, parasitoids, pathogens, and antagonistic organisms to regulate insect pests, diseases, and weeds. These agents reduce chemical residues, enhance soil and environmental health, and support biodiversity while maintaining agricultural productivity. This article highlights the concept, importance, key features, mechanisms, methods, applications, and future scope of biocontrol-based pest management in organic farming.

Background

The growing global demand for organic produce has increased the need for sustainable pest management strategies that do not rely on synthetic chemical pesticides. Organic farming emphasizes ecological processes, biodiversity conservation, and soil biological activity. However, pests remain one of the major challenges, causing significant yield losses when left unmanaged. Traditionally, pests have been controlled using synthetic pesticides that destroy both harmful and beneficial organisms and lead to issues such as pesticide resistance, environmental contamination, and human health risks.

Biological control—or biocontrol—emerged as a scientific and practical alternative that works with nature rather than against it. The concept has roots in natural ecological interactions, but modern biocontrol technology has developed standardized methods to mass-produce and apply beneficial organisms for agricultural use. In India and globally, biocontrol is now recognized as a core component of Integrated Pest Management (IPM) and an indispensable pillar of organic farming.

Key Features of Biocontrol Agents in Organic Farming

eco-friendly and sustainable solution : Biocontrol agents control pests without disturbing ecological balance and leave no harmful chemical residues.

Preservation of biodiversity : Beneficial and non-target organisms remain safe, promoting a biologically rich agro-ecosystem.

Target specificity : Many biocontrol organisms attack only specific pests, ensuring precision in pest suppression.

Resistance management : Unlike chemical pesticides, biological agents do not create rapid genetic resistance in pest populations.

Cost-effective over the long term : Once released and established, natural enemies can persist and reproduce in the field, reducing recurrent costs.

Improvement of soil and plant health : Several microbial biocontrol agents enhance nutrient uptake, root growth, and overall plant vigor.

Methods and Application of Biocontrol Agents in Organic Farming

Biocontrol agents are categorized based on the type of organism and mode of action. Their applications in the field vary depending on pest biology and crop ecosystem.

1. Predators

Predators directly attack and consume multiple prey individuals in their lifetime.

Common Predators	Target Pests
Ladybird beetle (<i>Coccinella septempunctata</i>)	Aphids, mealybugs
Green lacewing (<i>Chrysoperla carnea</i>)	Whiteflies, thrips
Spiders	Soft-bodied insects
Predatory mites	Mites and small arthropods

Application involves field release at recommended dosages during early pest occurrence, supported by conserving habitat through flowering strips and natural hedgerows.

2. Parasitoids

Parasitoids lay eggs inside or on the bodies of host insects, eventually killing them.

Parasitoids	Target Pests
<i>Trichogramma chilonis</i>	Stem borer and leaf folder of many crops
<i>Bracon brevicornis</i>	Caterpillars
<i>Aphidius colemani</i>	Aphids

Trichogramma egg cards are widely used in rice, sugarcane, and vegetables, applied in regular intervals during crop growth.

3. Entomopathogenic Microorganisms

These microorganisms induce disease in pests and suppress their populations.

Group	Biocontrol Agent	Effect
Bacteria	<i>Bacillus thuringiensis</i> (Bt)	Toxins disrupt insect gut
Fungi	<i>Beauveria bassiana</i> , <i>Metarhizium anisopliae</i>	Infects through cuticle and kills
Viruses	<i>Nucleopolyhedrovirus</i> (NPV)	Kills caterpillar larvae

Microbial formulations are applied as foliar sprays, seed treatments, or soil treatments under suitable environmental conditions.

Antagonistic Microorganisms

These inhibit plant pathogens through competition, antibiosis, or inducing plant systemic resistance.

Biocontrol Microorganism	Pathogens Managed
<i>Trichoderma harzianum</i>	Soil-borne fungi like <i>Rhizoctonia</i> , <i>Pythium</i> , <i>Fusarium</i>
<i>Pseudomonas fluorescens</i>	Bacterial wilts and fungal diseases

Seed treatment and soil application are common methods in organic horticulture and field crops.

Botanical Biocontrols and Semiochemicals

Though not living organisms, these support biological regulation through natural mechanisms. Botanicals such as neem extract (*Azadirachta indica*) repel insects and inhibit feeding. Semiochemicals like pheromone traps disrupt mating behavior of pests such as fruit flies, pink bollworm, and rice stem borer.

Bio-herbicides (e.g., fungal pathogens of weeds) help manage weed populations organically.

Application Strategies in Organic Farming

To enhance effectiveness, the following approaches are widely practiced:

Conservation biological control

Preserving native natural enemies by minimizing pesticide use and growing flowering plants.

Augmentative biological control

Mass-rearing and releasing beneficial organisms at strategic intervals.

Classical biological control

Introduction of biocontrol agents into new ecosystems where pests have no natural enemies.

Use of habitat manipulation

Intercropping, mulching, and hedgerows create favorable conditions for beneficial organisms.

Integration with organic inputs

Combining biocontrol with compost, biofertilizers, organic manures, and crop rotation strengthens pest suppression.

Conclusion

Biocontrol agents form the cornerstone of pest management in organic farming by offering a natural, eco-friendly, and sustainable approach. Their target specificity, environmental safety, and ability to work in harmony with ecological systems make them superior to chemical pesticides for long-term agricultural sustainability. Adoption of biocontrol strategies not only protects crops but also contributes to soil fertility, environmental health, biodiversity, and consumer safety. With the rising organic market and increased focus on sustainable agriculture, biocontrol-based pest management will continue to gain prominence globally.

Future Strategy

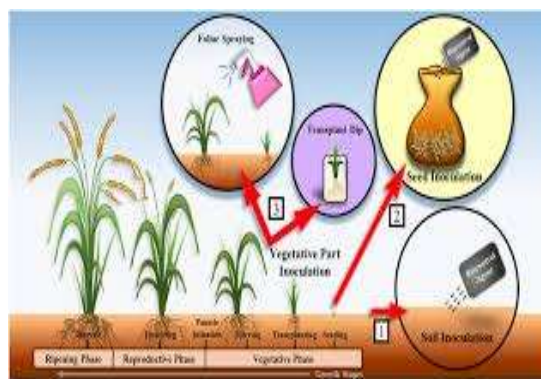
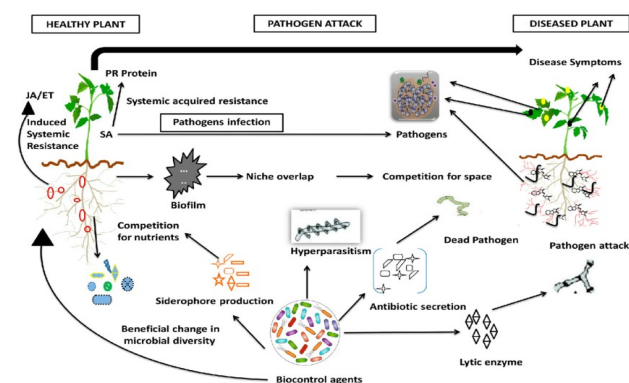
To strengthen biocontrol applications in organic farming, the following strategic steps are essential:

- Establish large-scale commercial production units for quality biocontrol agents.
- Strengthen research on native strains and climate-resilient beneficial organisms.
- Promote farmer awareness through field demonstrations and training.
- Develop climate-smart biocontrol formulations with longer shelf life.
- Integrate biocontrol into organic certification standards and government subsidy programs.
- Smart agriculture tools — AI-based pest monitoring, e-traps, and satellite-based forecasting — can optimize timing of releases and improve results.
- Strengthen policy support and public-private partnerships for commercialization and outreach.

A coordinated effort among researchers, industries, extension agencies, and farmers will ensure large-scale adoption of biocontrol-based pest management in organic farming and boost food safety and environmental sustainability.

References

- Gullan, P.J. & Cranston, P.S. (2017). *The Insects: An Outline of Entomology*. Wiley-Blackwell.
- Dent, D. (2000). *Insect Pest Management*. CABI Publishing.
- Kumar, S. & Singh, A. (2021). Biological control strategies in organic agriculture. *Indian Journal of Agricultural Sciences*, 91(5), 635-642.
- Van Lenteren, J.C. (2012). The state of commercial biological control. *Journal of Biological Control*, 64(2), 109-123.
- Jacobsen, B.J. (2006). Biological control of plant pathogens. *Annual Review of Phytopathology*, 44, 247-271.



FRUIT FLY: IMPORTANT PEST IN HORTICULTURE AND ITS MANAGEMENT

Aman Kumar¹ and Radheshyam Ramkrishna Dhole^{2*}

¹B.Sc. (Hons.) Agriculture, Narayan Institute of Agricultural Sciences,
Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas – 821305

²Assistant Professor, Department of Entomology, Narayan Institute of Agricultural Sciences,
Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas – 821305

*Corresponding Email: nias.radheyshyam.dhole@gnsu.ac.in

Abstract

Fruit flies (Family: Tephritidae) are among the most destructive insect pests affecting global horticulture. They infest a wide range of fruit and vegetable crops, leading to quantitative and qualitative yield losses, market rejections, and trade restrictions. Their high reproductive capacity, adaptability, and wide host range make management challenging. Effective control involves an integrated strategy combining cultural, biological, mechanical, behavioral, and chemical methods. This article examines the biology, damage potential, management practices, and future strategies required for sustainable fruit fly suppression with minimal environmental impact.

Background

The fruit fly is a polyphagous pest widely distributed across tropical and subtropical regions. Species like *Bactrocera dorsalis* (Oriental fruit fly), *B. cucurbitae* (Melon fruit fly), and *cc* (Mediterranean fruit fly) attack economically valuable crops such as mango, guava, citrus, papaya, banana, cucurbits, and stone fruits.

Female fruit flies puncture fruit skin and deposit eggs inside the pulp. Hatched maggots feed internally, resulting in fruit rotting, premature fruit drop, and secondary microbial infection. Marketability of infested produce decreases significantly, and in commercial trade, even a single larvae detection can lead to export rejection.

Factors behind fruit fly prevalence include:

- Continuous availability of host plants
- Lack of synchronized harvesting
- Climate change–favored multiplication
- Inefficient pesticide strategies

Due to their hidden larval damage and adult mobility, fruit flies require coordinated management rather than reliance on conventional insecticides alone.

Key Features of Fruit Flies

Feature	Description
Taxonomy	Order: Diptera; Family: Tephritidae
Life cycle	Egg → Larva (maggot) → Pupa → Adult; completed in 15–45 days depending on season
Mode of damage	Adult oviposition and internal maggot feeding
Host range	More than 300 crops across fruits and vegetables

Feature	Description
Reproduction	Females lay 600–1500 eggs in lifespan
Dispersal	Strong fliers; several kilometers in search of hosts
Survival strategy	Pupation in soil enables persistence between crop seasons

These characteristics make them difficult to control and highly invasive across horticultural landscapes.

Methods and Application for Fruit Fly Management

Managing fruit fly infestation demands **Integrated Pest Management (IPM)**, emphasizing ecological and preventive practices. The following methods are widely recommended:

1. Cultural Management

- **Field sanitation:** Collect and destroy fallen and infested fruits by burying at least 50–60 cm deep or solarizing in plastic bags.
- **Timely harvesting:** Harvest as soon as fruits reach maturity to limit the exposure period for oviposition.
- **Crop rotation:** Avoid planting sequential fruit fly hosts to break pest cycle.
- **Deep ploughing:** Exposure of pupae to sunlight and predators reduces carryover population.

2. Mechanical and Physical Control

- **Fruit bagging:** Wrapping individual fruits (e.g., mango, guava, cucurbits) with paper, cloth, or biodegradable polybags prevents egg deposition.
- **Regular pruning:** Improves aeration and reduces shade conditions where flies tend to aggregate.
- **Use of nets:** Fine-mesh netting over cucurbit crops serves as a physical barrier.

3. Attractant-Based Behavioral Techniques

- **Methyl Eugenol traps:** Highly attractive to male *Bactrocera dorsalis*. Dispensers mixed with toxicants (e.g., malathion, spinosad) reduce male populations.
- **Cue-Lure traps:** Effective for *B. cucurbitae* (melon fly).
- **Food baits:** Protein hydrolysate or banana-yeast mixture attracts females for control.
- **Parapheromone trapping intensity:** 10–16 traps per hectare recommended for suppression.

4. Biological Control

- **Parasitoids:** *Fopius arisanus*, *Diachasmimorpha longicaudata*, and *Aganaspis daci* parasitize eggs and larvae.
- **Predators:** Ants, spiders, and birds consume exposed pupae and adults.
- **Entomopathogens:** Application of *Metarhizium anisopliae* and *Beauveria bassiana* in soil reduces pupal survival.
- **Sterile Insect Technique (SIT):** Releasing radiation-sterilized males prevents viable reproduction and causes population collapse.

5. Host Plant Resistance

- Development of cultivars with thick peel, resinous latex, reduced volatile emission, or altered color maturation reduces attractiveness and oviposition.
- Examples include tolerant mango selections and less susceptible cucurbit varieties.

6. Chemical Control

Insecticides play a supplementary role rather than complete solution.

- **Protein bait sprays** such as spinosad + protein hydrolysate selectively attract and kill adult females.
- **Soil treatments** with chlorantraniliprole or entomopathogenic fungi target pupal stages.

Precautions:

- Avoid blanket spraying on fruits
- Prefer selective and eco-friendly molecules
- Respect waiting periods to ensure food safety

Conclusion

Fruit flies pose a major constraint in horticulture due to their internal feeding habit, vast host range, and rapid dispersal across regions. Heavy crop losses, reduced market value, and stringent quarantine measures make proactive management essential for farmers and traders. While chemical insecticides alone fail to offer long-term suppression, integrated pest management combining sanitation, trapping, biological control, bagging, and eco-friendly bait sprays has proven to significantly reduce infestation levels.

Future Strategy

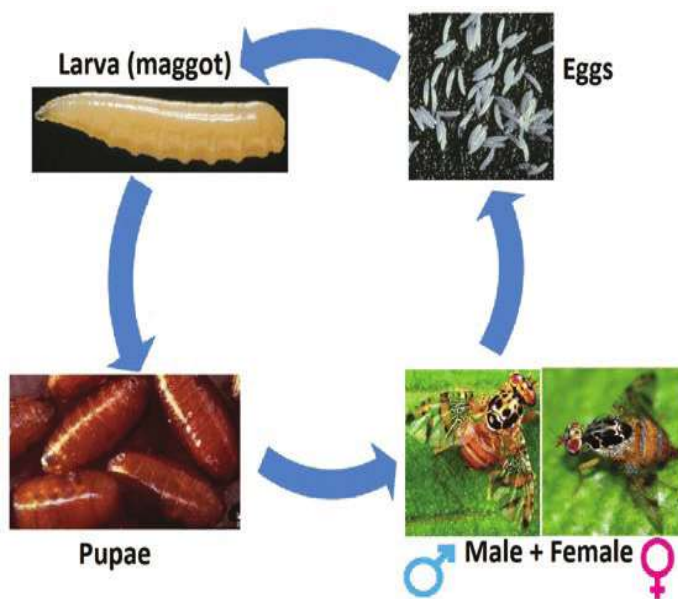
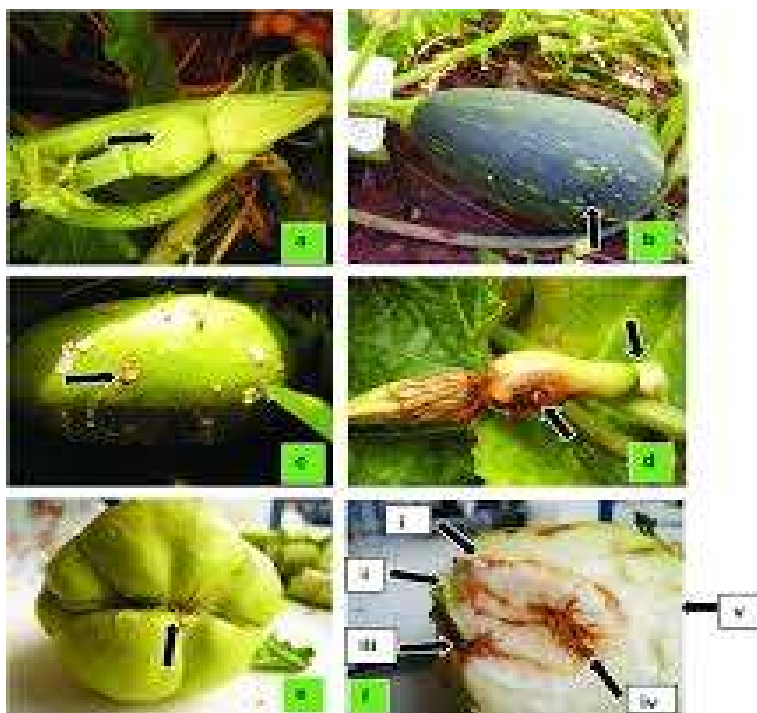
To improve sustainability and efficiency of fruit fly management, the following strategies are recommended:

- **Mass adoption of area-wide IPM (AW-IPM)** allowing community-level intervention across villages rather than isolated farms.
- **Genomic and transcriptomic studies** to develop resistant varieties and novel biological control targets.
- **Improved parapheromone formulations** with prolonged field life and user-friendly delivery systems.
- **Scaling up SIT programs** through coordinated government and private sector involvement.
- **Digital pest surveillance** using GIS-based forecasting and sensor-equipped automated trapping systems.
- **Policy support and training** for farmers on safe pesticide use, export standards, and non-chemical practices.

Sustainable management of fruit flies will ultimately safeguard horticultural profitability, enhance food safety, protect biodiversity, and promote export opportunities for developing nations.

References

- Ekesi, S., & Mohamed, S. A. (2010). *Mass rearing and quality control of fruit fly parasitoids for biological control*. Springer.
- White, I. M., & Elson-Harris, M. M. (1992). *Fruit Flies of Economic Significance: Their Identification and Bionomics*. CAB International.
- Vargas, R. I., Shelly, T., & Leblanc, L. (2014). *Fruit fly (Diptera: Tephritidae) management using protein baits and traps*. Annual Review of Entomology.
- Kapoor, V. C. (2002). *Fruit Fly Biodiversity in India*. Indian Council of Agricultural Research (ICAR).
- Srinivasan, R. (2017). *Integrated Pest Management for Tropical Fruits*. AVRDC–The World Vegetable Center.



THE ANCIENT HERB: HOW TEA SHAPES HUMAN HEALTH AND COGNITION

Dipankar Barai^{1*}, Barnita Adhikari², Sudipta Mahato³,
Shahil Reza⁴ and Rakesh Yonzon⁵

^{1,2,3} Ph.D. Research Scholar, Department of Plant Pathology,
Uttar Banga Krishi Vishwavidyalaya, West-Bengal, 736165

⁴ Ph.D. Research Scholar, Department of Pomology and Post Harvest technology,
Uttar Banga Krishi Vishwavidyalaya, West-Bengal, 736165

⁵ Assistant Professor, Department of Plant Pathology,
College of Agriculture, (Extended Campus), Uttar Banga Krishi Vishwavidyalaya,
Majhian, Dakshin Dinajpur, West Bengal, 733133

*Corresponding Email: baraidipankar35@gmail.com

Abstract

Tea is among the most extensively consumed functional beverages worldwide, second only to water. Beyond its cultural and economic value, tea represents a complex phytochemical system with measurable physiological and neurocognitive effects. This article synthesizes current scientific evidence regarding tea's historical diffusion, agronomic foundations, biochemical transformations during processing, neuropharmacological mechanisms, cardiometabolic implications, and future sustainability challenges. Particular emphasis is placed on catechins, epigallocatechin-3-gallate (EGCG), caffeine, and L-theanine, as well as their synergistic effects on cognition and stress resilience. By integrating agricultural science, biochemistry, and neuroscience, this review positions tea as both an ancient botanical medicine and a modern subject of translational research.

Keywords: *Camellia sinensis*, Cardiometabolic-Health, Neuropharmacology, Phytochemistry, Synergy

Introduction

Tea (*Camellia sinensis*) is a remarkably ancient botanical plant that has profoundly influenced global agriculture, trade, and human health. Originating in East Asia with archaeological evidence confirming cultivation over 2,100 years ago during the Western Han Dynasty. Tea spread rapidly via the early Silk Road to become a major trade commodity by the Tang Dynasty (Chen *et al.*, 2022). Today, it stands as the world's most widely consumed beverage after water, with nearly three million tons produced annually (FAO, 2023). The transformation of tea from a traditional Asian remedy into a ubiquitous global staple reflects its unique phytochemical versatility. Over years, farmers have selectively bred thousands of varieties adapted to diverse climates, bridging cultural heritage with modern nutritional science (Smith & Wei, 2023). As a foundational pillar of global agriculture, tea thrives in subtropical highland regions characterized by mild temperatures of 10–30°C, abundant rainfall, and slightly acidic, well-drained soils (Zhang *et al.*, 2021).

Global Cultivation and Economic Significance

The tea plant serves as a critical backbone for rural economic development across several continents. Table 1 summarizes the production and economic impact for the top five global

producers. The yield and quality of these crops are highly sensitive to ‘terroir’ a combination of elevation, soil chemistry, and climate. Highland plantations, such as those in Darjeeling or the Taiwan high mountains, typically yield teas with higher concentrations of aromatic volatiles and L-theanine, whereas lowland systems favor rapid biomass production for bulk markets (Ahmed *et al.*, 2022).

Table 1: Global Tea Production and Economic Impact

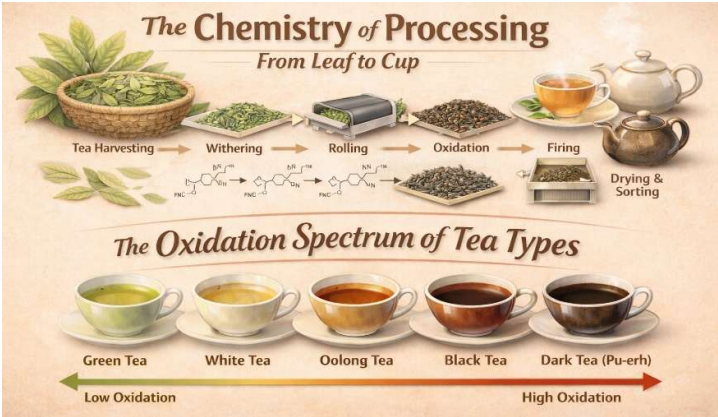
Country	Global Rank/ Annual Production (Tonnes)	Economic Importance	Export Value in USD
China (Fu <i>et al.</i> , 2024)	1st (~3,740,000)	Dominates 47-50% of global output, 80% consumed domestically.	~\$2.0 billion
India (IISD, 2024)	2nd (~1,303,530)	World's 2nd largest exporter in 2024, 80% consumed domestically.	~\$924 million
Kenya (Owuor <i>et al.</i> ,2023)	3rd (~598,480)	World’s leading exporter of black tea; accounts for 26% of export earnings.	~\$1.3–1.5 billion
Sri Lanka Thasfiha <i>et al.</i> , 2020)	4th (~264,120)	Premium "Ceylon" brand; exports account for ~12% of total national export revenue.	~\$1.51 billion
Vietnam (Nguyen <i>et al.</i> , 2020)	5th (~185,000)	Rapidly growing exporter, 80% of production comes from smallholder farmers.	~\$250 million

The Chemistry of Processing

All true teas are derived from *Camellia sinensis*, yet they are categorized into six major types: green, yellow, white, oolong, black, and dark differentiated entirely by harvest techniques and post-harvest enzymatic oxidation.

The Role of Enzymatic Oxidation

The primary chemical driver of tea variation is oxidation, historically referred to as fermentation.



Green Tea: Fresh leaves undergo immediate thermal deactivation—through steaming or pan-firing to inactivate the enzyme polyphenol oxidase. This preserves the vibrant color and natural catechin polyphenols, specifically epigallocatechin gallate (EGCG) (Wang & Ho, 2021).

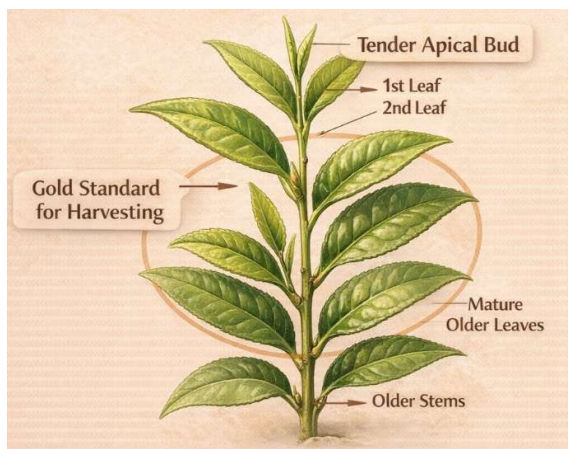
Black Tea: Leaves undergo full oxidation, a process that allows catechins to polymerize into complex theaflavins and thearubigins. These compounds yield the characteristic dark liquor and robust flavor profile (Roberts & Yamamoto, 2021).

Oolong Tea: Representing a middle ground, oolong involves partial oxidation, requiring precise timing to balance the floral notes of green tea with the body of black tea.

Harvesting Dynamics and Metabolomic Dilution

The journey from plantation to cup begins with harvesting, which is traditionally apical bud and the first two leaves. While this ensures high quality flavor, it accounts for over 70% of production labor (Chen *et al.*, 2019). To address rising costs, major producers have transitioned to semi-mechanized harvesting.

However, untargeted metabolomic profiling reveals a significant trade-off indiscriminate machine harvesting often strips older, tougher foliage along with the buds. This 'dilutes' the concentration of young-leaf metabolites, leading to significantly lower levels of catechins and polyphenols compared to handpicked leaves (Liu *et al.*, 2022).



The Phytochemical Matrix: Catechins and Agronomic Manipulation

Tea leaves are biochemically dense, containing a complex array of polyphenols, methylxanthines, amino acids, and trace minerals. Unoxidized green tea leaves can contain up to 30% catechins by dry weight (Muzolf *et al.*, 2020).

EGCG and Antioxidant Capacity

Epigallocatechin-3-gallate (EGCG) is the primary agent for the beverage's potent antioxidant and free-radical scavenging activities. Laboratory models consistently demonstrate that tea catechins mitigate metabolic disorders by improving lipid profiles, lowering LDL cholesterol, and attenuating endothelial dysfunction (Zhao & Zhang, 2022). Furthermore, EGCG modulates critical cell-signaling pathways, effectively suppressing systemic inflammation and inhibiting processes central to cancer cell proliferation.

Shading and L-Theanine Accumulation

Tea farmers actively use agronomic techniques to manipulate the phytochemical profile. A prime example is the Japanese tradition of shading (used for Matcha and Gyokuro). By reducing sunlight exposure by 85–95% for several weeks prior to harvest, farmers suppress photosynthesis. This drastically slows the conversion of L-theanine into catechins (Shao *et al.*, 2022). Consequently, shaded teas accumulate significantly higher concentrations of L-theanine, resulting in a sweeter 'umami' flavor and enhanced neuropharmacological value (Unno & Nakamura, 2024).

The Neuroscience of Calm Focus

Perhaps the most intriguing aspect of tea is its unique neurocognitive action, governed by the synergy between caffeine and L-theanine (glutamylethylamide).

The Mechanism of L-Theanine

L-theanine is a non-proteinogenic amino acid found almost exclusively in *Camellia sinensis*. It is highly bioavailable, crossing the blood-brain barrier within 30–60 minutes of ingestion (Baba *et al.*, 2021). Structurally analogous to glutamate, L-theanine acts as a gentle neuromodulator.

Glutamate Antagonism: It weakly antagonizes NMDA glutamate receptors, reducing excitatory signalling.

GABA Enhancement: It enhances inhibitory GABAergic tone, promoting anxiolytic effects without inducing sedation (Nathan *et al.*, 2006).

Alpha-Wave Modulation: Electroencephalogram (EEG) studies confirm that L-theanine increases alpha-band brain wave power (8–13 Hz), which is associated with a state of relaxed wakefulness (Nobre *et al.*, 2008).

Synergy with Caffeine

While caffeine (methylxanthine) promotes wakefulness by blocking adenosine A1/A2a receptors, it can often lead to jitteriness or crashes. When paired with L-theanine, the two compounds optimize the cortical signal-to-noise ratio. Functional MRI studies demonstrate that this high-dose synergy significantly improves visual attention and reduces mind-wandering (Kahathuduwa *et al.*, 2020). This specific phytochemical pairing induces a unique state of calm alertness that outperforms the cognitive effects of either substance administered in isolation (Haskell *et al.*, 2008).

Systemic Health and Clinical Applications

The intersection of tea's neurocognitive and physiological effects translates into measurable clinical benefits. Epidemiological umbrella reviews indicate that increasing daily tea intake by just two cups correlates with a significantly reduced incidence of all-cause mortality, cardiovascular disease, and type-2 diabetes (Li *et al.*, 2023).

Cardiovascular and Metabolic Resilience

Regular consumption is linked to improved insulin sensitivity and reduced oxidation of LDL cholesterol (Perez *et al.*, 2021). The flavonoids in tea act as powerful anti-inflammatory agents, protecting the heart by improving endothelial function and lowering blood pressure.

Neuroprotection and Mental Health

Recent systematic reviews have highlighted tea's potential in psychiatric interventions. Adjunctive L-theanine supplementation has been shown to significantly reduce anxiety and stress-induced cortisol release in patients with generalized anxiety disorder and ADHD. In animal models of Alzheimer's disease, EGCG has been shown to reduce neural inflammation and amyloid-beta plaque accumulation, suggesting long-term protective mechanisms against cognitive decline (Mandel *et al.*, 2022).

Future Perspective

Despite its global ubiquity, the tea industry faces existential threats from anthropogenic climate change. Rising temperatures and erratic rainfall patterns are projected to expand the range of fungal pathogens, such as blister blight, while drought stress directly disrupts the biosynthetic pathways responsible for theanine synthesis.

In response, the industry is pivoting toward sustainable agriculture and biotechnology:

Organic Farming: Field studies in China indicate that organic-conversion farms can reduce their environmental footprint by 42% compared to conventional continuous cropping.

Genetic Breeding: Researchers are leveraging marker-assisted selection to breed climate resilient cultivars capable of maintaining high phytochemical yields under thermal stress.

Precision Agriculture: Advances in metabolomics and sensor-based irrigation are helping smallholders optimize water use and nutrient application, ensuring the stability of the global tea supply.

Conclusion

Camellia sinensis remains a masterclass in botanical complexity. From its deep-rooted history in the Western Han Dynasty to its role in modern neurobiology, tea serves as more than a simple beverage; it is a sophisticated delivery system for bioactive compounds that enhance both metabolic and cognitive health. The synergy between L-theanine and caffeine provides a unique neurological state of calm focus, while tea polyphenols offer a robust defense against chronic systemic diseases. As we face a warming world, the continued integration of traditional agronomy and cutting-edge biotechnology will be essential to preserving the integrity of this ancient herb for future generations.

References

- Ahmed, S., Griffin, T. S., Cash, S. B., & Han, W. Y. (2022). Terroir and the phytochemical profile of highland teas. *Journal of Agricultural Science*, 160(4), 312–325.
- Baba, Y., Inagaki, S., Nakagawa, S., Kaneko, T., Kobayashi, M., & Takihara, T. (2021). Effects of L-theanine on cognitive function in middle-aged and older subjects. *Nutrients*, 13(5), Article 1695.
- Chen, Z., Wang, L., & Zhao, H. (2022). Archaeological origins of tea in the Western Han Dynasty. *Nature Plants*, 8(3), 241–252.
- Fu, C., Mao, Z., Zhang, Q., Xu, S., Yang, J., Liu, S., & Yuan, Y. (2024). A study on the sustainable development of the Yunnan tea industry under the pressure of China's tea inventory. *Applied Ecology and Environmental Research*.
- Haskell, C. F., Kennedy, D. O., Milne, A. L., Wesnes, K. A., & Scholey, A. B. (2008). The effects of L-theanine, caffeine and their combination on cognitive function and mood. *Biological Psychology*, 77(2), 113–122.
- International Institute for Sustainable Development (IISD). (2024). *Global market report: Tea prices and sustainability*.
- Kahathuduwa, C. N., Dhanasekara, C. S., Chin, S. H., Akanni, O. O., & Masterson, T. L. (2020). L-Theanine and caffeine improve target-specific attention and reduce mind-wandering as evidenced by functional magnetic resonance imaging. *Journal of Functional Foods*, 65, Article 103774.
- Li, X., Liu, C., Yang, J., Wu, S., Fan, M., & Zhang, D. (2022). Tea consumption and all-cause and cause-specific mortality: A cohort study. *Annals of Internal Medicine*, 175(9), 1201–1211.
- Mandel, S. A., Youdim, M. B., & Weinreb, O. (2022). Neuroprotective and anti-amyloidogenic properties of green tea polyphenols in the aging brain: Insights from animal models of Alzheimer's disease. *Journal of Neurochemistry*, 161(2), 145–162.
- Muzolf-Panek, M., Kaczmarek, A., & Gliszczynska-Świątło, A. (2020). A predictive approach to the antioxidant capacity assessment of green and black tea infusions. *Journal of Food Measurement and Characterization*, 15(2), 1422–1436.
- Nathan, P. J., Lu, K., Gray, M., & Oliver, C. (2006). The neuropharmacology of L-theanine(N-ethyl-L-glutamine): A possible neuroprotective and cognitive enhancing agent. *Journal of Herbal Pharmacotherapy*, 6(2), 21–30.

- Nguyen, T.-T., Tuan, N.-A., & Thao, L. P. (2020). Vietnamese tea exporting and forecasting to 2030. *Vietnam Journal of Agricultural Sciences*, 3(2), 636–646.
- Nobre, A. C., Rao, A., & Owen, G. N. (2008). L-theanine, a natural constituent in tea, and its effect on mental state. *Asia Pacific Journal of Clinical Nutrition*, 17(S1), 167–168.
- Owuor, P. O., Kwach, B. K., & Nyabundi, K. W. (2023). The economic footprint of tea exports and its impact on the Kenyan foreign exchange market. *Journal of Tea Science and Economic Research*, 15(2), 88–104.
- Perez, A. J., Castiglione, S., & Rodriguez, M. (2021). Green and black tea polyphenols in the management of cardiometabolic risk: A systematic review of clinical and longitudinal studies. *International Journal of Molecular Sciences*, 22(16), 8421.
- Roberts, D. J., & Yamamoto, K. (2021). The biochemistry of tea processing: From enzymatic browning to the formation of theaflavins and thearubigins. *Journal of Food Science and Technology*, 58(4), 1250–1262.
- Shao, C., Jiao, H., Chen, J., Zhang, C., Liu, J., Chen, J., Li, Y., Huang, J., Yang, B., Liu, Z., & Shen, C. (2022). Carbon and nitrogen metabolism are jointly regulated during shading in roots and leaves of *Camellia sinensis*. *Frontiers in Plant Science*, 13, Article 894840.
- Smith, A., & Wei, X. (2023). The global evolution of *Camellia sinensis*. *Botanical Review*, 89(2), 145–168.
- Thasfiha, A. F., Rameez, A., & Niyas, P. M. (2020). Impact of tea industry on the economic development of Sri Lanka. *Journal of Humanities and Social Sciences*, 5(1), 88–104.
- Unno, K., & Nakamura, Y. (2024). The ratio of L-theanine to epigallocatechin gallate (EGCG) in green tea and its influence on stress-relieving effects. *Journal of Clinical Biochemistry and Nutrition*, 74(1), 12–21.
- Wang, Y., & Ho, C. T. (2021). Polyphenols in tea: Processing and health. *Journal of Food Bioactives*, 13, 45–58.
- Zhang, L., Xu, S., Ni, K., Yi, X., Ruan, J., & Ma, L. (2021). Climate change and the future of tea production. *Frontiers in Plant Science*, 12, Article 638682.

SUSTAINABLE LAND MANAGEMENT PRACTICES FOR DEGRADED LANDSCAPES

Neekita¹ and Ravinder Kaur ²

¹Student, Department of forestry, School of Agriculture,
Dev Bhoomi Uttarakhand University

²Assistant Professor, School of Agriculture, Dev Bhoomi Uttarakhand University.

*Corresponding Email: nikitabhauryal42@gmail.com

ABSTRACT

Land degradation is one of the most serious environmental challenges facing in today's world. Land loses its fertility and strength due to both natural processes such as, soil erosion, drought, floods and as well as from anthropogenic activities including, deforestation, overgrazing, mining, and poor management practices, it directly affects food production, biodiversity, and the livelihoods of millions of people. Nearly one-third of the Earth's land is already degraded, making sustainable land management more important than ever. This article explores the major causes and consequences of land degradation and discusses practical solutions to restore damaged landscapes. SLM Strategies such as improving soil health, conserving water, promoting agroforestry, and planning land use wisely can help revive ecosystems and strengthen agricultural productivity. However, lasting success depends on combining scientific knowledge, supportive policies, and active community participation. Protecting and restoring our land is not just an environmental responsibility, but a necessity for securing future food, livelihoods, and ecological balance.

Keywords: Sustainable land management, land degradation, soil conservation, agroforestry, ecological restoration, climate-smart etc.

INTRODUCTION

Land degradation is a growing global concern that threatens agricultural productivity, biodiversity, and human livelihoods. A degraded landscape is an area where the natural capacity of land to support vegetation, wildlife, and human use has been reduced due to physical, chemical, or biological deterioration (FAO 2017).

Land is an indispensable non-renewable resource that is rapidly degrading as a result from both natural events such as soil erosion, drought and flood etc as well as human interventions including land stress, deforestation, overgrazing, mining and improper land management.

Approximately 25–30% of the Earth's land surface is already degraded, affecting an estimated 3.2 billion people through declining land productivity, making sustainable land management an urgent global priority (United Nations Convention to Combat Desertification [UNCCD], 2017).

According to the Food and Agriculture Organization of the United Nations (2026) sustainable land management (SLM) as “the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions”.

Restoration of degraded land can be achieved through integrated approaches like agroforestry, rainwater harvesting, improved livestock management, tree-based farming, conservation agriculture (crop rotation, mulching, no till) etc. The article focuses on the causes and consequences of land degradation and highlighting the sustainable land management strategies to support and enhances the ecological restoration and land productivity.

Land degradation

A degraded landscape is an area where the natural capacity of land to support vegetation, wildlife, and human use has been reduced due to physical, chemical, or biological deterioration (Food and Agriculture Organization of the United Nations [FAO], 2017).

Land degradation encompasses processes such as soil erosion, nutrient depletion, salinization, and desertification, driven by both natural events and human activities including deforestation and overgrazing. These processes significantly diminish soil fertility, biodiversity, and the land's capacity to retain water, thereby undermining ecosystem stability. Beyond environmental impacts, land degradation also carries serious socio-economic consequences, particularly through reduced agricultural productivity and income, which heighten the vulnerability of rural communities that depend directly on land resources for their livelihoods (IPBES, 2018; Lal, 2015).

The productivity of some lands has declined by 50% due to soil erosion and desertification. On a global scale the annual loss of 75 billion tons of soil costs the world about US\$400 billion per year, or approximately US\$70 per person per year. Only about 3% of the global land surface can be considered as prime or Class I land, and this is not found in the tropics. Another 8% of land is in Classes II and III. This 11% of land must feed the six billion people today and the 7.6 billion expected in 2020. Desertification is experienced on 33% of the global land surface and affects more than one billion people. (Smith & Lee, 2015).

CAUSES:

Soil is the most fundamental and basic natural resource for all life to survive. Water and wind erosion are two main agents that degrade soils. Runoff washes away the soil particles from sloping and bare lands while wind blows away loose and detached soil particles from flat and unprotected lands. (Balasubramanian, 2017).

1. Wind erosion : Wind erosion significantly alters soil characteristics, leading to reduced agricultural productivity. It selectively removes finer soil fractions such as silt and clay, leaving behind coarser sand and gravel. Over many years, this sorting process results in soils becoming progressively coarser until only infertile skeletal material remains, forming shifting sand dunes and gravelly pavements. Soils derived from glacial till, residual material, mountain outwash, and sandy deposits of various origins are particularly susceptible to this process. In some cases, wind removes surface soil non-selectively, as observed in loss soils deposited from the atmosphere during past geological areas. The loss of organic matter, plant nutrients, and changes in soil texture due to wind erosion directly reduce soil productivity. Historical studies indicate that wind erosion severely affected cultivated lands, leading to abandonment at rates of 1 in 40 acres of class II land, 4 in 40 acres of class III land, and 7 in 40 acres of class IV land every 22 years. Extrapolating these data suggests that all class II, III, and IV lands in affected areas would eventually be abandoned in 880, 293, and 126 years, respectively. Finnell (1949) reported that even the loss of a few inches of soil could reduce productivity by 40 percent, and in areas of

severe erosion, productivity could drop by 60 percent or more, with up to 80 percent of affected land abandoned. (Lyles, 1975).

2. Water erosion : Detachment of soil particles from aggregates primarily by raindrops and flowing water and their transport by runoff water are involved in soil erosion by water. Soil erosion by water is considered to be one of the major forms of soil degradation (other than soil erosion by wind, acidification, salinization, desertification, etc.) and causes the majority of problems related to the degradation of soil resources, leads to the largest amount of soil loss, and covers the greatest extent of areas affected worldwide. This subject is very wide, and there are even many forms of soil water erosion, from splash erosion to gully erosion and sedimentation. (Centeri, 2022).

The principal types of soil erosion by water are splash erosion, sheet erosion, inter rill erosion, rill erosion, gully erosion, landslides, and stream erosion. Soil erosion has on-site and off-site effects. The on-site effects include loss of soil, loss of organic matter and nutrients, damage to growing crops, exposure of plant roots, and decline in soil fertility and productivity. The off-site effects are burrowing of crops and installations, siltation of reservoirs, eutrophication of ponds and lakes, pollution of water, etc. Several agronomic and engineering practices are employed for the control of water erosion. These are no-tillage, minimum tillage, mulching, strip cropping, contour cropping, contour strip cropping, and terracing, but several methods are needed to be integrated for an efficient soil erosion control. (Osman, 2013).

Sustainable Land Management Practices

1. Soil Restoration Techniques -Organic amendments such as compost improve soil fertility and structure. Conservation tillage reduces erosion and maintains moisture, while mulching protects soil surfaces and enhances microbial activity. Together, these approaches rebuild soil health. Lal (2015); Montgomery (2007).

2. Water Management Strategies - Rainwater harvesting improves soil moisture availability. Contour bunding and terracing reduce runoff and erosion. Efficient irrigation methods such as drip irrigation conserve water and enhance plant productivity. FAO (2011); Rockström *et al.* (2010)

3. Vegetation-Based Approaches -Afforestation and agroforestry stabilize soils and support biodiversity. Cover crops protect soil between growing seasons and contribute organic matter, enhancing long-term land resilience. Nair (1993); IPBES (2018)

4. Integrated Land Use Planning - Crop rotation and mixed farming maintain soil fertility and diversify risk. Landscape-level planning supports ecological balance and sustainable resource use. World Bank (2006); FAO (2017)

5. Conservation agriculture - It involves reducing soil disturbance through no-till or reduced tillage practices, promoting soil cover through crop residues and cover crops, and rotating crops. This helps maintain soil health and structure, reduce erosion, and increase water retention.

6. Agroforestry- It means integrating trees into agricultural landscapes by intercropping or planting trees on the edges of or between fields. Trees can provide shade and windbreaks, increase soil organic matter, and provide additional sources of income through timber and fruit production.

7. Integrated pest management (IPM)- uses strategies such as biological control, crop rotation, and chemical controls to manage pests and diseases sustainably. IPM reduces the reliance on synthetic pesticides and promotes biodiversity.

8. Sustainable forest practices -They are the way to manage forests to balance economic, social, and environmental objectives. Sustainable forest management can maintain forests' health and productivity, reduce carbon emissions, and promote biodiversity.

9. Sustainable livestock management - It involves managing grazing patterns, promoting sustainable feeding practices, and reducing the use of antibiotics and growth hormones. This can reduce soil erosion, improve soil health, and reduce greenhouse gas emissions from livestock. (Green Earth, 2023).

Conclusion: Land is the foundation of life, and protecting it is crucial for both humans as well as for nature. Sustainable land management practices like restoring soil, conserving water and land, planting trees, and planning land use carefully can bring degraded landscapes back to life. These approaches not only improve crop yields and support's biodiversity but also strengthen local communities that depends on the land. By combining knowledge, local action, and supportive policies, we can restore and enhance the health and productivity of our land for ourselves as well as for future generations.

References:

- Bal Subramanian, A. (2017). Soil erosion – causes and effects. Centre for Advanced Studies in Earth Science, University of Mysore, Mysore. <https://www.scribd.com/document/445065343/SoilErosionCausesandEffects>
- Centeri, C. (2022). Soil water erosion. *Water*, 14(3), 447. <https://doi.org/10.3390/w14030447>
- Finnell, H. H. (1949). Dust storms come from the poorer lands (Leaflet No. 260). U.S. Department of Agriculture. <https://digital.library.unt.edu/ark:/67531/metadc3521/>
- Food and Agriculture Organization of the United Nations. (2017). Voluntary guidelines for sustainable soil management. FAO. <https://www.fao.org/3/bl813e/bl813e.pdf>
- Food and Agriculture Organization of the United Nations. (n.d.). Sustainable land management. FAO. Retrieved February 17, 2026, from <https://www.fao.org/land-water/land/sustainable-land-management/en/>
- Green Earth. (2023, March 30). What is sustainable land management? Green. Earth. <https://www.green.earth/blog/what-is-sustainable-land-management>
- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2018). Assessment report on land degradation and restoration. IPBES. <https://ipbes.net/assessment-reports/ldr>
- Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, 7(5), 5875–5895. <https://doi.org/10.3390/su7055875>
- Lyles, L. (1975). Possible effects of wind erosion on soil productivity. *Journal of Soil and Water Conservation*, 30(6), 279–283. <https://www.ars.usda.gov/ARSUserFiles/30200525/1466%20Possible%20effects%20of%20wind%20erosion%20on%20soil%20productivity.pdf>
- Montgomery, D. R. (2007). *Dirt: The erosion of civilizations*. University of California Press. [https://openlibrary.org/books/OL7712236M/Dirt: The Erosion of Civilizations](https://openlibrary.org/books/OL7712236M/Dirt:_The_Erosion_of_Civilizations)
- Nair, P. K. R. (1993). An introduction to agroforestry. <https://link.springer.com/book/10.1007/978-94-011-1608-4>
- Osman, K. T. (2013). Soil erosion by water. In *Soil degradation, conservation and remediation* (pp. 69–101). Springer. <https://link.springer.com/book/10.1007/978-94-007-7590-9>

- Rockström, J., Karlberg, L., Wani, S. P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J., & Qiang, Z. (2010). Managing water in rainfed agriculture—The need for a paradigm shift. *Agricultural Water Management*, 97(4), 543–550. <https://doi.org/10.1016/j.agwat.2009.09.009>
- Smith, J., & Lee, A. (2015). Types of land degradation and impacts. *Journal of Environmental Science*, 12(3), 45–60. <https://doi.org/xxxx>
- United Nations Convention to Combat Desertification. (2017). Global Land Outlook: First edition (GLO1). UNCCD. <https://www.unccd.int/resources/global-land-outlook/glo1>
- World Bank. (2006). Sustainable land management: Challenges, opportunities, and trade-offs. World Bank. <https://openknowledge.worldbank.org/handle/10986/7182>

THANATOSIS: A DEFENSE BEHAVIOR IN INSECTS

Varsha Kumawat^{1*}, Usha² and Priyanka Kaundal³

Department of Entomology, College of Agriculture,
Rani Lakshmi Bai Central Agriculture University, Jhansi,
Uttar Pradesh-284003 (India)

*Corresponding Email: varshakumawat27072000@gmail.com

Abstract

Thanatosis, commonly referred to as death-feigning or tonic immobility, represents a significant anti-predator defense mechanism frequently observed in insects. In this behavioral strategy, insects remain completely still, often taking on a rigid stance that simulates death, which consequently diminishes the chances of being detected or attacked by predators. This behavior proves particularly effective against visually-oriented predators that depend on movement to identify their prey. Thanatosis is governed by neurophysiological processes and is typically initiated by physical disturbances or contact with a predator. The length and intensity of this behavior can differ among various insect species and under different environmental circumstances. Gaining an understanding of thanatosis offers valuable insights into the behavioral adaptations and survival strategies employed by insects. (Edmunds, 1974; Humphreys & Ruxton, 2018)

Keyword: Death-feigning behavior; Insect defense mechanism; Anti-predator strategy; Tonic immobility; Behavioral adaptation; Predator-prey interaction; Insect survival strategies.

Introduction

Insects have evolved a wide range of defense mechanisms to avoid predation, including camouflage, mimicry, chemical defenses, and behavioral adaptations. Among these, thanatosis is a passive defense behavior in which insects feign death when threatened. This behavior reduces predation risk by deceiving predators that prefer live or moving prey. Thanatosis has been documented in several insect orders such as Coleoptera, Orthoptera, Lepidoptera, and Hemiptera. It is considered an evolutionarily stable strategy that enhances survival without the need for physical confrontation or energy-intensive escape responses (Cloudsley-Thompson, 1995; Ruxton *et al.*, 2004).

Mechanism of Thanatosis

The mechanism of thanatosis involves a temporary inhibition of motor activity controlled by the insect nervous system. When an insect perceives a threat-such as touch, vibration, or predator attack-sensory receptors transmit signals to the central nervous system, resulting in muscular rigidity or complete immobility. During this state, respiration rate may decrease, appendages are often folded close to the body, and the insect remains unresponsive to external stimuli. Neurotransmitters such as octopamine are believed to play a role in regulating this immobile state. The duration of thanatosis can range from a few seconds to several minutes, depending on predator presence and stress intensity. (Gallup, 1977; Miyatake *et al.*, 2004).

Examples of Thanatosis in Insects:

1. **Red Flour Beetle (*Tribolium castaneum*):** This beetle exhibits prolonged death-feigning behavior when disturbed, which significantly reduces predation by ants and spiders. Individuals showing longer immobility have higher survival rates (Miyatake *et al.*, 2004) Fig. 1.
2. **Grasshoppers (Order: Orthoptera):** Certain grasshopper species drop to the ground and remain motionless, blending with soil or litter and avoiding detection by birds (Edmunds, 1974) Fig. 2.
3. **Leaf Beetles (Chrysomelidae):** When threatened, many leaf beetles withdraw their legs and antennae and remain immobile, resembling dead insects or debris (Ruxton *et al.*, 2004) Fig. 3.
4. **Weevils (Curculionidae):** Weevils commonly exhibit tonic immobility when handled, a behavior that helps them escape predation during accidental encounters (Cloudsley-Thompson, 1995) Fig. 4.

Conclusion

Thanatosis is a highly effective behavioral defense strategy that enables insects to avoid predation by exploiting predator perception and behavior. By remaining motionless and mimicking death, insects reduce the likelihood of being attacked, especially by visually hunting predators. This behavior is neurologically controlled, energetically efficient, and widespread across diverse insect taxa. Thanatosis highlights the importance of behavioral adaptations in insect survival and provides valuable insights into predator-prey interactions and evolutionary ecology. (Humphreys & Ruxton, 2018; Edmunds, 1974).

References

- Cloudsley-Thompson, J. L. (1995). *Ecological adaptations of arthropods*. Springer.
Edmunds, M. (1974). *Defence in animals: A survey of anti-predator defences*. Longman.



Fig. 1. *Tribolium castaneum* feigning death. (Miyatake *et al.*, 2004)



Fig. 2. Grasshopper in thanatosis. (Edmunds, 1974)



Fig. 3. Leaf beetle feigning death. (Ruxton *et al.*, 2004)



Fig. 4. Weevil in tonic immobility. (Cloudsley-Thompson, 1995)

- Gallup, G. G. (1977). Tonic immobility: The role of fear and predation. *The Psychological Record*, 27, 41–61.
- Humphreys, R. K., & Ruxton, G. D. (2018). A review of thanatosis (death feigning) as an anti-predator behavior. *Behavioral Ecology and Sociobiology*, 72, 22.
- Miyatake, T., Katayama, K., Takeda, Y., Nakashima, A., Sugita, A., & Mizumoto, M. (2004). Is death-feigning adaptive? *Proceedings of the Royal Society B*, 271, 2293–2296.
- Ruxton, G. D., Sherratt, T. N., & Speed, M. P. (2004). *Avoiding attack: The evolutionary ecology of crypsis, warning signals and mimicry*. Oxford University Press.

CONJUNCTIVE USE OF SALINE AND FRESH WATER FOR SUSTAINABLE IRRIGATION IN ARID AND SEMI-ARID REGIONS: LESSONS FOR HARYANA AND BEYOND

Mohinder Singh^{1*}, Jitender Kumar², Sandeep Yadav³, Babita⁴ and RamAvtar⁵

¹Assistant Professor Agronomy, CCSHAU College of agriculture, Bawal

²Assistant Scientist Agronomy, CCSHAU Regional Research Station, Bawal

³Assistant Professor Physics, CCSHAU College of agriculture, Bawal

⁴Assistant Professor Microbiology, CCSHAU College of agriculture, Bawal

⁵FM, Faculty of Agricultural Sciences, SGT University, Gurugram

*Corresponding Email: Mohinder27481@gmail.com

Introduction

Water scarcity of acceptable quality has emerged as one of the most critical constraints to agricultural sustainability in arid and semi-arid regions. Rapid population growth, increasing food demand, climate variability, and over-extraction of groundwater have intensified pressure on limited freshwater resources. In many parts of India, particularly the north-western states, farmers increasingly depend on groundwater of marginal to poor quality for irrigation. It is estimated that 32 to 84% of the area in arid and semi-arid states is underlain by saline or alkali groundwater. Haryana, a leading food grain producing state, presents a striking example: 55% of its groundwater is of poor quality, comprising 18% sodic, 11% saline, and 26% saline-sodic. Despite these limitations, irrigation remains indispensable. Globally, irrigated agriculture consumes 60–80% of total freshwater withdrawals and contributes nearly 38% of global food production. In India, nearly 89% of available water resources are used for agriculture, while domestic and industrial sectors share the remainder. As freshwater availability declines, the judicious use of saline and marginal quality waters has become not merely an option but a necessity. Many research indicates that the conjunctive use of saline water (SW) and fresh water (FW)—through blending or cyclic application—can sustain crop production, improve irrigation water use efficiency (IWUE), and minimize soil degradation compared to the continuous use of saline water alone. When combined with salt-tolerant crop varieties, appropriate irrigation methods, and soil management strategies, this approach offers a scientifically sound pathway for sustaining productivity under water quality stress.

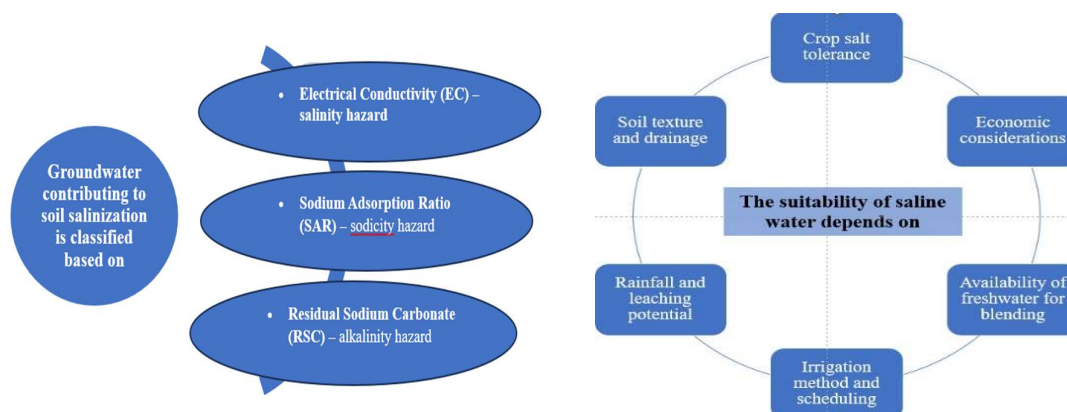
Global and National Water Scenario

Of the total global water resources, 97.5% is saline and only 2.5% is freshwater. India holds about 7–17% of the world's freshwater resources, distributed as 64% surface water and 36% groundwater. However, spatial and temporal variability in rainfall, coupled with excessive groundwater exploitation, has led to quality deterioration in many aquifers. FAO projections suggest that irrigated land area will continue to expand over the next three decades, further intensifying water demand. With freshwater resources shrinking, particularly for agriculture (Cai and Rosegrant, 2009), the use of saline water for irrigation is becoming unavoidable in several agro-ecological zones.

Groundwater Quality Problems in Arid and Semi-Arid Regions

Poor quality groundwater is most prevalent in arid, semi-arid, and coastal regions (Fig.1). Surveys across India reveal that 25–84% of developed groundwater in different states is of poor quality:

84% in Rajasthan, 62% in Haryana, 47% in Uttar Pradesh, and significant proportions in Gujarat, Karnataka, Andhra Pradesh, and Madhya Pradesh (Minhas, 1996).

**Fig. 1****Fig. 2**

Over View of Haryana

Haryana lies in the Indo-Gangetic plains between the Ganga and Indus basins and has about 80% of its area under agriculture. Tube-well irrigation dominates, but quality of underground water is good (37%), marginal (8%) and poor (55%). Among poor waters: 18% sodic, 11% saline, and 26% saline-sodic. Continuous use of such waters has led to

- Soil salinity and sodicity build-up
- Decline in soil permeability and structure
- Reduced crop yields and soil health

This needs continuous monitoring and improved management strategies for sustainable use.

Impact of Salinity on Plants and Soils

1. **Osmotic stress** – reduces water uptake
2. **Ion toxicity** – excess Na^+ and Cl^- accumulation
3. **Nutrient imbalance** – reduced uptake of K, Ca, and Mg
4. **Oxidative stress** – formation of reactive oxygen species (Gupta *et al.*, 2017)

Soil impacts include dispersion of clay particles, reduced infiltration, crust formation, and impaired root growth.

Suitability Criteria for Saline Water Irrigation

According to Ayers and Westcot (1985), waters with $\text{EC} > 3 \text{ dS/m}$ are severely restricted. However, many regions successfully irrigate with waters up to 8 dS/m under proper management. The suitability of saline water depends on many factors (Fig.2).

Conjunctive Use of Saline and Fresh Water

Research strongly supports the blending or cyclic use of saline and fresh water as an effective strategy. Methods and benefits of conjunctive use of water (Fig. 3). Boumans *et al.*, (1988) observed that farmers in Haryana successfully used shallow saline groundwater (up to 8 dS/m) for decades, often blending it with canal water. Yield reductions of 30–40% were considered acceptable compared to no irrigation.



Fig. 3

Leaching Requirement and Salt Management

Leaching is essential to prevent salt build-up.

Leaching Fraction (LF):

$$LF = \frac{D_d}{D_i} = \frac{EC_i}{EC_d}$$

Where: D_d = drainage depth, D_i = irrigation depth, EC_i = irrigation water EC, EC_d = drainage water EC. Adequate leaching through rainfall or irrigation helps maintain salinity below crop threshold levels.

Role of Irrigation Methods

Modern irrigation methods enhance saline water use:

1. **Drip irrigation:** localized wetting, reduced salt contact with roots
2. **Sprinkler irrigation:** uniform application, better leaching
3. **Furrow irrigation:** salts accumulate away from root zone

Salt-Tolerant Crops and Varieties

Crop selection is crucial. Adoption of salt-tolerant varieties significantly minimizes salinity effects.

Crops are grouped as:

1. **Sensitive:** Beans, onion, carrot
2. **Moderately sensitive:** Wheat, rice, maize
3. **Moderately tolerant:** Sorghum, mustard, sunflower
4. **Tolerant:** Barley, cotton, sugar beet

Adoption of salt-tolerant varieties significantly minimizes salinity effects.

Soil and Agronomic Management Practices

1. Application of gypsum for sodic waters
2. Addition of organic matter to improve structure
3. Conservation tillage to reduce evaporation
4. Raised bed planting
5. Mulching to prevent salt rise
6. Integrated nutrient management

These practices improve soil permeability and avoid crop failure where freshwater is absent. Though yields may decline moderately, net returns remain positive. Moreover, conjunctive use reduces environmental risks such as secondary salinization and groundwater deterioration.

Conclusion

The scarcity of good quality water in arid and semi-arid regions demands innovative irrigation strategies. Evidence from Haryana and other regions clearly demonstrates that conjunctive use of saline and fresh water, combined with appropriate crop selection, irrigation methods, and soil management, can sustain agricultural productivity while preserving soil health. Rather than viewing saline water as a liability, it should be treated as a valuable resource that, when managed scientifically, can significantly contribute to food security and rural livelihoods.

References

- Ayers, R. S. and Westcot, D. W. (1985). *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29 Rev. 1. FAO, Rome. 174 pp. ([Science and Education Publishing](#)).
- Boumans, J. H., Van Hoorn, J. W., Kruseman, G. P., and Tanwar, B. S. (1988). Water table control, reuse and disposal of drainage water in Haryana. *Agricultural Water Management*, **14** (1-4), 537-545.
- Cai, X. and Rosegrant, M. (2009). Global water demand projections. *Part 1. A Modeling approach*. Pages 159-169. <https://doi.org/10.1080/02508060208686989>
- Dagar, J. C., & Minhas, P. S. (2016). Saline irrigation for productive agroforestry systems. In *Agroforestry for the Management of Waterlogged Saline Soils and Poor-Quality Waters*, pp 145- 161. *Springer*, New Delhi.
- Gupta, D., Gulati, I. J., Yadav, N. S., & Singh, A. K. (2017). Response of Isabgol (*Plantago ovata*) to Bioregulators and Varying Water Salinity Levels Under Drip Irrigation. *Journal of Soil Salinity and Water Quality*, **9** (2), 194-199.
- Malash, N., Ghaibeh, A., Yeo, A., Ragab, R. & Cuartero, J. (2002). Effect of irrigation water salinity on yield and fruit quality of tomato. *Acta Horticulturae*, **573**, 415–423. DOI:10.17660/ActaHortic.2002.573.51. ([ishs](#))
- Minhas, P. S. (1996). Saline water management for irrigation in India. *Agricultural water management*, 30(1), 1-24.
- Minhas, P. S. (1998). Use of poor quality of waters. In: Singh GB, Sharma BR (eds) 50 years of natural resource management. ICAR, New Delhi, 327– 346.
- Minhas, P. S., & Gupta, R. K. (1992). Quality of irrigation water: assessment and management. Indian Council of Agricultural Research.

VERTICAL FARMING OF EXOTIC VEGETABLES: A FUTURE PERSPECTIVE

Saurabh Sonkar, Satya Prakash, Neetu and Akash Kumar*

Department of Vegetable Science, SVPUAT, Meerut (U.P.)

*Corresponding Email: saurabhsonkar5262@gmail.com

Abstract

Global food systems are facing unprecedented challenges due to rapid urbanization, climate change, and shrinking arable land. Vertical Farming has emerged as a disruptive technology in the field of Horticulture, offering a sustainable solution by cultivating crops in vertically stacked layers under controlled environments. This review focuses on the prospects of growing high-value exotic vegetables like lettuce, kale, and cherry tomatoes using VF. It discusses core technologies like Hydroponics, Aeroponics, and the role of LED "Light Recipes." The article concludes that while the initial investment is high, the resource efficiency and superior quality of exotic produce make vertical farming the future of urban agriculture in India.

Keywords : Vertical Farming, Exotic Vegetable, Hydroponics, Controlled Environment Agriculture (CEA), Urban Farming, Sustainability, Precision Horticulture, Food Security.

Introduction

Traditional open-field agriculture is becoming increasingly unpredictable due to erratic weather patterns and soil degradation. By 2050, nearly 70% of the global population will reside in cities, creating a massive demand for fresh produce in urban centers. Vertical Farming a component of Controlled Environment Agriculture (CEA), allows for the production of vegetables inside buildings, shipping containers, or warehouses.

In the context of Vegetable Science, exotic vegetables—those not native to India but in high demand due to changing dietary habits—are the ideal candidates for vertical farming. Crops like Broccoli, Asparagus, and Red Cabbage require specific micro-climates that are difficult to maintain in Indian fields year-round but can be easily optimized in a vertical farm.

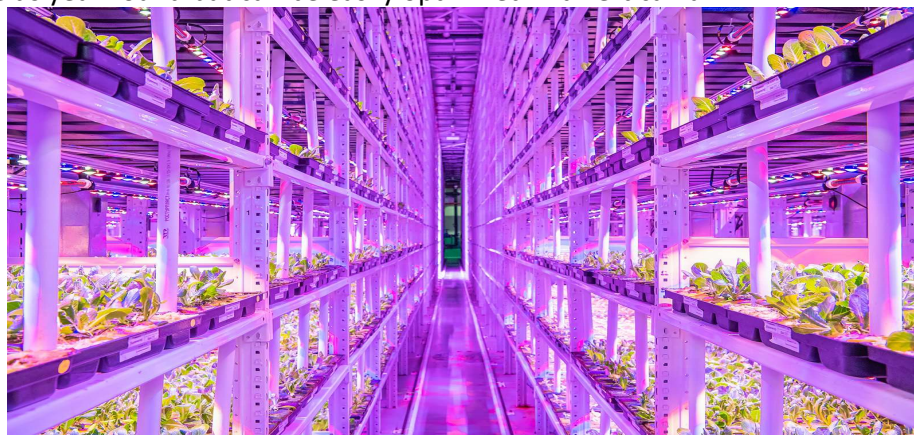


Fig. 1: A conceptual representation of a multi-tier Vertical Farming unit integrating LED lighting and stacked layers for space optimization. (Source: Wikimedia Commons)

Core Cultivation Technologies

Hydroponics: The Liquid Gold

Hydroponics is the oldest and most reliable method used in vertical farming. It involves growing plants in an "inert medium" (such as Cocopeat, Perlite, or Rockwool) that provides physical support to the roots, while nutrients are delivered directly through a water-based solution.

- **Nutrient Film Technique (NFT):** This system utilizes slightly sloped channels (typically PVC pipes) where a very thin layer (film) of nutrient-rich water flows continuously over the plant roots. This ensures that the roots remain in contact with the solution while receiving abundant oxygen. It is considered the most efficient method for fast-growing exotic leafy greens like **Lettuce** and **Arugula**.
- **Deep Water Culture (DWC):** In this system, plants are placed on floating rafts (usually styrofoam), with their roots completely submerged in an aerated nutrient solution. "Air Stones" are utilized to pump oxygen into the water to prevent root rot. DWC is highly effective for maintaining water temperature, making it ideal for high-demand herbs like **Basil** in warmer climates.
- **The Importance of EC and pH:** Monitoring **Electrical Conductivity (EC)** and **pH** is critical in hydroponics to ensure optimal nutrient bioavailability. For most exotic vegetables, the pH should be maintained between **5.5 and 6.5** to ensure the plants can effectively absorb the necessary minerals.

Aeroponics: Farming in the Air

Aeroponics is regarded as the most advanced and futuristic technique in Vertical Farming. Instead of submerging the roots in water or soil, they are "**suspended**" in the air within a closed environment.

- **Misting Mechanism:** A high-pressure pump system is used to spray the nutrient solution in the form of a fine "mist" or fog directly onto the roots. This misting occurs every few minutes, ensuring the roots stay hydrated while receiving maximum oxygen exposure.
- **Resource Efficiency:** Compared to traditional open-field agriculture, aeroponics uses **95% less water**. Because the roots are exposed to open air, plants in an aeroponic system grow up to **40% faster** than those in standard hydroponic setups.
- **Disease Control:** Since plants are physically separated and there is no continuous flow of water between them, the risk of root-borne diseases spreading from one plant to another is significantly reduced.
- **Exotic Crop Success:** Aeroponics is highly effective for crops like **Cherry Tomatoes** and **Kale**, as their root systems require high levels of oxygenation to support rapid growth and high yields.

Aquaponics: The Symbiotic Approach

Aquaponics combines aquaculture (raising fish) with hydroponics. The fish waste provides organic nutrients for the exotic vegetables, while the plants clean the water for the fish. This circular economy model is gaining traction in eco-friendly urban "Agri-tech" startups.



Fig. 2: Detailed view of an NFT (Nutrient Film Technique) setup showing the circulation of nutrient-rich water through PVC channels. (Source: Wikimedia Commons)

Why Exotic Vegetables?

Exotic vegetables are the most suitable candidates for vertical farming due to:

- **Market Demand:** High-end hotels, malls, and health-conscious urban populations create year-round demand.
- **High Profitability:** These vegetables command a premium price compared to local seasonal varieties.
- **Short Life Cycle:** Most leafy exotic greens are ready for harvest within 35–45 days, allowing for multiple harvests in a single year.

Table 1: Scientific Classification and Suitability of Exotic Vegetables in Vertical Farming

Common Name	Botanical Name	Growing System	Growth Cycle (Days)	Ideal pH Range	Market Potential in India
Lettuce	<i>Lactuca sativa</i>	NFT / DWC	25–35	5.5 – 6.5	Extremely High (Salad Industry)
Kale	<i>Brassica oleracea</i>	Aeroponics / NFT	45–60	6.0 – 7.0	High (Health & Superfood Market)
Basil	<i>Ocimum basilicum</i>	DWC	30–40	5.5 – 6.5	High (Culinary & Oil Extraction)
Cherry Tomato	<i>Solanum lycopersicum</i>	Aeroponics / Drip	70–90	6.0 – 6.8	Moderate to High (Gourmet Dining)
Arugula	<i>Eruca vesicaria</i>	NFT	20–30	6.0 – 7.0	High (Premium Italian Cuisine)



Fig. 3: High-value exotic crops cultivation at SVPUAT, Meerut: (A) Vertical Aeroponics Tower System (B) Hydroponic Floating Raft System (C) Vertical Trellising of Cherry Tomato under Protected Environment (Source: SVPUAT, Meerut)

Precision Environment Control: The Science of "Light Recipes"

One of the most technical aspects of Vertical Farming is the replacement of sunlight with **Artificial Lighting**.

- **Photosynthetically Active Radiation (PAR):** Plants only use specific wavelengths (400–700 nm).
- **Blue Light (450 nm):** Essential for chlorophyll synthesis and stomatal opening. It prevents "stretching" of exotic greens, keeping them compact and crisp.
- **Red Light (660 nm):** Promotes flowering and fruiting in crops like Cherry Tomatoes and Strawberries.
- **The "Recipe" Concept:** By adjusting the ratio of Red: Blue: Far-Red light, vegetable scientists can manipulate the flavor (sweetness or bitterness) and the texture of the leaves.



Fig. 4: The impact of specific "Light Recipes" (Red and Blue spectrum) on the growth and pigmentation of indoor-grown vegetables. (Source: Creative Commons)

Nutritional Bio-fortification in Vertical Farms

A review of recent studies suggests that vegetables grown in vertical farming can be more nutritious than field-grown ones.

1. **Secondary Metabolites:** By controlling UV-B exposure, we can increase the production of antioxidants like anthocyanins in red lettuce.
2. **Nitrate Reduction:** High nitrate levels in leafy greens are a health concern. In a controlled VF, increasing light intensity before harvest can significantly reduce nitrate concentrations.
3. **Clean Labels:** Since the environment is sealed, there is zero requirement for chemical pesticides, making the produce "Organic" in quality.

Economic Viability and Challenges

Despite the "Future Perspective," vertical farming faces hurdles in the Indian market:

- **Capital Intensity (CAPEX):** The cost of sensors, HVAC systems, and LED structures is high.
- **Operational Cost (OPEX):** High electricity consumption for 16–18 hours of lighting and climate control.
- **Technical Expertise:** Requires knowledge of both Horticulture and Engineering (IoT/Automation).

However, as solar energy becomes cheaper and automation (AI) reduces labor costs, the "Price per kg" of exotic vegetables in vertical farming is expected to drop by 40% in the next decade.

Future Perspectives: AI, Robotics, and Sustainability

The integration of Industry 4.0 technologies is turning Vertical Farming into "Precision Horticulture".

- **AI-Driven Analytics:** Artificial Intelligence is no longer a concept but a tool used to monitor "Plant Stress". Machine learning algorithms can analyze leaf color and spectral data to identify nutrient deficiencies—such as nitrogen or magnesium—up to 48 hours before any visual symptoms appear to the human eye.
- **Robotics in Harvesting:** To maintain "Clean Label" standards and hygiene, robotic arms are being developed to harvest delicate exotic greens. This reduces human contact, decreasing the risk of contamination and increasing the shelf life of the produce.
- **Circular Urban Economy:** The future envisions "Hyper-local" food systems where vertical farms are integrated into the basements of malls or residential complexes. This eliminates the "Food Miles" associated with transporting exotic produce from distant hills to urban centers, reducing the overall carbon footprint to nearly zero.



Fig. 5: Integration of Artificial Intelligence (AI) and IoT-enabled sensors for real-time monitoring of plant health, nutrient uptake, and micro-climatic variables in a smart vertical farm. (Source: AI-generated for conceptual representation)

Conclusion

Vertical Farming of exotic vegetables is no longer a science-fiction concept; it is a necessity for the 21st century. For Vegetable Science students and researchers, this field offers a vast landscape for innovation—from developing specific "Nutrient Cocktails" to designing energy-efficient LED systems. By merging traditional horticultural wisdom with modern technology, India can achieve a "Purple Revolution" in urban food production.

The Socio-Economic Impact of Vertical Farming in India Beyond the technical efficiency, Vertical Farming (VF) addresses a critical gap in the Indian supply chain: the "Last Mile" delivery. For exotic vegetables, which are highly perishable, traditional transport from hill stations (like Ooty or Shimla) to metropolitan areas (like Delhi or Bangalore) results in a 30% loss of produce due to spoilage. By establishing VF units within city limits, we can ensure "Farm-to-Fork" delivery within hours, drastically reducing post-harvest losses and ensuring that the nutrient density of the crops remains intact.

Concluding Remarks The shift from traditional horticulture to "Precision Horticulture" through Vertical Farming is no longer an option but a necessity for land-scarce, water-stressed nations like India. While the initial investment in LED technology and automation remains high, the long-term benefits of resource conservation and consistent, pesticide-free exotic produce outweigh the costs. As India moves toward becoming a global hub for smart agriculture, Vertical Farming will play a pivotal role in ensuring both food security and nutritional security for the growing urban population.

References

- Al-Chalabi, M. (2015). *Vertical farming: Skyscraper agriculture and its surprising yield*. Innovative Food Science & Emerging Technologies.
- Despommier, D. (2010). *The Vertical Farm: Feeding the World in the 21st Century*. St. Martin's Press, New York.
- Kozai, T., Niu, G., & Takagaki, M. (2018). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production*. Academic Press.
1. **NHB (2024)**. *National Horticulture Board Annual Report on Protected Cultivation*. Ministry of Agriculture & Farmers Welfare, Govt. of India.
 2. **Sharathkumar, M., et al. (2020)**. *Vertical Farming: The Future of Agriculture*. Journal of Agriculture and Ecology.
 3. **Toyoki, K. (2021)**. *Smart Plant Factory: The Next Generation of Indoor Vertical Farming*. Springer Nature.

WOMEN SCIENTISTS IN GENETICS AND PLANT BREEDING

Aprajita Singh* and Radheshyam Ramkrishna Dhole

Department of Genetics and Plant Breeding, Narayan Institute of Agricultural Sciences,
Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas (Bihar) 821305, India

*Corresponding Email: aprajita0504@gmail.com

Abstract

Genetics and plant breeding constitute the foundation of modern agriculture by enabling the development of improved crop varieties with enhanced yield potential, nutritional quality, and resilience to biotic and abiotic stresses. Over the past several decades, women scientists have played an increasingly important role in advancing research and innovation in genetics and plant breeding through contributions in classical breeding, molecular genetics, genomics, and biotechnology. Despite historical underrepresentation, women researchers have made substantial scientific, institutional, and societal contributions to crop improvement programs worldwide. This paper presents a comprehensive overview of the role of women scientists in genetics and plant breeding, highlighting their key characteristics, involvement in core components of breeding programs, operational workflows, and applications across agricultural sectors. The advantages of inclusive scientific participation and future strategies for strengthening gender equity and innovation in plant breeding are also discussed. Enhanced participation of women scientists is essential for sustainable agricultural development, food security, and climate-resilient farming systems.

Keywords: Women scientists, Plant breeding, Crop improvement, Genomics, and Sustainable agriculture.

Introduction

The scientific disciplines of genetics and plant breeding function as essential foundations for agricultural productivity, food security, and environmental sustainability. The application of genetic principles in plant breeding results in crop varieties with higher yield and better quality, increased resistance to pests and diseases, and improved environmental stress tolerance. The breeding methods have developed from basic selection together with hybridization methods into modern molecular and genomic techniques that enable scientists to control complex traits with exact precision. The agricultural sciences maintained a male-dominated structure throughout history because of social customs, educational systems, and institutional barriers that existed at that time. Women scientists have always played a vital role in genetic breakthroughs, germplasm preservation, crop research, and emerging breeding methodologies. The scientific community has developed a greater appreciation for women's accomplishments in genetics and plant breeding research because of the growing movement for gender equality in scientific fields. Women scientists currently work on various research projects that involve Mendelian genetics, quantitative genetics, marker-assisted selection, genomic selection, and genome editing. Their involvement has improved scientific productivity and fostered research partnerships between disciplines to achieve diverse agricultural development goals, which particularly benefit smallholder farmers and those operating under resource-limited conditions.

Key Characteristics of Contributions by Women Scientists

Scientific Innovation and Adaptability Women scientists have shown a strong ability to adapt their work to new technologies, which include genomics, bioinformatics, and high-throughput phenotyping. Their work with current scientific tools has enabled them to change genetic information into workable breeding methods at an accelerated rate.

Interdisciplinary Research Approach The research work led by women in plant breeding studies establishes its identity through multiple scientific fields. Women scientists use genetic and biotechnology, agronomy, and data science together to develop comprehensive solutions for agricultural problems that require advanced understanding.

Emphasis on Sustainability and Nutrition. Women researchers investigate three key areas, which include climate resilience, nutritional enhancement, and sustainable production systems. Their research combines breeding goals with international development objectives that include food security, nutrition, and environmental protection.

Capacity Building and Mentorship Women scientists provide essential support for educational programs, mentorship activities, and organizational development efforts. They develop expert human resources in genetics and plant breeding through their educational activities and student guidance work.

Important Components of Genetics and Plant Breeding

Women scientists actively contribute to all core components of genetics-based crop improvement:

Genetic Resources

The collection, characterization, and conservation of germplasm form the foundation of breeding programs. Women researchers are significantly involved in gene bank management and genetic diversity assessment.

Breeding Populations

The process of developing breeding populations involves hybridization, backcrossing, and selection to create new breeds with desirable traits and genetic diversity. The modern breeding process uses high-throughput genotyping systems together with precise phenotyping equipment. Women scientists conduct trait evaluation research in both laboratory settings and outdoor environments.

Statistical and Computational Tools

The breeding process depends on quantitative genetics, statistical modeling, and genomic prediction to make breeding decisions based on data. Women researchers play active roles in applying and refining these analytical tools.

Operational Workflow

The operational workflow of genetics and plant breeding follows a systematic and iterative process in which women scientists participate at all stages:

Germplasm Evaluation

Researchers assess different genetic materials through testing in both controlled environments and real-world agricultural settings to discover traits they seek to find.

Crossing and Population Development

Researchers cross-select parental lines to produce segregating populations, which enable them to study the entire range of genetic material.

Genotyping and Trait Analysis

Researchers employ molecular markers together with genomic tools to discover gene–trait relationships and quantitative trait loci in their study.

Selection and Advancement

Research teams choose promising lines based on their phenotypic performance together with genomic predictions and then advance these lines through multiple breeding cycles.

Applications

Applications for genetics and plant breeding research conducted or funded by female scientists are numerous. Agriculture production and food availability are increased through the development of high-yielding and stress-tolerant cultivars. Breeding for resistance to heat, salinity, drought, and flooding promotes climate-resilient farming. Programs for biofortification raise the amount of micronutrients in food, improving its quality. Additionally, women scientists support the biotechnology, hybrid creation, seed production, and crop biodiversity conservation sectors.

Advantages

There are several benefits to more female scientists working in genetics and plant breeding. Innovation and problem-solving skills are enhanced when different viewpoints are included. Research findings are more relevant and widely adopted when they are heavily focused on farmer-centric issues, especially for smallholder and female farmers. Women's leadership and mentoring roles foster collaborative research environments and increase institutional capability. Furthermore, by emphasizing sustainability, they hasten the adoption of ecologically friendly breeding techniques, strengthening agricultural systems.

Future Strategies

Specific tactics are needed to increase the contribution of female scientists in the fields of genetics and plant breeding. Equal leadership opportunities and gender-responsive policies are crucial at the institutional and policy levels. Prioritising advanced training in precision breeding, AI, and genomics is important. Multidisciplinary and international research partnerships can increase impact and visibility. Retaining talent requires flexible career options and supportive work environments. The incorporation of big data analytics, genome editing, and decision-support systems will further influence breeding initiatives in the future.

Conclusion

Women scientists have made essential contributions to genetics and plant breeding through their work, which has improved crops and advanced sustainable development and food security. Their growing participation in current breeding methods has led to scientific progress and benefits for society. Educational policy and institutional frameworks need strategic interventions to achieve their goal of empowering women researchers despite existing challenges. The advancement of gender equality in genetics and plant breeding functions as an essential scientific need that leads to the development of sustainable agricultural systems.

Reference

- Bevan, M. W., Uauy, C., Wulff, B. B. H., Zhou, J., Krasileva, K., & Clark, M. D. (2021). Genomic innovation for crop improvement. *Nature*, 590, 203–212.
- Hickey, J. M., Chiurugwi, T., Mackay, I., et al. (2020). Breeding crops to feed 10 billion. *Nature Biotechnology*, 38, 844–851.
- Tester, M., & Langridge, P. (2021). Breeding technologies to increase crop production in a changing world. *Science*, 327, 818–822.
- Bernád, V., Clarke, J. L., & Negrão, S. (2024). Women in plant science: Linking genome to phenome. *Frontiers in Plant Science*, 15, 1345678.
- Varshney, R. K., Bohra, A., Yu, J., et al. (2021). Designing future crops: Genomics-assisted breeding comes of age. *Trends in Plant Science*, 26(6), 631–649.

THE DARK SIDE OF SHINY GRAINS: WHEN POLISHING STEALS OUR NUTRITION

Yogavarsha M, R. Pungavi*, J Poojakrishna and Febavarghese

School of Agricultural Sciences, Joy University, Vadakangulam, Tirunelveli,
Tamil Nadu, India.

*Corresponding Email: r.pungavientomology@gmail.com

Introduction

The grains that shine on our plates today carry a dark nutritional truth. Polishing may enhance appearance and shelf life, but it strips away the very nutrients essential for human health. In a world driven by convenience and visual appeal, polished grains have quietly replaced their wholesome counterparts in most households—often without our awareness.

Truth behind polishing grains:

Grains are nature's nutritional storehouses. In their natural form, they consist of three parts: bran, germ, and endosperm. The bran is rich in dietary fiber and minerals, the germ contains essential vitamins and healthy fats, and the endosperm mainly provides carbohydrates. During polishing, the bran and germ are removed, leaving behind only the starchy endosperm. What remains may look clean and white, but it is nutritionally incomplete.

Hidden Nutrient Loss in Polished Grains

The growing preference for polished grains such as white rice and refined wheat flour has resulted in a significant loss of vital nutrients. Dietary fiber, B-complex vitamins, iron, magnesium, and antioxidants are stripped away during processing. Consequently, polished grains supply mostly calories with minimal nourishment often referred to as empty calories.

Health Implications of Increased Consumption of Refined Grains

One of the most serious health concerns associated with polished grains is their impact on blood sugar levels. These grains have a high glycemic index, causing rapid digestion and sudden spikes in blood glucose. Regular consumption increases the risk of insulin resistance, type-2 diabetes, obesity, and other lifestyle-related disorders. This is especially alarming in countries like India, where rice and wheat form the dietary backbone. Our grandparents thrived on coarse, unpolished grains. Today, we consume gleaming white cereals and face a rise in lifestyle diseases. The difference lies in polishing. The absence of fiber in polished grains also affects digestive health. Poor digestion, constipation, and weakened gut health are common consequences. Dietary fiber plays a vital role in maintaining beneficial gut bacteria, which support immunity and metabolism. Polished grains fail to nourish this internal ecosystem, weakening the body's natural defenses.

Traditionally, diets consisted of hand-pounded rice, millets, barley, and whole wheat. These grains provided sustained energy, strong immunity, and long-term health. The shift toward polished grains is a modern development, driven by industrial milling, urban lifestyles, and changing food preferences. Beyond health, the over-reliance on polished grains has agricultural and environmental implications. The decline in traditional grains like millets has encouraged monocropping, increased water consumption, and soil degradation. In contrast, whole grains and millets are climate-resilient, require fewer inputs, and promote sustainable farming systems.

Beyond health, the over-reliance on polished grains has agricultural and environmental implications. The decline in traditional grains like millets has encouraged monocropping, increased water consumption, and soil degradation. In contrast, whole grains and millets are climate-resilient, require fewer inputs, and promote sustainable farming systems.

Practical Steps to Overcome the Risks of Polished Grains

1. Replace polished white rice with hand-pounded rice or brown rice.
2. Choose whole wheat flour instead of refined flour (maida).
3. Include millets like ragi, jowar, bajra, and foxtail millet in daily meals.
4. Mix unpolished rice with white rice initially for gradual adaptation.
5. Read food labels and avoid highly refined grain products.
6. Encourage family members to adopt whole grains together.
7. Support local farmers and markets selling unpolished grains.
8. Create awareness that “Not all that is white is healthy.”

Conclusion

The shine of polished grains may attract the eye, but it silently steals nutrition from our plates. Polishing removes vital fiber, vitamins, and minerals, increasing the risk of lifestyle diseases. True health lies not in appearance, but in natural goodness. By choosing whole and traditional grains, we reconnect with our roots, nourish our bodies, and invest in a healthier future. In many ways, returning to whole grains is returning to wisdom.

UNVEILING BIOACTIVE PEPTIDES IN GERRES FILAMENTOUS: A NOVEL APPROACH TO FUNCTIONAL FOOD DEVELOPMENT

**S. T. Dhivya Bharathi, L. Vinoth Kumar*, G. Dhivagar, E. K. Devipriya,
M. Dhanu Pradeep and R. Gayathri**

Department of Fish Processing Technology, TNJFU- Dr.MGR. Fisheries College and Research
Institute, Ponneri, Thiruvallur District, Tamil Nadu 601204

*Corresponding Email: vinothkumar@tnfu.ac.in

Abstract

Bioactive peptides derived from marine fish proteins are increasingly recognized for their role in promoting human health and preventing lifestyle-related diseases. The present study focuses on *Gerres filamentosus*, an underutilized marine fish species, as a potential source of health-promoting bioactive peptides. Fish muscle proteins were subjected to enzymatic hydrolysis to release bioactive peptide fractions. These peptides are reported to exhibit antioxidant, antihypertensive, antimicrobial, and anti-inflammatory activities, highlighting their significance in functional food development. The utilization of *G. filamentosus* not only enhances its nutritional and economic value but also supports sustainable exploitation of marine bioresources. This review emphasizes the importance of fish-derived bioactive peptides and their application in the formulation of functional foods.

Keywords: *Gerres filamentosus*, Bioactive peptides, Functional foods, Fish protein hydrolysate, Marine resources.

Introduction

Marine organisms are considered rich sources of biologically active compounds with immense nutritional and therapeutic potential. Among marine resources, fish proteins have attracted considerable attention due to their ability to generate bioactive peptides during enzymatic hydrolysis or gastrointestinal digestion. Bioactive peptides are specific protein fragments that exert beneficial physiological effects beyond basic nutrition.

Gerres filamentosus, commonly known as whipfin silver-biddy, is widely distributed along the Indian coastal waters. Despite its abundance and nutritional richness, this species remains underexploited in value-added food processing industries. Exploring its protein profile for bioactive peptide production can open new avenues for functional food development. The present paper aims to highlight the potential of bioactive peptides derived from *G. filamentosus* and their relevance in health-oriented food applications.

Nutritional Profile of Gerres Filamentosus

Fish proteins are known for their high digestibility and balanced amino acid composition. *G. filamentosus* contains high-quality proteins, essential amino acids, low lipid content, and important micronutrients such as calcium, phosphorus, and iron. These nutritional attributes make it an ideal candidate for the extraction of functional bioactive compounds.

The presence of hydrophobic and aromatic amino acids in fish muscle proteins plays a crucial role in determining the bioactivity of derived peptides, particularly antioxidant and ACE-inhibitory properties.

Production of Bioactive Peptides

Bioactive peptides from *G. filamentosus* can be obtained through enzymatic hydrolysis using proteolytic enzymes such as pepsin, trypsin, alcalase, and papain. Enzymatic hydrolysis is preferred due to its specificity, safety, and ability to preserve peptide functionality.

The general process involves protein extraction, controlled enzymatic digestion, inactivation of enzymes, and purification of peptide fractions. The degree of hydrolysis significantly influences the biological activity of the resulting peptides.

Biological Activities of Fish-Derived Bioactive Peptides

Fish-derived bioactive peptides exhibit a range of health-promoting biological activities that make them promising ingredients for functional foods and nutraceuticals: they can act as **antioxidants** by scavenging free radicals, chelating metal ions, and inhibiting lipid peroxidation, thereby helping reduce oxidative stress linked to aging and chronic diseases; they demonstrate **antihypertensive activity** principally through inhibition of the angiotensin-converting enzyme (ACE), which limits the formation of the vasoconstrictor angiotensin II and contributes to blood pressure reduction; they possess **antimicrobial effects** against a variety of foodborne pathogens, making them useful as natural preservative agents, and they can modulate **inflammatory responses** by suppressing pro-inflammatory mediators and signalling pathways, supporting immune function and helping prevent chronic inflammation-related disorders.

Concept of Bioactive Peptides In Marine Fish

Bioactive peptides are specific protein fragments that exert beneficial physiological effects on human health beyond basic nutrition. In marine fish, these peptides are naturally encrypted within muscle proteins and are released during digestion, fermentation, or food processing. Fish-derived bioactive peptides are widely recognized for their high bioavailability, safety, and multifunctional health benefits. The protein composition of *Gerres filamentosus* makes it a promising candidate for generating such functional peptides.

Health Benefits of Bioactive Peptides From *Gerres Filamentosus*:

Bioactive peptides derived from marine fish proteins are associated with a wide range of health-promoting activities. Peptides from *Gerres filamentosus* may exhibit antioxidant properties that help neutralize free radicals and reduce oxidative stress. Certain peptide sequences can show antihypertensive activity by inhibiting angiotensin-converting enzyme, thereby supporting cardiovascular health.

In addition, fish-derived peptides are known for their antimicrobial and anti-inflammatory effects, which enhance immune response and contribute to disease prevention. These multifunctional properties highlight the importance of *G. filamentosus* as a valuable source of natural bioactive compounds for functional food applications.

Application in Functional Food Development

The incorporation of bioactive peptides derived from *Gerres filamentosus* into functional food products offers a novel approach to enhance nutritional quality and health benefits. These peptides can be utilized in protein supplements, functional beverages, nutraceutical capsules, and fortified seafood products. Their natural origin, safety, and multifunctional properties make them attractive ingredients for health-oriented food industries.

Conclusion

The present study highlights the potential of *Gerres filamentosus* as a valuable source of bioactive peptides for functional food development. The generation of health-promoting peptides from this underutilized marine fish species can improve its commercial value while contributing to human health and sustainable fisheries. Further research focusing on peptide characterization, safety evaluation, and product development is essential for successful industrial application.

References

- FAO Fisheries Technical Paper. Fish protein hydrolysates and their applications. <https://www.fao.org/3/i5555e/i5555e.pdf>
- FAO. (2020). The State of World Fisheries and Aquaculture. Food and Agriculture Organization of the United Nations, Rome. <https://www.fao.org/fishery/en>
- He, S., Franco, C., & Zhang, W. (2013). Functions, applications and production of bioactive peptides from fish proteins. *Food Research International*, 65, 247–254. <https://www.sciencedirect.com/science/article/pii/S0963996913003224>
- Kim, S. K., & Wijesekara, I. (2010). Development and biological activities of marine-derived bioactive peptides: A review. *Journal of Functional Foods*, 2(1), 1–9. <https://doi.org/10.1016/j.jff.2010.01.003>
- Korhonen, H., & Pihlanto, A. (2006). Bioactive peptides: Production and functionality. *International Dairy Journal*, 16(9), 945–960. <https://doi.org/10.1016/j.idairyj.2005.10.012>
- Nielsen, P. M., Petersen, D., & Dambmann, C. (2001). Improved method for determining food protein hydrolysis. *Journal of Food Science*, 66(5), 642–646. <https://ift.onlinelibrary.wiley.com/doi/10.1111/j.1365-2621.2001.tb04614.x>

ROLE OF VEGAN AND CRUELTY-FREE CERTIFICATIONS IN SHAPING ETHICAL CONSUMPTION

Kishor Anerao¹, Monali Joshi², Amol Dukare³ and Pratyush Kumari Rath⁴

¹Ph.D. Research Scholar, Department of Food Microbiology and Safety, CFT, VNMKV, Parbhani.

²Ph.D. Research Scholar, Department of Food Process Technology, CFT, VNMKV, Parbhani

³Ph.D. Research Scholar, Department of Food Engineering, CFT, VNMKV, Parbhani

⁴Ph.D. Research Scholar, Department of Agricultural Economics, COA, VNMKV, Parbhani

*Corresponding Email: kishoranerao135101@gmail.com

Abstract

The increasing shift toward ethical consumption has led to a growing demand for vegan and cruelty-free certifications, particularly in the cosmetics industry. Consumers are increasingly influenced by concerns related to animal welfare, environmental sustainability, and personal health, prompting them to seek products that align with their ethical values. Vegan and cruelty-free certifications serve as important tools that enhance consumer trust and guide informed purchasing decisions by providing recognizable and standardized indicators of ethical compliance. This article explores the key drivers behind the rising demand for such certifications, including increased consumer awareness, education and the influential role of social media in shaping ethical consumption patterns, especially among younger consumers. It further examines the role of certifications in legitimizing ethical markets, strengthening brand credibility and encouraging industry-wide adoption of sustainable practices. However, the article also highlights several challenges, such as consumer confusion regarding labelling, variability in certification standards, environmental concerns associated with certain vegan alternatives and cultural and regional differences in consumer behaviour. While vegan and cruelty-free certifications play a crucial role in promoting ethical consumption, a transparent and holistic approach addressing sustainability, certification rigor and consumer education is essential for ensuring long-term market credibility and impact.

Keywords: Vegan certification, Cruelty-free labelling, Ethical consumption, Sustainable cosmetics, Consumer awareness, Purchase intention

Introduction

The demand for vegan and cruelty-free certifications is growing as consumers increasingly prioritize ethical values in their purchasing decisions. This trend is particularly evident in the cosmetics industry, where consumers are motivated by concerns for animal welfare, environmental sustainability and personal health. Certifications serve as a crucial tool for consumers to identify products that align with their ethical values, thereby influencing their purchase intentions. This article explores the factors driving this demand, the role of certifications and the challenges faced by the industry.

Factors Driving Demand

Ethical and Environmental Concerns: Consumers are increasingly motivated by ethical considerations, such as animal welfare and environmental sustainability. Studies show that pro-environmental attitudes and altruistic values significantly influence the purchase of cruelty-free and vegan products (Effendi *et al.*, 2025) (Silva *et al.*, 2021).

Consumer Awareness and Education: The rise in consumer awareness about the impact of their purchasing decisions on the environment and animal welfare has led to a greater demand for products that are certified as vegan and cruelty-free (Urban, Giesey and Delost, 2022) (Gendel-Guterman & Derqui, 2021). This awareness is crucial for promoting informed choices and fostering ethical consumption within the cosmetics industry, ultimately benefiting both consumers and the environment.

Social Media Influence: Social media platforms play a significant role in spreading awareness and shaping consumer attitudes towards cruelty-free and vegan products. This has been particularly effective in reaching younger demographics who are more likely to prioritize ethical consumption (Silva *et al.*, 2021). The intersection of social media and ethical consumerism highlights the importance of targeted marketing strategies that resonate with younger audiences and their values.

Role of Certifications

Trust and Credibility: Certifications provide a level of trust and credibility that is crucial for consumers when making purchasing decisions. Recognizable logos act as visual cues that reinforce trust and brand preference, making it easier for consumers to identify products that meet their ethical standards (Effendi *et al.*, 2025). Furthermore, the effectiveness of these certifications hinges on consumers' understanding and recognition of the associated labels, which can vary significantly across different markets (Effendi *et al.*, 2025). The impact of these certifications extends beyond individual purchasing decisions, influencing broader market trends and encouraging brands to adopt more sustainable practices to meet consumer demands.

Market Legitimization: Certifications help legitimize the vegan and cruelty-free market by providing a standardized measure of compliance. This has encouraged traditional retailers to carry and develop products that meet these standards, further integrating ethical consumption into mainstream markets (Lamarche-Beauchesne, 2023). This integration not only benefits consumers seeking ethical options but also drives innovation within the cosmetics industry, pushing brands to adopt sustainable practices.

Challenges and Considerations

Confusion and Misunderstanding: Despite the growing demand, there is still confusion among consumers regarding the meaning and implications of vegan and cruelty-free labels. This highlights the need for better consumer education and clearer labeling practices (Urban, Giesey and Delost, 2022). To address this confusion, brands must prioritize transparency in their marketing strategies and enhance consumer education initiatives to clarify the significance of these certifications.

Environmental Impact of Vegan Products: While vegan products are generally perceived as environmentally friendly, some, like vegan leather, have been criticized for their environmental impact during production and disposal. This presents a challenge for the industry to balance ethical claims with actual environmental benefits (Oh *et al.*, 2023). To effectively navigate these challenges, the industry must prioritize transparency and provide consumers with comprehensive information about the environmental impacts of their products.

Cultural and Regional Differences: The motivations and purchasing behaviors of consumers can vary significantly across different cultural and regional contexts. For instance, studies in Indonesia

and Portugal highlight different factors influencing the purchase of cruelty-free products, suggesting that marketing strategies need to be tailored to specific markets (Silva *et al.*, 2021) (Amalia & Darmawan, 2023).

Conclusion

The demand for vegan and cruelty-free certifications is on the rise, it is important to consider the broader context of ethical consumption. Some critics argue that the focus on certifications can sometimes overshadow other important aspects of sustainability, such as the overall environmental impact of production processes. Additionally, the effectiveness of certifications in truly promoting ethical practices can vary, depending on the rigor and transparency of the certifying bodies. Therefore, a holistic approach that considers all aspects of sustainability and ethical consumption is essential for the continued growth and credibility of the vegan and cruelty-free market.

References

- Amalia, F. R., & Darmawan, A. (2023). Exploring consumer purchase intention towards cruelty-free personal care products in Indonesia. *Cleaner and Responsible Consumption*, 11, 100136–100136. <https://doi.org/10.1016/j.clrc.2023.100136>
- Effendi, A., Seng, N. D., & Shafiai, S. (2025). The Conceptual Framework of the Impact of Cruelty-Free and Vegan Logos on Consumer Purchase Intention towards Cosmetics in the United States. *International Journal of Research and Innovation in Social Science*, IX(VIII), 3755–3763. <https://doi.org/10.47772/ijriss.2025.908000304>
- Gendel-Guterman, H., & Derqui, B. (2021). The Vegetarian and Vegan Communities Supporting Sustainability Through Responsible Consumption. 65–76. https://doi.org/10.1007/978-3-030-76935-2_9
- Lamarche-Beauchesne, R. (2023). Vegan Consumption: Insights into the Consumer-driven Emergence of the Vegan Market. 281–296. https://doi.org/10.1007/978-3-031-33246-3_18
- Oh, J., Park, C., Ahn, D., Byun, J., & Jung, S. P. (2023). Veganomics: Current Status and Challenges. *Journal of Korean Society of Environmental Engineers*. <https://doi.org/10.4491/ksee.2023.45.7.296>
- Silva, A., Fonseca, M. J., Cardoso, P. R., Fonseca, M. C., & Teixeira, A. (2021). Factors Influencing the Purchase Intention of Cruelty-Free Cosmetics in Portuguese Consumers – An Exploratory Approach. 256–268. https://doi.org/10.1007/978-3-030-68418-1_25
- Urban, K., Giesey, R. L., & Delost, G. R. (2022). *A guide to informed skincare: The meaning of clean, natural, organic, vegan, and cruelty-free*. *Journal of Drugs in Dermatology*, 21(9), 1012–1013.

ROLE OF UNDER WATER VIDEO TECHNIQUE AND ROBOTICS IN FISHERIES

Vishva Barad*, Kailas Rathod and Niharika Chudasma

¹College of Fisheries Science, Kamdhenu University, Veraval, Gujarat, India

²College of Fisheries Science, Kamdhenu University, Veraval, Gujarat, India

³College of Fisheries Science, Kamdhenu University, Veraval, Gujarat, India

*Corresponding: vishvabarad0011@gmail.com

Introduction

Aquaculture, the farming of aquatic animals and plants has turned out to be an important industry worldwide. It occupies a very important place in the socio-economic development of the country. Successful fish culture is based on authentic breeding and feeding performance protocol. Growth and survival rates may not be sufficient to understand reasons for differences in breeding and feeding success and thus the reason of demand and supply gap. Performance based on trial and error may not provide a successful production protocols for each species. There is strong need to understand the behaviour of each species which help us to understand the condition of organism in well manner instead of trial and error of current scenario. Behaviour is the manifestation of an organism's response to both internal (physiological) and external (environmental) signals. Restriction of visibility under water makes this task more difficult but with the development of digital imaging techniques over the last decade, there are now new opportunities to study complex behavioural patterns in fish. The tracking of moving objects and the monitoring of their activities by image sequences obtained from video cameras. It is an automatized procedure that determines animal position over time and gives the resulting tracks with a large array of data such as distance travelled, speed or space used. Video multitasking, enable us to understand more than one individual tracking simultaneously. Specifically, in situations where a large number of individuals are involved, the use of video-tracking data is essential, as manual analyses would be complicated, time-consuming and sometimes even impossible. Today, multitasking allows us to observe directly the behaviours of groups and to determine the real interaction rules by sampling data collected in nature or in the laboratory, without any a previous record (Ballerini *et al.* 2008; Katz *et al.* 2011). The basic set-up of a video-tracking system consists in filming organisms, such as fish in an aquarium, with a video camera. The signal from the camera is then either transformed into a numerical video file through a frame grabber linking the camera to a computer or is directly available if the camera is digital. The signal can be processed in real time by video-tracking software.

History and importance of video techniques

The first published work reporting the use of underwater video systems in the coastal environment dates back to the 1950s. The Scottish Marine Biological Association of Millport developed an underwater video program in 1948, and tested it in the Aquarium of the Zoological Society of London in 1949 (Barnes, 1952, 1953). In 1951, the Royal Navy constructed a system which was successfully used to identify a Royal Navy submarine lost at sea in 1951. It then served for other projects on bottom fauna (Barnes, 1955) as suspended in a mid-water environment (Backus and Barnes, 1957) and for other Navy applications (Barnes, 1963). RUV has used more

frequently in marine sciences since the 1960s. It provided the first data on fish movement and behaviour in daytime and at night, which had not been previously studied without human disturbance (Barnes, 1952; Kumpf and Lowenstein, 1962). Underwater video techniques help us to understand animal behaviour and their activity, spatial and temporal pattern of fish abundance, assessment of species response to environmental condition, habitat mapping, human disturbance effect on fish species, breeding and feeding response toward any exogenous sources or disturbances. Through video techniques, one can store data first and analyse later, which is safer as this avoids a system crash or experimenter errors of calibration. Video tracking consists in recognizing and following spatially over time moving objects or organisms on the basis of typical features, which could be body shape, body colour or body greyscale level and which are visible in each frame of a video sequence (Delcourt *et al.* 2013).

Direct observation v/s video techniques

Under direct observation it's very difficult to examine fast events (fish attack, plankton escape). Based on the subjectivity of the observer it's difficult to compare with other studies and to quantify certain aspects of the behaviour: like speed, path complexity etc. while in video recordings and video analyses fast events can be examined easily, videos can be reanalyzed later. In this more behavioural aspects can be quantified which is difficult or even impossible in direct observation.

Types and assembly

- I. Remote Underwater Video (RUV)
 - a. Linked systems
 - b. Autonomous systems
- II. Baited Remote Underwater Video (BRUV)
 - a. Horizontally oriented BRUV
 - b. Vertically oriented BRUV
- III. TOWed Video (TOWV)
 - a. Seabed TOWV
 - b. Mid-water-TOWV
- IV. Diver-Operated Video (DOV)
- V. Stereo-video technique

Remote Underwater Video (RUV)

RUV systems exhibit different designs and technical features, including additional sensors, and can be distinguished in terms of their autonomy (linked or autonomous). Linked systems: the system developed by LaFond *et al.* (1961) filmed from the surface to the bottom (20 m depth) while moving up and down a vertical-rail track. It is used to study diurnal and nocturnal fish movements along with plankton dispersion and lights. The latest linked systems are permanent observatories using cables for energy supply, data transfer and instrument control (Aguzzi *et al.*, 2012). Autonomous system: Fedra and Machan (1979) used the first autonomous RUV in the North Adriatic Sea (Mediterranean) in order to study the behaviour and distribution of benthic and demersal species, their feeding activities and movement patterns, along with species interactions and the influence of environmental conditions.

Baited Remote Underwater Video (BRUV)

A BRUV system uses either a single camera or two cameras filming the area surrounding a bait used to attract fish. The bait bag is placed close to the camera, at a distance ranging between 0.5

m and 1.5 m (Ellis and DeMartini, 1995; Willis and Babcock, 2000; Heagney et al., 2007). BRUV systems are directly deployed from the boat (Watson et al., 2005; Cappo et al., 2007a, Bassett and Montgomery, 2011). The main differences among BRUV systems concern the orientation of the system in relation to the sea bottom (horizontal or vertical), which result in distinct observed abundances and species compositions (Langlois et al., 2006; Wraith, 2007). BRUV has also been used with infrared light to study nocturnal fish.

Horizontally oriented BRUV

Horizontal BRUV (H-BRUV) systems have been mainly used to study spatio-temporal variations in reef fish assemblages, the influence of depth and location upon fish and species distribution, and the effect of MPAs on biodiversity (Cappo et al., 2007b and section 3). H-BRUVs are generally set on the seafloor, though Heagney et al. (2007) used mid-water BRUV to study pelagic fish.

Vertically oriented BRUV (V-BRUV)

Vertically oriented BRUV (V-BRUV) has been used for studying the size and abundance of carnivorous fish (Babcock et al., 1999; Willis and Babcock, 2000) and the effect of protection by MPAs (Willis et al., 2000, 2003; Denny and Babcock, 2004; Denny et al., 2004; Willis and Millar, 2005). The restricted field of vision due to the camera pointing downwards ensures a constant field of view and a constant focal length, particularly where water clarity or topography varies between observations.

TOWed Video (TOWV)

Machan and Fedra (1975) introduced the first TOWed Video technique (TOWV) in shallow waters. The system was towed by a vessel at low speed (0.1 to 1 m s⁻¹). TOWV films along transect of predefined size and trajectory (30 m to 20 km). The various systems developed, were linked to the vessel by a coaxial cable and a rope. The main difference among them lies in the position at which the system operates in the water column, i.e. seabed or mid-water.

Seabed TOWV

In the coastal domain, the first TOWV systems were towed on the seabed using a sledge. The video camera is slightly angled downwards on the sledge, which carries additional equipment. Seabed-TOWVs have been used to study sea floor and epifaunal species (mostly crustaceans and flat fish). It should be noted that in shallow waters such as lagoon areas, vagile species were found to be sensitive to the boat noise.

Mid-water-TOWV

Mid-water-TOWV systems are more recent than seabed-TOWVs in shallow waters (Norris et al., 1997). These systems are towed at a constant elevation in the water column, thus providing a wider view of the seafloor compared to seabed-TOWVs. The system of Riegl et al. (2001) is set on each side of the boat with vertical tubes that can be lowered or raised between 0.5 and 3.5 m below the sea surface, so as to adjust to varying depth. They have mostly been used to characterize, quantify and assess changes in benthic flora (seagrass, macro-algae and coral) and fauna.

Diver-Operated Video (DOV)

The diver-operated video technique (DOV) consists of a diver holding a video system and filming a defined area. Observation area may vary in size (transects from 2 to 500 m,) DOV has been used to record benthic habitat along long transects (up to 500 m long). The DOV technique (Alevizon

and Brooks, 1975) involves a diver filming vertically along a transect line. DOV is generally conducted at a constant swimming speed over the entire transect (0.1 to 3 m s^{-1}).

Stereo-video technique

The stereo-video technique is not additional to those described above, but it involves a particular recording that produces a 3-dimensional (3D) image. It was developed by Harvey and Shortis (1995) to improve fish size estimation by divers. The technique simultaneously uses two cameras to record the same scene. Left and right images are synchronized on the computer based on a light-emitting diode (LED) placed at 2.5 m from the cameras and seen on both images. Images are then cross-checked from ad hoc software to obtain a 3D image allowing individual size measurement. A 1.4 m distance between the two cameras was found to provide a trade-off between the precision afforded by a greater distance and diver's ability to manoeuvre the system (Harvey and Shortis, 1995). This system recorded and measured individuals in a distance range of 2 to 10 m, depending on underwater visibility. Stereo video has been shown to provide more accurate estimates of both fish length and distance than visual estimation by divers (Harvey et al., 2001a, 2001b, 2002a, 2004) or single video (Harvey et al., 2002b). As such, it also helps distinguishing individuals (Harvey et al., 2003, 2007). Several comparisons of underwater observation techniques used stereo-video (Watson et al., 2005, 2010; Langlois et al., 2010). Shortis et al. (2009) provide a detailed review of the status of underwater stereo-video measurement and marine and ecology applications. With the same objective of measuring fish, Heppell et al. (2012) used two lasers fixed on each side of a single camera, rather than stereo-video.

What is under water drones?

Underwater drones (or ROVs) are submersible, waterproof drones that enable users to explore marine environments remotely. These drones are able to navigate through underwater currents thanks to one or more propellers. They are generally equipped with cameras, obstacle avoidance sensors, and powerful lighting to record good quality footage even in dark underwater environments.

Under water drone with camera	Battery life (min)	4 K camera	Wireless/Tethered	Country	Release year	Diving depth	Price (Dollar)
ROBOsea BIKI	120	Yes	Wireless	China	2017	60 m	799
Notilo plus iBubble	60	Yes	Wireless	France	2019	60 m	4499
Aquarobotman Memo	180	Yes	Tethered	China	2018	100m	1399
QYSEA FIFISH V6	270	Yes	Tethered	China	2019	100 m	1599
PowerVision powerRay	240	Yes	Tethered	China	2017	30 m	1987
Navatics MITO	240	Yes	Tethered	China	2019	40	1999
Blue Robotics BlueRoV2	180	No	Tethered	US	2019	100	3483
ShenZhen VxFly CCROV	270	Yes	Tethered	China	2017	100	3699
BLUE ROBOTICS PIONIOR	120	No	Tethered	Norvy	2019	150	9878
DeeP Trekker REVOLUTION	480	YES	Tethered	CANADA	2019	305	10K – 50K

SoFi – Soft Robotics Fish

SoFi - which stands for *soft robot fish* - is an aquatic android remote controlled by scientists. A team from MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) unveiled "SoFi," a soft robotic fish that can independently swim alongside real fish in the ocean. During test dives in the Rainbow Reef in Fiji, SoFi swam at depths of more than 50 feet for up to 40 minutes at once, nimbly handling currents and taking high-resolution photos and videos using a fisheye lens. Using its undulating tail and a unique ability to control its own buoyancy, SoFi can swim in a straight line, turn, or dive up or down. Existing autonomous underwater vehicles (AUVs) have traditionally been tethered to boats or powered by bulky and expensive propellers. SoFi has a much simpler and more lightweight setup, with a single camera, a motor, and the same lithium polymer battery that's found in consumer smartphones. To make the robot swim, the motor pumps water into two balloon-like chambers in the fish's tail that operate like a set of pistons in an engine. These alternating actions create a side-to-side motion that mimics the movement of a real fish. By changing its flow patterns, the hydraulic system enables different tail maneuvers that result in a range of swimming speeds, with an average speed of about half a body length per second. "The robot is capable of close observations and interactions with marine life and appears to not be disturbing to real fish," says Rus.

Future prospects

Human operated systems will continue to be used, particularly for research. But there is a wide scope for automated systems. These can be permanent stations with multiple sensors, either cabled or mobile systems transmitting information, e.g. programmed gliders (Moline and Schofield, 2009). Such advances will considerably increase the amount of data collected by underwater video systems. Several projects have been set up, example Fish4Knowledge project, which aims to analyse undersea fish videos (www.Fish4Knowledge.eu, Phoenix et al., 2013). Properly managed data is the second issue, particularly in view of long-term monitoring. Furthermore, data for biodiversity monitoring and assessment are often collected at the scale of an entire ecosystem, and they are to be shared within collaborative projects. Global commitments to conservation also entail research issues at larger scales, particularly regarding spatial patterns of biodiversity and ecosystem approaches to management and conservation (Christensen et al., 1996). Hence, for both research and monitoring purposes, observations with improved spatial coverage and resolution should be carried out in all habitats; they should document exploited and non-exploited species, as well as benthic coverage, including sensitive taxa such as sea grass and coral. These considerable information needs cannot be achieved solely through the techniques used so far, and complementary observation techniques are needed, among which video techniques, either on stand-alone basis or preferably combined with other techniques, are definitely a good idea.

Scopes and constrains

Video multitracking can make important contribution to the applied sciences. Firstly, it can be used to test potential drugs or pollutants at the social level. Second it will be useful for characterize the parameters controlling social behaviours and by monitoring the social behaviours one could study quantitatively the well-being of social species, notably in the laboratory, and in fish farms, finally challenge would be leaving the laboratory to track fish and other animal individually in nature.

Conclusion

Video multitracking is one of the techniques which can provide huge scope to understand the physiology and behaviour of the organism in an efficient manner. Which is utmost important for development of perfect protocols of feeding and breeding of any culture able species. Apart of that, this technique brings us very close to the nature and it will be easy for the researcher to work according to the nature law.

References

- Bassett, D.K., Montgomery, J.C., 2011. Investigating nocturnal fish populations in situ using baited underwater video: With special reference to their olfactory capabilities. *Journal of Experimental Marine Biology and Ecology* 409, 194-199.
- Cappo, M., De'ath, G., Speare, P., 2007a. Inter-reef vertebrate communities of the Great 830 Barrier Reef Marine Park determined by baited remote underwater video stations. *Marine 831 Ecology Progress Series* 350, 209–221.
- Delcourt, J., Denoël, M., Ylief, M., Poncin, P., 2012. Video multitracking of fish behaviour: a
- Moline, M.A., Schofield, O., 2009. Remote Real-Time Video-Enabled Docking for Underwater Autonomous Platforms. *Journal of Atmospheric and Oceanic Technology* 26, 2665-2672.
- Watson, D.L., Harvey, E.S., Anderson, M.J., Kendrick, G.A., 2005. A comparison of temperate reef fish assemblages recorded by three underwater stereo-video techniques. *Marine Biology* 148, 415 - 425.

WASTE TO WEALTH: USING AGRICULTURAL RESIDUES TO GROW MUSHROOMS FOR SUSTAINABLE RURAL DEVELOPMENT

Ayandip Maity* and Nandita Das

Department Of Agriculture, Brainware University, Barasat,
Kolkata-700125, West Bengal, India

*Corresponding Email: maityayandip@gmail.com

Abstract

Paddy straw, wheat straw, sugarcane bagasse, and banana leaves are examples of agricultural leftovers that are frequently disposed of or burnt, seriously polluting the environment. These lignocellulosic wastes can be turned into high-protein food through the creative and environmentally beneficial process of mushroom farming. The scientific foundation, culture method, economic feasibility, environmental advantages, and business possibilities of growing mushrooms from agricultural waste are all covered in this article. The study emphasises how growing mushrooms might be a viable "waste-to-wealth" paradigm, especially for small-scale farmers and young people living in rural areas.

Keywords: Mushroom cultivation, Agricultural residues, Waste-to-wealth model, Sustainable agriculture, Rural entrepreneurship

Introduction

Every year, India generates millions of tonnes of agricultural waste. Fields burn a large amount of paddy straw and other agricultural leftovers, which causes serious air pollution, soil nutrient loss, and greenhouse gas emissions. In contemporary agriculture, managing waste sustainably has grown to be a significant challenge. Agricultural waste can be broken down by the powerful lignocellulolytic enzymes found in mushrooms, especially oyster mushrooms (*Pleurotus spp.*). In about 20 to 30 days, these fungi transform low-value wastes into nutrient-dense edible biomass. Therefore, growing mushrooms is an effective biological method of recycling agricultural waste while creating jobs and revenue.

Utilising Agricultural Waste as a Substrate

Organic substrates high in cellulose, hemicellulose, and lignin are ideal for the growth of mushrooms. Frequently utilized agricultural residues include:

- **Paddy straw:** The most popular and ideal material for growing oyster mushrooms.
- **Wheat straw:** In northern India, it is widely accessible.
- **Sugarcane bagasse:** Found in large quantities in areas that produce sugar.
- **The pseudo-stem and leaves of bananas:** Beneficial in tropical regions.
- **Groundnut shells and maize cobs:** Substitute substrates

These materials are accessible locally, reasonably priced, and, if improperly handled, environmentally hazardous. By using them to produce mushrooms, trash is converted into nutritious food.

The biological foundation of waste conversion

As members of the Basidiomycetes family, mushrooms generate extracellular enzymes such cellulase, ligninase, and hemicellulase. The fungus grows by absorbing the simpler chemicals that

these enzymes break down from complex plant polymers. This biological breakdown enhances nutrient composition and decreases waste volume.

Oyster mushrooms are perfect for rural production systems since they may grow on a variety of substrates.

Methodology: Growing Mushrooms from Agricultural Waste

Gathering and Getting Ready for Substrate

After being gathered, agricultural leftovers are cut into tiny pieces (3–5 cm).

Soaking and Pasteurization

The substrate needs to be cleaned after cutting in order to get rid of impurities like mould, germs, and undesirable fungi. Various techniques can be employed based on the facilities that are available:

- **Pasteurisation with Hot Water (Low-Cost Approach)**

After soaking in clean water for six to eight hours, the chopped straw is heated to 65 to 70 degrees Celsius for one hour. This approach works well for small-scale farming.

- **Sterilisation by Autoclave (Laboratory Method)**

The wet substrate can be autoclaved for 15 to 20 minutes at 121°C and 15 psi of pressure in a laboratory or institutional setting. This approach guarantees total contamination removal and offers a greater success rate, particularly in commercial spawn production or research.

- **Sun-Drying / Solar Pasteurisation (Conventional Method)**

The substrate can be spread widely and exposed to direct sunshine for one to two days after soaking. Excess moisture and microbial burden are reduced by solar heat. It is more cost-effective and appropriate for production at the village level, but being less accurate than autoclaving.

Spawning

Within polythene bags, the cooled mushroom spawn is layered with the substrate.

1. **Incubation process** : The bags are stored in a dark, 22–30°C chamber with a humidity level of 70–80%. The substrate is colonised by mycelium in 7–10 days.
2. **Fruiting and Gathering** : Mushrooms are picked within 20 to 25 days of the appearance of tiny pinheads.

Analysis of the Economy

The facilities and land needed for mushroom farming are modest. One hundred cultivation bags can fit in a compact space.

Economic Approximation (Oyster Mushroom Model)

- Price per bag: ₹35–40 (including spawn and straw).
- Yield: 1–1.2 kilogram per bag
- Retail price: ₹120–200 per kilogram.
- The approximate net profit for 100 bags (one cycle) is ₹8,000–12,000.

It can provide rural households with consistent additional income with four to five cycles each year.

Environmental Advantages

- Lessens the burning of stubble
- Reduces emissions of greenhouse gases

- Utilises organic waste recycling
- Encourages sustainable farming
- Increases soil fertility by reusing discarded substrate.

Growing mushrooms promotes sustainable development and the circular economy.

Utilization of Spent Mushroom Substrate (SMS)

The residual substrate (SMS) is still nutrient-rich after harvest.

Uses consist of :

- Organic manure
- Synthesis of vermicompost
- The soil conditioner
- The creation of biogas
- Additive for animal feed
- This optimises resource efficiency and guarantees zero-waste output.

Nutrition and Health Significance

Mushrooms are incredibly nourishing.

- 20–30% protein (dry weight basis)
- Packed with vitamins B-complex
- Vitamin D is present in sun-dried mushrooms.
- Free of fat and cholesterol
- A lot of dietary fibre

They provide vegetarian cultures with an inexpensive source of protein.

The Potential of Rural Entrepreneurship

Cultivating mushrooms can be combined with:

- Self-help organisations (SHGs)
- FPOs, or Farmer Producer Organisations
- Businesses run by women
- Young businesses

Opportunities for value addition include:

- Dehydrated mushrooms
- Powdered mushrooms
- Pickle
- A soup mixture
- Snacks made with mushrooms

The growing of mushrooms as a source of revenue is being promoted by agricultural universities and government training programs.

Problems and Potential Fixes

Challenge	Solution
Contamination	Maintaining hygiene and pasteurisation
Variability in temperature	Budget-friendly humidity chambers
Access to markets	Local branding along with direct marketing
Insufficient awareness	Programs for training and extension

Conclusion

Growing mushrooms from agricultural waste is a sustainable and lucrative "waste-to-wealth" business strategy. It creates jobs and revenue while addressing significant environmental issues like burning crop residue. It provides small farmers and rural youth with a workable option with low investment and quick production cycles.

Mushroom farming makes a substantial contribution to sustainable agriculture, the circular economy, and rural development by turning agricultural waste into wholesome food and organic manure. Agricultural waste management can become a chance for economic development if this model is promoted at the local level.

References

- Chang, S. T., & Miles, P. G. (2004). Mushrooms: Cultivation, nutritional value, medicinal effect, and environmental impact (2nd ed.). CRC Press.
- Food and Agriculture Organization of the United Nations. (2013). Mushroom cultivation for people with disabilities. FAO.
- Kumar, P., & Sharma, V. (2018). Utilization of crop residues for mushroom production. *Journal of Agricultural Sustainability*, 12(3), 45–58.
- Royse, D. J., Baars, J., & Tan, Q. (2017). Current overview of mushroom production in the world. *Applied Microbiology and Biotechnology*, 101(20), 7337–7353. <https://doi.org/10.1007/s00253-017-8498-5>

WEED SEED BANK DYNAMICS AND ITS IMPLICATION FOR MANAGEMENT

Balamurugan S¹, R. V. A. Reddy², Malothu Chandu Lal³ and Gourav Sabharwal⁴

^{1,2&3} Ph. D. Scholar, Department of Agronomy, Navsari Agricultural University, Navsari, Gujarat - 396 450.

⁴ Ph. D. Scholar, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu - 641 003.

*Corresponding Email: balaagronomy06@gmail.com

Weed seed bank

The weed seed bank serves as a storage reservoir for dormant weed seeds and is a vital part of the weed life cycle. It acts as the source of future weed populations for both annual weeds and perennial weeds that reproduce solely through seeds. The weed seed bank comprises viable weed seeds present on the soil surface as well as those distributed throughout the soil profile. It includes newly shed seeds and older seeds that have remained viable in the soil for several years. Agricultural soils may harbour thousands of weed seeds along with numerous vegetative weed propagules per square foot. Understanding the nature and dynamics of the weed seed bank enables better prediction and management of potential crop-weed competition, thereby helping to minimize adverse effects on crop yield and quality.

Fate of weed seeds in the seed bank

- After dispersal into a field, weed seeds may experience several possible outcomes, but only a small proportion ultimately emerge and develop into plants.
- The majority of seeds perish due to death, decomposition or consumption before germination occurs. Even among those that germinate, many fail to survive long enough to form mature plants.
- Seed predation is generally highest when weed seeds remain on the soil surface and adequate crop residue is present to support predator activity, as in no-till systems. Predators such as ground beetles and crickets can lower weed seed emergence by about 5 to 15%, while larger animals like rodents and birds are also capable of consuming substantial quantities of weed seeds. When seeds are buried and inaccessible to predators, they are more likely to be attacked by soil-borne pathogens.
- Lethal germination occurs when seeds germinate from greater soil depths, causing seedlings to exhaust their stored energy reserves before reaching the soil surface. Many weed species, such as *Kochia scoparia* (L.), can detect their depth of burial and adjust germination behaviour to reduce the risk of lethal germination.
- Seed desiccation is another important mortality factor, especially under extreme summer or winter conditions. However, seeds rapidly lose their tolerance to desiccation when exposed to repeated short cycles of wetting and drying before germination is completed.

Management of weed seed bank

Soil and crop management

- Minimizing the addition of seeds to the seed bank is the most straightforward approach to lowering the weed seed bank.

- Any practice that decreases the population and size of seed-producing weeds will consequently reduce the number of seeds returned to the seed bank.
- While many agronomic practices influence the weed seed bank indirectly, only a limited number of key methods have a direct impact on weed seed input, the persistence of seeds in the seed bank and their germination from the seed bank.

Herbicides

- Herbicides have been and remain, the most effective tools for weed management throughout the 20th century.
- Pre-harvest applications of glyphosate can reduce seed production and negatively affect seed viability in late-flowering weeds. However, because glyphosate acts slowly, weeds must be controlled well in advance of maturity to prevent seed shedding.

Tillage

- The extent of soil inversion and the depth of tillage have a strong influence on the vertical distribution of weed seeds within the soil seed bank.
- When a mouldboard plough is used, about 37% of the viable weed seeds are located in the upper 5 cm of the soil profile, whereas under no-till conditions this proportion increases to 74%. In contrast, chisel ploughing places approximately 61% of the weed seeds near the soil surface.
- In addition, tillage exposes buried weed seeds to a brief exposure of light, which can break seed dormancy. Soil disturbance caused by tillage also enhances nitrogen mineralization, thereby stimulating the germination of certain weed seeds.
- The accumulation of seeds on the soil surface under reduced tillage systems increases their accessibility to predators and may result in higher seed removal rates. Reduced soil disturbance can also support larger predator populations.
- Consequently, no-till fields often exhibit greater numbers, diversity and activity of seed-feeding organisms compared with conventionally tilled fields, likely due to improved habitat conditions and reduced mortality.

Crop rotation

- Introducing perennial crops in annual cropping systems tends to deplete the soil seed bank of annual species over a period of time.

Mulching

- Crop residues form micro-habitats that offer shelter for animals that consume weed seeds. These residues also help buffer soil temperature variations, which can influence the dormancy status of many small-seeded broadleaf weeds.
- In addition, residues from certain crop species contain allelopathic compounds that suppress seed germination, such as those released by rye (*Secale cereale* L.) and clover (*Trifolium* spp. L.).

Nutrient management

- In the long term, proper timing and placement of nitrogen fertilizer can decrease the seed banks of many weed species by as much as 50%, with spring band application at the time of seeding proving to be the most effective method.

- Notably, banding nitrogen fertilizer significantly lowered populations of green foxtail and stinkweed, particularly under no-tillage cropping systems.
- In contrast, broadcasting nitrogen fertilizer on the soil surface during the fall enhances weed competitiveness by increasing their access to nutrients, thereby promoting weed growth and expanding the weed seed bank.
- Additionally, composting manure prior to field application reduces the viability of weed seeds, thus limiting the introduction of new weed seeds into the seed bank.

Conclusion

One of the most critical, though frequently overlooked, approaches to weed management is lowering the quantity of weed seeds present in the field, thereby restricting future weed infestations during crop production. This goal can be achieved through effective management of the weed seed bank. Limiting the addition of new seeds to the seed bank is a key aspect of this approach, while practices such as no-till cropping systems and mulching can directly influence weed seed germination, survival and mortality. Consequently, weed seed bank management forms an essential part of integrated weed management strategies.

References

- Hossain, M. M.; Begum, M.; Hashem, A.; Rahman, M. M.; Haque, M. E. and Bell, R. W. (2021). Continuous practice of Conservation Agriculture for 3-5 years in intensive rice-based cropping patterns reduces soil weed seedbank. *Agriculture*. 11(9): 895.
- Hossain^b, M. M.; Begum, M.; Hashem, A.; Rahman, M. M.; Ahmed, S.; Hassan, M. M. and Bell, R. W. (2021). Strip tillage and crop residue retention decrease the size but increase the diversity of the weed seed bank under intensive rice-based crop rotations in Bangladesh. *Agronomy*, 11(6): 1164.
- Hossain, M. M. and Begum, M. (2015). Soil weed seed bank: Importance and management for sustainable crop production-A Review. *Journal of the Bangladesh Agricultural University*. 13(2): 221-228.

SUSTAINABLE LAND MANAGEMENT PRACTICES FOR DEGRADED LANDSCAPES

Neekita^{1*} and Ravinder Kaur²

¹Student, Department of forestry, School of Agriculture,
Dev Bhoomi Uttarakhand University

²Assistant Professor, School of Agriculture, Dev Bhoomi
Uttarakhand University

*Corresponding Email: nikitabhauryal42@gmail.com

Abstract

Land degradation is a critical global challenge that threatens agricultural productivity, biodiversity, and human livelihoods. It results from both natural processes, such as soil erosion, drought, and flooding, and anthropogenic activities, including deforestation, overgrazing, mining, and improper land management. Approximately 25–30% of the Earth's land surface is degraded, affecting billions of people and making sustainable land management (SLM) an urgent priority. This article reviews the causes and consequences of land degradation and highlights key SLM strategies for restoring productivity and ecological health. Approaches such as soil restoration techniques, water management practices, vegetation-based interventions like agroforestry, and integrated land use planning are discussed. The study emphasizes that adopting these practices can enhance soil fertility, conserve water, support biodiversity, and improve livelihoods. Effective implementation requires the integration of scientific knowledge, community participation, and policy support. The findings underscore that sustainable land management is essential for ecological restoration, long-term land productivity, and environmental security.

Keywords: Sustainable land management, land degradation, soil conservation, agroforestry, ecological restoration, climate-smart etc.

Introduction

Land degradation is a growing global concern that threatens agricultural productivity, biodiversity, and human livelihoods. A degraded landscape is an area where the natural capacity of land to support vegetation, wildlife, and human use has been reduced due to physical, chemical, or biological deterioration (Food and Agriculture Organization of the United Nations [FAO], 2017).

Land is an indispensable non-renewable resource that is rapidly degrading as a result from both natural events such as soil erosion, drought and flood etc, as well as human interventions including land stress, deforestation, overgrazing, mining and improper land management. Approximately 25–30% of the Earth's land surface is already degraded, affecting an estimated 3.2 billion people through declining land productivity, making sustainable land management an urgent global priority (United Nations Convention to Combat Desertification [UNCCD], 2017).

According to the Food and Agriculture Organization of the United Nations (2026), sustainable land management (SLM) as “the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions”.

Restoration of degraded land can be achieved through integrated approaches like agroforestry, rainwater harvesting, improved livestock management, tree-based farming, conservation agriculture (crop rotation, mulching, no till) etc.

The article focuses on the causes and consequences of land degradation and highlighting the sustainable land management strategies to support and enhances the ecological restoration and land productivity.

Land degradation

A degraded landscape is an area where the natural capacity of land to support vegetation, wildlife, and human use has been reduced due to physical, chemical, or biological deterioration (Food and Agriculture Organization of the United Nations [FAO], 2017). Land degradation encompasses processes such as soil erosion, nutrient depletion, salinization, and desertification, driven by both natural events and human activities including deforestation and overgrazing. These processes significantly diminish soil fertility, biodiversity, and the land's capacity to retain water, thereby undermining ecosystem stability. Beyond environmental impacts, land degradation also carries serious socio-economic consequences, particularly through reduced agricultural productivity and income, which heighten the vulnerability of rural communities that depend directly on land resources for their livelihoods (IPBES, 2018; Lal, 2015).

The productivity of some lands has declined by 50% due to soil erosion and desertification. On a global scale the annual loss of 75 billion tons of soil costs the world about US\$400 billion per year, or approximately US\$70 per person per year. Only about 3% of the global land surface can be considered as prime or Class I land and this is not found in the tropics. Another 8% of land is in Classes II and III. This 11% of land must feed the six billion people today and the 7.6 billion expected in 2020. Desertification is experienced on 33% of the global land surface and affects more than one billion people. (Smith & Lee, 2015).

Causes : Soil is the most fundamental and basic natural resource for all life to survive. Water and wind erosion are two main agents that degrade soils. Runoff washes away the soil particles from sloping and bare lands while wind blows away loose and detached soil particles from flat and unprotected lands. (Balasubramanian, 2017).

Wind erosion - Wind erosion significantly alters soil characteristics, leading to reduced agricultural productivity. It selectively removes finer soil fractions such as silt and clay, leaving behind coarser sand and gravel. Over many years, this sorting process results in soils becoming progressively coarser until only infertile skeletal material remains, forming shifting sand dunes and gravelly pavements. Soils derived from glacial till, residual material, mountain outwash, and sandy deposits of various origins are particularly susceptible to this process. In some cases, wind removes surface soil non-selectively, as observed in loss soils deposited from the atmosphere during past geological areas.

The loss of organic matter, plant nutrients, and changes in soil texture due to wind erosion directly reduce soil productivity. Historical studies indicate that wind erosion severely affected cultivated lands, leading to abandonment at rates of 1 in 40 acres of class II land, 4 in 40 acres of class III land, and 7 in 40 acres of class IV land every 22 years. Extrapolating these data suggests that all class II, III, and IV lands in affected areas would eventually be abandoned in 880, 293, and 126 years, respectively. Finnell (2013) reported that even the loss of a few inches of soil could

reduce productivity by 40 percent, and in areas of severe erosion, productivity could drop by 60 percent or more, with up to 80 percent of affected land abandoned. (Lyles, 1975).

Water erosion

Detachment of soil particles from aggregates primarily by raindrops and flowing water and their transport by runoff water are involved in soil erosion by water. Soil erosion by water is considered to be one of the major forms of soil degradation (other than soil erosion by wind, acidification, salinization, desertification, etc.) and causes the majority of problems related to the degradation of soil resources, leads to the largest amount of soil loss, and covers the greatest extent of areas affected worldwide. This subject is very wide, and there are even many forms of soil water erosion, from splash erosion to gully erosion and sedimentation. (Centeri, 2022).

The principal types of soil erosion by water are splash erosion, sheet erosion, interrill erosion, rill erosion, gully erosion, landslides, and stream erosion. Soil erosion has on-site and off-site effects. The on-site effects include loss of soil, loss of organic matter and nutrients, damage to growing crops, exposure of plant roots, and decline in soil fertility and productivity. The off-site effects are burrowing of crops and installations, siltation of reservoirs, eutrophication of ponds and lakes, pollution of water, etc. Several agronomic and engineering practices are employed for the control of water erosion. These are no-tillage, minimum tillage, mulching, strip cropping, contour cropping, contour strip cropping, and terracing, but several methods are needed to be integrated for an efficient soil erosion control. (Osman, 2013).

Sustainable Land Management Practices

Soil Restoration Techniques

Organic amendments such as compost improve soil fertility and structure. Conservation tillage reduces erosion and maintains moisture, while mulching protects soil surfaces and enhances microbial activity. Together, these approaches rebuild soil health. Lal (2015); Montgomery (2007).

Water Management Strategies

Rainwater harvesting improves soil moisture availability. Contour bunding and terracing reduce runoff and erosion. Efficient irrigation methods such as drip irrigation conserve water and enhance plant productivity. FAO (2011); Rockström *et al.*, (2010).

Vegetation-Based Approaches

Afforestation and agroforestry stabilize soils and support biodiversity. Cover crops protect soil between growing seasons and contribute organic matter, enhancing long-term land resilience. Nair (1993); IPBES (2018).

Integrated Land Use Planning

Crop rotation and mixed farming maintain soil fertility and diversify risk. Landscape-level planning supports ecological balance and sustainable resource use. World Bank (2006); FAO (2017).

Conclusion : Our land is the foundation of life, and protecting it is crucial for both humans as well as for nature. Sustainable land management practices like restoring soil, conserving water, planting trees, and planning land use carefully—can bring degraded landscapes back to life. These approaches not only improve crop yields and support wildlife, but also strengthen local communities that depends on the land. By working together, combining knowledge, local action, and supportive policies, we can restore and enhance the health and productivity of our land for ourselves as well as for future generations.

References

- Bal Subramanian, A. (2017). Soil erosion – causes and effects. Centre for Advanced Studies in Earth Science, University of Mysore, Mysore. <https://www.scribd.com/document/445065343/SoilErosionCausesandEffects>
- Centeri, C. (2022). Soil water erosion. *Water*, 14(3), 447. <https://doi.org/10.3390/w14030447>
- Finnell, H. H. (1949). Dust storms come from the poorer lands (Leaflet No. 260). U.S. Department of Agriculture. <https://digital.library.unt.edu/ark:/67531/metadc3521/>
- Food and Agriculture Organization of the United Nations. (2017). Voluntary guidelines for sustainable soil management. FAO. <https://www.fao.org/3/bl813e/bl813e.pdf>
- Food and Agriculture Organization of the United Nations. (n.d.). Sustainable land management. FAO. Retrieved February 17, 2026, from <https://www.fao.org/land-water/land/sustainable-land-management/en/>
- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2018). Assessment report on land degradation and restoration. IPBES. <https://ipbes.net/assessment-reports/ldr>
- Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, 7(5), 5875–5895. <https://doi.org/10.3390/su7055875>
- Lyles, L. (1975). Possible effects of wind erosion on soil productivity. *Journal of Soil and Water Conservation*, 30(6), 279–283. <https://www.ars.usda.gov/ARSUserFiles/30200525/1466%20Possible%20effects%20of%20wind%20erosion%20on%20soil%20productivity.pdf>
- Montgomery, D. R. (2007). *Dirt: The erosion of civilizations*. University of California Press. [https://openlibrary.org/books/OL7712236M/Dirt: The Erosion of Civilizations](https://openlibrary.org/books/OL7712236M/Dirt:_The_Erosion_of_Civilizations)
- Nair, P. K. R. (1993). An introduction to agroforestry. <https://link.springer.com/book/10.1007/978-94-011-1608-4>
- Osman, K. T. (2013). Soil erosion by water. In *Soil degradation, conservation and remediation* (pp. 69–101). Springer. <https://link.springer.com/book/10.1007/978-94-007-7590-9>
- Rockström, J., Karlberg, L., Wani, S. P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J., & Qiang, Z. (2010). Managing water in rainfed agriculture—The need for a paradigm shift. *Agricultural Water Management*, 97(4), 543–550. <https://doi.org/10.1016/j.agwat.2009.09.009>
- Smith, J., & Lee, A. (2015). Types of land degradation and impacts. *Journal of Environmental Science*, 12(3), 45–60. <https://doi.org/xxxx>
- United Nations Convention to Combat Desertification. (2017). *Global Land Outlook: First edition (GLO1)*. UNCCD. <https://www.unccd.int/resources/global-land-outlook/glo1>
- World Bank. (2006). *Sustainable land management: Challenges, opportunities, and trade-offs*. World Bank. <https://openknowledge.worldbank.org/handle/10986/7182>

BAMBOO SHOOTS: NUTRITIONAL, MEDICINAL AND VALUE-ADDED POTENTIAL

Ankit Yadav¹, K.N. Shah¹, Indra Jeet Chaudhary², D.K. Rana¹ and Abhay Singh^{1*}

¹Department of Horticulture, HNBGU Srinagar-246174, Uttarakhand, India

²Savitribai Phule Pune University, Pune-411007, Maharashtra

*Corresponding Email: abhaysingh3757@gmail.com

Abstract

Bamboo shoots, the tender emerging culms of bamboo species, are widely consumed in Asian countries and are increasingly valued as nutritionally rich functional foods. They are low in fat and calories but rich in dietary fiber, quality protein, essential amino acids, minerals, vitamins, and bioactive compounds such as phenolics and phytosterols. However, the presence of cyanogenic glycosides (taxiphyllin) necessitates proper processing before consumption. Traditional and modern techniques including boiling, fermentation, drying, and canning effectively reduce cyanide content while enhancing shelf life and sensory quality. Bamboo shoots also exhibit antioxidant, hypolipidemic, anti-inflammatory, and anti-diabetic properties. Their growing industrial value addition offers promising opportunities for nutrition, health, and rural livelihoods.

Keywords: Bambooshoot; Detoxification; Nutrition; Phytochemicals; Sustainability

Introduction

Bamboo shoots are the tender, edible emerging culms that develop from the underground rhizomes of bamboo plants belonging to the family *Poaceae* and subfamily *Bambusoideae* (Singhal *et al.*, 2013; Wang *et al.*, 2020; Sarkar *et al.*, 2025). Globally, bamboo comprises more than 1,200 species distributed primarily in tropical and subtropical regions of Asia, Africa, and Latin America (Choudhury *et al.*, 2012). Several of these species produce edible shoots that are widely consumed in Asian countries such as China, Japan, Thailand, and India, where they are integral to traditional cuisines (Acharya *et al.*, 2023; Wang *et al.*, 2020). In India, particularly in the North-Eastern states, bamboo shoots hold significant cultural and dietary importance (Sarkar *et al.*, 2025).

The shoots are typically harvested at an early developmental stage, around 20–30 cm in height, before lignification and fiber accumulation increase (Chetia *et al.*, 2022). Early harvesting ensures improved tenderness, enhanced palatability, and better nutrient retention (Wang *et al.*, 2020; Acharya *et al.*, 2023). Beyond their role as a traditional vegetable, bamboo shoots are increasingly recognized as functional foods due to their low energy value, high dietary fiber, and presence of diverse bioactive compounds (Singhal *et al.*, 2013; Sarkar *et al.*, 2025).

Nutritionally, bamboo shoots are characterized by high moisture content (85–92%), low caloric value (27–45 kcal/100 g), and minimal fat content, making them suitable for weight-management diets (Wang *et al.*, 2020; Singhal *et al.*, 2013). They contain moderate protein levels (2.3–3.9 g/100 g) with essential amino acids such as lysine and leucine, along with carbohydrates and dietary fiber that support digestive and metabolic health (Nirmala *et al.*, 2011; Choudhury *et al.*, 2012). Additionally, they provide essential minerals including potassium, calcium, and iron, as well as vitamins like vitamin C and B-complex vitamins (Singhal *et al.*, 2013; Chetia *et al.*, 2022).

Anti-Nutritional Factors and Detoxification

While bamboo shoots offer significant nutritional benefits, they inherently contain cyanogenic glycosides, particularly taxiphyllin, which can generate hydrogen cyanide (HCN) through enzymatic hydrolysis and may cause toxicity if eaten raw (Singhal *et al.*, 2013; Chetia *et al.*, 2022). The concentration of taxiphyllin varies among species and is influenced by maturity stage and environmental conditions, with higher levels generally observed in freshly harvested and immature shoots (Wang *et al.*, 2020; Sarkar *et al.*, 2025).

Thermal processing plays a crucial role in detoxification because taxiphyllin is heat-labile and water-soluble, allowing significant reduction through boiling and steaming (Wang *et al.*, 2020; Singhal *et al.*, 2013). Boiling sliced bamboo shoots for 10–30 minutes, particularly in mild saline solutions, has been reported to effectively reduce cyanide content to safe levels while preserving nutritional quality (Chetia *et al.*, 2022). Discarding the cooking water further enhances cyanide removal due to leaching of soluble compounds (Wang *et al.*, 2020; Chetia *et al.*, 2022). Traditional fermentation practices, widely adopted in North-East India and Southeast Asia, also contribute to detoxification by promoting microbial degradation of cyanogenic compounds and improving flavor and shelf stability (Acharya *et al.*, 2023).

Medicinal and Functional Properties

Bamboo shoots are increasingly recognized as functional foods due to their high dietary fiber, phenolic compounds, flavonoids, and phytosterols, which are associated with various health-promoting effects (Singhal *et al.*, 2013; Wang *et al.*, 2020). These bioactive constituents provide significant antioxidant activity by neutralizing free radicals and reducing oxidative stress, a key factor linked to chronic diseases such as cardiovascular disorders and diabetes (Acharya *et al.*, 2023; Sarkar *et al.*, 2025). Experimental studies have demonstrated notable free radical scavenging potential in bamboo shoot extracts, with variations influenced by species, maturity stage, and processing methods (Singhal *et al.*, 2013; Chetia *et al.*, 2022).

In addition to antioxidant activity, bamboo shoots exhibit hypolipidemic and metabolic benefits due to their fiber and phytosterol content, which enhance bile acid excretion and reduce intestinal cholesterol absorption (Sarkar *et al.*, 2025; Wang *et al.*, 2020). Their low-glycemic and fiber-rich composition may also improve glycemic control and insulin sensitivity (Singhal *et al.*, 2013; Wang *et al.*, 2020). Furthermore, anti-inflammatory and antimicrobial properties have been reported, particularly in fermented products, although further clinical studies are required to validate these therapeutic effects (Acharya *et al.*, 2023; Choudhury *et al.*, 2012).

Processing and Value Addition

Fresh bamboo shoots are highly perishable due to rapid respiration, moisture loss, and post-harvest lignification, which reduce tenderness and shelf life within a few days of harvest (Choudhury *et al.*, 2012; Singhal *et al.*, 2013). Increased fiber accumulation during lignification negatively affects sensory quality, making timely processing essential to preserve nutritional and organoleptic properties (Wang *et al.*, 2020; Sarkar *et al.*, 2025). Traditional preservation methods such as fermentation, drying, salting, and pickling are widely practiced in bamboo-growing regions to enhance shelf stability and safety (Sarkar *et al.*, 2025). Fermentation is particularly important as it improves flavor, reduces cyanogenic glycosides, and enhances microbial safety, while drying reduces moisture content but requires optimization to minimize nutrient losses (Acharya *et al.*, 2023; Chetia *et al.*, 2022; Wang *et al.*, 2020).

Modern technologies including blanching, canning, freezing, and vacuum packaging have further improved commercial viability and storage stability (Choudhury *et al.*, 2012; Wang *et al.*, 2020). These processes ensure enzyme inactivation, microbial safety, and extended shelf life, while value-added products such as bamboo shoot powder, ready-to-eat snacks, and fortified bakery items enhance market diversification and nutritional appeal (Sarkar *et al.*, 2025; Acharya *et al.*, 2023).

Socio-Economic Importance

Bamboo shoots play a significant socio-economic role in bamboo-growing regions, especially in North-East India, where they contribute to household nutrition, seasonal income generation, and food security (Sarkar *et al.*, 2025; Acharya *et al.*, 2023). Bamboo-based agroforestry systems provide ecological sustainability while supporting rural livelihoods through harvesting, processing, and local marketing activities (Singhal *et al.*, 2013; Wang *et al.*, 2020). In many indigenous communities, bamboo shoots are closely linked to cultural traditions and local dietary practices, strengthening economic resilience and social identity (Choudhury *et al.*, 2012).

The commercialization of bamboo shoots has expanded to national and international markets, particularly in processed forms such as canned and fermented products (Choudhury *et al.*, 2012). Growing global demand for plant-based and functional foods has encouraged the development of organized processing industries in several Asian countries (Wang *et al.*, 2020; Sarkar *et al.*, 2025). In rural India, value addition through fermentation, drying, and small-scale processing units enhances income opportunities, supports women-led enterprises, and reduces post-harvest losses through improved value chains and infrastructure (Acharya *et al.*, 2023).

Conclusion

Bamboo shoots are nutritionally valuable due to their high fiber, moderate protein, essential minerals, vitamins, and bioactive compounds. Their low calorie and fat content supports heart health and metabolic balance, while antioxidant properties enhance their functional significance. Although the presence of cyanogenic glycosides requires proper processing, methods such as boiling and fermentation effectively ensure safety. In addition to health benefits, bamboo shoots also support rural livelihoods and sustainable agroforestry systems, underscoring their nutritional and socio-economic importance.

Reference

- Acharya, B., Behera, A., Sahu, P. K., Dilnawaz, F., Behera, S., Chowdhury, B., & Mishra, D. P. (2023). Bamboo shoots: An exploration into its culinary heritage in India and its nutraceutical potential. *Journal of Ethnic Foods*, 10(22), 1–14.
- Bhatt, B. P., Singha, L. B., Singh, K., & Sachan, M. S. (2003). Commercial edible bamboo species of the North Eastern Himalayan region, India. *Journal of Bamboo and Rattan*, 2, 347–354.
- Bhatt, B. P., Singha, L. B., Singh, K., & Sachan, M. S. (2005). Some commercial edible bamboo species of North East India: Production and utilization. *Journal of Bamboo and Rattan*, 4, 1–7.
- Chetia, I., Rathi, S., Purkayastha, M. D., Saikia, A., & Baishya, S. (2022). Bamboo shoot processing—Effects on nutritional and anti-nutritional quality from Assam, India. *International Journal of Environment and Climate Change*, 12(12), 460–471.

- Choudhury, D., Sahu, J. K., & Sharma, G. D. (2012). Value addition to bamboo shoots: A review. *Journal of Food Science and Technology*, 49(4), 407–414.
- Nirmala, C., Bisht, M. S., & Bajwa, H. K. (2008). Bamboo shoots as a health food: Nutritional and functional properties. *Food Reviews International*, 24(3), 318–334.
- Nirmala, C., Bisht, M. S., & Haorongbam, S. (2011). Nutritional properties of bamboo shoots: Potential and prospects for utilization as a health food. *Comprehensive Reviews in Food Science and Food Safety*, 10(3), 153–169.
- Sarkar, P. K., Bhattacharjee, B., Das, S., Das, B., Singh, N. R., Bhutia, P. L., Chakrabarti, A., Podder, R., & Choudhury, B. U. (2025). Edible bamboo shoots: A sustainable nexus of nutrition, livelihood, and food security for rural communities in India. *Frontiers in Nutrition*, 12, 1654510.
- Singhal, P., Bal, L. M., Satya, S., Sudhakar, P., & Naik, S. N. (2013). Bamboo shoots: A novel source of nutrition and medicine. *Critical Reviews in Food Science and Nutrition*, 53(5), 517–534.
- Wang, Y., Chen, J., Wang, D., Ye, F., He, Y., Hu, Z., & Zhao, G. (2020). A systematic review on the composition, storage, and processing of bamboo shoots: Focusing on the nutritional and functional benefits. *Journal of Functional Foods*, 71, 104015.

INTERVENTIONS OF NANOTECHNOLOGY IN HORTICULTURE

**H. Bhavana*, S. Akshitha, B. Ashok, P. Parameshwar,
R. Preetham Goud and D. Naga Harshitha**

Teaching Associate, Department of fruit science, College of Horticulture,
Malyal, SKLTGHU, Telangana.

*Corresponding Email: harshambhavana06@gmail.com

Abstract

Nano technology has been thriving as a cutting-edge instrument in many scientific fields, such as chemistry, physics, medicine, materials science, aerospace, pharmaceutical, agriculture, food science, and even horticulture. Nanoparticles due to their unique properties offer innovative solutions in crop improvement and protection. Nanomaterials such as nano fertilizers enhance nutrient uptake efficiency, reducing environmental impact and optimizing resource utilization. Similarly, nano pesticides exhibit increased efficacy in pest and disease management, reducing the need for conventional chemical treatments. Furthermore, nano sensors contribute to real-time monitoring of environmental parameters, offering valuable insights for precision horticulture. Despite the promising applications, the integration of nanotechnology in horticulture faces challenges related to environmental impact, ethical considerations, and regulatory frameworks. From enhancing nutrient management to revolutionizing pest control and growth regulation, nanotechnology holds immense potential for advancing sustainable and efficient practices in horticultural systems.

Keywords: Nanotechnology, nanoparticles, nano fertilizers, nano-sensors

Introduction:

The continual expansion of the global population has significantly increased the demand for all types of agricultural crops. Although the conventional farming system, via the application of chemical fertilizers and pesticides, increases crop yield, these chemicals have detrimental effects on the environment. Farmers have inclined to overuse these fertilizers, much more than the amount required by the plants. A high dose of conventional fertilizer does not further increase crop yield; instead, it gets wasted in the agricultural field. Nano technology has been applied in agriculture to increase crop yield. Applying different nano formulations, such as nano fertilizers and nano pesticides, has demonstrated encouraging results. Nano fertilizers add nutrient value to plants, which can alleviate certain nutrient deficiencies caused by low consumption of calcium, zinc, and iron. Nano fertilizers positively influence varied stages of plant growth, including seed germination, plant growth, flowering, and fruiting. In addition, some nano fertilizers, such as zinc oxide nano particles and nano molybdenum, can remediate soil contaminated with heavy metals (e.g., cadmium, arsenic, and copper). Nano technology in horticulture is used as nano-fertilizers, nano-pesticides, nano-sensors and also as smart packaging and in post-harvest management (Akshay *et al.*, 2024).

Nano-fertilizers in Horticulture

Nano-fertilizers are gaining increased importance in horticulture as they hold the potential to address the distinct requirements and challenges associated with cultivating fruits, vegetables,

and ornamental crops. In horticulture, precise management of nutrients is paramount for achieving optimal crop quality and yields. Nano-fertilizers present a promising solution by enabling the controlled and targeted release of nutrients to plants. This precision guarantees that crops receive the correct nutrients at the appropriate times and in optimal quantities, resulting in healthier plants with enhanced resilience against diseases and pests. Moreover, nano-fertilizers can be tailored to tackle specific nutrient deficiencies commonly found in horticultural crops (Vermal *et al.*, 2024).

Nanoscale characteristics facilitate more effective penetration of plant tissues, promoting improved nutrient uptake and utilization. This not only reduces fertilizer wastage but also contributes to sustainable farming practices by minimizing nutrient runoff and groundwater contamination. Additionally, nano-fertilizers hold the potential to alleviate the environmental impact of horticulture. By enhancing nutrient utilization efficiency, they can help mitigate the adverse consequences associated with excessive fertilizer application, such as soil degradation and water pollution. As horticulturists strive to meet the escalating demand for high-quality fruits, vegetables, and ornamental plants, nano-fertilizers emerge as a valuable tool for achieving these objectives while simultaneously addressing sustainability and environmental considerations.

Nanocomposite fertilizers, including ZnFeMnB (zinc, iron, manganese, boron) and NPKMg (nitrogen, phosphorus, potassium, magnesium), along with macro- and micro-scale nano fertilizers such as zinc, boron, chitosan, and calcite, have been demonstrated to significantly enhance the vegetative and reproductive characteristics of several fruit trees, including coffee, date palm, strawberry, pomegranate, mango, and grape (Zahedi *et al.*, 2019). Nano N & K - 2 ml/l (M1) in combination with nano (Zn+Fe+B+Mg)-2 ml/l (N1) has recorded significant results with respect to flowering, fruiting, shelf life and quality of mango when compared to M3N5 - KNO₃-10g/l in combination with micro-nutrient mix (Bhavana *et al.*, 2025).

Nano-pesticides in Horticulture

Nano-pesticides present an alternative to address the limitations associated with conventional insecticides. These are plant protection chemicals where either the active ingredient or the carrier molecule is developed using nanotechnology. Similar to other pesticide formulations, nano-pesticide formulations consist of the active ingredient, the carrier molecule, and surfactants. Key advantages of nanoparticles include improved solubility of active ingredients, enhanced formulation stability, gradual release of the active ingredient, and increased mobility due to smaller particle size and larger surface area. Nano-pesticides are expected to enhance the mode of action against target pests compared to bulk materials. Additionally, nano- formulations provide systemic properties, uniform leaf coverage, and improved soil characteristics, supporting their constructive application in agriculture (Rana *et al.*, 2021).

A key advantage of nano pesticides lies in their capacity for targeted pest control. Their nanoscale dimensions enable superior adherence to plant surfaces, ensuring comprehensive coverage and facilitating penetration of pests' protective barriers, such as exoskeletons. This targeted strategy amplifies pest control efficacy while minimizing the quantity of pesticides needed, thereby reducing environmental impact and potential harm to non-target organisms. This controlled release not only improves crop yield and quality but also diminishes the need for frequent pesticide applications, resulting in cost savings for growers and a reduced environmental

footprint. In horticulture, where the aesthetics and quality of produce are paramount, nano pesticides represent a transformative tool. Their precise application minimizes the risk of pesticide residues on harvested fruits, vegetables, or ornamental plants, ensuring consumer safety and meeting rigorous quality standards.

Nanomaterial-based kaolin particle films act as a physical barrier to manage insect pests, including the Mediterranean fruit fly (*Ceratitis capitata*) (Diptera: Tephritidae) and the Southern green stink bug (*Nezara viridula*) (Heteroptera: Pentatomidae) (Salerno *et al.*, 2019). Furthermore, nano gel-based low molecular mass gelators of methyl eugenol (ME) have been developed for the effective management of *Bactrocera dorsalis*, a major pest impacting various commercial fruit crops (Bhagat *et al.*, 2013).

Nano-sensors in Horticulture

Nano-sensors are instrumental in detecting or sensing various quantities like temperature, humidity, and moisture. Leveraging the unique properties of nanomaterials, nano-sensors have the capability to identify and measure physical volumes on the nanoscale. These nanoscale devices play a crucial role in measuring physical quantities, converting them into detectable signals for analysis. In today's landscape, diverse types of nano-sensors have been introduced to the market and are under development for a range of applications, prominently in the defense, environmental, healthcare sectors and also brings significant advancements to horticulture, transforming the monitoring and management of crops. Comprising nanomaterials, these minuscule sensors are employed in agricultural settings to collect real-time data on factors critical for crop well-being and productivity. In horticulture, nano sensors play a pivotal role in monitoring soil conditions, including moisture levels, nutrient content, and pH, exhibiting exceptional precision. This data empowers horticulturists to optimize irrigation schedules, ensure timely nutrient supply to plants, and maintain ideal soil conditions for optimal crop growth. Additionally, nano sensors prove invaluable in disease and pest management. They can identify early signs of pathogen infestations or pest attacks by monitoring changes in plant physiology or the presence of specific biomarkers. This early detection enables growers to implement timely interventions, minimizing crop losses and decreasing the reliance on chemical treatments. Nano sensors also play a crucial role in precision agriculture in horticulture by providing insights into microclimatic conditions such as temperature, humidity, and light levels. By gathering data at the microscale, horticulturists can create optimal growing environments in greenhouses or controlled settings, ensuring year-round cultivation of high-value crops.

Nano-technology in smart packaging and post-harvest management in Horticulture

Many fruits are highly perishable and have a short shelf life. Tender tropical fruits like bananas, mangoes, and papayas are in high demand in export markets and are essential for the livelihoods of producers. Maintaining freshness is critical, as these fruits deteriorate rapidly and are prone to damage. It is estimated that up to 40% of produce in tropical countries is lost during post-harvest handling. Collaborative research involving partners from Canada, India, and Sri Lanka has uncovered a promising innovation: the use of nanotechnology with a natural plant extract called hexanal to slow down fruit ripening. Hexanal works by inhibiting an enzyme in plants that disrupts cell membranes during the ripening process. Nanotechnology in horticultural smart packaging revolutionizes post-harvest management by extending shelf life, maintaining quality, and reducing waste through nanocomposite films, antimicrobial coatings (silver, zinc oxide), and

sensors. These materials regulate gas exchange, moisture, and temperature, while active packaging protects against contaminants and pathogens.

Post-harvest spoilage from pathogens (including fungi and bacteria) further contributes to fruit decay. Stable silver nanoparticles (AgNPs) obtained from the peel of black grapes (*Vitis vinifera*) have been assessed for their effectiveness against a range of pathogens, including *Bacillus cereus*, *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa*, demonstrating significant antibacterial activity. These AgNPs nanofibers have been found to prevent decay and enhance the shelf life of strawberries and lemons (Kowsalya *et al.*, 2019). Additionally, silver nanoparticles produced from various citrus peel extracts have shown antibacterial properties against *Pseudomonas aeruginosa*, *Escherichia coli*, and *Salmonella typhimurium* (Reenaa and Aathira, 2017). Kumar *et al.* (2019) described that using a fabricated agar-ZnO nanocomposite film improved the postharvest shelf life of green grapes. In studies involving Mazafati dates.

Constraints of Nanotechnology in Horticulture

- The potential uptake of nanoparticles by plants, along with their biotransformation and translocation pathways, yields both positive and negative consequences. However, the lack of recognized formulations, comprehensive monitoring, and risk management impedes the development and deployment of nanoparticles as nano-fertilizers.
- Nanomaterials exhibit associations with soil microbes, influencing nutrient uptake in plants due to their ability to modify intercellular activity. Concerns arise in human health as nanoparticles can readily enter biological systems and cross cell membranes during spraying, potentially reaching vital organs like the liver, brain, or heart.
- Findings suggest negative impacts of nano-fertilizers, emphasizing the need for systematic assessments covering risks to human health, food security, ecosystem impacts, standardized crop formulas, and guidelines.
- Cost remains a limiting factor, as the development and production of nanomaterials can be expensive, hindering accessibility for small-scale farmers or resource-limited horticultural operations.

Reference

- Akshay Mehta, Alkesh Yadav, Aman Kumar, Kanika and Manish (2024). Role of nanotechnology in horticulture: An overview *International Journal of Advanced Biochemistry Research*. 8(1): 702-708
- Bhagat, D., Samanta, S. K., & Bhattacharya, S (2013). Efficient management of fruit pests by pheromone nanogels. *Scientific Reports*, 3(1), 1–8.
- Bhavana H, Bhagwan A and Samuel Sparjan Babu D (2025). *International Journal of Research in Agronomy*. 8(5): 593-600
- Kowsalya, E., Mosa, C. K., Balashanmugam, P., Tamil, S. A., Jaquiline, & Chinna Rani, I. (2019). Biocompatible silver nanoparticles/poly (vinyl alcohol) electrospun nanofibers for potential antimicrobial food packaging applications. *Food Packaging and Shelf Life*, 21, 100379.
- Kumar, S., Boro, J. C., Ray, D., Mukherjee, A., & Dutta, J (2019). Bionanocomposite films of agar incorporated with ZnO nanoparticles as an active packaging material for shelf life extension of green grape. *Heliyon*, 5(6), e01867.

- Rana RA, Siddiqui MN, Skalicky M, Brestic M, Hossain A, Kayesh E (2021). Prospects of nanotechnology in improving the productivity and quality of horticultural crops. *Horticulturae*. 258.7(10):332.
- Reenaa, M., & Aathira, S. M. Synthesis of silver nanoparticles from different citrus fruit peel extracts and a comparative analysis on its antibacterial activity (2017). *International Journal of Current Microbiology and Applied Sciences*, 6(7), 2358-2365.
- Ruchi Verma, Nitisha Chettri, Rahul Kumar, R. K. Roshan, Preeti Kumari, Satyarath Sonkar, Suman Kumari and Abhijit Rongpi. 2024. Nanotechnology Interventions in Fruit Production: Enhancing Production and Quality. *International Journal of Plant and Soil Sci.*, vol. 36, no. 11, pp. 575-586.
- Salerno, G., Rebora, M., Kovalev, A., Gorb, E., & Gorb, S. (2019). Kaolin nano-powder effect on insect attachment ability. *Journal of Pest Science*.

CABLE BACTERIA: THE LIVING ELECTRICAL WIRES BENEATH OUR FEET

Ganga Nair* and Aleena Joy

College of Agriculture, Vellanikkara, Thrissur

Corresponding Email: gnair181102@gmail.com

Abstract

The discovery of cable bacteria introduced multicellular filamentous organisms that work as living electrical wires beneath the soil and sediment surface. They belong to the family Desulfobulbaceae and can form chains of upto 10000 cells extending several centimetres in length. They have the unique ability to perform Long Distance Electron Transport (LDET), where they harvest energy by oxidising sulfide in the deep anaerobic layers and transporting the resulting electrons to the oxygen consuming cells in the surface layers. This conduction of electrons is takes place through the special conductive fibres arranged inside the cell envelope, utilizing a novel nickel dependent co- factor which provides them a unique identity distinguishing from other electron transporting microbes. They have several applications especially in agricultural sector such as helping to mitigate sulfide toxicity, mobilizing essential nutrients and reducing methane emissions in rice ecosystem. They are being explored as sustainable biomaterials for biodegradable electronics and environmental remediation.

Keywords: cable bacteria, LDET, nickel dependent co- factors, sustainable biomaterials

Beyond beneficial microbes: Introducing the live electrical wires

We have heard and read widely about a wide range of beneficial microorganisms such as *Rhizobium* which fixes atmospheric nitrogen in soil, *Pseudomonas* which solubilizes phosphate and mobilizes potassium in soil, *Lactobacillus* which helps in digestion of lactose and supports immunity, *Bifidobacterium* which dominates the gut and helps in the breakdown of complex carbohydrates and *Saccharomyces*, a beneficial yeast that prevents diarrhea and supports gut health. The relatively recent discovery of filamentous bacteria among sediments, whose interactions occur via electricity aroused the interests of the scientific community around the globe. Now, let us dive deeper to various aspects of these 'living electrical wires'.

Discovery

About a decade ago, the studies of Lars Peter Nielsen, a microbiologist from Aarhus University in Denmark, led to the discovery of the cable bacteria. He noticed that the sediments collected from Aarhus harbour were stinky and saturated with hydrogen sulfide. Eventually in a span of weeks it was found that the sediments turned paler and the sulfide levels dropped. This observation was vital and mysterious at the same time, as no geochemical process could result in the depletion of sulfide. Further, scientists detected the presence of an electric current through mud. They ruled out the possibility of metallic shuttling of electrons which led to a conclusion that the only plausible source of these occurrences seemed to be a biological entity that consumed sulfide to liberate electrons.

Electron microscopic studies of the samples led to the identification of thin, long, bacterial filaments consisting of stacks of cells. They gave the name cable bacteria upon being inspired by

the structure of bacterial filaments, which resembled long cables. On performing 16S rRNA sequencing, the bacteria was placed in the family Desulfobulbaceae which also contained other sulfate-reducing and aerobic sulfide-oxidizing microbes. The cable bacteria clade includes *Candidatus Electronema*, a freshwater cable bacterium, and *Candidatus Electrothrix*, a marine cable bacterium. Freshwater cable bacteria was selectively enriched through agar pillar gradient columns, but they have not yet been isolated in pure culture. As predicted by scientists the cable bacteria genomes had similarities with sulfate-reducing bacteria. Still, they are classified as mixotrophs and chemolithoautotrophs which oxidize sulfide by reversing the sulfate reduction pathway. The establishment of Center for Electromicrobiology at Aarhus University is solely for studying this microbial wonder for unravelling the mechanisms of electron transport and metabolism.

The Architecture of the Biological Cables

After several experiments and discussions, the scientists got to know about the architecture of cable bacteria. They are long, multicellular, filamentous micro-organisms capable of generating and mediating electrical currents across centimeter scale distances. They are found to be residing in the surface layer of marine, freshwater and aquifer sediments. Their filaments consist of long, unbranched chains of cells which can extend up to 30-70mm length. In a single filament about 10^4 cells are included. In addition, they possess a gliding motility to orient themselves in the redox gradients in aquatic sediments. They form dense networks in these sediments and their metabolism can affect the local ecosystem functioning and elemental cycling.

On further analysis it was found that the conductive structures are located within the cell envelope of the cable bacterium filaments. Scanning electron microscopy (SEM), indicated that the outer surface of the filaments possessed unusual topography with parallel ridge compartments running along the whole length of the cable bacterium filaments. Across cell junctions the ridges were continuous and unbranched. The diameter varied between 0.63 and 2.40 micrometers and the number of parallel ridge structures varied between 15 and 54 micrometers. After the observations it was found that ridge compartments of the cable bacteria could harbour the conductive structures. On advanced technological studies it was observed that cable bacteria possess a sturdy and resilient cell envelope structure and can withstand osmotic forces. The ridge compartments had a half circular shape and the cell junctions had an internal structure resembling a cartwheel with a central node and spokes arising radially from it.

Long Distance Electron Transport

The discovery of cable bacteria led to the research based on long distance electron transport. Researches on the physiology and metabolism of these bacteria helped us to understand the mechanism of electricity generation from biological entities. They harvest energy from the deeper layers of sediments. Sulfide from these sediments is initially oxidized to elemental sulfur through the enzyme sulfide: quinone oxidoreductase (SQR), then sulfur is oxidized to sulfate and the last step involves the production of ATP by substrate level phosphorylation by the enzyme sulfate adenylyltransferase.

As they can assimilate carbon from both inorganic and organic sources, they are classified as mixotrophs or facultative chemoautotrophs. Further analysis indicated the presence of CO_2 fixation in them. They store energy as polyphosphate and polyglucose. The mechanism of electron

conduction in cable bacteria is still under debate, but once the electrons from the oxidation of sulfides are loaded into the conductive fiber their unloading onto an electron acceptor occurs in the oxic zone. The earlier studies on sediments provided evidence that cable bacteria could monopolize the oxygen consumption in the sediments i.e. at high densities nearly 81% of the oxygen consumption could be attributed to LDET (Long Distance Electron Transport). It is interesting to note that only 10% of the bacterial cells were found in the oxic zone, which means that a small number of cells directly in contact with oxygen handles the electrons produced in the deeper sediment layers by the oxidation of sulfide which reaches the upper cells through LDET. This 10% of cells consumes oxygen at a very high rate. Genetic studies reveal that cable bacteria have special oxygen reducing enzymes and these are not mainly used for energy production. Also, cable bacteria uses oxygen to dispose excess electrons, rather than producing energy efficiently similar to what is seen in some other bacteria such as *Geobacter*.

The detailed study on the growth cycle of cable bacteria revealed that its growth was too rapid to be apical as in the case of *Streptomyces* and fungi. Its life cycle was connected with anodic and sub oxic metabolism progressing through four stages resembling Gram-negative bacteria along with a series of modifications for the elongation of fibers and construction of cartwheel structure. The assimilation stops and electrons are internally accumulated waiting to be discharged when the filaments do not have access to oxygen.

After the conduct of several experiments, it was found that conduction in cable bacteria occurs through proteins with nickel dependent co-factors. This observation is remarkable as biological electron transport involves Fe and Cu metalloproteins. A particular nickel group found in periplasmic fibers has a unique chemical fingerprint (Raman signature) which suggests the discovery of a completely new kind of co-factor and this finding offered new insights in studying cable bacteria. Electron conduction in cable bacteria needs to span centimeters, as a result, the electron transport needs to be highly efficient, requiring organic structures with high conductivity. Periplasmic fibers which are the current bearing structures have high mean fiber conductivities. The electron transport mechanism in cable bacteria remains unclear, but the importance of novel nickel co-factor cannot be ignored. The electron transporting metalloproteins depends on distance between metal centers and that the nickel atoms are homogenously distributed throughout the conductive fiber core. The distance between nickel atoms is 1.4 to 1.9nm leading to an electron tunneling time of 50-90ns.

Applications

After understanding the fundamental aspects of cable bacteria, many applications have been conceived. They are found to be associated with the roots of aquatic plants such as rice and this could mitigate sulfide toxicity in rice and sea grass meadows. It plays an important role in biogeochemical cycling by acidifying their immediate surroundings which in turn mobilizes essential plant nutrients like phosphates and iron. They also have a potential role in nitrogen fixation eventually leading to generation of ammonia and thus improving nitrogen availability to plants. Inoculation of cable bacteria can significantly reduce methane emissions in rice-vegetated soils, since cable bacteria compete with methanogens for the same substrates.

Conductive fiber sheaths from cable bacteria can serve as biomaterials for designing electronic components, development of biodegradable electronics and to reduce e-wastes. Nano wires from electroactive bacteria like *Geobacter* can also be used for the same purpose but its use is limited

due to short distance electron transfer. Cable bacteria have successfully transcended the micrometer conduction range and can be used in long range electron transfer which proves its use in designing electronic components. Cable bacteria were also demonstrated to work as transistors in designing computational circuits. Their activity can account for oxygen consumption and sulfide depletion in the sediments resulting in sulfate accumulation and pH fluctuations. They can also affect the fluxes of elements such as calcium, iron, manganese, nitrogen and phosphorus. They also play a major role in element recycling contributing to mitigation of environmental problems such as recovering self-purification capacity, enhancing petroleum hydrocarbon degradation, alleviating phosphorus eutrophication and delaying euxinia (A condition where there is no dissolved oxygen and sulfides are at a high level which usually occurs in stagnant water).

Conclusion

The discovery of cable bacteria reshaped our understanding of microbial metabolism and long distance electron transport in natural environment. They demonstrate how multicellular prokaryotes can couple redox reactions exerting control over sediment chemistry and biogeochemical cycling. With the help of their unique filamentous architecture, conductive periplasmic fibers and novel nickel based co-factors they bridge the gap between biology and electricity. Apart from mitigating sulfide toxicity regulating oxygen consumption influencing nutrient cycling they also hold biotechnological applications. Their roles in sustainable agriculture, methane emission reduction and development of biodegradable and bioelectronic materials must be given relevance for ruling out their future prospects. Several aspects of the electron transport mechanism of cable bacteria are yet to be unveiled but further research can contribute more to the field of electro-microbiology making it one of the most interesting discoveries of the modern era.

Reference

Aiyer, K. Cable Bacteria: Electric Marvels of the Microbial World. ASM Microbiology Resource (2022). American Society for Microbiology. <https://share.google/6QKa4l6LcdxMXGxmA>

CAPERS: THE UNTAPPED MEDITERRANEAN SPICE WITH EMERGING POTENTIAL FOR INDIAN AGRICULTURE

Enugula Naveen^{1*}, Manchyala Divya¹ and Y. Deepthi²

^{1*} Ph.D. Scholar, Department of Plantation, Spices, Medicinal and Aromatic Crops, HC&RI, Tamil Nadu Agricultural University, Coimbatore (T.N.).

¹Ph.D. Scholar, Department of Floriculture and Landscaping, Dr. YSR Horticultural University, College of Horticulture, Anantharajupeta, Andhra Pradesh.

²Ph.D. Scholar, Department of Fruit Science, Dr. YSR Horticultural University, College of Horticulture, Anantharajupeta, Andhra Pradesh.

***Corresponding Email:** navin.enugula@gmail.com

Abstract

Capers -the pickled unopened flower buds of *Capparis spinosa* L. are an ancient Mediterranean condiment prized for their sharp, tangy flavour and distinctive aroma. Beyond culinary value, they are rich in bioactive compounds such as flavonoids (quercetin and rutin), offering antioxidant and potential health benefits. Adapted to arid and semi-arid climates with minimal inputs, capers thrive on marginal soils where many conventional crops struggle. Despite growing global demand in gourmet and nutraceutical markets, India largely depends on imports. This article examines caper biology, agro-climatic suitability, propagation, cultivation practices, post-harvest processing, economic prospects, constraints and pathways to develop capers as a high-value niche spice crop for Indian farmers.

Keywords : *Capparis spinosa*; capers; spice crop; arid agriculture; quercetin.

Introduction

Spice crops have shaped India's agricultural heritage and global culinary identity for millennia. Black pepper, cardamom, turmeric and chilli command significant acreage and export value, but the changing global palate and rising interest in functional foods have opened opportunities for new, high-value crops. One such crop is the **caper** -harvested as the green unopened flower bud of the *Capparis* shrub. Although little known in mainstream Indian agriculture, capers are integral to Mediterranean cuisine and are gaining prominence in international markets.



Capers possess a unique flavour profile combining saltiness, acidity and floral bitterness, making them indispensable in sauces, salads, pasta and pickles. Scientifically, they are rich in flavonoids such as quercetin and rutin, which are associated with antioxidant and anti-inflammatory properties, positioning them as ingredients in nutraceutical and functional food sectors. Their ecological adaptability, especially to drought and poor soils, makes them viable for climate-smart agriculture, particularly in India's semi-arid landscapes.

What Are Capers?

Capers are the unopened flower buds of *Capparis spinosa*, a perennial shrub of the Capparaceae family. After harvest, buds are dried or wilting-treated and then *cured* in salt, brine, or vinegar to develop their signature pungent aroma and piquant taste. Caper *berries*, the mature fruit, are also processed similarly and valued as a gourmet product. Capers are classified by bud size; smaller buds fetch higher prices due to superior texture and flavour.

Agro-Climatic Suitability and Adaptation

Capers are native to Mediterranean climates characterized by hot, dry summers and mild, wet winters. They perform well in:

- **Temperature:** 20-35°C
- **Rainfall:** Low to moderate
- **Soils:** Sandy, gravelly, calcareous, well-drained
- **pH:** Neutral to slightly alkaline

These attributes align with conditions in India's semi-arid zones, parts of Rajasthan, Gujarat andhra Pradesh, Telangana, Karnataka and Tamil Nadu, where water scarcity and soil salinity limit the productivity of many conventional crops. Capers' deep root systems and drought tolerance make them suitable for *dryland agriculture*, enabling productive use of rocky or marginal lands with limited input investment.

Propagation and Cultivation Practices

Capers can be established from seeds or vegetative cuttings. However, seed propagation poses challenges due to seed dormancy and slow germination rates. Dormancy-breaking treatments (e.g., scarification, temperature stratification) are necessary to improve uniformity and establishment. Vegetative propagation (stem cuttings) is often preferred for faster establishment and uniform crop stands.

Key cultivation practices include:

- **Land preparation:** Light tilling to create a well-drained seedbed
- **Planting:** Wider spacing (e.g., 2 × 2 m) due to bushy habit
- **Irrigation:** Minimal; only during establishment
- **Fertilization:** Low nutrient input; organic manures recommended
- **Weed management:** Critical in early growth stages
- **Pest and disease:** Generally low incidence; root rot can occur under excessive moisture

Capers are *perennial* and can remain productive for up to 20–30 years, providing long-term returns once established. However, productive yields typically begin after 2–3 years, requiring patience and investment in early years.

Harvesting and Post-Harvest Processing

Harvesting capers is labour-intensive and must be done by hand to capture buds at the right stage, tight and green, for optimal quality. Harvesting usually occurs early morning to preserve bud freshness.

Processing is where value addition occurs. Typical steps include:

1. Wilting or partial drying to reduce moisture
2. Size grading (smaller buds command premium prices)

3. Curing in salt, brine, or vinegar
4. Packaging and storage for domestic or export markets

Proper grading and hygienic processing are essential to meet international quality standards and food safety regulations.

Nutritional and Pharmacological Importance

Capers are rich in flavonoids (quercetin, rutin) and phenolic compounds with strong antioxidant activities. These compounds have been studied for anti-inflammatory, hepatoprotective, antidiabetic and antimicrobial properties, expanding capers' appeal beyond gastronomy into nutraceutical markets. However, because cured capers are high in sodium, consumption should be balanced in sodium-restricted diets.

Economic Prospects and Market Dynamics

Global demand for capers is growing, driven by interest in Mediterranean cuisine and premium food products. Countries such as Turkey, Spain, Morocco and Italy are major producers and exporters. In contrast, India currently imports most capers, despite having suitable agro-climatic zones for cultivation.

For Indian farmers, capers represent:

- Crop diversification into high-value commodities
- Import substitution potential
- Export opportunities in niche markets
- Climate-resilient farming options for drylands

The economics of caper cultivation are favourable due to low input costs, long productive lifespan and premium prices in international markets, especially for smaller, well-processed buds.

Challenges and Way Forward

Despite promising prospects, several constraints hinder caper mainstreaming in India:

- Limited quality planting material
- Seed dormancy and propagation challenges
- Lack of farmer awareness and extension support
- Absence of organized processing and market linkages

Addressing these gaps requires:

- Development of certified nurseries and germplasm pools
- Standardized propagation and agronomic packages
- Training programs for farmers and processors
- Cooperative processing units for curing and packaging
- Market linkage pilots targeting export and high-end domestic buyers

Research institutions, agribusinesses and policymakers must collaborate to realize capers' potential as a specialty spice crop.

Conclusion

Capers, long appreciated in Mediterranean cuisine, hold significant promise for Indian agriculture as a high-value, climate-smart spice crop. Their suitability for arid and marginal lands, low input requirements and growing global demand for gourmet and functional foods position them well for inclusion in crop diversification strategies. With focused research, extension and value-chain

development, capers can transform dryland farming landscapes, offering enhanced income opportunities for smallholder farmers and contributing to India's spice export portfolio.

Literature Cited

- Annaz H, Sane Y, Bitchagno G.T.M, Ben Bakrim W, Drissi B, Mahdi I, El Bouhssini M and Sobeh M (2022). Caper (*Capparis spinosa* L.): An Updated Review on Its Phytochemistry, Nutritional Value, Traditional Uses and Therapeutic Potential. *Frontiers in pharmacology*. 13:1-22
- Chedraoui S, Abi-Rizk A, El-Beyrouthy M, Chalak L, Ouaini N and Rajjou L (2017). *Capparis spinosa* L. in A Systematic Review: A Xerophilous Species of Multi Values and Promising Potentialities for Agro systems under the Threat of Global Warming. *Frontiers in Plant Science*. 8:1-18.
- Foschi, M. L, Juan, M, Pascual, B and Pascual-Seva, N (2022). The Imbibition, Viability and Germination of Caper Seeds (*Capparis spinosa* L.) in the First Year of Storage. *Plants*. 11(2): 1-10.
- Foschi, M. L, Juan, M, Pascual, B and Pascual-Seva, N (2023). Influence of Seed-Covering Layers on Caper Seed Germination. *Plants*. 12(3): 439-454.
- Koufan, M, Belkoura, I. and Mazri, M. A (2022). In Vitro Propagation of Caper (*Capparis spinosa* L.): A Review. *Horticulturae*. 8(8): 737-752.
- Olas B (2023). The Current State of Knowledge about the Biological Activity of Different Parts of Capers. *Nutrients*. 15(3):623-635.

CROSS-KINGDOM RNA INTERFERENCE AND THE ROLE OF PATHOGEN-DERIVED SMALL RNAs IN MODULATING HOST DEFENSE

Enugula Naveen^{1*}, Ujwala Chennareddy², Ch Eshwar Sai Prasad³ and Pulla Pavani⁴

¹Ph.D. Scholar, Department of Plantations, Spices, Medicinal and Aromatic Crops, HC&RI, Tamil Nadu Agricultural University, Coimbatore, 641 003

²Ph.D. Scholar, Department of Genetics and Plant Breeding, AC&RI, Tamil Nadu Agricultural University, Coimbatore, 641 003

³Ph.D. Scholar, Department of Genetics and Plant Breeding, S.V. Agricultural College, Tirupati, 517 502

⁴M.Sc. Graduate, Department of Genetics and Plant Breeding, S.V. Agricultural College, Tirupati, 517 502

*Corresponding Email: navin.enugula@gmail.com

Abstract

Food security is threatened by plant diseases caused by fungal and oomycete pathogens, which cause about 20–40% crop losses annually. Cross-kingdom RNA interference (ckRNAi) is a crucial layer in plant–pathogen interactions. In the interacting organisms, small RNAs (sRNAs) move between the species to regulate gene expression. Pathogens such as *Botrytis cinerea*, *Verticillium dahliae*, and *Puccinia striiformis* deliver sRNAs into plant cells to suppress immunity. Plants in turn export defensive sRNAs, often targeting pathogen virulence genes. These sRNAs are transferred between plants and pathogens *via* extracellular vesicles or environmental absorption. The knowledge of ckRNAi contributed to the development of innovative crop protection strategies, including host-induced gene silencing and spray-induced gene silencing, which may provide sustainable RNA-based alternatives to chemical fungicides.

Keywords: cross-kingdom RNAi, virulence genes, sRNAs, host-induced gene silencing, spray-induced gene silencing.

Introduction

Every year, plant diseases caused by fungi and other pathogens wipe out nearly 20–40% of global crop yields. Plants and pathogens are locked in an endless evolutionary arms race. While plants deploy immune receptors, antimicrobial compounds, physical barriers to defend invaders, pathogens evolve proteins and toxins to overcome them. In recent years, scientists have uncovered a surprising new layer in this battle: tiny RNA molecules that cross species boundaries to silence each other's genes. This process, called cross-kingdom RNA interference (ckRNAi), has not only deepened our understanding of host–pathogen interactions but also inspired new strategies for sustainable crop protection.

The Basics of Cross-Kingdom RNA interference (ck-RNAi)

RNA interference (RNAi) is a conserved gene-silencing mechanism in eukaryotes, driven by small RNAs (sRNAs) that are typically 20–30 nucleotides long. These molecules regulate gene expression either by cutting messenger RNAs (post-transcriptional silencing) or by altering DNA methylation patterns (transcriptional silencing). In plants, sRNAs play vital roles in development, stress responses, and immunity, while in fungi they help regulate gene expression and maintain genome stability (Mahanty *et al.*, 2023).

What makes cross-kingdom RNA interference (ckRNAi) remarkable is that these sRNAs are not confined to their organism of origin. Instead, they can move between interacting species, directly influencing the outcome of infection. Pathogens, for instance, release sRNAs into plant cells to silence host defense genes, weakening their immunity (Figure 1). Conversely, plants can export sRNAs into pathogens, targeting and suppressing genes required for virulence.

In this way, ckRNAi functions as a molecular dialogue, a subtle exchange of genetic messages that can either promote disease or strengthen resistance, depending on which side gains the upper hand.

Pathogens Exploit ckRNAi to Suppress Plant Immunity

One of the landmark discoveries in this field came from the necrotrophic fungus *Botrytis cinerea*, a pathogen responsible for grey mold on over 200 plant species. Researchers showed that *B. cinerea* produces multiple sRNA effectors, many derived from transposable element regions, that migrate into plant cells. Once inside, these sRNAs bind to the plant's Argonaute 1 (AGO1) protein, hijacking the plant's own RNAi machinery to silence immunity genes (Cai *et al.*, 2018; Mahanty *et al.*, 2023). For example: Bc-siR37 targets at least 15 host defense genes, including transcription factors (WRKYs), receptor-like kinases, and enzymes linked to pathogen resistance. Other *B. cinerea* sRNAs target genes involved in signaling and cell wall modification, creating a more susceptible environment.

This mechanism is not just confined to *B. cinerea*, it is also seen in:

- *Verticillium dahliae* produces sRNAs that silence Arabidopsis defense genes.
- *Puccinia striiformis* (wheat stripe rust fungus) releases miR1, a microRNA-like RNA that suppresses the wheat *Pathogenesis-related 2 (PR2)* gene, weakening the host's defense.
- Even oomycetes like *Hyaloperonospora arabidopsidis* use sRNAs that hijack plant AGO1 to silence host immunity genes.

In each case, pathogens use ckRNAi as a molecular weapon, delivering sRNAs that act like stealth effectors to dampen host immunity and promote infection.

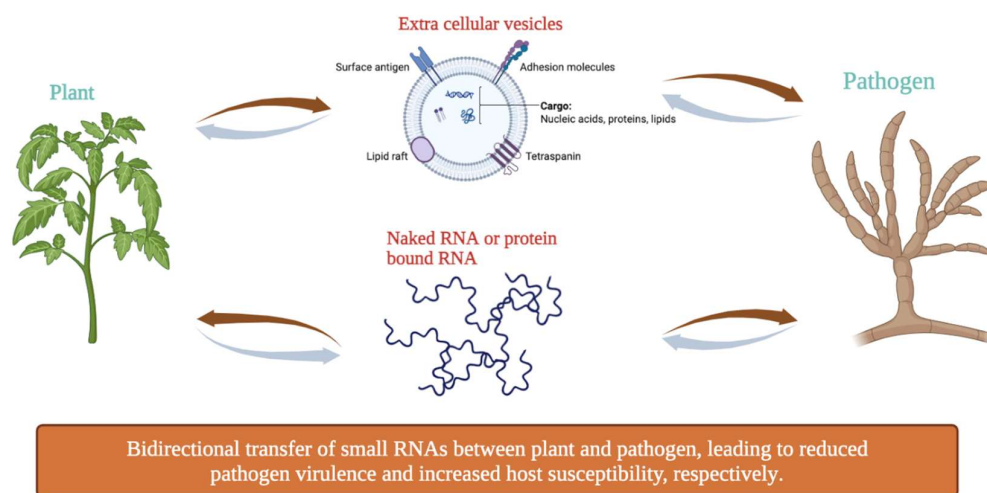


Figure 1. Mechanism of cross-kingdom RNA interference (ckRNAi)

Plants Strike Back with sRNAs Against Pathogens

The ckRNAi war is not one-sided. Plants can also export their own sRNAs to disarm fungal pathogens.

- Cotton plants send miR166 and miR159 into *V. dahliae*, silencing genes such as *calpain* and *hydroxylase*, both of which are required for fungal virulence.
- Arabidopsis packages defensive sRNAs into extracellular vesicles (EVs) coated with tetraspanin proteins (like TET8), which are secreted into the apoplast and then absorbed by *B. cinerea*. Once inside, these sRNAs target fungal genes involved in growth and pathogenicity.
- Other crops, including tomato and sunflower, have been shown to use similar EV-mediated sRNA transfer to suppress fungal infection.

This bidirectional RNA trafficking means that plants and pathogens are literally exchanging genetic messages during infection, with each side trying to tip the balance of the interaction in its favor (Mahanty *et al.*, 2023).

How do sRNAs travel across kingdoms?

The exact transport mechanisms remain under investigation, but current evidence suggests multiple routes:

1. **Extracellular Vesicles (EVs):** Membrane-bound packages carrying sRNAs, proteins, and lipids. In plants, EVs are secreted from multivesicular bodies and fuse with the plasma membrane to release their cargo into the apoplast. Fungi also release vesicles that may deliver pathogenic sRNAs.
2. **Naked RNAs or Protein-Bound RNAs:** Some sRNAs move outside of vesicles, stabilized by RNA-binding proteins, and can still function effectively once absorbed by the recipient organism.
3. **Direct Uptake:** Pathogens like *B. cinerea* and *Fusarium graminearum* can absorb RNA directly from the environment, a phenomenon known as **environmental RNAi**.

Harnessing ckRNAi for Crop Protection

The discovery of ckRNAi has opened the door to innovative, eco-friendly crop protection tools:

- **Host-Induced Gene Silencing (HIGS):** Plants are genetically engineered to produce dsRNAs that target pathogen genes. When pathogens infect, they absorb these RNAs and lose their virulence.
- **Spray-Induced Gene Silencing (SIGS):** Instead of genetic modification, scientists spray dsRNAs or sRNAs directly onto leaves or fruits. Pathogens absorb them from the environment, leading to disease suppression.

With the advent of nanotechnology, recent innovations like nanocarrier-based sprays (nSIGS) are making these approaches more practical. Layered double hydroxide (LDH). For example nanoclays, can deliver dsRNAs that remain effective for over 20 days on treated plants. These RNA-based “green pesticides” are highly specific, biodegradable, and safer for both humans and the environment than chemical fungicides.

Conclusion

Cross-kingdom RNA interference has revealed that the battle between plants and pathogens is not fought only with proteins and chemicals, but also with molecular messages. By exchanging sRNAs,

each side can reprogram the other pathogens suppressing immunity and plants suppressing virulence. Understanding and harnessing this dialogue could transform crop protection, reduce reliance on pesticides, and contribute to a more sustainable food future. In this silent conversation between kingdoms, tiny RNAs may well hold the key to feeding the world.

References

- Cai, Q., He, B., Kogel, K. H., & Jin, H. (2018). Cross-kingdom RNA trafficking and environmental RNAi—nature's blueprint for modern crop protection strategies. *Current opinion in microbiology*, 46, 58-64.
- Mahanty, B., Mishra, R., & Joshi, R. K. (2023). Cross-kingdom small RNA communication between plants and fungal phytopathogens-recent updates and prospects for future agriculture. *RNA biology*, 20(1), 109-119.

CLIMATE-RESILIENT VEGETABLE CROPS FOR SUSTAINABLE HORTICULTURE

**Karakambadi Vaishnavi^{1*}, Syed Sadarunnisa², Siriki Anusha³ and
Sangaraju Reddy Veera Nagaveni**

^{1*}PhD Scholar, Department of Vegetable Science, Dr. Y.S.R. Horticultural University,
College of Horticulture, Anantharajupeta-516105, Andhra Pradesh, India

²Professor and Head, Department of Vegetable Science, Dr. Y.S.R. Horticultural University,
College of Horticulture, Anantharajupeta-516105, Andhra Pradesh, India

³PhD Scholar, Department of Fruit Science, Dr. Y.S.R. Horticultural University,
College of Horticulture, Anantharajupeta-516105, Andhra Pradesh, India

⁴PhD Scholar, Department of Vegetable Science, College of Agriculture – JNKVV

*Corresponding Email: vaishnavikarakambadi1998@gmail.com

Abstract

Vegetables are vital to global food and nutritional security, yet they are highly vulnerable to climate change due to their short growth cycles, high water demand and sensitivity to environmental stresses. In India, where vegetables contribute nearly 60% of horticultural production, rising temperatures, erratic rainfall, drought, flooding, salinity and increasing atmospheric CO₂ and ozone threaten yield stability, quality and farmer profitability. Climate-induced pest outbreaks, emerging diseases and declining pollinators further intensify production risks. Studies indicate significant yield reductions in vegetable crops under warming trends and extreme weather events. To sustain productivity, adoption of climate-resilient strategies such as stress-tolerant varieties, conservation agriculture, protected cultivation, organic amendments, biofertilizers and efficient irrigation systems is essential. Climate-resilient vegetables are no longer a choice but an essential strategy for safeguarding food security, enhancing farmers' livelihoods and promoting long-term environmental sustainability.

Keywords: Climate change, Climate-resilient vegetables, Sustainable vegetable production, Food and nutritional security

Introduction

Agriculture is increasingly threatened by climate change, which is disrupting established production systems worldwide through rising temperatures, erratic rainfall and frequent extreme weather events. Elevated CO₂ and ozone levels, declining soil health, and shifting pest and disease dynamics further intensify production risks. Together, these changes reduce yields and adversely affect crop growth, development and nutritional quality. Among agricultural commodities, vegetable crops are particularly vulnerable due to their short growth cycles, shallow root systems, high water requirements and sensitivity to temperature fluctuations. Even slight deviations from optimum climatic conditions can impair flowering, fruit set, pollination efficiency and nutrient accumulation. Heat stress may cause flower drop in tomato and capsicum, while irregular rainfall often leads to cracking, rotting and disease outbreaks in cucurbits and leafy vegetables. Furthermore, climate-induced shifts in insect populations and pathogen virulence threaten the stability of vegetable-based farming systems Zhao *et al.*, (2023).

In this evolving scenario integrating stress-tolerant varieties with improved agronomic practices such as efficient irrigation, protected cultivation, soil health management and biological inputs can significantly enhance system resilience. Promoting climate-resilient vegetable production is therefore not merely an adaptive response, but a forward-looking strategy to safeguard food security, nutritional quality and farmer livelihoods in the face of an uncertain climatic future.

Climate-Resilient Vegetables

Climate-resilient vegetables are crop species or varieties that can tolerate or adapt to adverse climatic conditions such as drought, heat, excess rainfall, and poor soil fertility. These crops are capable of producing stable yields with fewer inputs and under fluctuating weather conditions. Many indigenous and traditional vegetables naturally possess such adaptive traits.

Significance of climate-resilient vegetables

Vegetables play a vital role in human nutrition by supplying vitamins, minerals, dietary fibre, and antioxidants. Climate change threatens their availability and affordability. Promoting climate-resilient vegetables helps to minimize the risk of crop failures, ensure a steady year-round supply of nutritious produce, strengthen nutritional security, stabilize farmers' incomes and contribute to the long-term sustainability of agricultural systems.

Characteristics of climate-resilient vegetables

Climate-resilient vegetable crops generally show the following features:

- Drought tolerance and efficient water use
- Heat tolerance and ability to flower and fruit under high temperatures
- Short duration or flexible growth habit
- Perennial or regenerative nature
- Resistance to pests and diseases
- Ability to grow in marginal or rainfed conditions

Indigenous and underutilized vegetables as climate-smart crops

Many indigenous and underutilized vegetables have evolved under diverse local agro-climatic conditions in India and possess inherent resilience to climatic stresses. Traditional cucurbits such as spine gourd, ivy gourd, snake gourd, ridge gourd and ash gourd, along with hardy crops like cluster bean and drumstick (moringa), perform reliably under heat and moisture stress. Similarly, climate-resilient legumes including cowpea, moth bean, field bean (hyacinth bean), horse gram and winged bean tolerate drought and poor soils while enriching soil fertility through biological nitrogen fixation. A wide range of leafy vegetables such as amaranthus, bathua, purslane, moringa leaves, colocasia leaves, basella (Malabar spinach), fenugreek and mustard greens are fast-growing, nutrient-dense and adaptable to variable conditions Vaishnavi *et al.*, (2023). Root and tuber crops like sweet potato, cassava, taro, elephant foot yam, greater yam and arrowroot also withstand moisture stress and regenerate after adverse weather. These underutilized crops generally require fewer external inputs, exhibit tolerance to abiotic stresses and continue yielding under suboptimal environments. Importantly, many are rich in vitamins, minerals, antioxidants and bioactive compounds, making them valuable components of climate-smart and nutrition-sensitive farming systems Purba and Krishnaswamy (2025).

Role of climate-resilient vegetables in sustainable farming

Climate-resilient vegetables play a vital role in promoting sustainable agriculture by enhancing resource-use efficiency and minimizing external inputs. Their ability to tolerate abiotic stresses such as heat and drought reduces dependence on frequent irrigation and excessive chemical

fertilizers or pesticides. Many resilient varieties improve soil health by supporting organic matter buildup, conserving moisture and maintaining soil fertility. In addition, diversified vegetable systems contribute to on-farm biodiversity and ecological balance, thereby strengthening natural pest regulation and system stability. These advantages collectively help lower cultivation costs, particularly benefiting small and marginal farmers. Perennial and tuber-based vegetables are especially valuable in this context, as their regenerative growth habit enables them to survive seasonal fluctuations and withstand climatic stresses while ensuring consistent productivity.

Benefits to Farmers

For farmers, especially those in rainfed and resource-poor regions, climate-resilient vegetables offer several advantages:

- Stable yields even under climate stress
- Lower production costs due to reduced inputs
- Regular income from local market demand
- Better adaptability to mixed and intercropping systems

These crops can also be integrated into kitchen gardens, backyard farming, and small holdings to improve household nutrition.

Climate-resilient vegetables and nutritional security

Climate-resilient vegetables are not only tolerant to environmental stresses but also highly nutrient-dense. Many indigenous and underutilized crops are rich in essential micronutrients such as iron, zinc, calcium and vitamins A and C, along with dietary fibre and antioxidants. Their regular consumption helps address hidden hunger and micronutrient deficiencies, while also supporting the prevention of lifestyle-related diseases such as diabetes and cardiovascular disorders. Integrating these vegetables into kitchen gardens, school feeding programs and local markets can significantly enhance dietary diversity and household nutrition. Owing to their adaptability to low-input and marginal conditions, they are particularly suitable for small and resource-poor farmers. Thus, climate-resilient vegetables connect sustainable agriculture with improved nutritional and public health outcomes Saeed *et al.*, (2023).

Conclusion

Climate-resilient vegetables represent a strategic foundation for sustaining vegetable production in the face of increasing climatic uncertainties. Their inherent adaptability to heat, drought, salinity and emerging biotic stresses, combined with high nutritional value and relatively low input requirements, makes them highly suitable for future farming systems. However, realizing their full potential requires coordinated action. Popularizing indigenous and underutilized crops, strengthening seed systems and quality planting material supply, and integrating these vegetables into government nutrition and agricultural development schemes are critical steps forward. By aligning policy, research and grassroots efforts, climate-resilient vegetables can safeguard farmer livelihoods, stabilize vegetable supply chains and reinforce food and nutritional security, thereby advancing a more sustainable and resilient agricultural future.

References

Purba N.H. and Krishnaswamy K. 2025. Exploring the potentials of neglected underutilized crops (NUCs): an integrative review for developing a sustainable food system model. *npj Science of Food*. 9:1-12.

- Saeed F, Chaudhry U.K, Raza A, Ali S, Chitikineni A, Saeed Y, Visser, R.G.F. and Varshney R.K. 2023. Developing future heat-resilient vegetable crops. *Functional & Integrative Genomics* 23 (47):1-23.
- Vaishnavi K, Chandana J.L, Reddy P.S.K, Nagaveni S.R.V, Anusha S. and Gladis B. 2023. Ethnic vegetable production. In: *Advances in Horticulture and Allied Sciences*. 1st ed. pp.164-178. ISBN 9789395423724.
- Zhao J, Liu D. and Huang R. 2023. A review of climate-smart agriculture: Recent advancements, challenges, and future directions. *Sustainability*. 15:1-15.

COMPARATIVE DISTRIBUTION AND ABUNDANCE OF SCYLLA OLIVACEA IN PICHAVARAM AND SUNDARBANS MANGROVE ECOSYSTEMS

E.K.Devipriya, L.Vinoth Kumar*, G.Dhivagar, M.Dhanu Pradeep, R.Gayathri and S.T.Dhivya Bharathi

Department of Fish Processing Technology, TNJFU- Dr.MGR. Fisheries College and Research Institute, Ponneri, Thiruvallur District, Tamil Nadu 601204

*Corresponding Email: vinothkumar@tnfu.ac.in

Abstract

Scylla olivacea, the orange mud crab, is an economically important species closely associated with mangrove ecosystems. This study compares its distribution, abundance, and fishing pressure in the Pichavaram and Sundarbans mangroves. In Pichavaram, the species shows a localized distribution mainly within shallow tidal creeks and mangrove root zones, with moderate abundance and clear seasonal variation influenced by salinity changes. In contrast, the Sundarbans mangroves support a broader spatial distribution and comparatively higher abundance due to extensive habitat availability and strong tidal connectivity. The study also highlights differences in human influence, with early harvesting of immature crabs observed in Pichavaram and high exploitation levels reported from the Sundarbans.

Introduction

Mud crabs of the genus *Scylla* belong to the Portunidae family. *Scylla olivacea*, commonly known as the orange mud crab, is an economically important mangrove-dwelling species. It has a broad and oval carapace, strong walking legs, and large claws adapted for digging and feeding. The crab's life cycle begins with spawning in saline waters, followed by planktonic zoea and megalopa stages, which later settle in mangrove creeks as juveniles and grow into adults. *S. olivacea* is an opportunistic feeder, consuming small fish, molluscs, crustaceans, detritus, and plant matter, making it an active scavenger and predator. These orange mud crabs are found across the Indo-Pacific region, especially in estuaries, backwaters, and muddy mangrove areas with brackish water. *Scylla olivacea* is widely distributed along the Indian coastline, particularly in estuarine and mangrove habitats of the Bay of Bengal. However, its population density and spatial occurrence differ markedly among mangrove systems due to environmental variability and habitat structure. Pichavaram and the Sundarbans represent two contrasting mangrove ecosystems, providing an opportunity for comparative assessment of *S. olivacea* distribution and abundance.

Mangrove Habitats

Mangroves are tropical coastal vegetation areas that can develop and grow well within tidal systems. Mangrove ecosystems are fundamental habitats for mud crabs because they function as a feeding ground, nursery ground, and spawning ground for various organisms and it is stated that all life stages of male mud crabs stay within the mangrove ecosystem while the female mud crabs migrate to the sea for spawning. When we see about the Indian mangroves the Pichavaram mangrove ecosystem is relatively small, with shallow tidal creeks and limited freshwater input, resulting in restricted habitat availability for benthic fauna. In contrast, the Sundarbans mangroves form an extensive and highly complex system with numerous

interconnected rivers, creeks, and intertidal mudflats, creating diverse microhabitats for mud crabs.

Distribution of Orange Mud Crab

Studies conducted in the Pichavaram mangrove ecosystem show that *Scylla olivacea* is not evenly distributed throughout the mangrove area but is spatially concentrated in specific habitats that provide suitable environmental conditions. The species is primarily found in shallow tidal creeks, mangrove-lined channels, and muddy substrata rich in organic matter. The distribution of *S. olivacea* within Pichavaram is strongly influenced by salinity gradients and tidal movement. Crabs are more frequently recorded in zones with moderate salinity, particularly during post-monsoon and pre-monsoon seasons, when salinity conditions remain relatively stable. During periods of heavy freshwater inflow associated with the monsoon, the spatial occurrence of the species becomes restricted, with individuals moving towards creek mouths and areas less affected by dilution. The distribution in Sundarban mangrove ecosystem indicate that *Scylla olivacea* exhibits a broad but environmentally structured spatial distribution. The species is primarily associated with tidal creeks, estuarine channels, and mangrove-lined waterways where muddy substrates and organic detritus are abundant. These habitats provide favorable conditions for shelter, feeding, and burrowing, which strongly influence the spatial occurrence of the species. In the same way as in Pichavaram mangroves the distribution is more frequently encountered in intermediate to higher salinity zones compared to low-salinity upstream areas. Size-related spatial segregation further distinguishes the two ecosystems. In Pichavaram, smaller and subadult crabs are predominantly found in interior mangrove creeks and root zones, indicating nursery function, while larger individuals occur in deeper channels with stronger tidal. In the Sundarbans, the extensive habitat availability allows all size classes to be distributed across broader areas, reducing spatial confinement of specific life stages and supporting continuous population mixing across the system.

The Abundance of Scylla Olivacea

Scylla olivacea occurs in moderate abundance in the Pichavaram mangroves and is present throughout the year in local crab catches. Studies indicate that its abundance shows clear seasonal variation, with higher availability during periods of relatively stable salinity and reduced abundance during the monsoon months when freshwater inflow lowers salinity levels. Population structure data reveal that the stock is dominated by small and medium-sized individuals, suggesting continuous recruitment but a lower proportion of large crabs. This pattern indicates that, although the species is regularly available, overall abundance is limited by the small spatial extent of the mangrove ecosystem and sustained fishing pressure. Consequently, *S. olivacea* maintains a stable but moderate population level in Pichavaram rather than forming dense or highly abundant stocks. *Scylla olivacea* shows comparatively high abundance in the Sundarban mangrove ecosystem and forms an important component of the mud crab fishery. The species is commonly recorded across different tidal creeks and fishing grounds, with abundance closely linked to salinity conditions, being higher in intermediate to high salinity zones and lower in freshwater-influenced areas. The extensive mangrove area, habitat heterogeneity, and strong tidal connectivity support continuous recruitment and the presence of multiple size groups throughout the year. Fishery observations further suggest that *S. olivacea* remains consistently available in catches.

Effects of Fishery Pressure and Human Influence in Orange Mud Crab

In the Pichavaram mangroves, research shows that mud crab fisheries are exerting noticeable pressure on *Scylla olivacea*, evidenced by the frequent capture of undersized and immature crabs in the fishery. This indicates that harvesting often occurs before many individuals have a chance to spawn. In contrast, in the Sundarbans mangrove forest of Bangladesh high fishing mortality and exploitation rates with fishing mortality often exceeding natural mortality and estimated exploitation (E) values above the widely accepted optimum level of 0.50 have been reported, particularly at smaller size classes are heavily harvested and that current exploitation is close to or above the maximum sustainable levels signalling overexploitation.

Conclusion

The comparative analysis shows that the distribution and abundance of *Scylla olivacea* differ markedly between the Pichavaram and Sundarban mangrove ecosystems. Pichavaram supports a stable but moderate population with spatially restricted distribution, strongly influenced by seasonal salinity fluctuations and localized fishing pressure. In contrast, the Sundarbans sustain higher abundance and wider distribution due to extensive mangrove coverage and habitat connectivity, although fishing pressure is more intense and approaches unsustainable levels. These differences underline the importance of ecosystem-specific management strategies to ensure the long-term sustainability of *S. olivacea* populations in mangrove habitats.

Reference

- https://www.researchgate.net/profile/C-Viswanathan/publication/332110768_Reproductive_biology_of_the_orange_mud_crab_Scylla_olivacea_Herbst_1796_from_the_Pichavaram_mangroves_of_south-east_India
- <https://www.cambridge.org/core/journals/journal-of-the-marine-biological-association-of-the-united-kingdom/article/carapace-widthweight-relationship-age-growth-and-longevity-of-the-mud-crab-scylla-olivacea-herbst-1796-in-the-pichavaram-mangroves-southeast-india/2081407DF696938EA8E45F7F55078E0C>
- <https://onlinelibrary.wiley.com/doi/abs/10.1002/aff2.42>
- <https://onlinelibrary.wiley.com/doi/abs/10.1002/aff2.70045>
- <https://banglajol.info/index.php/JSciTR/article/view/67373>

**DAIRY SECTOR DEVELOPMENT IN NORTH-EAST INDIA:
BRIDGING THE YIELD GAP FOR INCLUSIVE GROWTH****Poulami Ray^{1*}, Bhagirath Das² and Ajmer Singh³**¹Ranchi Agriculture College, Birsa Agricultural University, Ranchi, 834006, Jharkhand, India²ICAR-Indian Agricultural Research Institute-Assam, Dirpai, Gogamukh, 787035, Assam, India³ICAR-National Dairy Research Institute, Karnal-132001, Haryana, India.*Corresponding Email: ray.poulami2@gmail.com**Abstract**

Although India is the world's largest milk producer, the North-Eastern region contributes less than one percent to national milk output and continues to face low per capita milk availability. The central challenge is not livestock numbers but a wide yield gap between potential and actual milk productivity. Average yields in many North-Eastern states remain significantly lower than those in leading dairy regions due to limited breed improvement, inadequate feeding practices, weak veterinary services, and insufficient market infrastructure. Bridging this productivity gap offers a sustainable pathway for inclusive growth. Enhancing milk yield per animal can increase household income without expanding herd size, strengthen women's economic participation, improve nutritional security, and generate rural employment. Productivity-led dairy development is also environmentally sustainable, as it reduces emission intensity per litre of milk. With region-specific interventions in genetics, fodder development, animal health, and institutional strengthening, dairy can emerge as a viable engine of rural transformation in North-East India.

Keywords: Dairy development, Yield gap, North-East India, Livelihoods, Inclusive growth**Introduction**

India's dairy sector represents one of the most significant agricultural achievements of the country, with milk production approaching 240 million tonnes in 2023–24 and per capita availability exceeding 470 grams per day (Department of Animal Husbandry & Dairying [DAHD], 2024). The sector contributes substantially to agricultural Gross Value Added and supports more than 80 million rural households, the majority of whom are small and marginal farmers (National Dairy Development Board [NDDB], 2024). Beyond its economic contribution, dairy plays a central role in poverty reduction, women's empowerment, and household nutritional security.

Despite this national progress, pronounced regional disparities persist. The North-Eastern region—comprising Assam, Tripura, Meghalaya, Manipur, Mizoram, Nagaland, Arunachal Pradesh, and Sikkim—contributes less than one percent to national milk production (Basic Animal Husbandry Statistics [BAHS], 2024). Per capita milk availability in several states of the region remains significantly below the national average, and urban centres continue to depend on milk supplies from outside the region. This situation reflects structural inefficiencies rather than a lack of livestock resources.

The fundamental constraint is a persistent yield gap—the difference between potential milk yield under improved breeding, feeding, and management practices and the actual yield realized at the farm level. While crossbred cattle in advanced dairy states produce 8–12 litres per day, average yields in many parts of the North-East remain around 2–4 litres (NDDB, 2024). Empirical evidence

indicates that productivity gains of 20–30 percent are achievable through improved feed management and veterinary care without expanding herd size; however, adoption remains limited due to genetic constraints, fodder shortages, weak veterinary outreach, and limited institutional support.

Given the region's small and fragmented landholdings, the dominant role of women in livestock rearing, and its ecologically sensitive environment, productivity-led dairy development offers a strategic pathway for income diversification, improved nutrition, and climate-resilient rural growth. In this context, examining the structural determinants of the yield gap and identifying region-specific policy interventions becomes both timely and necessary. This article therefore analyzes the current status of dairy in North-East India and proposes targeted strategies to bridge the yield gap and promote inclusive dairy-led development.

Current Status of Dairy in North-East India

Despite India's remarkable growth in milk production, the North-Eastern region remains a marginal contributor to overall output, constrained by structural and productivity challenges.

1. Low Share in National Milk Production

Recent data indicates that the eight North-Eastern states collectively produced approximately 1.61 million tonnes of milk in 2022–23, accounting for only about 0.70% of India's total milk output in the same period (i.e., out of ~239 million tonnes).

2. State-wise Production Patterns

Within the region, production is unevenly distributed:

- Assam remains the leading milk producer among North-Eastern states, contributing a major share of the region's total output.
- Tripura and Meghalaya have shown relatively higher growth rates compared to other North-Eastern states, with Tripura registering an annual growth of around 5.2% and Meghalaya around 3.5% over recent years.
- States like Sikkim and several hill states contribute minimally to total production, with almost negligible growth (e.g., Sikkim's milk production growth at ~0.01%).

3. Per Capita Availability Far Below National Standard

For example, Assam's milk availability is around 78–84 grams per day in 2024–25, far below the national average of ~471 grams per day reported at the recent national level. In contrast, the all-India per capita availability of milk now exceeds 450–470 g/day, reflecting broader productivity gains in more developed dairy states.

4. Slow Growth and Productivity Constraints

The North-East's milk production growth rate lags behind national trends. Between 2010 and 2023, the compounded annual growth rate (CAGR) of milk production in the North-Eastern states was around 1.59%, significantly lower than the national CAGR of 3.83% observed during the same period.

Several states within the region even experienced stagnation or negative growth in certain years, reflecting persistent productivity constraints in terms of genetics, feed, health services, and institutional support.

5. Implications for Supply and Demand Balance

As a result of low production and low per capita availability, North-Eastern states remain dependent on milk supplies from outside the region to meet both domestic and urban demand.

Urban centres such as Guwahati, Imphal, and Agartala increasingly rely on milk transported from other states, further highlighting the production–demand imbalance.

- North-East India contributes less than 1% to national milk production despite having livestock populations.
- Production growth in the region remains slow compared to the national average.
- Per capita availability is significantly lower than national and nutritional benchmarks.
- These patterns reflect deep structural constraints that explain why the yield gap, not livestock numbers, is the binding growth limit in the region.

Understanding the Yield Gap

The yield gap in dairy refers to the difference between potential milk yield under improved genetic, nutritional, and management practices and the actual yield realized at the farm level. In India, crossbred cows can produce 8–12 litres per day, while indigenous cattle typically yield 2–4 litres (NDDB, 2022; DAHD, 2023). The gap is more pronounced in North-East India, where productivity remains below the national average (BAHS, 2023). This gap reflects structural constraints rather than merely biological limitations.

Genetic Limitations

Low productivity in the North-East is largely due to the dominance of non-descript indigenous cattle with limited genetic potential (Rao et al., 2019). Artificial insemination coverage remains inadequate because of difficult terrain and limited veterinary infrastructure (DAHD, 2023). Although crossbreeding has doubled productivity in other regions (Birthal & Negi, 2012), genetic upgradation in the North-East remains slow.

Feed and Fodder Deficiencies

Feed accounts for 60–70% of milk production costs (Rao et al., 2019). The region faces fodder shortages and relies heavily on open grazing and crop residues. Balanced ration feeding can increase yields by 10–20% (NDDB, 2022), yet adoption remains limited. Seasonal fodder deficits further constrain productivity.

Poor Veterinary Coverage and Animal Health Management

Limited veterinary outreach and preventive healthcare reduce lactation performance and increase productivity losses (DAHD, 2023). Improved herd health management can raise productivity by 15–25% (Birthal & Negi, 2012), but service delivery gaps persist in remote areas.

Weak Institutional and Market Linkages

Unlike regions with strong cooperative systems (Kurien, 2007), the North-East has limited organized procurement and cold-chain infrastructure. Weak market access reduces incentives for productivity-enhancing investments (NDDB, 2022).

Dairy as a Catalyst for Inclusive and Sustainable Growth

Dairy supports income stability, women's empowerment, nutritional security, and rural employment (DAHD, 2023; NDDB, 2023). Increasing productivity per animal enhances household income without herd expansion and reduces emission intensity per litre of milk (Gerber et al., 2013). Bridging the yield gap therefore promotes inclusive and climate-resilient rural development in North-East India.

Strategic Interventions for Bridging the Yield Gap

Reducing the yield gap in North-East India requires integrated, region-specific interventions addressing genetics, nutrition, animal health, infrastructure, and institutional support. Given the region's unique agro-climatic and socio-economic conditions, targeted strategies are essential for sustainable dairy development.

1. Region-Specific Crossbreeding Programs

Genetic improvement is fundamental to productivity enhancement. Crossbred cattle produce significantly higher milk yields than indigenous stock (Birthal & Negi, 2012). Region-specific breeding programs emphasizing climate resilience and adaptability are crucial for the North-East's humid and hilly conditions.

2. Expansion of Artificial Insemination (AI) Coverage

AI services remain limited due to terrain and infrastructure constraints (DAHD, 2023). Expanding mobile AI units and training para-veterinary workers can accelerate genetic upgradation and improve reproductive efficiency.

3. Promotion of Fodder Cultivation and Silage Technology

Feed accounts for 60–70% of milk production costs (Rao et al., 2019). Promoting fodder cultivation, silage preparation, and balanced ration advisory can improve feed efficiency and increase milk yield by 10–20% (NDDB, 2023).

4. Establishment of Village-Level Milk Chilling Centers

Decentralized milk chilling infrastructure can reduce spoilage, improve quality, and encourage commercialization. Strengthening cold-chain systems enhances farmer confidence and market participation (DAHD, 2023).

5. Strengthening SHG-Based Dairy Clusters

Group-based dairy models, including SHGs and FPOs, can improve collective marketing, access to credit, and women's participation, especially in geographically dispersed areas (Kurien, 2007).

6. Digital Extension and Veterinary Tele-Advisory Services

Digital platforms and tele-veterinary services can overcome remoteness, provide timely advisory support, and reduce productivity losses.



Figure 1. Bridging the yield gap in North-East India through genetic improvement, scientific feeding, and strengthened dairy infrastructure.

Conclusion and Policy Implications

The dairy sector in North-East India presents a paradox: despite adequate livestock resources, the region remains milk-deficit due to a persistent yield gap. Low productivity—stemming from genetic constraints, feed shortages, limited veterinary services, and weak market infrastructure—continues to restrict income growth and commercialization. Improving productivity per animal, rather than expanding herd size, offers a more efficient and sustainable pathway for inclusive dairy development.

A region-specific strategy is essential. Climate-resilient breed improvement, expanded artificial insemination, fodder development, strengthened veterinary outreach, decentralized milk chilling infrastructure, and SHG-based dairy clusters must be prioritized. Greater coordination between central and state programs is also critical. With sustained policy support, dairy can evolve from a subsistence activity into a driver of income diversification, nutritional security, and climate-resilient rural transformation in North-East India.

References

- Birthal, P. S., & Negi, D. S. (2012). Livestock for higher, sustainable and inclusive agricultural growth. *Economic & Political Weekly*, 47(26–27), 89–99.
- Department of Animal Husbandry & Dairying. (2023). *Annual report 2022–23*. Ministry of Fisheries, Animal Husbandry & Dairying, Government of India. <https://dahd.gov.in>
- Department of Animal Husbandry & Dairying. (2023). *Basic animal husbandry statistics 2023*. Ministry of Fisheries, Animal Husbandry & Dairying, Government of India. <https://dahd.gov.in>
- Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., & Tempio, G. (2013). *Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities*. Food and Agriculture Organization of the United Nations. <https://www.fao.org/3/i3437e.pdf>
- Kurien, V. (2007). *I too had a dream*. Roli Books.
- National Dairy Development Board. (2023). *Annual report 2022–23*. NDDB. <https://www.nddb.coop>
- Rao, S. V. N., Raju, S. S., & Kumar, A. (2019). Economics of dairy production and feed cost dynamics in India. *Indian Journal of Dairy Science*, 72(4), 405–412.

REVIVING TRADITIONAL FERMENTED FOODS AT HOME: A DIY KIT APPROACH

Kishor Anerao^{1*}, Deshpande H. W², Sachin Giri³ and Dukare Amol³

¹Ph.D. Research Scholar, Department of Food Microbiology and Safety, CFT, VNMKV, Parbhani

²Professor, Department of Food Microbiology and Safety, CFT, VNMKV, Parbhani

³Ph.D. Research Scholar, Department of Food Engineering, CFT, VNMKV, Parbhani

*Corresponding Email: kishoranerao135101@gmail.com

Abstract

DIY food fermentation kits are emerging as a popular, accessible approach for preparing probiotic-rich fermented foods such as kombucha and kimchi at home. This article examines the growing interest in these kits by highlighting their health, cultural and practical significance. Fermented foods are known for improving gut health, enhancing immune response and increasing the bioavailability of essential nutrients through the degradation of anti-nutritional factors. Kombucha additionally offers antioxidant and antimicrobial benefits, while kimchi represents a culturally significant staple of Korean cuisine. DIY kits empower individuals to reconnect with traditional fermentation practices, promote sustainable food habits and encourage culinary creativity. However, the safe and effective use of these kits requires proper knowledge of fermentation conditions to prevent contamination and spoilage. Although fermented foods are widely associated with health benefits, more rigorous clinical research is needed to validate certain claims.

Keywords: DIY food kits, fermentation, kombucha, kimchi, probiotics, gut health and sustainable food systems.

Introduction

The growing interest in DIY food kits for making fermented foods at home, such as kombucha and kimchi, is driven by the increasing awareness of their health benefits and culinary appeal. Fermented foods are well known for their unique flavors, preservation properties and potential health benefits, which include improved gut health and enhanced nutritional profiles. The DIY approach allows individuals to engage with traditional fermentation practices, offering a hands-on experience in preparing these health-promoting foods. This article explores the significance of DIY food kits for fermented foods, focusing on their health benefits, cultural importance and the practical aspects of home fermentation.

Health Benefits of Fermented Foods

Fermented foods like kombucha and kimchi are rich in probiotics, which are beneficial for gut health. These foods contain live microorganisms that can improve digestion and boost the immune system (Gondaliya *et al.*, 2024) (Dimidi *et al.*, 2019). Additionally, the consumption of probiotic-rich fermented foods has been linked to reduced inflammation and enhanced immune responses, contributing to overall health and well-being. (Pilco, 2023) (Adebo, 2025). Moreover, incorporating these foods into the diet can also support mental health, as emerging research suggests a connection between gut health and mood regulation.

The fermentation process enhances the nutritional quality of foods by increasing the bioavailability of nutrients and degrading anti-nutritional factors (Terefe & Augustin, 2020). This improvement in nutrient absorption is particularly significant for minerals often hindered by antinutritional factors found in plant-based foods (Mehak *et al.*, 2021). By reducing compounds like phytic acid and tannins, fermentation can significantly enhance the bioavailability of essential minerals, thereby improving overall nutrient absorption from plant-based sources (Azra *et al.*, 2023) (Rousseau *et al.*, 2020).

Kombucha, specifically, is noted for its potential nutraceutical properties, including antioxidant and antimicrobial activities, which contribute to its popularity (Melo *et al.*, 2024).

Cultural and Culinary Significance

Fermented foods have deep cultural roots, with kimchi being a staple in Korean cuisine and kombucha having a long history of consumption in various cultures (Patra *et al.*, 2016) (Melo *et al.*, 2024). The resurgence of interest in these traditional foods reflects a broader movement towards health-conscious eating and sustainable practices. This revival not only preserves cultural heritage but also promotes community engagement and food security, especially in regions where traditional fermentation practices are at risk of disappearing (Katz, 2025).

The DIY kits allow individuals to explore these cultural traditions in their own kitchens, fostering a deeper appreciation for the culinary arts and the science of fermentation (Youle, 2016). Furthermore, the hands-on experience provided by DIY kits can empower individuals to take control of their food choices, encouraging healthier dietary habits and fostering a sense of connection to cultural practices. This connection to cultural practices can enhance community bonds and promote the sharing of knowledge surrounding traditional fermentation methods, ultimately contributing to the sustainability of these culinary arts.

The growing popularity of DIY food kits not only facilitates the revival of traditional culinary practices but also encourages sustainable food systems and enhances community resilience. This trend highlights the intersection of health, culture and sustainability, making fermented foods a vital part of modern dietary practices.

Practical Aspects of DIY Fermentation Kits

DIY kits provide the necessary ingredients and instructions for home fermentation, making the process accessible to beginners. These kits often include starter cultures, such as SCOBY for kombucha, which are essential for successful fermentation (Laureys *et al.*, 2020) (Melo *et al.*, 2024). The accessibility of these kits plays a crucial role in explaining the fermentation process, allowing more individuals to experience the benefits of homemade fermented foods.

The resurgence in home fermentation is partly attributed to the availability of resources and guides, such as Sandor Katz's books, which have inspired many to experiment with fermentation at home (Youle, 2016) (Lehmann, 2012). Additionally, the convenience of DIY kits encourages individuals to experiment with various fermentation techniques, encouraging creativity in the kitchen and promoting a deeper understanding of food science.

Challenges and Considerations

While DIY fermentation kits offer numerous benefits, there are challenges, such as ensuring the correct fermentation conditions to prevent spoilage and contamination. Proper education and

adherence to guidelines are crucial for safe home fermentation (Suhre & Hickert, 2023). Moreover, understanding the risks associated with improper fermentation practices is essential to ensure food safety and prevent potential health issues related to microbial contamination (Nout, 1994).

Despite the health benefits, there is limited clinical evidence supporting the effectiveness of some fermented foods in improving gastrointestinal health, highlighting the need for more high-quality trials (Dimidi *et al.*, 2019). Future research should focus on rigorous clinical trials to substantiate the health claims associated with fermented foods, particularly regarding their efficacy in enhancing gastrointestinal health.

Conclusion

DIY food kits for making fermented foods at home provide an engaging way to explore the health benefits and cultural significance of these foods. They offer a practical solution for individuals interested in incorporating fermented foods into their diets, while also presenting challenges that require careful consideration. As the popularity of fermented foods continues to grow, further research and education will be essential to maximize their potential benefits and ensure safe home fermentation practices.

References

- Adebo, O. A. (2025). Discovering Health-Promoting Effects of Fermented Foods: From Diabetes Prevention to Anti-Cancer Possibilities. <https://doi.org/10.52439/ykwh3828>
- Azra, B. H., C.S., V., Abhinandana, K. R., Rout, S., & Kalaimani, P. S. (2023). Essential Antinutrients in Plant-based Proteins and Exploring their Nutritional Implications. 2(2), 5–8. <https://doi.org/10.51470/jpb.2023.02.02.05>
- Dimidi, E., Cox, S. R., Rossi, M., & Whelan, K. (2019). Fermented Foods: Definitions and Characteristics, Impact on the Gut Microbiota and Effects on Gastrointestinal Health and Disease. *Nutrients*, 11(8), 1806. <https://doi.org/10.3390/NU11081806>
- Gondaliya, S. M., Sheth, J., & Shah, S. (2024). Exploring the culinary and health significance of fermented foods: A comprehensive review. *World Journal Of Advanced Research and Reviews*. <https://doi.org/10.30574/wjarr.2024.21.3.1000>
- Katz, S. F. (2025). Fermentation: The Importance of Maintaining Cultural Practices and Knowledge. <https://doi.org/10.52439/cwxf6257>
- Laureys, D., Britton, S. J., & Clippeleer, J. D. (2020). Kombucha Tea Fermentation: A Review. *Journal of The American Society of Brewing Chemists*, 78(3), 165–174. <https://doi.org/10.1080/03610470.2020.1734150>
- Lehmann, G. (2012). Katz, Sandor Ellix: <i>Wild Fermentation. The Flavor, Nutrition and Craft of Live Culture Foods</i>; Deleted Journal, 114–114. <https://doi.org/10.1558/ppc.28575>
- Mehak, M., Deepti, S., Kumar, A. G., Singh, S. J., Shilpa, V., & Deepansh, S. (2021). Role of lacto-fermentation in reduction of antinutrients in plant-based foods. *Journal of Applied Biology and Biotechnology*, 7–16. <https://doi.org/10.7324/JABB.2021.9302>
- Melo, L. M. de, Soares, M. G., Bevilacqua, G. C., Schmidt, V. C. R., & Lima, M. de. (2024). Historical overview and current perspectives on kombucha and SCOBY: A literature review and bibliometrics. *Food Bioscience*, 59, 104081–104081. <https://doi.org/10.1016/j.fbio.2024.104081>

- Nout, M. J. R. (1994). Fermented foods and food safety. *Food Research International*, 27(3), 291–298. [https://doi.org/10.1016/0963-9969\(94\)90097-3](https://doi.org/10.1016/0963-9969(94)90097-3)
- Patra, J. K., Das, G., Paramithiotis, S., & Shin, H.-S. (2016). Kimchi and Other Widely Consumed Traditional Fermented Foods of Korea: A Review. *Frontiers in Microbiology*, 7, 1493–1493. <https://doi.org/10.3389/FMICB.2016.01493>
- Pilco, C. R. J. (2023). Uso de probióticos en función de mejorar actividad inmunitaria y digestiva. *LATAM Revista Latinoamericana de Ciencias Sociales y Humanidades*, 4(1). <https://doi.org/10.56712/latam.v4i1.515>
- Rousseau, S., Kyomugasho, C., Celus, M., Hendrickx, M., & Grauwet, T. (2020). Barriers impairing mineral bioaccessibility and bioavailability in plant-based foods and the perspectives for food processing. *Critical Reviews in Food Science and Nutrition*, 60(5), 826–843. <https://doi.org/10.1080/10408398.2018.1552243>
- Suhre, T., & Hickert, L. R. (2023). Produção caseira de bebidas fermentadas: uma alternativa biotecnológica para melhorar a saúde em comunidades carentes brasileiras. *Research, Society and Development*, 12(4), e18312441128–e18312441128. <https://doi.org/10.33448/rsd-v12i4.41128>
- Terefe, N. S., & Augustin, M. A. (2020). Fermentation for tailoring the technological and health related functionality of food products. *Critical Reviews in Food Science and Nutrition*, 60(17), 2887–2913. <https://doi.org/10.1080/10408398.2019.1666250>
- Youle, M. (2016). Reviews and Resources: The Art of Fermentation: An In-depth Exploration of Essential Concepts and Processes from Around the World: BOOK. *Microbe Magazine*, 11(2), 88–88. <https://doi.org/10.1128/MICROBE.11.88.1>

STATISTICAL ANALYSIS OF DISSOLVED OXYGEN AND TEMPERATURE IN RELATION TO FISHERIES AND AQUACULTURE

R. J. Abisha^{1*} and L. Surulivel²

¹PhD Scholar, Department of Aquatic Environment Management,
Dr. M.G.R. Fisheries College and Research Institute, Ponneri, Tamil Nadu -601204.

²Assistant Professor, Department of Fisheries Extension, Economics and Statistics,
Dr. M.G.R. Fisheries College and Research Institute, Ponneri, Tamil Nadu -601204.

*Corresponding Email: abisharj1097@gmail.com

Abstract

Dissolved oxygen (DO) and water temperature are critical physico-chemical parameters influencing fish survival, growth, and productivity in aquaculture ponds. The present study statistically evaluates the relationship between dissolved oxygen and temperature in a freshwater aquaculture pond using 20 field observations. Dissolved oxygen concentrations ranged from **5.4 to 6.5 mg/L**, with a mean value of **5.9 ± 0.31 mg/L**, while water temperature varied between **25.0 and 27.0 °C**, with a mean of **25.9 ± 0.55 °C**. A moderate inverse correlation was observed between temperature and dissolved oxygen, consistent with established limnological principles. The observed values remained within the optimal range recommended for warm-water aquaculture species.

Introduction

Water quality assessment is essential for sustainable fisheries and aquaculture management. Among various water quality parameters, dissolved oxygen and temperature are considered critical limiting factors for aquatic organisms. Dissolved oxygen is required for aerobic respiration and energy metabolism, while temperature regulates metabolic rate, feeding behaviour, growth, and oxygen solubility in water. Temperature regulates metabolic rate in poikilothermic organisms, increasing oxygen demand as thermal conditions rise (Brett, 1979). Simultaneously, higher temperatures reduce oxygen solubility in water, potentially creating a physiological constraint on fish growth (Wetzel, 2001).

In aquaculture systems, stable DO and temperature regimes are associated with improved feed conversion efficiency, enhanced growth rates, and reduced physiological stress (Boyd, 1998; Jobling, 1994). For warm-water freshwater fish such as common carp, dissolved oxygen levels of approximately 5–7 mg/L and water temperatures in the range of 23–30 °C are considered optimal for supporting metabolic activity, growth, and physiological performance in aquaculture systems (Patil et al., 2024). Evaluating the statistical relationship between these parameters therefore contributes to predicting growth performance and environmental stability. The objective of the present study is to statistically examine the relationship between dissolved oxygen and temperature in a freshwater aquaculture pond and to interpret their combined influence on fish growth from a statistical perspective.

Materials and methods

Primary data were collected from a freshwater pond used for rearing warm-water fish species such as carps. Dissolved oxygen and temperature were monitored through 20 recorded field

observations. Dissolved oxygen was measured using Winkler's titration method, and temperature was recorded using a calibrated thermometer. DO was expressed in milligrams per litre (mg/L), and temperature in degrees Celsius (°C) (APHA, 2017).

Primary Data

Sample No.	Dissolved Oxygen (mg/L)	Temperature (°C)
1	5.8	26.1
2	6.1	25.8
3	5.5	26.5
4	6.3	25.4
5	5.9	26.0
6	6.0	25.7
7	5.6	26.8
8	6.4	25.2
9	5.7	26.3
10	6.2	25.6
11	5.8	26.1
12	6.0	25.9
13	5.4	27.0
14	6.5	25.0
15	5.9	26.2
16	6.1	25.5
17	5.6	26.7
18	6.3	25.3
19	5.7	26.4
20	6.2	25.6

Statistical Analysis

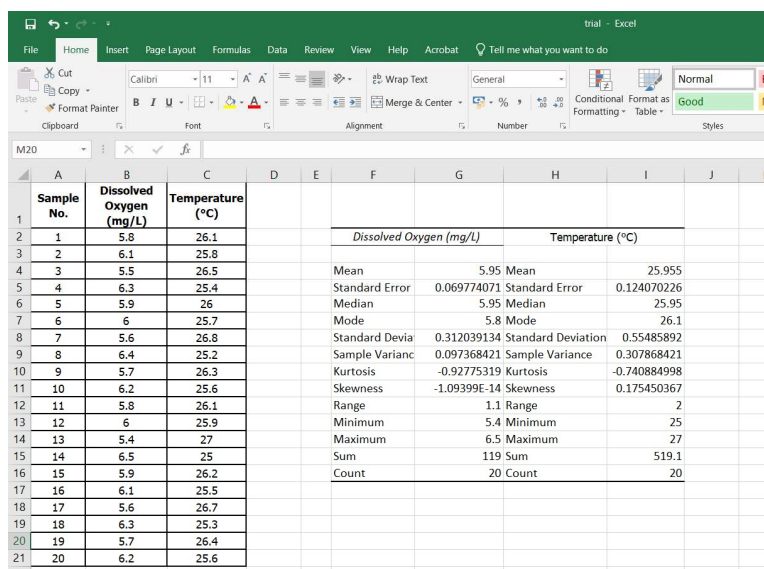
The collected data were subjected to descriptive statistical analysis, including calculation of mean, minimum, maximum, and standard deviation, to evaluate water quality stability and suitability. Mean values were calculated to understand average environmental conditions, while minimum and maximum values indicated extreme conditions. Standard deviation was used to assess variability and stability of the pond environment.

Results

Descriptive Statistics

Table 1. Descriptive Statistics of Dissolved Oxygen and Temperature

Parameter	Mean	Minimum	Maximum	Standard Deviation
Dissolved Oxygen (mg/L)	5.95	5.4	6.5	0.31
Temperature (°C)	25.9	25.0	27.0	0.55



Sample No.	Dissolved Oxygen (mg/L)	Temperature (°C)
1	5.9	26.1
2	6.1	25.8
3	5.5	26.5
4	6.3	25.4
5	5.9	26
6	6	25.7
7	5.6	26.8
8	6.4	25.2
9	5.7	26.3
10	6.2	25.6
11	5.8	26.1
12	6	25.9
13	5.4	27
14	6.5	25
15	5.9	26.2
16	6.1	25.5
17	5.6	26.7
18	6.3	25.3
19	5.7	26.4
20	6.2	25.6

Dissolved Oxygen (mg/L)		Temperature (°C)	
Mean	5.95	Mean	25.955
Standard Error	0.069774071	Standard Error	0.124070226
Median	5.95	Median	25.95
Mode	5.8	Mode	26.1
Standard Devia	0.312039134	Standard Deviation	0.55485892
Sample Varianc	0.097368421	Sample Variance	0.307868421
Kurtosis	-0.92775319	Kurtosis	-0.740884998
Skewness	-1.09399E-14	Skewness	0.175450367
Range	1.1	Range	2
Minimum	5.4	Minimum	25
Maximum	6.5	Maximum	27
Sum	119	Sum	519.1
Count	20	Count	20

Interpretation

Descriptive analysis showed relatively low variability in both dissolved oxygen (SD = 0.31 mg/L) and temperature (SD = 0.55 °C). Therefore, the observed data suggested an inverse association between temperature and dissolved oxygen, where slight increases in temperature corresponded with marginal reductions in oxygen concentration. This pattern reflects the thermodynamic principle that oxygen solubility decreases as water temperature increases. The relatively low standard deviation values indicate limited environmental fluctuation and stable physicochemical conditions.

Discussion

In the present study, Dissolved oxygen remained consistently above 5 mg/L, a level considered critical for sustaining aerobic metabolism and optimal growth in warm-water fish (Boyd, 1998). The relatively low standard deviations of both parameters indicate environmental stability, which is essential for consistent growth in aquaculture systems. Previous studies have demonstrated that fluctuations in DO and temperature can significantly affect feed intake, respiration efficiency, and somatic growth in carps and other warm-water fishes (Boyd, 1998; Jobling, 1994). Statistical monitoring of these variables allows early detection of stress conditions and supports predictive management strategies.

Conclusion

Statistical analysis of DO and temperature provides a valuable framework for interpreting environmental influences on fish physiology and growth dynamics. The present study demonstrates a statistically measurable inverse relationship between dissolved oxygen and temperature in a freshwater aquaculture system. Stable environmental conditions and adequate oxygen availability support efficient metabolic functioning and growth in warm-water fishes. However, continuous monitoring and quantitative evaluation of these parameters are essential for aquaculture management.

References

APHA (2017). *Standard Methods for the Examination of Water and Wastewater*.

- Boyd, C. E. (1998). *Water Quality for Pond Aquaculture*. Auburn University Press.
- Brett, J. R. (1979). Environmental factors and growth. In: Hoar, W. S., Randall, D. J., & Brett, J. R. (Eds.), *Fish Physiology, Vol. 8: Bioenergetics and Growth* (pp. 599–675). Academic Press.
- FAO (2020). *Water Quality Management in Aquaculture*. FAO Fisheries Technical Paper.
- Jobling, M. (1994). *Fish Bioenergetics*. Chapman & Hall.
- Patil, A. R., Shinde, S. V., & Rathod, N. (2024). Optimizing artificial propagation of *Cyprinus carpio* in semi-intensive aquaculture: A case study from Pachora, Jalgaon. *International Journal of Research in Agronomy*, 7(9), 269–274.
- Wetzel, R. G. (2001). *Limnology: Lake and River Ecosystems*. Academic Press.

EFFECT OF FEED QUALITY ON FISH FLESH

**Shivkumar Swamy^{1*}, Dhanalakshmi M², A. Chandrasekhara Rao¹,
Sashti Risha K¹, K. Bheemeshwarrao¹ and Paneerselvan Dheeran¹**

¹Fisheries Research Station, Undi, West Godavari, Andhra Pradesh Fisheries University,
Camp office, Vijayawada, Andhra Pradesh, 521134, India

²Fisheries Resource Management Department, College of Fisheries,
Gumla. Jharkhand 835207, India

*Corresponding Email: shivkumarswamy17@gmail.com

Abstract

Feed composition plays a decisive role in determining fish flesh quality, which directly influences consumer acceptance and market value of aquaculture products. This article reviews the effects of dietary nutrients, feed ingredients, and culture systems on key flesh-quality attributes of fish. Dietary protein level and amino acid balance significantly affect muscle composition, texture, water-holding capacity, and post-mortem pH, with deficiencies or excesses leading to deterioration in flesh firmness and quality. Dietary lipid level and fatty acid composition strongly influence organoleptic properties, flesh tenderness, and flavour, as the fatty acid profile of the feed is largely reflected in fish muscle. Feed ingredients such as plant oils, insect meals, algal meals, and unconventional protein sources may alter sensory characteristics, colour, and proximate composition of fish flesh, although responses are highly species-specific. In addition, rearing systems such as recirculating aquaculture systems and biofloc technology have been shown to modify texture, water-holding capacity, and sensory attributes of fish flesh. Overall, the reviewed studies demonstrate that strategic feed formulation and ingredient selection are essential for maintaining optimal flesh quality while supporting sustainable aquaculture practices.

Introduction

Feed composition is a critical determinant of fish growth performance and flesh quality attributes, ultimately influencing consumer acceptance and market value. It is well established that dietary inputs significantly affect several qualitative characteristics of fish and fillets, including colour, texture, proximate composition, nutritional and functional properties, flavour, odour, and shelf life (Tibaldi *et al.*, 2015). In modern aquaculture systems, formulated feeds increasingly rely on diverse protein, lipid, and functional ingredients, as well as additives, to optimize production efficiency. However, variations in the nutrient profile and chemical composition of these feeds are directly reflected in the biochemical and physical properties of fish muscle. Consequently, any alteration in dietary formulation—whether through changes in macronutrient levels, amino acid balance, fatty acid composition, or inclusion of novel ingredients—can influence flesh quality traits. Understanding the relationship between feed composition and fish flesh quality is therefore essential for developing nutritionally balanced diets that ensure both optimal growth and high-quality end products.

Effect of Dietary Protein on Flesh Quality

Dietary protein level and amino acid composition play a fundamental role in determining muscle composition and flesh quality in fish. Several studies have demonstrated that increasing dietary

protein levels enhances whole-body protein deposition and dressing percentage. For instance, juvenile hybrid bluegill (*Lepomis cyanellus* × *L. macrochirus*) fed diets containing 40–48% protein exhibited significantly higher whole-body protein content compared to fish fed a 35% protein diet (Webster *et al.*, 1997). Similarly, in channel catfish fingerlings, dressing percentage increased as dietary protein levels rose from 26% to 32%, and superior weight gain was observed in fish fed casein- and gelatin-based protein sources compared with soy-based proteins.

Beyond total protein levels, muscle texture-related parameters such as firmness and water-holding capacity (WHC) are widely regarded as key indicators of flesh quality. A decline in these parameters is often associated with deterioration in post-harvest quality (Gan *et al.*, 2014). Both deficiency and excess of specific amino acids, particularly isoleucine (Ile), have been shown to adversely affect muscle quality. In grass carp, imbalanced dietary Ile levels resulted in a 20–30% reduction in muscle shear force, indicating softer flesh. Conversely, Larsson *et al.* (2014) reported that glutamate supplementation improved fillet firmness in Atlantic salmon, likely by enhancing collagen synthesis in muscle tissue. Adequate dietary Ile has also been linked to increased collagen content, thereby contributing to improved muscle integrity.

Muscle pH is another critical determinant of flesh quality, as low post-mortem pH is associated with protein denaturation and reduced texture quality. Gan *et al.* (2014) observed that grass carp fed Ile-deficient diets exhibited significantly lower muscle pH, while pH values improved with increasing dietary Ile levels. This effect was attributed to reduced lactate accumulation in muscle tissue. Similar trends have been reported in Atlantic salmon, reinforcing the importance of balanced amino acid nutrition for maintaining muscle pH and preventing deterioration in flesh quality (Acerete *et al.*, 2014).

Effect of Dietary Lipid on Flesh Quality

Lipid content and fatty acid (FA) composition are major contributors to the organoleptic quality of fish flesh. Increased lipid deposition generally results in softer, more tender flesh and influences flavour perception. Importantly, the fatty acid profile of the diet is closely mirrored in the fish muscle (Robin *et al.*, 2003). For example, rainbow trout fed diets containing high levels of corn oil exhibited elevated concentrations of n-6 fatty acids (18:2n-6) in their flesh, whereas diets rich in fish oil resulted in higher levels of long-chain n-3 highly unsaturated fatty acids (HUFAs).

Excessive dietary lipid levels, however, can negatively affect flesh texture. Andersen *et al.* (1997) reported that rainbow trout fed high-lipid diets produced softer and less firm fillets compared to those fed lower-lipid diets. In Atlantic salmon, the long-standing issue of muscle gaping has been linked to the use of high-energy diets and alterations in muscle collagen structure during chilled storage. Although fish muscle texture is generally less responsive to dietary manipulation than in terrestrial animals, certain feed additives such as algal supplements have been reported to influence muscle texture and structural integrity (Nakagawa & Montgomery, 2007).

Effect of Feed on Flavour and Odour of Flesh

Dietary ingredients are well known to influence the sensory attributes of farmed fish, particularly flavour and odour. Research conducted over several decades has shown that lipid sources play a dominant role in determining “fishy” characteristics. Channel catfish fed diets containing menhaden oil were described as having stronger fishy odours and flavours compared to fish fed plant oil-based diets (Dupree *et al.*, 1979). Similarly, rainbow trout were perceived as less fishy

when sunflower oil was replaced with fish oil in their diets (Skonberg *et al.*, 1993). These findings highlight the importance of carefully selecting dietary lipid sources to meet consumer preferences.

Effect of Feed on Flesh Appearance

Dietary pigments, particularly carotenoids, are crucial for maintaining desirable flesh and skin coloration in many cultured fish species. Teimouri *et al.* (2013) demonstrated that feeding rainbow trout (*Oncorhynchus mykiss*) with *Spirulina platensis* resulted in stable carotenoid content in the flesh during storage at 4 °C and for at least three months at -20 °C. Similarly, Manganaro *et al.* (2012) reported that supplementation with synthetic carotenoids significantly enhanced redness and yellowness indices in red porgy (*Pagrus pagrus*), a species that often loses its characteristic red-pink coloration under culture conditions.

Effect of RAS and Biofloc Systems on Fish Flesh Quality

The influence of rearing systems such as recirculating aquaculture systems (RAS) and biofloc technology on flesh quality varies among species. Komolka *et al.* (2020) evaluated four fish species reared in RAS and reported marked interspecific differences in shear force, with European perch exhibiting the highest value (53.89 N), followed by rainbow trout, whitefish, and pikeperch. Water-holding capacity was highest in pikeperch and lowest in European perch, while muscle pH decreased by 4–6% post-harvest across all species. Impulse impedance values were also higher in percids compared to salmonids.

In biofloc systems, Fajrin *et al.* (2020) reported improved organoleptic quality in dumbo catfish (*Clarias gariepinus*), with sensory scores ranging from 7 to 9, compared to 6 to 7 in conventionally reared fish. In contrast, Martinez-Porchas *et al.* (2020) observed no significant differences in post-harvest quality attributes of *Litopenaeus vannamei* reared under biofloc conditions compared to controls, indicating species-specific responses.

Effect of Selected Feed Ingredients on Fish Flesh Quality

The use of insect meals has gained considerable attention as a sustainable alternative protein source in aquafeeds, with variable effects on flesh quality depending on insect and fish species. Salmon fed *Hermetia illucens* meal exhibited reduced dressing yield, whereas such effects were not observed in carp species (Piccolo *et al.*, 2017; Lie *et al.*, 2016). In rainbow trout, *Tenebrio molitor* meal increased fillet dry matter and ether extract without significantly affecting protein and ash content (Renna *et al.*, 2017; Iaconisi *et al.*, 2018). Most studies report no adverse effects on WHC or texture in species such as blackspot seabream, gilthead seabream, and rainbow trout. However, changes in fillet colour have been noted, including increased redness and yellowness in blackspot seabream and reduced yellowness in rainbow trout at higher inclusion levels (Iaconisi *et al.*, 2017; Mancini *et al.*, 2018).

Algal meals have also been shown to influence flesh quality, particularly colour. Promya and Chitmanat (2011) reported increased yellowness in catfish flesh when diets contained 5% *Cladophora*. Certain unconventional ingredients can also affect flesh odour; for example, common carp fed 20–25% earthworm meal developed a garlic-like aroma (Nandeeshha *et al.*, 1988). In contrast, silkworm pupae meal did not induce off-flavours up to 50% inclusion (Nandeeshha *et al.*, 2000).

Conversely, several studies indicate that dietary ingredient variation does not always translate into perceptible changes in flesh quality. Iqbal et al. (2014) reported no significant differences in sensory attributes of *Labeo rohita* fed various plant and animal protein combinations. Similarly, Pulido-Rodríguez et al. (2021) found that fillet quality of gilthead seabream was largely unaffected by diverse dietary protein sources, except for colour variations associated with microalgae inclusion.

Conclusion

Feed composition plays a pivotal role in determining the quality of fish flesh and overall market acceptance. Balanced dietary protein and amino acid profiles are essential for maintaining optimal muscle texture, water-holding capacity, and post-mortem pH. Dietary lipid level and fatty acid composition significantly influence tenderness, flavour, and sensory characteristics of fish flesh. Alternative feed ingredients such as insect and algal meals can modify colour and sensory attributes, with effects varying across species. In addition, rearing systems such as RAS and biofloc systems interact with diet to further influence flesh quality. Therefore, species-specific and nutritionally balanced feed formulations are crucial for producing high-quality fish flesh in sustainable aquaculture.

Reference

- Acerete L and Zhou X Q (2014). Flesh quality loss in response to dietary isoleucine deficiency and excess in fish: A link to impaired Nrf2-dependent antioxidant defence in muscle *Aquaculture* 287: 139–144.
- Andersen U B Thomassen M S and Rora A M B (1997). Texture properties of farmed rainbow trout (*Oncorhynchus mykiss*): Effects of diet muscle fat content and time of storage on ice *J Sci Food Agric* 73: 347–353.
- Dupree H K Gauglitz Jr E J Hall A S and Houle C R (1978). Effects of dietary lipids on the growth and acceptability (flavor) of channel catfish (*Ictalurus punctatus*) *Proc Symp Finfish Nutr Feed Technol Hamburg* 20–29.
- Fajrin A Utomo N P Ekasari J and Nuryati S (2020). Evaluation of health status and meat quality of dumbo catfish (*Clarias gariepinus*) maintained in a biofloc system *J Akuakultur Indones* 19(2): 190–198.
- Gan L Jiang W D Wu P Liu Y Jiang J Li S H Tang L Kuang S Y Feng L and Zhou X Q (2014). Flesh quality loss in response to dietary isoleucine deficiency and excess in fish: A link to impaired Nrf2-dependent antioxidant defense in muscle *PLoS One* 9(12): e115129.
- Iaconisi V Bonelli A Pupino R Gai F and Parisi G (2018). Mealworm as dietary protein source for rainbow trout: Body and fillet quality traits *Aquaculture* 484: 197–204.
- Iaconisi V Marono S Parisi G Gasco L Genovese L Maricchiolo G Bovera F and Piccolo G (2017). Dietary inclusion of *Tenebrio molitor* larvae meal: Effects on growth and quality traits of blackspot sea bream *Aquaculture* 476: 49–58.
- Iqbal K J Ashraf M Abbas F Javid A Hafeez-ur-Rehman M Abbas S Rasool F Khan N Khan S A and Altaf M (2014). Effect of plant-based feeds on growth and flesh quality of *Labeo rohita* *Pak J Zool* 46(1): 1–8.
- Komolka K Bochert R Franz G P Kaya Y Pfuhl R and Grunow B (2020). Determination and comparison of physical meat quality parameters of Percidae and Salmonidae in aquaculture *Foods* 9(4): 388.

- Larsson T Koppang E O Espe M Terjesen B F and Krasnov A (2014). Fillet quality and health of Atlantic salmon (*Salmo salar* L) fed a diet supplemented with glutamate Aquaculture 426: 288–295.
- Li S Ji H Zhang B Tian J Zhou J and Yu H (2016). Influence of black soldier fly (*Hermetia illucens*) larvae oil on growth and lipid deposition in juvenile Jian carp Aquaculture 465: 43–52.
- Mancini S Medina I Iaconisi V Gai F Basto A and Parisi G (2018). Impact of black soldier fly larva meal on chemical and nutritional characteristics of rainbow trout fillets Animal 12: 1672–1681.
- Manganaro A Sanfilippo M Fortino G Daprà F Palmegiano G B Gai F Lembo E Reale A and Ziino M (2012). Artificial pigmentation and flesh quality in red porgy (*Pagrus pagrus*) Int Aquat Res 4(1): 1–12.
- Martinez-Porchas M Ezquerro-Brauer M Mendoza-Cano F Higuera-Ciapara J E Vargas-Albores F and Martinez-Cordova L R (2020). Effect of supplementing heterotrophic and photoautotrophic biofloc on production and post-harvest quality of whiteleg shrimp Aquac Rep 16: 100257.
- Nakagawa H and Montgomery W L (2007). Algae In: Nakagawa H Sato S and Gatlin III D C (Eds) Dietary supplements for the health and quality of cultured fish CABI Cambridge MA USA pp 133–168.
- Nandeesha M C Gangadhara B Varghese T J and Keshavanath P (2000). Growth response and flesh quality of common carp fed non-defatted silkworm pupae Asian Fish Sci 13(3): 235–242.
- Nandeesha M C Srikanth G K Basavaraja N Keshavanath P Varghese T J Bano K Ray A K and Kale R D (1988). Influence of earthworm meal on growth and flesh quality of common carp Biol Wastes 26(3): 189–198.
- Panini R L Pinto S S Nobrega R O Vieira F N Fracalossi D M Samuels R I Prudencio E S Silva C P and Amboni R D (2017). Dietary replacement of fishmeal by mealworm meal and its effect on muscle quality of shrimp (*Litopenaeus vannamei*) Food Res Int 102: 445–450.
- Piccolo G Iaconisi V Marono S Gasco L Loponte R Nizza S Bovera F and Parisi G (2017). Effect of *Tenebrio molitor* larvae meal on growth performance and marketable traits of gilthead sea bream (*Sparus aurata*) Anim Feed Sci Technol 226: 12–20.
- Promya J and Chitmanat C (2011). Effects of *Spirulina platensis* and *Cladophora* algae on growth meat quality and immunity of African sharp-tooth catfish (*Clarias gariepinus*) Int J Agric Biol 13(1): 77–82.
- Pulido-Rodriguez L F Cardinaletti G Secci G Randazzo B Bruni L Cerri R Olivotto I Tibaldi E and Parisi G (2021). Alternative dietary proteins modulate growth performance and quality of gilthead sea bream (*Sparus aurata*) Animals 11(7): 1919.
- Renna M Schiavone A Gai F Dabbou S Lussiana C Malfatto V Prearo M Capucchio M T Biasato I Biasibetti E and De Marco M (2017). Evaluation of partially defatted black soldier fly larvae meal in rainbow trout diets J Anim Sci Biotechnol 8(1): 1–13.
- Robin J H Regost C Arzel J and Kaushik S J (2003). Fatty acid profile of fish following a change in dietary fatty acid source: A model of fatty acid composition using a dilution hypothesis Aquaculture 225: 283–293.
- Skonberg D I Rasco B A and Dong F M (1993). Effects of feeding high monounsaturated sunflower oil diets on sensory attributes of salmonid fillets J Aquat Food Prod Technol 2(1): 117–133.

- Teimouri M Amirkolaie A K and Yeganeh S (2013). The effects of dietary supplement of *Spirulina platensis* on blood carotenoid concentration and fillet color stability in rainbow trout (*Oncorhynchus mykiss*) *Aquaculture* 414: 224–228.
- Tibaldi E Zittelli G C Parisi G Bruno M Giorgi G Tulli F Venturini S Tredici M R and Poli B M (2015). Growth performance and quality traits of European sea bass (*Dicentrarchus labrax*) fed diets containing freeze-dried *Isochrysis* sp biomass *Aquaculture* 440: 60–68.
- Webster C D Tiu L G and Tidwell J H (1997). Growth and body composition of juvenile hybrid bluegill (*Lepomis cyanellus* × *L. macrochirus*) fed practical diets containing various protein levels *J World Aquac Soc* 28(3): 230–240.

POTENTIAL ROLE OF GUT MICROFLORA IN FISH

**Khushbu Kumari*, Sarvendra Kumar, Sagarika Swain,
Aishwarya Sharma & Parmanand Prabhakar**

College of Fisheries, Kishanganj, Bihar Animal Sciences University, Patna

*Corresponding Email: khushbusahu1225@gmail.com

Abstract

The gut microbiota plays a crucial role in maintaining health of the host, metabolism, and immunity. In fish and other animals, intestinal microbial communities contribute to nutrient digestion, the synthesis of essential metabolites, and the enhancement of feed efficiency. Beneficial microbes improve gut barrier integrity, modulate inflammatory responses, and protect against pathogenic infections through competitive exclusion and the production of antimicrobial compounds. Environmental factors, composition of diet, and stress significantly influence microbial diversity and stability. In aquaculture, modulation of gut microbiota through probiotics, prebiotics, and functional feeds has emerged as a sustainable strategy to enhance growth performance, disease resistance, and overall physiological status of cultured species.

Keywords: Probiotics, Prebiotics, Gut microbiota, Aquaculture, Antimicrobial

Introduction

Gut microbiota plays an indispensable role in physiology, metabolism and nutrition, thereby influencing the host's overall health. The microbial community also resides in the gut of fish, as in humans and other mammals and acts as an important indicator for evaluating fish health. The occurrence and frequency of diseases in fish have increased with intensified aquaculture production. Unfortunately, the usage of antibiotics and probiotics in preventing and treating diseases in aquaculture could not be successful due to concerns regarding environmental pollution, consumer safety and lack of consistency in probiotics performance. A possible strategy to mitigate emerging diseases in aquaculture could be modulation of the microbiota. The microbiota has been studied extensively in various fish species, including model animals, economic fish, and wild fish species. The microflora of the digestive tract of fish plays an important role in communicating resistance to infectious diseases by producing antibacterial materials that prevent pathogenic bacteria. The bacterial community of the fish gut differs significantly from that of other vertebrates. The gastrointestinal tract bacteria participate actively in the decomposition of nutrients and provide the host with physiologically active material such as enzymes, vitamins and amino acids.

The microbiota composition of the fish depends on the host, diet and environmental factors. The intestinal microbiota affects the nutritional metabolism, immunity and resistance to the disease of the fish host. The gut Microbiome itself is shaped by several host-associated factors emphasize the digestive and immune systems in fish for the improvement of fish health and its performance and also regulates the intestinal microbiota for better production of aquaculture.

Nature of digestive tract microflora in fish

The development of gut microflora in fish is strongly influenced by environmental microorganisms, particularly those present in the surrounding water. The digestive tract provides

a nutrient-rich environment that supports greater bacterial growth than water. Gut structure, which varies among species from early embryonic stages, plays a key role in microbial colonisation (Ganguly & prasad, 2012). In larvae and fry, microflora establishment is gradual and affected by egg deposition, diet, and environmental microbes. Dominant genera include *Aeromonas*, *Pseudomonas*, *Clostridium*, and *Bacteroides*, with *Bacteroides* appearing later in development. Diet, feeding intensity, and farming conditions significantly shape intestinal bacterial composition, though limited information exists on xenobiotic impacts (Voveriene *et al.*, 2002).

Effects of the intestinal microbiota on the fish host

Commensal bacteria can regulate many key aspects of the function of the host involving feeding behaviour, energy balance, nutrient metabolism, and immune response.

Biodegradative role of Microflora in digestive system of fish

The health of the host can be improved effectively by improving the abundance of beneficial bacteria in the gut, which may be the direct addition of probiotics bacteria and prebiotics that can improve the abundance of beneficial bacteria in the gut. In general, the population of the gut microbiota represents a very important and diversified enzymatic potential, and in the digestive tract, the enzymatic mass interferes metabolism of the host. The composition of the gut microbiota of fish is influenced by the bacteria present in the aquatic environment (Cahill 1990). Cellulolytic and amylolytic activity has been found in different microbes isolated from the digestive tract of different fishes e.g., Tilapia, Chinese grass carp and Common carp (Saha *et al.* 2006). The amylolytic bacterial populations consisting of *Bacillus* spp. are present significantly in the digestive tract of *L. bata* and *C. mrigala*, which support the presence of enzyme-producing microbial population in fish gut. The effect bacterial load in feeds also has an influence on intestinal microflora (Savas *et al.* 2005). Three species under the genus *Bacillus* from the Indian major carp gut, *Labeo rohita* were identified as *B. circulans*, *B. pumilus* and *B. cereus*, respectively, based on morphological, physiological and biochemical features (Ghosh *et al.* 2002). Autochthonous bacteria persist in the intestinal tract of Rohu and exhibit enzymatic activities that may benefit the host fish (Ghosh *et al.*, 2010). Microorganisms capable of producing enzymes from the digestive tract can be effectively utilized as probiotics in feed formulation, particularly during the larval stages of fish. The primary approach to probiotic use involves isolating beneficial intestinal bacteria from adult animals and incorporating them in high concentrations into the feed of young animals of the same species (Ganguly *et al.*, 2010). The use of probiotics in commercial aquaculture is necessary for formulating diets at larval stages to minimise the cost of feed preparation. The essential microflora are responsible for the digestion and metabolism of starch and cellulose. The microbial population present in water significantly influences the development of gut microflora in fish. As the main structural component of plant cell walls, cellulose is the most abundant carbohydrate found in nature.

Cellulose utilization in fish depends on the enzyme cellulase, which hydrolyses glycosidic bonds to release glucose. Although fish generally do not synthesise cellulase themselves, their digestive tracts harbour aerobic and facultative anaerobic microorganisms that aid in the breakdown of plant materials. Starch is an important dietary carbohydrate for freshwater species such as carp and tilapia, and it is digested into simple sugars by amylase present in the digestive system. Digestive enzymes may originate from the pancreas, intestinal secretory cells, or intestinal microflora. Fish typically show limited carbohydrate utilization; however, cellulose digestion

occurs through endogenous or microbial enzymes. In Indian major carps, endogenous cellulase production and a stable cellulolytic microflora contribute to cellulose breakdown. The extent of cellulolytic activity is associated with feeding habits. Nevertheless, due to the absence of a specialised fermentation chamber and short gut retention time, cellulose is often inefficiently utilized despite the presence of symbiotic bacteria.

Enzymes obtained from fish digestive tracts can be advantageously used as probiotics in feeds rich in cellulose and starch. The primary approach in using probiotics is to extract beneficial intestinal bacteria from adult animals and add them in high quantities to the feed of young animals belonging to the same species. Probiotics have been traditionally used in animal husbandry, but their application in aquaculture remains limited. Incorporating probiotics in commercial aquaculture is important, particularly during the larval stage, to help reduce feed costs. Microorganisms that produce enzymes and are isolated from the digestive tracts of fish can serve as effective probiotics when developing diets, especially for fish larvae.

Nutrient metabolism

The gut microbiota has been regarded as an important factor in regulating nutrition and metabolism in fish. Dietary supplementation of different feed additives e.g. Immunostimulant, probiotics and prebiotics usually in small quantities have been found to improve the immunity, feed efficiency and growth performance of crustaceans and fishes. The composition of gut microbiota had a close relationship with the activity of the intestinal digestive enzymes of fish, such as cellulase, amylase, trypsin, and lipase (Liu *et al.*, 2021). Gut Microbiome of freshwater fish with different feeding habits revealed that the gut microbial composition of carnivorous fish species was more related to trypsin activity, while the gut microbiota of herbivorous fish was correlated with cellulase and amylase activities (Liu *et al.* 2016).

The gut microbiota has an essential role in controlling energy metabolism in mammalian hosts. Similar findings have been reported in fish. In zebrafish, gut microorganisms enhance energy absorption and regulate the expression of genes involved in lipid and energy metabolism (Sheng *et al.*, 2018). Microbiota can stimulate the uptake of fatty acids and lipid droplet formation in the intestinal epithelium and liver in zebra fish (Semova *et al.*, 2012). The gut microbiota of zebrafish fed nucleotides reduced the standard metabolic rate, leading to energy gain and growth performance of the fish. The ability of carbohydrate utilization in fish is low compared with that in mammals. It has been suggested that the gut microbiota of herbivorous fish can convert dietary carbohydrates into short-chain fatty acids, which play an important role in the nutrition and health of the host.

The feed conversion rate of farmed fish determines the growth and production of the fish to some extent and is directly linked to the economic effect. The intestinal microbiota plays an important role in the feed conversion of fish.

Immunomodulatory role of microflora in the digestive tract of fish

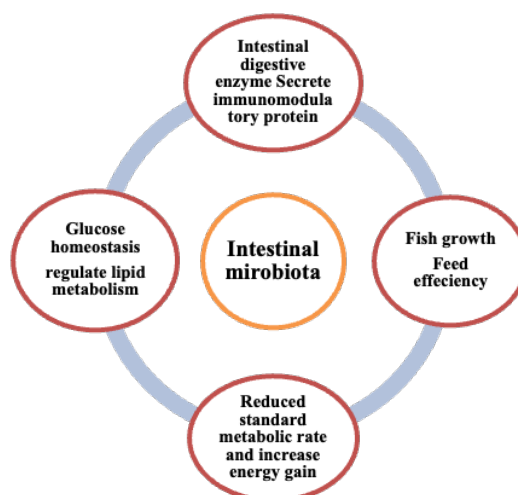
Regulation of Immunity can be mediated by bacterial components or microbial metabolites. Commensal microbes are essential in maintaining the development and maturation of the immune system. The colonization of microbiota in germ-free zebrafish was found to induce the intestinal expression of genes related to innate immune responses, including serum amyloid A1

(Saa1), myeloperoxidase (MPO), and complement component 3 (C3), indicating the function of the microbiota in the innate immunity of fish (Rawls *et al.*, 2004).

The intestinal bacteria produce bioactive compounds like tetradoxin (Noguchi *et al.*, 1987), Eicosapentaenoic acid (Yazawa *et al.*, 1988), biotin (Sugita *et al.*, 1992) and antibacterial substances (Westerdahl *et al.*, 1991) which may benefit the host fish. There exists a symbiotic relationship between fish with its constituent microflora.

Colonization of intestinal microbiota stimulates NF- κ B activity in both the intestine and extra-intestinal tissues of uninfected zebrafish, highlighting the role of microbiota in immune regulation (Kanter *et al.*, 2011). The NF- κ B signaling pathway is crucial for both innate and adaptive immune responses. Additionally, the microbiota influences intestinal leukocyte populations, leading to a reduction in macrophages and an increase in neutrophils in zebrafish. (Koch *et al.* 2018).

Probiotics modulated the microbiota with an enrichment of short-chain fatty acid-producing bacteria. Interaction of a Commensal bacterium *Aeromonas veronii*, and a zebrafish host, and found that the bacterium can secrete an Immunomodulatory protein, AimA, which can ameliorate inflammation in the gut (Rolig *et al.*, 2018).



Factors influencing the gut microbiota

Host- Host selection is the major determinant of bacterial community. The fish microbiota is highly dissimilar from the environmental bacterial communities. Intestinal microbiota of different species of carp (grass carp, crucian carp, and bighead carp) reared in the same pond were found to be different. The gut microbial communities of the different carp species were dominated by *Fusobacterium*, *Firmicutes*, *Proteobacteria*, and *Bacteroidetes*, but the abundance varied significantly among species. The intestinal microbiota of fish can be affected by life stages, and the composition of the gut microbial community showed significant changes corresponding to the host age.

Diet

Diet plays a key role in the development of the Microbiome. Gut microbiota is associated with different dietary patterns, foods and nutrients in humans. Similar conclusions have been made in fish. The largest change in the Microbiome of larval Yellowtail Kingfish occurred during a transition

of the diet from live feeds to formulated pellets (Walburn *et al.*, 2019). Guo *et al.*, 2021, found that vegetable oils with different fatty acid compositions had a significant effect on the abundance and diversity of gut microbes in juvenile golden pompano, and that fish fed with saturated fatty acids had greater gut microbial diversity. Dietary fatty acids can alter the microbial community of fish. Feeding an insect-based diet significantly changed the composition of the gut microbiota of Atlantic salmon, with a significant increase in the relative abundance of *Bacillus* in the gut (Li *et al.*, 2022). The impact of diet and starvation also influences the intestinal microbiota of fish. The microbial diversity underfeeding was greater than that under fasting. Starvation generally leads to a decrease in gut microbial diversity and impacts the microbiota structure. The gut microbiota of grass carp changes during starvation (Tran *et al.*, 2018).

Environmental factors

Host selection and diet play major roles in the formation of gut microbiota, but environmental factors also influence the gut microbiota. The environmental factors influencing fish microbial communities are mainly water and sediments (Zeng *et al.*, 2020). Notably, the relative contribution of water and sediments to fish intestinal microbiota can differ among fish species. The gut microbiota of fish is closely related to the microbial species, temperature, and salinity of the surrounding water. Changes in bacterial communities in environments with different osmotic pressures suggest that gut bacteria may play a role in facilitating host acclimation. Rudi *et al.* 2018, studied the effect of a transition from fresh to salt water on the gut microbiota of farmed Atlantic salmon and found that the bacterial quantity increased by 100-fold in salt water, with enrichment of Firmicutes and decreased abundance of Actinobacteria and Proteobacteria. Cold stress reduced the diversity and richness of the intestinal microbiota of blue tilapia, as well as the microbial composition (Kokou *et al.* 2018).

Chemical

In aquaculture, antibiotics are often used to prevent and treat bacterial diseases. The use of antibiotics may lead to an increase in the relative abundance of opportunistic pathogens, creating a potential hazard to fish health. Bozzi *et al.* (2021) found that the intestinal microbiota of Atlantic salmon treated with formalin showed more similarity to that of sick fish than healthy ones, indicating a negative effect of formalin treatment on fish microbiota. The impact of the organotin compound tributyltin (TBT)-a chemical formerly applied in antifouling paints and known to accumulate in marine sediments-was examined on the gut microbiota of zebrafish. Exposure to TBT changed the composition of the intestinal microbiota, notably decreasing the relative abundance of *Plesiomonas* bacteria (De *et al.*, 2021).

Conclusion

Gut microbiota has diversified roles in the health, performance, and various physiological functions of fish. There is a need for enhanced survivability, disease resistance, feed efficiency and growth performance of fish for upscaling aquaculture production. Gut microflora plays a significant role in improving growth performance and aquaculture production.

References

Ganguly S, Paul I, Mukhopadhyay SK (2010). Immunostimulant, probiotic and prebiotic-their applications and effectiveness in aquaculture. Israeli J. Aquacult—Bamidgeh. 62(3): 130–138.

- Ganguly, S., & Prasad, A. (2012). Microflora in fish digestive tract plays significant role in digestion and metabolism. *Reviews in fish biology and fisheries*, 22, 11-16.
- Guo H, Chen C, Yan X, Li Y, Wen X, You, C. (2021). Effects of different dietary oil sources on growth performance, antioxidant capacity and lipid deposition of juvenile golden pompano *Trachinotus ovatus*. *Aquaculture*; 530:735923.
- Li Y, Gajardo K, Jaramillo-Torres A, Kortner TM, Krogdahl A. (2022). Consistent changes in the intestinal microbiota of Atlantic salmon fed insect meal diets. *AnimMicrobiome* 2022;4(1):8.
- Savaş, S., Kubilay, A., & Basmaz, N. (2005). Effect of bacterial load in feeds on intestinal microflora of seabream (*Sparus Surata*) larvae and juveniles.
- Semova I., Carten J.D., Stombaugh J., Mackey L.C., Knight R., Farber S.A. (2012). Microbiota regulate intestinal absorption and metabolism of fatty acids in the zebrafish. *Cell Host Microbe*. 12(3):277–88.
- Sheng Y, Ren H, Limbu SM, Sun Y, Qiao F, Zhai W. (2018). The presence or absence of intestinal microbiota affects lipid deposition and related genes expression in zebrafish (*Danio rerio*). *Front Microbiol*; 9: 1124.
- Sugita, H., Takahashi, J., Deguchi, Y. (1992). Production and consumption of biotin by the intestinal microflora of cultured freshwater fishes. *Biosci. Biotechnol. Biochem.* 56, 1678 – 1679.

FRENCHBEAN CULTIVATION GUIDE

Lalthazuali and Banridamon K Sohkhia

College of Agriculture, Kyrdemkulai, Meghalaya, Ri-Bhoi District, 793105

*Corresponding Email: thateilianhna42@gmail.com

Introduction

Frenchbean is also known as Common bean or Kidney bean or Garden bean. Its scientific name is *Phaseolus vulgaris*. Frenchbean chromosomes no. is $2n=22$. In Hindi it is also called as Farashbean or Rashmah. It is consumed as vegetable when the pods are immature, delicate and tender, green shelled or as dry pulse. The green pods are rich in Calcium, Potassium, Phosphorus and Iron. The seeds are proteanacious. Important French bean States are Karnataka, Andhra Pradesh, Maharashtra, Tamil Nadu, Gujarat and West Bengal.

Status of French bean cultivation in Meghalaya

Frenchbean cultivation in Meghalaya: Frenchbean cultivation is significant in Meghalaya Ri-bhoi district particularly in mid altitude area (800-1200m), with Umiam a noted location for high disease incidence (suggesting extensive farming) and Umsning block having many growers indicating good adoption, though specific area figures are not in detail, it's a key crop alongside maize and rice offering profitability through intercropping. Varieties like Contender, Meghalaya Local (bush/pole) and Tripura Sel-1 are the common varieties.

Demography and environment condition of Ri-Bhoi District Meghalaya

Ri-Bhoi district in Meghalaya is primarily rural with a majority Khasi population depending on agriculture, experiencing high population growth and significant tribal presence (88.89%) scheduled tribe as per 2011. Environmentally it is characterized by a humid sub tropical climate. It has a moderate climate with temperatures typically ranging from around 10 degree Centigrade (winter lows) to 30 degree Centigrade (summer highs), acidic loamy soil prone to erosion and abundant water resources like rivers and reservoirs, but faces issues from unscientific farming and quarrying impacting its fragile ecology (Sukal Mardi, 7th August 2018).

Recommended cultivation practices:

Soil: light sandy loam soil with pH 5.5 is best suited for its cultivation. But it cannot withstand alkalinity to even a mild degree.

Preparation of soil: Plough the land about 25 cm deep, break clods and remove the weeds and leave it for aeration for about two weeks.

Variety: Varieties found suitable for cultivation in Meghalaya are as follows

I. Bush type:

1. Contender: with 65-75 maturity days
2. Meghalaya tender: with 70-75 maturity days
3. Tripura Sel-1: 80-90 maturity days

II. Pole type:

1. Meghalaya Local: with 85-90 maturity days



Fig: Pole type



Fig: Bush type

Seed treatment: Treat seed in Bavistin@2g/kg seed for 24 hours before sowing

Seed rate: For bush type is 60-65 kg/ha and for pole type it is 25-30 kg/ha

Sowing time: February to March for lowland and August to September for upland

Sowing of seeds: Seeds are sown by hand dibbling. A spacing of 40 x 15 cm for bush type and 90 x 15 cm for pole type maybe maintained. Seeds germinate in 3-4 days after sowing and plant flower in four weeks and pod are ready for picking 10-15 after flowering. Staking of pole type variety is necessary to get more and quality yield. The crop can be profitably inter crop with Maize, Soybean, Groundnut.

Manures and fertilizer:

FYM 10 tonnes/ha

DAP:70 kg/ha

MOP: 30 kg/ha

Full dose of FYM, MOP and half dose of DAP should be applied at the time of seed sowing and remaining half dose of DAP at the time of flowering.

Weed control: Suppression of weed through cultural practice is safe and involved low inputs.

Harvesting : The first crop of the green pods become ready for harvest within two months from sowing. Pick the pods by hands before they are fully grown.

Yield:

Bush type: 40-50 q/ha

Pole type:70-80 q/ha

Plant production problem:

Diseases:

1. Anthracnose: symptoms : black sunken cankers with light colour or grey center

Management: Use disease free seeds

Treat the seed with Bavistin@2g/kg seeds

In the infested field spray Bavistin @50 g/100lt of water at 8-10 days interval

2. Rhizoctonia blight: Symptoms: formation of sunken, reddish, brown lesion on stem near the soil line

Management: treat the seeds with Bavistin@2g/kg seeds

3. Angular leaf spot: Reddish brown angular lesion appear on leaves

Management: treat the seed with Bavistin@2g/kg seeds

In the infested field spray Bavistin @50g/kg seeds

Pests and their management:

1. Mites: symptoms sucks sap from tender leaves and leaves dries up

Management : Spray malathion 0.05% (100 ml malathion 50EC/100 L water)

2. Blister beetles: symptoms: feed on flower resulting poor fruit setting

Management: spray malathion 0.05% (100ml malathion 50EC/100 L water)

Economics and marketing:

Economics of French bean cultivation:

Profitability intercropping French bean with maize offer significant additional income boosting overall farm profits (Utpal Baruah, Mokidul Isalm, G Nongtdu and AK Tripathi, 2017).

Cost factors: major cost involved human labour, land value, machinery, fertilizer and plant protection yield: Good management can yield 40-50 and 70-80 q/ha with potential profit of 120000-320000 per acre.

After cost according to general report

Marketing aspects in Ri Bhoi

- Markets: Nongpoh (on NH-40): serve as a vital market hub for farmers around Nongpoh region with sellers operating there for years, lewduh market in Shillong for farmers around Umiam and Byrnihat market for farmers around Byrni
- Marketing channel: a participatory approach involving self-help groups (SHGs) and farmer club supported by ICAR and NABARD aims to improve market efficiency
- Challenges: Lack of market infrastructure, insufficient labour and irrigation is to hinder market efficiency

Conclusion

French bean cultivation in Meghalaya holds considerable potential due to the states favourable agroclimatic condition, the crop fits well into existing cropping systems and provide farmers with a short duration high value vegetables option that can enhance income and national security. With proper adoption of improve varieties, balance nutrient management, timely sowing and effective pest and disease control productivity of frenchbean can be significantly increase. Meghalaya emphasized in ecofriendly agriculture strengthening extension service, improving access to quality seeds and developing market linkage will further support farmers in realising the full economic potential of frenchbean cultivation in the state.

References:

https://www.telegraphindia.com/1130717/jsp/northeast/story_17124444.jsp

<https://www.scribd.com>

<https://kvkribhoi.nic.in>

GANODERMA LUCIDUM – THE “MUSHROOM OF IMMORTALITY”

Sanchita Gautam¹, Sachin Upmanyu^{2*} and Savita Jandaik³

¹Ph.D. Scholar, Department of Plant Sciences, School of Life Sciences, Central University of Himachal Pradesh, Shahpur, Kangra, Himachal Pradesh, 176206, India

²Associate Professor, Department of Plant Sciences, School of Life Sciences, Central University of Himachal Pradesh, Shahpur, Kangra, Himachal Pradesh, 176206, India

³Assistant Professor, Department of Plant Pathology, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.)-173230, India

*Corresponding Email: sachinupmanyu1974@hpcu.ac.in

Abstract

Ganoderma lucidum, commonly known as Reishi or Lingzhi, is a renowned medicinal mushroom used for over two millennia in traditional Asian medicine. Popularly referred to as the “Mushroom of Immortality,” it contains diverse bioactive compounds including triterpenoids (ganoderic acids), β -glucans, sterols, phenolic compounds, and proteins. Scientific investigations suggest that these constituents exhibit immunomodulatory, antioxidant, anti-inflammatory, hepatoprotective, antihyperlipidemic, and potential anticancer properties. Although many findings are based on preclinical and clinical studies, *Ganoderma lucidum* continues to gain attention as a promising functional food and complementary therapeutic agent. This article highlights its scientific basis, health potential, and necessary precautions for safe use.

Keywords: *Ganoderma lucidum*, Reishi, Lingzhi, Medicinal Mushroom, Triterpenoids, β -glucans, Immune Modulation

Introduction

Ganoderma lucidum is a wood-decaying basidiomycete fungus belonging to the family Ganodermataceae that naturally grows on hardwood trees in tropical and subtropical regions. It is easily recognized by its glossy, reddish-brown, kidney-shaped fruiting body with a lacquered surface, which has earned it the name “varnished conk.” Known as “Lingzhi” in China and “Reishi” in Japan, *Ganoderma lucidum* has been documented in traditional Chinese pharmacopeias for more than 2,000 years and was historically regarded as a superior tonic herb believed to promote vitality, enhance disease resistance, and support longevity. Due to its rarity in ancient times, it was often associated with royalty and spiritual symbolism, leading to its popular title as the “Mushroom of Immortality.” Unlike commonly consumed edible mushrooms, *Ganoderma lucidum* possesses a hard, woody texture and is therefore not eaten directly as food, instead, it is processed into decoctions, powders, capsules, teas, and standardized extracts. In recent decades, growing global interest in natural health products and functional foods has significantly expanded its commercial cultivation in countries such as China, Japan, Korea, the United States, and India. Scientific research intensified in the late twentieth century following the identification of its major bioactive constituents, particularly triterpenoids (ganoderic acids) and polysaccharides (β -glucans), which are believed to contribute to its biological activities. Advances in analytical techniques such as chromatography, mass spectrometry, and molecular characterization have

enabled detailed investigation of its chemical diversity and pharmacological mechanisms. Today, *Ganoderma lucidum* is considered one of the most extensively studied medicinal mushrooms worldwide, with ongoing research exploring its immunomodulatory, antioxidant, anti-inflammatory, hepatoprotective, and potential anticancer properties, thereby bridging traditional knowledge with modern biomedical science.

Bioactive Compounds of *Ganoderma lucidum*

Compound	Biological Function
Ganoderic acids (Triterpenoids)	Anti-inflammatory, cytotoxic activity in tumor cell studies
β -glucans (Polysaccharides)	Immunomodulatory, enhances macrophage and NK cell function
Ergosterol	Precursor of Vitamin D ₂ , antioxidant activity
Proteins (LZ-8)	Immune regulation
Phenolic compounds	Free radical scavenging activity
Peptidoglycans	Immune-modulating effects
Adenosine	Supports cardiovascular function

More than 400 bioactive compounds have been reported, with over 150 triterpenoids identified across *Ganoderma* species.

Health-Promoting Properties

1. Immunomodulatory Activity

- β -glucans interact with immune receptors such as Dectin-1.
- Enhance activity of macrophages, dendritic cells, and natural killer (NK) cells.
- May regulate cytokine production including IL-2 and IFN- γ . Acts as an immune regulator rather than simply an “immune booster.”

2. Antioxidant and Anti-Inflammatory Effects

- Experimental studies show free radical scavenging activity.
- May suppress inflammatory pathways such as NF- κ B.
- Helps reduce oxidative stress in laboratory models.

3. Anticancer Research

- Certain triterpenoids induce apoptosis in tumor cell lines.
- Polysaccharides may support immune responses during chemotherapy.
- Some clinical studies suggest improved quality of life in cancer patients.

However, current evidence does not support *Ganoderma lucidum* as a standalone cure for cancer, and further well-designed large-scale clinical trials are required to establish its therapeutic efficacy.

4. Cardiovascular Support

- Assists in lowering serum cholesterol levels.
- Modulates lipid metabolism in experimental studies.
- Adenosine content may support blood circulation.

5. Hepatoprotective Potential

- Demonstrated protective effects on liver cells in preclinical models.
- Reduce oxidative damage in hepatic tissues.

6. Antiviral and Antimicrobial Activity

- Laboratory studies indicate activity against certain viral and microbial pathogens.

Scientific Considerations

The therapeutic potential of *Ganoderma lucidum* depends on several factors including species and strain variation, cultivation substrate, geographic origin, developmental stage, and extraction method. Modern analytical tools such as high-performance liquid chromatography (HPLC) and mass spectrometry are being used to ensure quality control, chemical profiling, and species authentication. Proper standardization is essential for comparing research findings and ensuring product efficacy.

Side Effects

Ganoderma lucidum is generally considered safe when consumed appropriately. However, some individuals may experience:

- Mild digestive discomfort.
- Dry mouth or throat irritation.
- Allergic reactions (rare cases).
- Possible interaction with anticoagulant or antihypertensive medications.

Precautions

- Use standardized and quality-controlled products.
- Avoid excessive dosage without medical supervision.
- Consult a healthcare professional during pregnancy, lactation, or chronic illness.
- Patients on blood-thinning medication should seek medical advice before use.

Conclusion

Ganoderma lucidum bridges ancient traditional knowledge and modern biomedical research. Revered for centuries as the “Mushroom of Immortality,” it contains diverse bioactive compounds with measurable biological activities in laboratory and limited clinical studies. While preclinical evidence supports its immunomodulatory, antioxidant, anti-inflammatory, and potential anticancer properties, more large-scale human trials are required to fully validate its therapeutic applications. With proper standardization and accurate use, *Ganoderma lucidum* remains a promising medicinal mushroom and functional food of significant scientific and therapeutic interest.

References

- Bishop K.S., Kao C.H.J., Xu Y., Glucina M.P., Paterson R.R.M., Ferguson L.R. 2015. From 2000 years of *Ganoderma lucidum* to recent developments in nutraceuticals. *Phytochemistry* 114: 56–65.
- Boh B., Berovic M., Zhang J., Zhi-Bin L. 2007. *Ganoderma lucidum* and its pharmaceutically active compounds. *Biotechnol Annu Rev* 13: 265–301.
- Lin Z.B. 2005. Cellular and molecular mechanisms of immunomodulation by *Ganoderma lucidum*. *J Pharmacol Sci* 99: 144–153.
- Paterson RRM. 2006. *Ganoderma* – A therapeutic fungal biofactory. *Phytochemistry* 67: 1985–2001.
- Wasser SP. 2005. Reishi or Ling Zhi (*Ganoderma lucidum*). In: *Encyclopedia of Dietary Supplements*. New York: Marcel Dekker; pp. 603–622.
- Zhu M., Chang Q., Wong L.K., Chong F.S., Li R.C. 1999. Triterpene antioxidants from *Ganoderma lucidum*. *Phytother Res* 13: 529–531.

GENETICS AND PLANT BREEDING APPROACHES FOR CLIMATE-RESILIENT CROPS

Aprajita Singh^{1*} and Radheshyam Ramkrishna Dhole¹

Department of Genetics and Plant Breeding, Narayan Institute of Agricultural Sciences,
Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas (Bihar) – 821305, India

*Corresponding Author: aprajita0504@gmail.com

Abstract: Climate change has emerged as a major threat to global agricultural productivity by intensifying both abiotic and biotic stresses that adversely affect crop growth, yield stability, and nutritional quality. Rising temperatures, erratic rainfall patterns, prolonged droughts, floods, soil salinity, and the expanding prevalence of pests and diseases are increasingly challenging conventional crop production systems. In this context, genetics and plant breeding provide sustainable and long-term solutions for developing climate-resilient crop varieties capable of maintaining productivity under adverse environmental conditions. Recent advances in molecular genetics, genomics, high-throughput phenotyping, and biotechnology have transformed traditional breeding into precision-based approaches. Modern tools such as marker-assisted selection, genomic selection, speed breeding, and genome editing have significantly accelerated the identification and deployment of stress-tolerant traits. This paper presents a comprehensive overview of genetics and plant breeding strategies for climate-resilient crops, emphasizing their key characteristics, essential components, operational workflow, applications, advantages, and prospects. The integration of advanced genetic tools with sustainable breeding frameworks is essential for ensuring food security and agricultural resilience under changing climatic scenarios.

Keywords: Climate-resilient crops, Plant genetics, Molecular breeding, Abiotic stress tolerance, Genomic selection.

Introduction

In the past, plant breeding has been essential for improving crop quality, productivity, and resistance to biotic and abiotic challenges. However, breeding methods that go beyond traditional phenotypic selection are required due to the unparalleled speed and complexity of climate change. Breeders can better comprehend the molecular underpinnings of stress tolerance and environmental adaptation because to developments in plant genetics. Modern breeding techniques combined with genetic information can create crop types that function consistently in a variety of uncertain conditions. Thus, the foundation of climate-resilient agriculture and sustainable food production is genetics-based plant breeding.

To improve crop quality, productivity, and resilience to biotic and abiotic challenges, plant breeding has long been essential. Breeding techniques that go beyond traditional phenotypic selection are necessary, nonetheless, due to the unparalleled speed and complexity of climate change. The molecular underpinnings of stress tolerance and environmental adaptation are now understood by breeders thanks to developments in plant genetics. It is feasible to create crop varieties that perform consistently in a variety of uncertain situations by combining genetic information with contemporary breeding procedures. Consequently, a key component of climate-resilient agriculture and sustainable food supply is genetically based plant breeding.

Key Characteristics of Climate-Resilient Crops

Climate-resilient crops developed through genetic improvement exhibit specific adaptive traits that enable them to withstand environmental stresses. A primary characteristic is enhanced tolerance to abiotic stresses such as drought, heat, salinity, and flooding. These traits are often associated with improved root architecture, efficient osmotic regulation, stress-responsive gene expression, and sustained photosynthetic efficiency under stress conditions.

Resistance to disease and pest outbreaks brought on by climate change is another essential component. Incorporating lasting resistance genes has become a top objective in breeding efforts as the global range of diseases and insect pests is expanded by rising temperatures and changed rainfall patterns. Another feature that distinguishes climate-resilient crops is yield stability, which guarantees steady production in a variety of settings rather than maximum yield under ideal circumstances. Climate-smart crop adaptability for low-input and resource-constrained farming systems is further enhanced by improved resource-use efficiency, especially for water and nutrients. Furthermore, addressing food and nutritional security is greatly aided by the capacity to preserve nutritious quality in stressful circumstances.

Important Components of Genetics and Plant Breeding

The development of climate-resilient crops relies on several interconnected components:

- **Germplasm and genetic resources:** Diverse collections of landraces, elite lines, and wild relatives provide the raw material for adaptation. Systematic characterization of germplasm for stress tolerance is essential.
- **Genotyping platforms:** Technologies such as SNP arrays, whole-genome sequencing, and imputation pipelines generate high-resolution genetic data for mapping and prediction.
- **High-throughput phenotyping:** Remote sensing, imaging systems, drones, and automated field sensors enable large-scale, precise measurement of stress-related traits.
- **Statistical genetics and predictive models:** Genome-wide association studies, genomic selection, and genotype $\times$ environment interaction models guide selection decisions.
- **Genome editing and functional genomics:** Tools such as CRISPR/Cas systems enable targeted modification of stress-responsive genes.
- **Decision-support and deployment systems:** Databases, bioinformatics pipelines, and variety testing networks translate research outputs into breeder- and farmer-ready products.

Operational Workflow

The breeding workflow for climate-resilient crops typically follows a structured sequence:

1. **Problem definition and trait prioritization:** Identification of major climatic constraints and target traits using climate projections, yield-gap analysis, and farmer feedback.
2. **Germplasm identification and pre-screening:** Evaluation of diverse genetic materials under controlled and multi-location field conditions.
3. **Trait dissection and gene discovery:** Application of QTL mapping, GWAS, transcriptomics, and other omics approaches to identify candidate genes.
4. **Model development and genomic prediction:** Construction of genomic selection models incorporating environmental covariates and G $\times$ E interactions.
5. **Selection and accelerated breeding:** Use of genomic selection, speed breeding, doubled haploids, and genome editing to shorten breeding cycles.

6. **Multi-location testing and release:** Evaluation of elite lines across environments followed by seed multiplication and variety release.

Applications

Climate-resilient breeding based on genetics has several uses in many agricultural systems. Climate-adapted cultivars in marginalized areas stabilize yields and livelihoods in smallholder farming. Rapid-cycle genomic selection makes it possible to create robust hybrids and inbred lines in commercial agriculture. Precision breeding enhances post-harvest quality and stress tolerance in horticulture and specialty crops. By lowering greenhouse gas emissions and increasing the efficiency of water and fertilizer use, climate-resilient cultivars also support sustainability. Supportive seed systems and regulatory frameworks are also necessary for effective implementation.

Advantages

Compared to traditional methods, modern genetic and breeding techniques have a number of advantages. These consist of quicker breeding cycles, more accurate trait selection, the ability to simultaneously improve several traits, increased resource efficiency, and improved adaptation to a variety of climatic situations. Long-term performance stability and robustness are guaranteed by incorporating G×E-aware models.

Future Strategies

Future breeding plans should concentrate on using artificial intelligence and multi-omics data to increase prediction accuracy. Priorities should be prioritized to further ethically managed genome editing, improve availability to varied germplasm, and strengthen G×E-aware breeding pathways. Decentralized seed systems and active farmer involvement are also necessary to guarantee the successful adoption and regional adaption of enhanced cultivars.

Conclusion

Modern plant breeding and genetics offer the most efficient means of creating crops that can flourish in a variety of climate conditions. High-throughput phenotyping, genomic prediction, precision genome editing, and the integration of various germplasm allow for more rapid and focused genetic improvements while minimizing environmental effects. Coordinated efforts spanning science, policy, and practice, along with consistent funding for data-rich breeding initiatives and fair access to improved cultivars, will be necessary to achieve climate-resilient agriculture.

Reference

- Benítez-Alfonso, Y., Soanes, B. K., & Zimba, S. (2023). *Enhancing climate change resilience in agricultural crops*. *Current Opinion in Plant Biology*, 72, 102–114.
- Xiong, W. (2022). *Climate change challenges plant breeding*. *Trends in Plant Science*, 27(11), 1001–1013.
- Budhlakoti, N., et al. (2022). *Genomic Selection: A Tool for Accelerating the Efficiency of Breeding for Climate-Resilient Crops*. *Frontiers in Genetics*, 13, 832153.
- Gaba, Y., et al. (2021). *Raising Climate-Resilient Crops: Opportunities and Approaches*. *Frontiers in Plant Science* (review).
- Robles-Zazueta, C. A. (2024). *Climate change impacts on crop breeding: Targeting biotic and abiotic interactions*. *The Plant Genome* (2024).

HEALTH-ENHANCING INGREDIENTS IN FUNCTIONAL FOODS: ROLE, BENEFITS AND FUTURE PERSPECTIVES

Anerao Kishor K^{1*}, Deshpande H. W² and Pratyush Kumari Rath³

¹Ph.D. Research Scholar, Department of Food Microbiology and Safety, CFT, VNMKV, Parbhani.

²Professor, Department of Food Microbiology and Safety, CFT, VNMKV, Parbhani

³Ph.D. Research Scholar, Department of Agricultural Economics, COA, VNMKV, Parbhani

*Corresponding Email: kishoranerao135101@gmail.com

Abstract

Health-enhancing ingredients such as probiotics, prebiotics, adaptogens and antioxidants are increasingly incorporated into functional foods due to their proven potential to improve human health and prevent lifestyle-related diseases. Probiotics and prebiotics play a vital role in modulating the gut microbiota, enhancing digestive health, immunity and metabolic functions. Their synergistic use as synbiotics further amplifies these benefits, contributing to reduced inflammation and improved overall well-being. Adaptogens, though less explored, are gaining importance for their ability to support stress resilience and mental health. Antioxidants derived from natural food sources help combat oxidative stress, thereby lowering the risk of chronic conditions such as cardiovascular diseases, diabetes and cancer. Despite their promising applications, challenges remain regarding their bioavailability, stability during food processing and variability in individual responses. Recent innovations in encapsulation techniques, AI-enabled formulation design and precision nutrition approaches are addressing these issues to improve the effectiveness and consumer acceptance of functional foods.

Key words: Functional foods, Probiotics, Prebiotics, Synbiotics, Adaptogens, Antioxidants, Gut microbiome, Immune health.

Introduction

The incorporation of health-enhancing ingredients such as probiotics, prebiotics, adaptogens and antioxidants into foods has gained significant attention due to their potential benefits in promoting health and preventing diseases. The growing interest in functional foods reflects a shift towards preventive health measures, emphasizing the importance of bioactive compounds in enhancing quality of life and reducing disease risk (Toy et al., 2025). These functional ingredients are increasingly being used in the food industry to create products that offer more than basic nutrition, aiming to improve immune function, gut health and overall well-being. The following sections explore the roles and benefits of these ingredients, supported by evidence from recent literature.

Probiotics and Prebiotics

Probiotics are live microorganisms that, when consumed in adequate amounts, confer health benefits, primarily by modulating the gut microbiota. Common strains include *Bifidobacterium* and *Lactobacilli*, which are often found in fermented dairy products (Nath, 2016) (Pandey *et al.*, 2015). These beneficial bacteria not only support digestive health but also play a role in enhancing the immune system and preventing gastrointestinal disorders (Evangelista-Barreto & Jesus, 2025). Prebiotics, on the other hand, serve as food for these probiotics, promoting their growth and

activity in the gut (Grajek *et al.*, 2005). The synergy between probiotics and prebiotics is crucial, as their combined effect can optimize gut health and enhance overall well-being (Sridhar, 2024). This interplay between probiotics and prebiotics forms the basis of synbiotics, aiming to maximize health benefits through their complementary actions (Sridhar, 2024). Additionally, the incorporation of these functional ingredients into everyday diets represents a proactive approach to health maintenance and disease prevention (Evangelista-Barreto & Jesus, 2025).

Prebiotics are non-digestible fibers that promote the growth of beneficial gut bacteria. Examples include inulin and fructooligosaccharides (FOS), which enhance the survival and activity of probiotics in the gut (Jain *et al.*, 2014) (Pandey *et al.*, 2015). The benefits of prebiotics extend beyond gut health, as they also contribute to improved metabolic functions and may reduce the risk of certain chronic diseases (Evangelista-Barreto & Jesus, 2025).

The combination of probiotics and prebiotics, known as synbiotics, can have synergistic effects, improving gut health, enhancing immune function, and potentially reducing the risk of metabolic diseases (Al-Habsi *et al.*, 2024) (Pandey *et al.*, 2015). Incorporation of synbiotics into functional foods can significantly enhance their health benefits, promoting a balanced gut microbiome and improving overall metabolic health (Verma *et al.*, 2023) (Toy *et al.*, 2025).

Foods fortified with these ingredients have shown benefits such as improved intestinal flora, enhanced immune response, and reduced inflammation (Gomes *et al.*, 2024) (Al-Habsi *et al.*, 2024). Moreover, the integration of probiotics and prebiotics into daily diets not only supports digestive health but also plays a pivotal role in enhancing overall wellness and preventing chronic diseases (Probiotics and Prebiotics: The Power of Beneficial Microbes for Health and Wellness, 2019).

Adaptogens

Adaptogens are natural substances that help the body adapt to stress and exert a normalizing effect upon bodily processes. While the provided papers do not specifically focus on adaptogens, they are often included in functional foods for their potential to enhance resilience to stress and improve mental clarity. The inclusion of antioxidants in functional foods is essential for promoting health, as they contribute to reducing the risk of chronic diseases and improving overall well-being (Toy *et al.*, 2025). The integration of these health-promoting ingredients into diets not only supports physical health but also aligns with a growing emphasis on preventive strategies in public health initiatives.

The combination of these functional ingredients represents a holistic approach to health, fostering both physical and mental well-being while addressing the rising prevalence of lifestyle-related diseases. This comprehensive strategy highlights the importance of incorporating functional foods into daily diets to combat lifestyle-related diseases and achieve long-term health benefits.

Antioxidants

Antioxidants are compounds that inhibit oxidation and combat free radicals, thereby reducing oxidative stress and inflammation. They are found in various functional foods, including those enriched with polyphenols and vitamins (Skenderidou *et al.*, 2025) (Peng *et al.*, 2020). Antioxidants play a vital role in reducing the risk of chronic diseases by neutralizing free radicals and enhancing overall health outcomes (Singh, 2024). Their incorporation into functional foods is essential for maximizing health benefits and promoting well-being.

Foods like chocolate, which are rich in antioxidants, can serve as carriers for probiotics, enhancing their stability and delivery to the gut (Hossain *et al.*, 2021). This dual functionality not only improves the viability of probiotics but also enriches the overall health benefits of the food product, making it a valuable addition to functional diets.

Challenges and Innovations

Despite the promising benefits, challenges such as bioavailability, stability during processing, and individual variability in response to these ingredients remain. Innovations in encapsulation technologies and AI-enabled design are being explored to overcome these challenges and improve the efficacy of functional foods (Zhao *et al.*, 2025). The ongoing development of advanced delivery systems and formulation strategies is crucial for enhancing the effectiveness and consumer acceptance of functional foods.

The development of novel delivery systems and precision nutrition approaches may further enhance the health benefits of these ingredients, making them more effective and accessible to consumers (Skenderidou *et al.*, 2025) (Zhao *et al.*, 2025). The integration of these advanced technologies into functional food development could significantly improve the stability and bioavailability of bioactive compounds, ultimately leading to better health outcomes for consumers.

Conclusion

The integration of health-enhancing ingredients into foods offers significant potential for improving public health, it is important to consider the variability in individual responses and the need for further research to establish long-term safety and efficacy. The ongoing advancements in food technology and personalized nutrition hold promise for addressing these challenges and maximizing the benefits of functional foods.

References

- Al-Habsi, N., Al-Khalili, M., Haque, S. A., Elias, M. C., Olqi, N. A., & Uraimi, T. A. (2024). Health Benefits of Prebiotics, Probiotics, Synbiotics, and Postbiotics. *Nutrients*, 16(22), 3955–3955. <https://doi.org/10.3390/nu16223955>
- Evangelista-Barreto, N. S., & Jesus, M. (2025). Alimentos funcionais e bioativos: contribuições de probióticos, prebióticos e compostos naturais para a saúde humana. 80–96. <https://doi.org/10.37885/25081999>
- Gomes, E. da S., Schipfer, C. W. T., Oliveira, V. de A. F. de, Freitas, M. M. G. de, Muxfeldt, L. C., Maestro, A. D., Frez, F. L. V., & Santos, O. de O. (2024). Alimentos funcionais integrados com prebióticos e probióticos: uma revisão. *Observatorio de La Economía Latinoamericana*, 22(5), e4911–e4911. <https://doi.org/10.55905/oelv22n5-198>
- Grajek, W., Olejnik, A., & Sip, A. (2005). Probiotics, prebiotics and antioxidants as functional foods. *Acta Biochimica Polonica*, 52(3), 665–671. https://doi.org/10.18388/ABP.2005_3428
- Hossain, N., Ranadheera, C. S., Fang, Z., & Ajlouni, S. (2021). Healthy chocolate enriched with probiotics: a review. *Food Science and Technology International*, 41(3), 531–543. <https://doi.org/10.1590/FST.11420>
- Jain, M., Gupta, K., & Jain, P. (2014). Significance of Probiotics and Prebiotics in Health and Nutrition. 3, 181–195.

- Nath, A. H. (2016). Probiotic Foods: Health Booster. *International Journal of Home Science*, 2(3), 187–194.
- Pandey, K. R., Naik, Suresh. R., & Vakil, B. V. (2015). Probiotics, prebiotics and synbiotics- a review. *Journal of Food Science and Technology-Mysore*, 52(12), 7577–7587. <https://doi.org/10.1007/S13197-015-1921-1>
- Peng, M., Tabashsum, Z., Anderson, M. G., Truong, A., Houser, A., Padilla, J., Akmel, A., Bhatti, J., Rahaman, S. O., & Biswas, D. (2020). Effectiveness of probiotics, prebiotics, and prebiotic-like components in common functional foods. *Comprehensive Reviews in Food Science and Food Safety*, 19(4), 1908–1933. <https://doi.org/10.1111/1541-4337.12565>
- Probiotics and Prebiotics: The Power of Beneficial Microbes for Health and Wellness. (2019). 1(1), 1–6. <https://doi.org/10.51470/ma.2019.1.1.1>
- Singh, Mrs. N. (2024). Functional Foods. 155–178. <https://doi.org/10.58532/nbennurdsch16>
- Skenderidou, I., Leontopoulos, S., & Skenderidis, P. (2025). Functional Food Ingredients Enhancing Immune Health. *International Journal of Molecular Sciences*, 26(17), 8408–8408. <https://doi.org/10.3390/ijms26178408>
- Sridhar, S. (2024). Exploring the Interplay of Prebiotic and Probiotics. *International Journal of Science and Research*, 13(9), 1081–1084. <https://doi.org/10.21275/sr24917205915>
- Toy, J. Y. H., Yu, L., & Huang, D. (2025). Functional Foods for Health: Evidence and Insights. 1–15. <https://doi.org/10.1039/9781837674046-00001>
- Verma, S., Gupta, N., Reshi, M., Chib, A., & Kumari, A. (2023). Applications of probiotics and prebiotics in the food industry: a review. *Plant Archives*. <https://doi.org/10.51470/plantarchives.2023.v23.no2.075>
- Zhao, L., Ju, W., Wang, L., Ye, Y.-B., Liu, Z., Cavender, G., Sun, Y., & Sun, S. (2025). Functional Ingredients: From Molecule to Market—AI-Enabled Design, Bioavailability, Consumer Impact, and Clinical Evidence. *Foods*, 14(17), 3141–3141. <https://doi.org/10.3390/foods14173141>

ENHANCING FARM INCOME THROUGH SHORT-DURATION GREEN GRAM CULTIVATION UNDER RESIDUAL SOIL MOISTURE CONDITIONS

Shubham Pandey^{1*}, Rashmirekha Senapati², S.R. Mishra³,
Abhishek Tiwari⁴ and Ekanshi Shreshtha⁵

^{1,3,5}Department of Agricultural Meteorology,

Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya

²NEPPA Project, Indian Institute of Water Management, Bhubaneswar-Odisha

⁴Department of Soil Science and Agricultural Chemistry,

Dr. Ram Manohar Lohia Avadh University Faizabad - Uttar Pradesh

*Corresponding Author: pandeyshubham0121@gmail.com

Abstract

Short-duration green gram (*Vigna radiata* L.) grown under residual soil moisture provides a low-cost, climate-resilient option to enhance farm income in cereal-based systems of India. Cultivation of 60–70 days varieties after rabi harvest without irrigation yields 0.8–1.2 t ha⁻¹ with minimal inputs. Improved varieties from the Indian Council of Agricultural Research and Indian Institute of Pulses Research perform well under such conditions. Practices like seed treatment and integrated nutrient management increase productivity and reduce pests. Farmers can earn ₹25,000–40,000 per hectare in 65 days while improving soil fertility through biological nitrogen fixation and utilizing fallow periods efficiently.

Key Words : Residual soil moisture, climate-resilient, integrated nutrient management and nitrogen fixation.

Introduction

In India, agriculture remains the backbone of rural livelihood, with small and marginal farmers making up a large proportion of producers. Enhancing farm income without expanding land area is a key challenge. One effective strategy is to optimize the utilization of residual soil moisture left after the harvest of major crops like rice or wheat. By growing *short duration green gram* (also called Mungbam or moong), farmers can add an additional crop within the same year, enhancing cropping intensity and generating additional income with minimal irrigation and inputs). Green gram (*Vigna radiata* L. Wilczek) is a short-duration legume, typically maturing in 60–70 days, with the ability to thrive with limited water, fix atmospheric nitrogen, and improve soil health (residual moisture cropping).

Current Status of Green Gram Cultivation in India

India is the largest producer of green gram in the world, contributing more than 70 % of global production. In recent agricultural seasons, approximately 1.66 million hectares were sown to green gram across the country, with total production around 3.74 million tonnes in 2022–23. However, the average national productivity of green gram still lags behind its potential. National productivity is about 468 kg/ha, but state-level performance varies—Uttar Pradesh, for example, achieved an average yield of 686 kg/ha, ranking highest in the country. Green gram's short growth

cycle and low water requirement make it ideal for exploiting residual soil moisture after harvesting a preceding crop (e.g., rice or wheat) during the dry season. The crop's adaptability and drought tolerance also enable it to fit well into various cropping systems without heavy reliance on irrigation.

Why Green Gram After Harvest – Leveraging Residual Moisture

Residual Moisture Advantage

When a main crop like rice or wheat is harvested, the soil typically retains moisture in the upper layers. This residual moisture is often under-utilized, leading to a period where fields lie fallow until the next major season. Growing short duration green gram capitalizes on this moisture, reducing the need for irrigation. This practice is especially applicable in regions with a monsoon climate, where rains recharge soil moisture during the wet season before harvest. Short duration pulses like green gram can be planted immediately after harvesting the main crop and harvested before soil moisture drops below critical levels.

Agronomic Practices for Green Gram Cultivation Using Residual Moisture

Crop Duration and Suitable Varieties

Short duration green gram varieties mature in 60–70 days and are well suited to exploiting residual moisture. These varieties include:

- **Pusa Vishal** – Matures in 60–65 days with estimated yield 12–14 q/ha.
- **TJM-3 (Tambe Jawahar)** – Matures in 60–70 days with potential yield 10–12 q/ha.
- **Narendra Moong-1** – Mature in 70–75 days with 12–14 q/ha yield potential.



Land Preparation and Sowing

After harvesting rice or wheat, fields should be prepared by light tillage to create a fine seedbed. Incorporation of organic matter like well-decomposed farmyard manure helps improve soil structure and water retention. Sowing should be timed immediately after harvest to capture maximum residual moisture. Seed rates of 12–15 kg/ha are recommended in sole cropping.

Soil and Water Management

Green gram performs best in loamy, well-drained soils with a pH between 6 and 7.5. It requires relatively low water (approximately 600–720 mm per season), and in residual moisture systems, supplemental irrigation may only be necessary in extreme dry spells.

Nutrient and Pest Management

Legumes like green gram naturally fix atmospheric nitrogen, improving soil fertility for subsequent crops. Inoculation with rhizobium and balanced fertilization (P and K) further enhances plant growth and yield. Weed control is crucial early in crop growth, and practices like mulching or appropriate herbicide use can significantly increase yield by reducing competition.

Yield Performance and Income Potential**Yield Gains over Fallow Systems**

Under residual moisture conditions with short duration green gram, farmers can expect yields ranging from 800–1400 kg/ha depending on variety, soil, and climate. While typical rainfed yields are often lower, improved varieties and best agronomic practices have demonstrated higher outputs. For example: Improved mechanized sowing, certified seed, and optimized agronomy have enabled yields up to 1.99 t/ha, compared to farmers' typical practice of 0.63 t/ha, in demonstration fields in parts of India.

Economic Benefits and Income Enhancement**6.1. Gross Returns and Profitability**

Green gram's market value is consistently strong due to demand for pulses. As a protein-rich pulse, it commands relatively premium prices compared to cereal crops. When farmers sell green gram grain or dal, they earn significantly higher returns per hectare.

Reduced Production Costs

Green gram cultivation using residual moisture drastically reduces irrigation costs. Since the crop completes its life cycle within 60–70 days with minimal water, farmers save on diesel or electric irrigation expenses and associated labour costs. Furthermore, green gram's nitrogen fixation reduces future fertilizer requirements for succeeding crops, contributing to overall cost savings.

Soil Health and Long-Term Sustainability

Growing green gram between main crops also improves soil health by:

- ❖ Increasing organic matter through biomass residue.
- ❖ Enhancing soil nitrogen content through biological fixation (30–40 kg N/ha).

These soil benefits support better yields in subsequent crops like rice or wheat and reduce fertilizer dependence, indirectly increasing future farm income.

Integrating Green Gram into Cropping Systems**Rice–Green Gram and Wheat–Green Gram Systems**

Residue cropping with green gram especially fits into rice–green gram or wheat–green gram rotations, where:

- ❖ Rice/wheat is harvested.
- ❖ Green gram is sown immediately, exploiting leftover moisture.

Studies have found that integrating green gram into these systems increases overall cropping intensity and total system productivity compared to leaving fields fallow.

Conservation Agriculture Benefits

Residue retention (such as leaving rice straw on the field) can further enhance soil moisture conservation. Combined with green gram cultivation, this practice sustains soil water for longer, benefiting both current and subsequent crops.

Challenges and Solutions**Seed Availability and Quality**

Access to improved short duration seed varieties may be limited in some regions. Promoting decentralized seed production and timely availability at local markets can improve adoption.

Knowledge and Extension Services

Many smallholder farmers lack awareness of optimized residual moisture cropping techniques. Strengthening extension services and farmer training programs on green gram best practices is crucial for wider adoption.

Market Linkages

While green gram has strong demand, ensuring market access and fair pricing remains a priority. Encouraging farmer cooperatives and linking to pulse processing units can help farmers capture better value.

Conclusion

Cultivating short duration green gram in residual moisture offers a practical, income-enhancing strategy for Indian farmers, particularly smallholders who face limited land and water resources. By exploiting moisture left in the soil after harvest, farmers can grow an additional crop with minimal irrigation costs, improve soil fertility, and significantly boost net income. Improved practices, access to high-yielding varieties, and appropriate management can elevate yields to around 1.5–2.0 t/ha, thereby transforming green gram cultivation into a profitable component of crop diversification in India.

References

https://idc.icrisat.org/idc/wp-content/uploads/2017/10/Annual-Report_Bhoosamrudhi-progress-Report_old-four-districts-2015-16.pdf?utm_source=chatgpt.com

Peramaiyan, P., Srivastava, A. K., Kumar, V., Seelan, L. P., Banik, N. C., Khandai, S. and Malik, R. K. 2023. Crop establishment and diversification strategies for intensification of rice-based cropping systems in rice-fallow areas in Odisha. *Field Crops Research*, 302, 109078.

Rank P.H., Patel R.J., Lunagaria M.M., Tiwari M.K. 2025. Enhancing the Green Gram Production by Leveraging New Dimensions of Land and Water Resources Management Technologies: A Comprehensive Review. *Legume Research*. 48(6): 909-918. doi: 10.18805/LR-5257.

Tripathi, S., Kaur, A., Brar, A. S., Sekhon, K. S., Singh, S., Malik, A. and Kisi, O. 2024. Optimizing yield and water productivity in summer mung bean (*Vigna radiata* L.) through crop residue management and irrigation strategies. *BMC Plant Biology*, 24(1), 1012.

ROLE OF AGRICULTURE IN THE INDIAN ECONOMY

Jasmine Keziah Puli^{1*}, Jassica Keren Puli² and Davuluri Babysridivya³

¹Department of Agricultural Economics, Agricultural College, Bapatla

²Department of Floriculture and Landscaping,

Dr. YSRHU-College of Horticulture, Anantharajupeta, Andhra Pradesh

³Department of Floriculture and Landscaping, HC & RI,

Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu

*Corresponding Author: jasmine.puli1912@gmail.com

Abstract

Agriculture remains a foundational pillar of the economy of India, contributing significantly to employment generation, food security, rural development, and industrial growth. Despite a declining share in GDP due to structural transformation, the sector continues to sustain nearly half of the population through farming and allied activities. Agriculture supplies essential raw materials to agro-based industries, supports export earnings, and plays a vital role in poverty alleviation and nutritional security. However, challenges such as climate change, fragmented landholdings, and market volatility persist. Strengthening sustainable practices, technological innovations, and policy interventions is essential to enhance productivity, ensure farmer welfare, and achieve inclusive and resilient economic growth.

Keywords: Agriculture, Indian economy, employment, food security, economic growth

Introduction

Agriculture has long been regarded as the backbone of the Indian economy, playing a crucial role in ensuring food security, employment generation, rural development and overall economic stability. In a country like India, where a significant proportion of the population resides in rural areas and depends directly or indirectly on farming, agriculture is not merely an economic activity but a socio-cultural foundation. Despite rapid industrialization and the growth of the service sector, agriculture continues to be a vital sector contributing to national income, livelihoods and sustainable development.

The importance of agriculture in India extends beyond crop production to include allied sectors such as horticulture, floriculture, livestock, fisheries and agro-processing. These interconnected activities collectively support economic growth, reduce poverty and promote inclusive development. In recent decades, agricultural transformation driven by technological advancements, policy support and institutional reforms has further enhanced its role in shaping the Indian economy.

Contribution to National Income

Agriculture plays a significant role in contributing to India's Gross Domestic Product (GDP). Although its share in GDP has declined over the decades—from over 50% at independence to around 15–18% in recent years—it still remains a critical sector supporting the economy. The decline in percentage contribution reflects structural transformation toward industry and services rather than reduced importance of agriculture.

Agriculture serves as the foundation for food production and raw materials for various agro-based industries such as textiles, sugar, edible oils and food processing. The performance of the agricultural sector directly influences overall economic growth, especially during years of favorable monsoons and high agricultural output. A good harvest often leads to increased rural demand, stimulating industrial production and service sector growth.

According to data from the World Bank, growth in agriculture is two to three times more effective in reducing poverty compared to growth in other sectors. Thus, the sector plays a critical role not only in income generation but also in equitable distribution of wealth.

Employment Generation

Agriculture is the largest source of employment in India, providing livelihoods to nearly half of the country's workforce. A majority of rural households depend on farming and allied activities such as dairy, poultry, fisheries and horticulture for their income. Even in urban areas, many industries rely on agricultural raw materials, creating indirect employment opportunities.

The labor-intensive nature of agriculture makes it a crucial sector for absorbing rural labor, especially in regions where industrial development is limited. Seasonal employment in crop cultivation, harvesting, processing and marketing provides income opportunities to millions of small and marginal farmers and agricultural laborers.

Furthermore, diversification into high-value crops, floriculture, organic farming and agri-entrepreneurship has opened new avenues for employment generation among rural youth and women. The promotion of agribusiness and value addition has strengthened the role of agriculture as a major employer in the Indian economy.

Food Security and Nutritional Security

One of the most important contributions of agriculture is ensuring food and nutritional security for the country's vast population. India is one of the largest producers of cereals, pulses, fruits, vegetables, milk and spices globally. The Green Revolution and subsequent agricultural advancements have enabled the country to achieve self-sufficiency in food grain production.

Agriculture ensures the availability of staple foods such as rice, wheat and pulses, which are essential for national food security. In addition, horticultural crops provide vital nutrients, contributing to improved dietary diversity and health outcomes. The Public Distribution System (PDS) and food security schemes rely heavily on stable agricultural production.

The Food and Agriculture Organization emphasizes that sustainable agriculture is essential for eradicating hunger and malnutrition. In India, agricultural growth directly influences food availability, accessibility and affordability for millions of people.

Source of Raw Materials for Industries

Agriculture supplies raw materials to numerous agro-based and food processing industries. Cotton supports the textile industry, sugarcane feeds sugar mills, oilseeds are processed into edible oils and fruits and vegetables are used in food processing industries. These industries contribute significantly to industrial growth, export earnings and employment generation.

The linkage between agriculture and industry creates a multiplier effect in the economy. Increased agricultural production leads to higher demand for fertilizers, machinery, transport, storage and marketing services. This interdependence strengthens both rural and urban economies.

The development of agro-processing industries has also enhanced value addition in agriculture, reducing post-harvest losses and increasing farmers' income. Policies encouraging food processing, cold storage and supply chain development further strengthen agriculture's contribution to industrial growth.

Role in Rural Development

Agriculture is central to rural development and poverty alleviation. Since a large proportion of India's population resides in rural areas, agricultural growth directly influences rural income, employment and living standards. Improved agricultural productivity leads to higher farm income, better housing, education and healthcare in rural communities.

Government initiatives implemented by the Ministry of Agriculture & Farmers Welfare focus on enhancing productivity, irrigation, crop insurance and market access. Programs promoting sustainable agriculture, mechanization and digital farming are transforming rural economies.

Agriculture also supports rural infrastructure development, including roads, storage facilities, irrigation systems and market yards. These developments improve connectivity and facilitate economic activities in rural areas, contributing to balanced regional growth.

Agricultural Trade and Foreign Exchange Earnings

Agriculture plays a vital role in India's foreign trade by contributing significantly to export earnings. Major agricultural exports include rice, spices, tea, coffee, marine products, fruits, vegetables and floricultural products. These exports generate foreign exchange and strengthen India's position in global agricultural markets.

India is among the leading exporters of basmati rice, spices and tea. The promotion of export-oriented agriculture and value-added products has increased farmers' income and enhanced global competitiveness. Agricultural trade policies, quality standards and supply chain improvements have further supported export growth.

At the same time, imports of certain commodities such as edible oils highlight the need for increased domestic production and self-reliance. Balanced trade policies are essential for ensuring both farmer welfare and national economic stability.

Role in Sustainable Development

Agriculture is closely linked to environmental sustainability and natural resource management. Sustainable agricultural practices such as organic farming, conservation agriculture and integrated farming systems help conserve soil, water and biodiversity. These practices contribute to long-term economic and ecological sustainability.

The NITI Aayog emphasizes the importance of climate-resilient agriculture for achieving sustainable development goals. Climate change poses significant challenges to agricultural productivity, making it essential to adopt adaptive strategies such as drought-resistant crops, efficient irrigation and precision farming.

Sustainable agriculture not only protects natural resources but also ensures stable income for farmers and food security for future generations.

Challenges Facing Indian Agriculture

Despite its importance, Indian agriculture faces several challenges, including fragmented landholdings, dependence on monsoons, low productivity in some regions, price fluctuations and

inadequate market infrastructure. Climate change, soil degradation and water scarcity further complicate the situation.

Small and marginal farmers often struggle with limited access to credit, technology and markets. Strengthening agricultural research, extension services and digital technologies is essential for addressing these challenges. Policy reforms focusing on market linkages, value addition and farmer welfare are crucial for sustaining agricultural growth.

Conclusion

Agriculture remains a cornerstone of the Indian economy, supporting livelihoods, ensuring food security, generating employment and contributing to national income and exports. Its multifaceted role extends beyond production to encompass rural development, industrial growth and environmental sustainability. As India progresses toward becoming a developed nation, the agricultural sector must undergo continuous transformation through technological innovation, policy support and sustainable practices. Strengthening agricultural infrastructure, promoting value addition and enhancing farmers' income will be key to achieving inclusive and sustainable economic growth. In conclusion, agriculture is not merely an economic sector in India; it is the foundation of social stability, cultural heritage and national prosperity. Ensuring its growth and sustainability is essential for the overall development of the Indian economy.

IMPACT OF INDIA'S BLUE REVOLUTION PROGRAMME ON FISHERIES PRODUCTION: A DECADAL ASSESSMENT (2015–2025)

Jayasri Ravi^{1*} and L. Surulive²

¹PG Scholar, Department of Aquaculture, Dr. M.G.R. Fisheries College and Research Institute, TNJFU, Ponneri, Tamil Nadu, India.

²Assistant Professor, Department of Fisheries Extension, Economics & Statistics, Dr. M.G.R. Fisheries College and Research Institute, TNJFU Ponneri, Tamil Nadu, India.

*Corresponding Email: jayasriravi340@gmail.com

Abstract

India's fisheries sector has experienced a marked structural shift since 2015 following the Blue Revolution and related reforms. Blue Revolution: Integrated Development and Management of Fisheries" scheme. It was implemented during 2015–16 under the Department of Animal Husbandry, Dairying & Fisheries. It continued until 2019–20, after which it was subsumed under the larger flagship scheme Pradhan Mantri Matsya Sampada Yojana (PMMSY) launched in 2020. Between 2015–16 and 2024–25, total fish production rose from 10.76 to 19.77 MMT (CAGR 7.01%). Inland aquaculture was the main driver, growing at 8.66% CAGR and accounting for nearly 88.8% of the total increase, while marine capture fisheries expanded modestly at 2.78%. Statistical analysis shows a very strong association between inland aquaculture and total output ($r \approx 0.996$), with an average annual production rise of 1.13 MMT. The results confirm a clear transition from capture-based fisheries to aquaculture-led growth, underscoring the policy impact of Blue Revolution initiatives and the PMSSY on India's fisheries expansion (Department of Fisheries, 2024; FAO, 2023).

Keywords: Aquaculture, Blue Revolution, PMMSY, Fisheries Production Trends

Introduction

India's fisheries sector has become one of the fastest-growing segments of the agricultural economy in the post-2015 period. Following the launch of the Blue Revolution strategy, fish production increased from 10.76 MMT in 2015–16 to 19.77 MMT in 2024–25, supporting employment, nutrition, and rural livelihoods (Press Information Bureau, 2024). As the world's second-largest aquaculture producer, inland aquaculture drives growth, while marine capture faces ecological constraints (FAO, 2023). Between 2004 and 2014, output rose from 6.399 to 9.579 MMT, mainly due to inland aquaculture expansion (PIB, 2014). Policy measures including the Blue Revolution, FIDF, Kisan Credit Card extension, a dedicated Ministry of Fisheries, and PMMSY (₹20,050 crore) have strengthened infrastructure and value chains (Department of Fisheries, 2020; PIB, 2015; PIB, 2023). Despite this, the pattern and scale of growth require statistical evaluation, which this study addresses.

Objectives

1. Assess the growth and long-term trends of India's fisheries production post-2015, including inland aquaculture and marine capture, using CAGR.
2. Examine sectoral contributions, growth differentials, and production variability through descriptive statistics and coefficient of variation.

- Evaluate relationships between sectoral production components using correlation analysis, estimate long-term production trends using a linear regression model.

Data Table

Table 1. Fish Production in India (2015–16 to 2024–25)

Fiscal Year	Inland (Aquaculture) (In MMT)	Marine (Capture) (In MMT)	Total Production (In MMT)
2015-16	7.16	3.60	10.76
2016-17	7.77	3.63	11.40
2017-18	8.92	3.69	12.61
2018-19	9.71	3.85	13.56
2019-20	10.43	3.72	14.15
2020-21	11.25	3.48	14.73
2021-22	12.12	4.13	16.25
2022-23	13.11	4.43	17.54
2023-24	13.91	4.49	18.40
2024-25	15.16	4.61	19.77

Source: Department of Fisheries (DoF), Handbook on Fisheries Statistics; PIB (2024 provisional estimates)

Data Source

Production statistics were compiled from, Department of Fisheries (DoF), Ministry of Fisheries, Animal Husbandry and Dairying, Handbook on Fisheries Statistics (annual editions), Press Information Bureau (2024 sectoral updates), FAO Global Fisheries Statistics

Methodology

The following statistical tools were applied: Overall Production Growth (2015–2025), Compound Annual Growth Rate (CAGR), Sectoral Contribution Analysis, Growth Differential, Descriptive Statistics (Mean, Median, SD), Coefficient of Variation (CV), Correlation Analysis, Linear Regression Trend Model.

Result

Overall Production Growth (2015–2025)

Total fisheries production increased from 10.76 MMT in 2015–16 to 19.77 MMT in 2024–25, registering an absolute increase of 9.01 million metric tonnes (MMT) over a ten-year period. In contrast, during the decade preceding the Blue Revolution phase (2004–05 to 2013–14), India's total fish production increased from 6.399 MMT to 9.579 MMT, representing an absolute growth of 3.18 MMT over the corresponding ten-year period. The markedly higher increase in the recent decade reflects accelerated fisheries growth driven by Blue Revolution initiatives.

Compound Annual Growth Rate (CAGR)

CAGR is the average annual growth rate of a variable over a specified period, assuming constant, compounded growth from the initial to the final value.

Table 2. CAGR of Inland, Marine and total fish production (2015–16 to 2024–25)

Sector	Initial (2015–16) MMT	Final (2024–25) MMT	CAGR (%)
Inland (Aquaculture)	7.16	15.16	8.66%
Marine (Capture)	3.60	4.61	2.78%
Total Fish Production	10.76	19.77	7.01%

Between 2015–16 and 2024–25, India's total fish production increased from 10.76 to 19.77 MMT, registering a CAGR about 7.01%. The growth was primarily driven by inland aquaculture, which nearly doubled from 7.16 to 15.16 MMT with a strong CAGR of 8.66%. In contrast, marine capture production grew from 3.60 to 4.61 MMT, showing a CAGR of 2.78%. Overall, the data indicates a clear structural shift toward aquaculture-led growth.

Sectoral Contribution Analysis

The Overall Absolute Increase from 2015 to 2025 is 9.01 MMT, For Inland aquaculture its 8.00 MMT, and for Marine capture its 1.01 MMT. Inland Contribution to the total production is 88.8%, Marine Contribution to the total production is 11.2%. The inland sector remained the dominant contributor to total fisheries production across all years, accounting for more than two-thirds of total output at the beginning of the period and expanding its proportional share toward the end of the study period.

Growth Differential

During 2015–16 to 2024–25, inland aquaculture recorded an absolute increase of 8.00 MMT, whereas marine capture fisheries increased by 1.01 MMT. The resulting growth differential of 6.99 MMT indicates that sectoral expansion was overwhelmingly driven by inland aquaculture.

Descriptive Statistics (Mean, Median, SD)

The inland aquaculture sector in India exhibited a mean production of 10.95 million metric tonnes (MMT), with a median value of 10.84 MMT and a sample standard deviation of 2.65 MMT. The marine capture sector recorded a mean production of 3.96 MMT, a median of 3.85 MMT, and a standard deviation of 0.42 MMT. Overall, total fisheries production averaged 14.92 MMT, with a median of 14.44 MMT and a standard deviation of 3.01 MMT, indicating that variability in inland aquaculture largely drives fluctuations in total fisheries output. Inland aquaculture exhibited substantially higher dispersion compared to marine capture fisheries, reflecting stronger expansion dynamics and greater variability.

Coefficient of Variation (CV)

The coefficient of variation (CV), which measures relative variability, was computed using the sample standard deviation. Inland aquaculture recorded a CV of approximately 24.16%, indicating considerable variability relative to its mean production of 10.95 MMT. Marine capture fisheries exhibited a lower CV of 10.52%, reflecting comparatively stable production around its mean of 3.96 MMT. Overall, total fisheries production showed a CV of 20.21%, suggesting that fluctuations in aggregate output are largely influenced by variability in inland aquaculture production.

Correlation Analysis

Correlation analysis (2015–16 to 2024–25) shows an almost perfect positive relationship between inland aquaculture and total production ($r \approx 0.998$), confirming that overall fisheries growth is largely driven by inland output. Marine capture is also strongly correlated with total production ($r \approx 0.898$) but contributes less to overall growth. The strong correlation between inland and marine sectors ($r \approx 0.866$) indicates parallel upward trends, with inland aquaculture playing the dominant role in expansion.

Linear regression trend model

A linear regression trend analysis was conducted to examine the growth pattern of inland aquaculture, marine capture, and total fisheries production from 2015–16 to 2024–25, taking time

($t = 1$ to 10) as the independent variable. The estimated trend equation for total fisheries production $Y = 9.47 + 0.99t$ indicating an average annual increase of approximately 0.99 million metric tonnes (MMT) over the study period.

For inland aquaculture, the regression model was estimated as $Y=6.14+0.89t$ demonstrating a annual increase of about 0.89 MMT, confirming that inland aquaculture remains the primary driver of overall fisheries expansion. In contrast, marine capture production followed the trend equation: $Y=3.33+0.10t$ showing a comparatively modest annual increase of approximately 0.10 MMT, reflecting relatively slow growth dynamics. These findings confirm a strong and consistent upward linear trend in total fisheries production during the study period, largely driven by sustained expansion in inland aquaculture, while marine capture fisheries exhibited gradual growth.

Conclusion

India's fisheries sector has experienced accelerated growth after 2015, largely driven by policy support under the Blue Revolution. Inland aquaculture accounted for nearly 88.8% of the production increase and showed a very strong association with total output, confirming an aquaculture-led expansion. Overall, the sector has undergone a clear structural shift toward aquaculture dominance.

Reference

- Department of Fisheries. (2020). Annual report 2019–20. Ministry of Fisheries, Animal Husbandry and Dairying, Government of India.
- Department of Fisheries. (2024). Handbook on fisheries statistics. Government of India.
- Food and Agriculture Organization of the United Nations. (2023). The state of world fisheries and aquaculture 2023. FAO.
- Press Information Bureau. (2014). Growth of fisheries sector in India (2004–2014). Government of India.
- Press Information Bureau. (2015). Launch of Blue Revolution initiative. Government of India.
- Press Information Bureau. (2023). Progress under PMMSY and fisheries sector reforms. Government of India.

JOURNEY OF BUTTON MUSHROOM CULTIVATION AT COMMERCIAL LEVEL

Simran

M.Sc. Student, Department of Basic Sciences, College of Forestry,
Dr. Yashwant Singh Parmar University of Horticulture and Forestry,
Nauni, Solan, Himachal Pradesh
Corresponding Email: simranchouhan.1232@gmail.com

Abstract

Button mushroom (*Agaricus bisporus*) is a widely cultivated and economically important edible mushroom valued for its high nutritional content, including essential minerals and vitamin B₁₂. Regular consumption has been associated with several health benefits, increasing its demand in the market and creating opportunities for entrepreneurial ventures. Commercial cultivation is carried out under indoor, controlled conditions and can be practiced year-round with proper management of temperature, humidity, and ventilation. The cultivation process requires a specifically prepared compost substrate, followed by spawning and casing with pasteurized soil after complete spawn run. Successful crop production depends on effective protection against pests and diseases. Under optimal environmental conditions, button mushroom cultivation can yield approximately 20 kg of fresh mushrooms per 100 kg of compost, highlighting its potential as a sustainable, high-value crop for nutrition, income generation, and Agri-based entrepreneurship.

Introduction

Agriculture has long been the foundation of human civilization, but increasing pressure on natural resources necessitates a transition from conventional farming to sustainable intensive agriculture to reduce poverty, ensure food security, and maintain ecological balance. In this context, mushroom cultivation has emerged as a viable and sustainable agricultural enterprise, particularly suitable for landless and smallholder farmers. Mushrooms are nutritious edible macro-fungi cultivated for both dietary benefits and economic returns, and their production requires minimal land and inputs while being less affected by environmental stresses. Although mainly practiced in urban and semi-urban areas, the expansion of mushroom cultivation in rural regions can significantly enhance farm income through the effective use of agricultural by-products as substrates. In India, technological advancements, training, and entrepreneurial initiatives have led to a substantial increase in mushroom production over the past decade (Bijla & Sharma. 2023). Commercial mushroom cultivation is carried out under controlled conditions and offers high profitability, with production costs of about ₹44,823 per unit and net returns of approximately ₹90,000. Despite challenges such as limited technical expertise, inadequate marketing systems, and poor access to quality inputs mushroom farming remains an effective strategy for improving rural livelihoods and promoting sustainable agricultural development, highlighting the need for continued training and capacity-building efforts (Mazumdar et al. 2020). This article aims to provide its readers with an insight into the cultivation of mushrooms at a commercial level.

Production and procurement of Spawn

Spawn is the functional equivalent of a plant seed in mushroom cultivation; however, it consists of actively growing mycelium rather than an embryo. It is produced by allowing pure mycelium of

Agaricus bisporus to colonize sterilized cereal grains. Clean wheat grains are soaked, cooked until soft, drained, and mixed with calcium carbonate (0.5%) and calcium sulphate (2%) to maintain pH and prevent clumping. The grains are then packed in polyethylene bags, sterilized at 121°C under 15 lb pressure, and inoculated with a pure culture. Incubation at 25–26°C for 1–2 weeks results in fully mycelium-coated, disease-free spawn suitable for commercial mushroom production. Alternatively, high-quality spawn can be procured directly from government agricultural universities for large-scale cultivation.

Mycelium growth substrate preparation/(Compost preparation)

A short-method composting technique is widely used in commercial button mushroom cultivation, as it produces quality compost within 16–20 days. The process involves two phases. Phase I (outdoor composting) lasts 10–12 days and begins with thorough wetting of 9–10 tonnes of wheat straw to about 75% moisture. Nitrogen-rich materials such as 6–7 tonnes of chicken manure, 0.7 tonnes of urea, 0.4 tonnes of mustard cake, and 0.6–0.7 tonnes of gypsum are added, followed by regular turning to ensure uniform decomposition. The compost is then transferred to open bunkers with perforated floors, where forced aeration maintains temperatures of 65–70°C, and 3–4 turnings are given. By the end of Phase I, the compost becomes uniformly brown with 72–75% moisture. Phase II (pasteurization and conditioning) is carried out in insulated tunnels for about 7 days. The compost is pasteurized at 58–60°C to destroy pests and pathogens, followed by conditioning at 50–52°C to remove ammonia and stabilize nutrients. Finally, the compost is cooled to 25–28°C, resulting in a selective, disease-free substrate suitable for spawn running. The entire composting process is completed within 18–20 days.



Fig 1 Spawn bag



Fig 2 Staking and proper wetting of wheat straw



Fig 3 Making aerobic stack after adding gypsum, urea, chicken



Fig 4 Bunkers used for turning of the unprepared compost



Fig 5 Pasteurization and conditioning of compost in tunnel

Spawning and Mycelium growth

When the spawn is prepared using the short method now it is utilized for spawning, which involves mixing mushroom spawn (mycelium) into the compost. Spawning is frequently performed in bag cultivation, where the necessary amount of spawn is evenly blended with compost and placed into polyethylene bags (approximately 10-15 kg per bag). Prior to spawning, the space is sanitized and compost is moved from the tunnel to the spawning area. Spawn bags

kept at 14–18 °C should be permitted to reach room temperature prior to mixing. The packed bags are bent and placed tightly on shelves with the room temperature kept at 22–25 °C and relative humidity at 80–85%. A thin layer of spawn can be scattered on the surface (top spawning), then gently press the compost to ensure good contact. While spawn running, the room remains dark and sealed, as fresh air isn't necessary and elevated carbon dioxide levels promote mycelial development. In these conditions, white cotton-like mycelium disseminates throughout the compost in 14–15 days signaling a successful spawn run; cooler temperatures hinder this process, whereas warmer temperatures inhibit mycelial development.

Preparation of casing and its application on the bags

Casing soil is commonly prepared using cocopeat (80 kg) mixed with lime (10 kg), gypsum (5 kg), and ash (15 kg). The cocopeat is soaked in water for about 24 hours and thoroughly blended with the additives under hygienic conditions, after which the material is kept in a separate clean room and chemically disinfected, usually with diluted formalin, to eliminate harmful organisms. Casing involves applying a thin cocopeat-based layer as a top dressing over fully spawn-run compost and is essential for initiating fruit body formation by triggering the transition from vegetative to reproductive growth. It also acts as a moisture reservoir, maintaining optimal water availability for mushroom development; without casing, mushroom emergence is poor or negligible. For application, spawn-run compost bags are opened, levelled, gently pressed, and covered with a 2–2.5-inch-thick casing layer. During this stage, the growing room is maintained at 22–25°C and 80–85% relative humidity, with light misting to sustain casing moisture and ensure uniform mushroom growth (Munshi *et al.*, 2010).

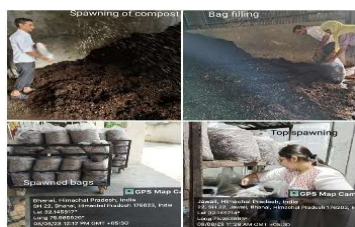


Fig 6 Method of filling of spawned compost bag along with top spawning which is done when the bags are placed inside the

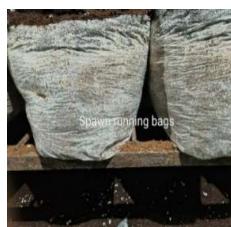


Fig 7 Spawn run on compost form thread like structure on compost.



Fig 8 Casing soil preparation and its application on the spawn running compost

Mushroom Crop Development and Harvesting

When the mycelium reaches the casing layer's surface, mushroom fruiting is triggered by reducing the temperature to approximately 16–18 °C. At this point, the casing must be kept damp through gentle water spraying to uphold 70–80% relative humidity, and sufficient fresh air circulation is crucial—larger yields need more ventilation. Mushrooms develop in separate flushes, with the initial flush occurring about three weeks after casing and later flushes appearing at nearly weekly intervals. Pinheads transform into button-stage mushrooms in 7–8 days. In arid conditions, regular light watering is essential; water must consistently be applied as a fine spray to avoid disturbing the casing layer, preventing crust development and ensuring adequate oxygen delivery for optimal mushroom growth. Mushrooms are harvested by gently rotating the mushroom cap clockwise and anti-clockwise, then softly pulling the mushroom upwards. If numerous pin heads

are present around a mushroom ready for harvesting, it's best to cut the mushroom using a sharp knife to avoid disturbing the nearby pins. Once all the wanted size of mushrooms has been gathered, the created holes should be quickly filled with sterilized soil. The bed's surface must remain even, and whenever new casing is applied, it should be compacted by giving it a light tap. The length of cropping depends on the current conditions; in a commercial farm, 4-5 flushes are harvested before the crop is cleared to prepare for the next one.



Fig 9 Mushroom



Fig10 Harvesting of mushroom crop



Fig 11 Showing the grading and packaging of mushroom

Grading, packaging and Transportation of mushroom

Mushroom grading is crucial for marketing, typically achieved by categorizing them into different grade standards according to market needs. The button mushroom is classified into grade A, B, C according to DMI standards. For packaging, the mushrooms are placed in a box, followed by grading. The weight of the mushrooms is then checked using a weighing scale if it is approximately 200 grams then plastic boxes are wrapped with PVC films. These plastic containers are subsequently stored in CFB cartons that are favoured for long distance transportation for local market polyethylene bags are utilized for packaging and are sealed using sealer machine. The advantages of packaging can diminish if mushrooms are kept or transported in high temperature environments. Due to the high perishability of mushrooms keeping low temperature during transportation is crucial for retaining quality and freshness. Refrigerated vehicles are necessary for long -distance transport, whereas for short distances. Mushrooms are typically packed in cartons along with ice or cooling packs to ensure a cooling environment while in travel.

Conclusion

Button mushrooms (*Agaricus bisporus*) are a globally important crop that provides significant nutritional and therapeutic benefits despite challenges in production, storage, and marketing. The adoption of sustainable cultivation practices, including the use of locally available substrates, has strengthened production systems. Their low-calorie content and richness in essential vitamins, minerals, and antioxidants make them valuable for health promotion and disease prevention. Advances such as Modified Atmosphere Packaging have improved shelf life and marketability during storage and transport. The growing demand for plant-based and functional foods has increased interest in value-added mushroom products. Therefore, continued research and development in cultivation, postharvest technology, and marketing is essential to ensure sustainable growth of the button mushroom industry worldwide.

References

Bijla, S. and Sharma, V.P. 2023. Status of mushroom production: Global and national scenario. *Mushroom Research* 32(2): 91-98.

Mazumdar, F., Hoskins, O.J., Brooks, R. and T. Bennett. 2020. Development of an interactive multimedia instructional module. *J Appl Instr Des* 3(3): 5-18.

Munshi, N. A., Dar, G. H., Ghani, M. Y., Kauser, S., & Mughal, N. (2010). Button mushroom cultivation. *Communication and Publication Centre SKUAST-K, 1*, 1-33.

MAHOGANY FARMING IN INDIA: THE NEW GREEN GOLD**Sachin Kumar^{1*}, Rahul Yadav², Chandana S³ and Seema Kousar⁴**

¹Department of Silviculture and Agroforestry, Forest College and Research Institute, Mulugu, Siddipet, 502 279 Hyderabad, Telangana, India

⁴Department of Forest Resource Management, Forest College and Research Institute, Mulugu, Siddipet, 502 279 Hyderabad, Telangana, India

²Department of Silviculture and Agroforestry, Acharya Narendra Deva University of Agriculture and Technology, Ayodhya, 224 229 Uttar Pradesh, India

³Department of Silviculture and Agroforestry, Navsari Agriculture University, Navsari, 396 450 Gujarat, India

*Corresponding Email: sachinkumar69634@gmail.com

Abstract

Mahogany (*Swietenia macrophylla*.) plantation is increasingly recognized as a profitable and environmentally sustainable land-use option in India and is commonly referred to as “green gold” due to its high economic and ecological value. A mahogany sapling, costing about ₹200, can attain a market value of approximately ₹60,000 to ₹1,00,000 within a rotation period of 12–20 years, depending on site conditions and management practices. These long-term returns provide farmers with financial security and serve as a dependable biological investment. Mahogany timber is highly valued for its strength, durability, and attractive grain, making it a preferred material for furniture, interior décor, shipbuilding, and luxury handicrafts. Strong domestic and international demand ensures stable market prospects. In addition to economic benefits, mahogany cultivation contributes to environmental sustainability through carbon sequestration, soil conservation, and enhancement of on-farm biodiversity by improving habitat and microclimatic conditions. Mahogany plantations are well suited to agroforestry systems, particularly during the initial growth phase, allowing intercropping with short-duration crops for supplementary income. Emerging opportunities in carbon credit markets further enhance its relevance to climate change mitigation. Successful examples from several Indian states indicate that mahogany farming is a low-maintenance, high-return option that aligns with India’s sustainable development and climate goals.

Keywords: Green Gold, High-value timber, Sustainable agroforestry, Carbon sequestration, Rural livelihood enhancement

Introduction

Swietenia macrophylla, commonly known as mahogany, is a valuable tree species from the Meliaceae family. It is a fast-growing tree with good adaptability, attractive form, high-quality timber, and excellent management potential. Farmers appreciate it not only for its timber but also because it responds well to care practices like pruning, fertilizing, and thinning, especially when done early in its development. These practices have shown better growth outcomes compared to untreated stands. Climate change continues to evolve unpredictably, and while the exact relationship between tropical forests and climate change is still being explored, one thing is clear trees like mahogany can play a major role in carbon sequestration. Planting trees is one of the

most effective tools developing countries have under the Clean Development Mechanism (CDM) of the UNFCCC to fight climate change.

Agroforestry, which involves growing trees alongside crops, brings many benefits such as improving soil health, conserving biodiversity, controlling pests naturally, managing water efficiently, and enhancing local microclimates. It can also help reduce poverty and food insecurity, especially in tropical regions. However, for such systems to succeed long-term, local communities must be actively involved and empowered in forest management. In recent years, mahogany tree farming has emerged as a game-changer in India's agricultural landscape, earning the nickname "green gold" for its remarkable economic and environmental potential. With a single sapling costing as little as ₹200 and the promise of yielding ₹1 lakh or more after 12–20 years, mahogany is transforming rural livelihoods while contributing to sustainability. This review explores the rise of mahogany farming in India, its economic and ecological benefits, challenges, practical considerations, and its broader implications for farmers and the environment.

Mahogany, particularly *Swietenia macrophylla* (big-leaf mahogany), is a tropical hardwood native to Central and South America but well-adapted to India's diverse climates. Its rich, reddish-brown wood is highly valued for furniture, musical instruments, shipbuilding, and luxury interiors due to its durability and aesthetic appeal. Unlike traditional crops like rice or wheat, which require intensive labor and yield annual returns, mahogany is a long-term investment that promises substantial profits with minimal maintenance. The term "green gold" reflects mahogany's high market value.

A mature tree can produce 20–40 cubic feet of timber, fetching ₹1,500–₹5,000 per cubic foot, translating to ₹60,000–₹1 lakh per tree. For farmers planting 120–400 trees per acre, this could mean millions in revenue after 12–20 years. According to *News18* (2023), planting 500 trees could potentially generate ₹3 crore over 12 years, making mahogany a "living fixed deposit" for farmers. The boom in mahogany farming is driven by several factors: rising global demand for sustainable timber, government support for agroforestry, and growing awareness of its environmental benefits. From Gujarat's arid plains to Karnataka's fertile soils, farmers are embracing mahogany as a way to diversify income and secure their financial future.



Fig.1 Classification of Mahogany Tree

Economic Benefits

High Returns on Investment: Mahogany (*Swietenia macrophylla*) plantation offers high long-term economic returns, with a sapling costing about ₹200 growing into a tree valued at ₹60,000 or more. High planting density and strong market demand make it a reliable biological investment for farmers (Times of India, 2025; AgriFarming.in, 2023).

Intercropping Opportunities: Although mahogany has a long rotation period, intercropping with short-duration crops during early growth stages provides regular income and efficient land use. This practice improves economic viability, especially for small and marginal farmers (ResearchGate, 2019; AgriFarming.in, 2023).

Carbon Credits and Additional Income: Mahogany plantations generate additional income through carbon credits due to their high carbon sequestration potential. Participation in carbon trading supports climate mitigation while enhancing farm income (Mahargh Agribuilder, 2022).

Global Market Demand: Mahogany timber is globally valued for its durability and aesthetic quality, with increasing demand from furniture and handicraft industries. Plantation-grown mahogany in India is well positioned to meet global demand amid declining natural stocks (AgriFarming.in, 2023).



Fig.2 Economic Benefits

Practical Considerations for Mahogany Farming

Starting a mahogany plantation requires careful planning.:

Site Selection and Climate

Mahogany thrives in tropical and subtropical climates with well-drained, fertile soils (pH 6.0–6.5) and annual rainfall of 1,200–2,500 mm. Regions like Maharashtra, Gujarat, Karnataka, Telangana, and Bihar are ideal due to their favorable conditions. Farmers must ensure access to water for irrigation, especially in the first 2–3 years (Annadata Trading Company, 2024).

Quality Saplings

Choosing the right saplings is critical. *Swietenia macrophylla* is the preferred species for its commercial value. Farmers should source saplings from reputable nurseries like Mahindra Nursery or companies like *Mahargh Agribuilder* to ensure healthy, disease-free plants. Proper seed treatment and nursery care are essential for strong seedlings.

Planting and Maintenance

Plant during the monsoon for optimal growth, spacing saplings 4x4 meters apart to allow room for canopy development. Regular watering, balanced NPK fertilizers (200–250 grams per tree), and pruning are necessary in the early years. Mahogany is relatively pest-resistant, but farmers should monitor for termites or borers and use organic solutions like neem oil (1500 ppm) for control (*Mahargh Agribuilder*, 2022).

Harvesting and Market Access

Trees are typically harvested after 12–20 years, with longer waits yielding higher-quality timber. Farmers can sell to local timber markets, export traders, or industries like furniture or musical instrument manufacturing. Certifications like the Forest Stewardship Council (FSC) can help access premium international markets, boosting profits (*Swasya Living*, 2025).

Success Stories and Case Studies

Mahogany farming is already making a difference across India. In Sakleshpur, *Swasya Living's Sannidhi Eco Farms* has become a model for sustainable mahogany cultivation. By combining responsible harvesting, community engagement, and eco-friendly practices, the farm maximizes yields while preserving biodiversity. Investors and farmers benefit from expert supervision and guaranteed returns, making mahogany a low-risk, high-reward venture (*Swasya Living*, 2025).

Similarly, *Mahogani Vishwa Agro Limited (MVAL)* is implementing a massive afforestation project across 15,000 hectares in Maharashtra, Madhya Pradesh, Karnataka, Gujarat, and Telangana. Involving over 25,000 farmer families, MVAL uses satellite monitoring and intercropping to ensure optimal land use and income diversification. Their efforts are creating sustainable livelihoods while promoting environmental conservation (*Mahogani Vishwa Agro Limited*).

In Rajasthan, Vasudev Joshi's story illustrates the potential for small-scale farmers. His single mahogany tree, planted for just ₹200, is a growing asset in an arid region where traditional farming is challenging. Such stories highlight mahogany's accessibility and transformative impact (*Times of India*, 2025).

Broader Implications for India's Future

Mahogany farming aligns with India's goals of sustainable development and rural empowerment. Economically, it provides farmers with a high-value crop that requires minimal upkeep, reducing dependence on volatile agricultural markets. Environmentally, it supports climate resilience by improving soil health, sequestering carbon, and reducing deforestation. The trees' medicinal properties, fruits, leaves, and bark used for ailments like malaria and diabetes add further value (*Natural Mangoes*, 2023). Beyond economics and ecology, mahogany plantations create opportunities for agritourism. Farms lined with majestic mahogany trees can attract eco-tourists, offering serene retreats and generating additional income. The cultural significance of mahogany as the "king of timbers" enhances its appeal, making it a symbol of prosperity and heritage.

Conclusion

Mahogany tree farming is more than a trend it's a transformative opportunity for Indian farmers. Dubbed "green gold" for its high economic returns and environmental benefits, mahogany offers a sustainable path to prosperity. While challenges like the long gestation period and regulatory hurdles exist, the potential rewards financial, ecological, and social are immense. From small farmers like Vasudev Joshi to large-scale projects like MVAL, mahogany is proving its worth as a crop of the future. As India strives for economic growth and environmental sustainability, mahogany farming stands out as a model of how agriculture can balance profit with planet.

References

- AgriFarming.in, "Mahogany Farming in India: Cultivation Benefits, Production Cost, Profit, and Project Report," 2023-01-23
- AgriTimes, "How Indian Farmers can benefit from Mahogany plantation," 2024-05-05
- Annadata Trading Company, "Mahogany Farming: Cultivation Requirements, Grow Tips & Care," 2024-10-14
- Mahargh Agribuilder, "Mahogany Farming for Carbon Credit Income in India," 2022-11-20
- Mahogani Vishwa Agro Limited, "Project Details," mahoganivishwaagro.com
- Natural Mangoes, "Mahogany Tree Plantation: Guide for Sustainable Source of Income," 2023-01-10
- News18, "How Mahogany Trees Have Emerged As A Lucrative Investment For Farmers," 2023-10-18
- ResearchGate, "Mahogany (*Swietenia macrophylla* King): a suitable timber species for agroforestry," 2019-12-19
- Swasya Living, "A Complete Guide About Mahogany Tree & its Benefits," 2025-01-31
- Times of India, "Turn Rs 200 into Rs 1 Lakh: Why Mahogany tree farming is India's new green gold," 2025-07-23

MAKHANA: THE AQUATIC GOLD AND THE PRIDE OF BIHAR**Ravi Kumar Rman^{1*}, Avinash Kumar² and Nitu Kumari³**¹Guest Faculty, College of Agribusiness Management, BAU, Sabour-813210^{2,3}Assistant Professor-cum- junior scientist, Bihar Agricultural Collage, BAU, Sabour-813210*Corresponding Email: ramanravi121@gmail.com**Abstract**

Makhana, an aquatic crop primarily grown in stagnant water bodies like ponds and lakes, has transformed from a traditional Indian "fasting food" into a global superfood. India dominates the sector, accounting for 80-85% of total world production, with Northern Bihar serving as the undisputed powerhouse by contributing 90% of India's output. Between 2020 and 2025, production nearly tripled, and export volumes surged fourfold. This "Makhana Revolution" is bolstered by the 2022 Geographical Indication (GI) tag for Mithila Makhana and the 2025 establishment of the National Makhana Board. Valued at USD 1.46 billion in 2025, the industry supports over 7 lakh families in Bihar. With substantial government subsidies and an expanding footprint in global retail, Bihar is transitioning from a raw material supplier to a branded global exporter of "White Gold".

Keywords: White Gold, Geographical Indication, Makhana**Introduction**

Makhana (*Euryale ferox*) also known as Fox Nuts or Gorgon Nuts is a popped expanded kernel of an aquatic crop that grows in stagnant water bodies such as ponds, lakes, and swamps. Tropical and sub-tropical regions are the main growing areas in the world e.g. India, China, Nepal, Bangladesh, Japan, Russia, and Korea (Sinha, 2023). Makhana is no longer just a traditional "fasting food" found in Indian households; in the last five years, it has undergone a radical transformation, emerging as a global superfood that rivals the popularity of kale and quinoa. For the state of Bihar, Makhana is not merely an agricultural product; it is a cultural legacy, a source of livelihood for millions, and a key driver of the regional economy. As of 2026, the industry is witnessing a "Makhana Revolution," spurred by the GI (Geographical Indication) Tag and the establishment of the National Makhana Board.

Production of Makhana: Global and National Dominance

In 2023, the global fox nuts market stood at \$44.4 million and by 2030, it is projected to reach \$97.5 billion, with India, the largest producer, contributing a significant share, accounting for over 81 per cent of the global revenue (PII, 2025). While India maintains a significant presence in the Eastern and North-Eastern regions, as well as Jammu & Kashmir, it is the undisputed global leader in this sector, accounting for 80-85% of total world production. From 2020 and 2025, the sector witnessed a significant expansion: the cultivated area rose by 40–50% (from 25,000–27,000 hectares to 35,000–40,000 hectares), while total production almost tripled, increasing from 40,000–45,000 MT to 1.1–1.2 lakh MT. In Bihar seed Makhana output now stands at ~1.2 lakh MT, translating into 55,000–60,000 MT of popped Makhana after processing (APEDA, 2026).

In India its commercial cultivation is limited to Bihar, Manipur, some parts of Assam, West Bengal and Madhya Pradesh. Despite this broad distribution, large-scale commercial farming is almost exclusively centered in Northern Bihar. Within Bihar, Makhana cultivation is concentrated in the

flood-prone belts of Mithilanchal, Kosi, and Seemanchal. These specific regions are the powerhouse of the industry, contributing a staggering 90% of India's total Makhana output.

Supply Chain and Export Dynamics: The 4X Growth Story

India is a net exporter, with domestic consumption accounting for 60% of produce and exports taking up the remaining 40%. Indian Makhana exports have witnessed an explosive surge in recent years. This expansion is characterized by a shift toward premium, high-grade products and a diversifying global footprint.

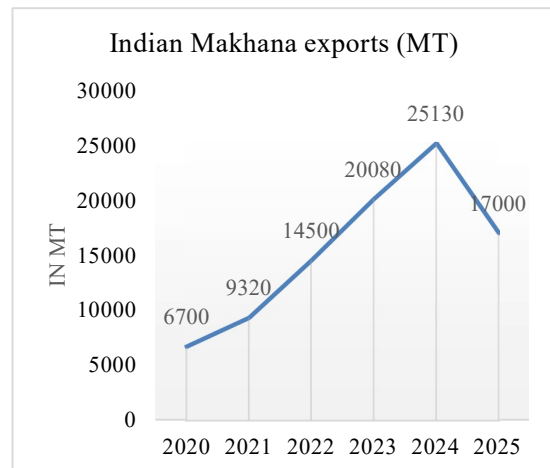
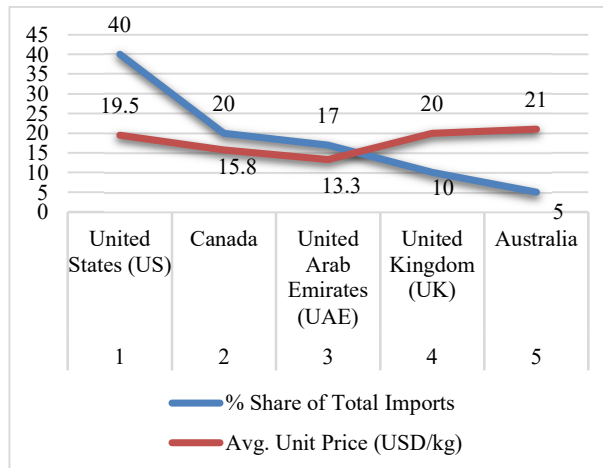
Export Growth Statistics (2020–2024)

Between 2020 and 2024, the volume of exports jumped from 6,700 MT to 25,130 MT—a nearly fourfold increase. This growth was sustained by a remarkable 39% Compound Annual Growth Rate (CAGR).

Key Export Grades

International markets show a strong preference for larger kernels. The export market is classified by size, measured in "Suta":

- **Premium Category (7 Suta):** These are extra-large, high-value seeds measuring over 21 mm. They are considered export-ready and represent the highest quality.
- **High Category (6 Suta):** Measuring between 18–21 mm, this is the standard grade for the premium market.
- **Good Category (5 Suta):** These mid-sized seeds (15–18 mm) are the most popular choice for regular snacking.
- **Regular Category (4 Suta):** The most economical option, sized at 12–15 mm. These are widely used for flavoring and secondary processing.



Source: apeda.gov.in

Economic Impact: Transforming Bihar's Economy

The industry is now valued at approximately USD 1.46 Billion (2025) (MarkNtel, 2025) and is projected to reach USD 2.23 Billion by 2030 (TraceData, 2025).

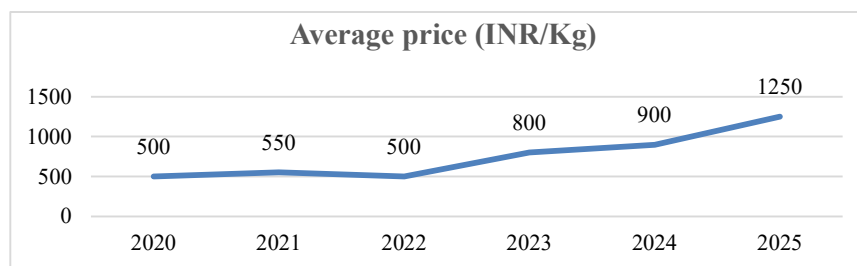
- **Livelihood:** Supports over 7 lakh families in Bihar (Government of Bihar).
- **National Makhana Board:** Established in 2025 with an INR 100-crore allocation to modernize the "popping" process and reduce labour strain (PIB, 2025).

- **Startup Boom:** Over 100 Agri-Tech startups in Bihar are now exporting flavored, "Ready-to-Eat" Makhana directly to global retail chains like Whole Foods and Costco (Merakisan, 2025).

Effect of GI on Makhana Price

The Geographical Indication (GI) tag for Mithila Makhana (awarded in August 2022) has transitioned the crop from a local commodity to a premium global "superfood."

Driven by GI tagging and global demand, Makhana prices witnessed a 150% jump, reaching an average of ₹1,250 in 2025 compared to just ₹500 in 2020.



Source: apeda.gov.in

Makhana is no longer just a local staple; it's a booming industry. With an annual growth rate of nearly 18% over the last few years, the market is thriving as consumers trade up for branded, healthy alternatives. Even when export markets turn volatile, India's internal demand keeps the sector steady. By the end of the decade, this 'white gold' market is projected to skyrocket to a staggering ₹12,000 crore from current India market size ₹8500 crore.

Nutritional Value: The Anatomy of a Superfood

Nutritional content (per 100 g)					
Nutrient Name	Cashew	Almond	Popcorn	Raw Makhana Seeds*	Popped Makhana
Moisture (g)	4.4	4.37	3.32	11.3	12
Ash (g)	2.25	2.62	1.42	0.45	0.38
Protein (g)	18.78	18.41	12.9	9.15	11.03
Fiber (g)	3.86	13.06	14.5	2.56	3.26
Fats (g)	45.2	58.49	4.54	0.46	0.33
Carbohydrates (g)	25.46	3.04	77.8	87.52	84.87

Nutritional comparison of makhana with other dry fruits and Popcorn (USDA, 2024)

Government Support for Makhana Producer

- **PMFME Scheme:** Under the "One District One Product" (ODOP) initiative, makhana processors can get a 35% credit-linked capital subsidy (up to ₹10 lakh) for setting up or upgrading units (PMFME, 2025).
- **Seed Capital for SHGs:** Members of Self-Help Groups (SHGs) involved in makhana processing are eligible for ₹40,000 per member as seed capital for working capital and tools (MOFPI, 2025)

- **Makhana Vikas Yojana (Bihar):** Grants of 75% of the cost (up to ₹16,575/-) for traditional tools (i.e. Auka, Ganj, Kara, Khainchi, Chalni, Chatai, Afra, and Thaapi used in Makhana cultivation) (Gol).
- **SFURTI Cluster:** This scheme is funded for the regeneration of traditional industries is organising artisans in to makhana cluster and equipping them with modern machinery. A cluster in Madhubani (Bihar) received ₹303 lakh to modernise operations for nearly 900 traditional makhana workers (Gol).
- **Subsidized Seeds:** Seeds of recommended varieties (Swarn Vaidehi and Sabour Makhana-1) will be made available to farmers at the rate of 30 Kg/Ha.
- **Daak Niryat Kendra (Darbhanga)** (IBEF 2025) -By offering comprehensive support in documentation and logistics, India Post's facilitation centers are transforming the makhana trade in Mithilanchal. The DNK effectively links rural producers to global seaports, empowering small-scale exporters to overcome traditional hurdles and reach customers worldwide.

Conclusion: The Way Forward

Makhana is Bihar's answer to the world's demand for sustainable and healthy food. While challenges like price volatility and the need for mechanization persist, the future is bright. As India moves toward becoming a global food processing hub, Makhana stands as the flagship "Made in India" product.

For Bihar, the mission is clear: transition from being a "raw material supplier" to a "branded global exporter." With the "White Gold" of its ponds, Bihar is not just feeding the world; it is reclaiming its economic pride.

References

- PEDA (2026). *MIC November Monthly Dashboard: Makhana*. Agricultural and Processed Food Products Export Development Authority. Available at: https://apeda.gov.in/sites/default/files/2026-001/MIC_November_Monthly_dashboard_Makhana_311225.pdf (Accessed on 18/02/2026).
- Government of Bihar. *Directorate of Horticulture*. Available at: horticulture.bihar.gov.in
- Government of India (Gol). *Mukhya Mantri Yuva Udyami Yojana*. Available at: <https://www.myscheme.gov.in/schemes/mvvyb>
- Government of India (Gol). *SFURTI Cluster Reports*. Available at: https://sfurti.msme.gov.in/SFURTI/Reports/DPR_Functional_During.aspx
- IBEF (2025). *India Brand Equity Foundation*. Available at: <https://www.ibef.org/>
- MarkNtel (2025). *India Makhana Market Analysis*. Available at: <https://www.marknteladvisors.com/research-library/makhana-market-india>
- MeraKisan (2025). *Makhana Price in India: 7 Suta Makhana (Bihar)*. Available at: <https://merakisan.com/makhana-price-in-india/>
- MOFPI (2025). *Ministry of Food Processing Industries*. Available at: <https://pmfme.mofpi.gov.in/pmfme/#/Home-Page>
- PIB Delhi (2025). *Press Information Bureau & Gazette Notification (September & December 2025)*. Government of India.
- PII (2025). *Press Institute of India*. Available at: <https://pressinstitute.in/>
- PMFME (2025). *Pradhan Mantri Formalisation of Micro food processing Enterprises Scheme*. Available at: <https://pmfme.mofpi.gov.in/pmfme/#/Home-Page>
- Sinha, R. K. (2023). *Supply Chain of Makhana Marketing and Processing in Bihar*. Bhagalpur: Agro-Economic Research Centre for Bihar & Jharkhand, T M Bhagalpur University. Available at: <http://aercbhagalpur.org/complete%20study/study%20No.%2056.pdf>
- TraceData (2025). *India Makhana Market Size and Trends*. Available at: <https://www.tracedataresearch.com/blog/india-makhana-market-size>
- USDA (2024). *Food Data Central: Snacks, popcorn, air-popped*. Washington D.C.: United States Department of Agriculture. Available at: <https://fdc.nal.usda.gov/food-details/167959/nutrients>

FUTURE OF WATER MANAGEMENT: INNOVATIONS AND EMERGING TECHNOLOGIES IN NAGALAND

S. Niamkoi Khamniungan¹ and Krishna Kumar^{2*}

¹M.Tech Scholar, Department of Soil and water Conservation Engineering,
CAU-College of Agricultural Engineering and Post Harvest Technology,
Ranipool Sikkim-737135

²M.Tech Scholar, Department of Irrigation and Drainage Engineering,
CAU-College of Agricultural Engineering and Post Harvest Technology,
Ranipool Sikkim-737135

*Corresponding Email: Kumarkrishna79773@gmail.com

Abstract

Nagaland has received significant amounts of rainfall every year, the state experiences periodic shortages of freshwater because of rapid runoff, limited capacity for storage, degradation of springs, and lack of adequate infrastructure. Indigenous traditional community-based systems of water security (Ruza and Jalkund) have been in practice for many years and provided water security to the people of Nagaland, but are now increasingly affected by the pressures of urbanization, land-use change, and climate variability. This article describes how emerging technologies, including Internet of Things (IoT)-based monitoring systems, decentralized systems for rainwater harvesting, and smart distribution networks and nature-based watershed restoration, can complement indigenous practices. If Nagaland can integrate these advanced technologies with community-based governance of water. However, the study discusses current and potential strategies that can improve the reliability and efficiency of water resources in mountainous, high-rainfall regions, such as Nagaland, with uneven distributions of water.

Keywords: Water management, Rainwater harvesting, Indigenous conservation systems, Climate resilience.

Introduction:

Nagaland is characterized by high rainfall and a dense network of streams and spring-fed water sources, and forested catchments. Annual average rainfall ranges on the low end from 859.97mm at the top of its range to over 2123mm; however in many districts the average rainfall exceeds that of the national average; regardless, the state consistently struggles with water access, especially during its dry seasons. This situation emphasizes a major issue facing the region-while there is an abundance of water in Nagaland, what lacks are both the temporal and spatial distribution.

The hilly terrain of the state naturally promotes surface runoff, thereby minimizing the amount of water available to recharge ground water sources; this problem is further exacerbated by the general lack of water storage infrastructure combined with the significant degradation of numerous springs and other surface water systems within Nagaland. These issues have begun to restrict the availability of dependable water sources for domestic, agricultural, and environmental purposes throughout the state.

Traditionally, water management in Nagaland has been predominantly community-based, relying primarily on the use of spring-fed systems in rural areas, gravity-based systems for distributing and using the amount of water available to them, as well as using indigenous conservation techniques that were developed by local populations through ecological and cultural sustainability to ensure equal access to water resources (Singh *et al.*, 2003). However, with the rapid development of new socio-economic conditions in addition to rapid rates of deforestation, and extensive changes in land use (especially in the newly created urban centres), communities are increasingly being unable to rely on traditional practices for accessing water resources. Climate change has also continued to increase the variability of available water supplies due to longer durations of dry seasons, significant fluctuations in the amount and intensity of rainfall events; therefore, it is likely that continuing problems with the availability and reliability of water will continue as long as the current climate remains (Singh & Panda, 2012).

While there is a growing trend of decentralized and resilient water management solutions, this trend is not universally applicable to Nagaland. For Nagaland, the future of water management will depend on the ability to transition away from short-term, reactive management and move to integrated, resilient, and technology-enabled systems. There are opportunities to address Nagaland's long-standing structural issues through new innovations in water management; such as smart monitoring, data-driven planning, nature-based solutions and decentralized storage solutions. When combined with traditional knowledge systems, these new technologies have the potential to enhance water security while ensuring ecological integrity and community ownership of water resources. Specifically, the purpose of this article is to evaluate how modern tools may enhance efficiency, reliability and climate resilience in the provision of drinking water supplies, agricultural production and watershed management.

Therefore, the scope of the article extends across technological, institutional, and environmental dimensions of water management. It explores current challenges, reviews promising innovations suited to high-rainfall hill regions, and discusses pathways for integrating digital technologies with community-led governance models. While the analysis is grounded in the realities of Nagaland, the insights generated are relevant to other mountainous and ecologically sensitive regions facing similar water management dilemmas. Together, these perspectives aim to contribute to a forward-looking discourse on building sustainable and resilient water systems for the future.

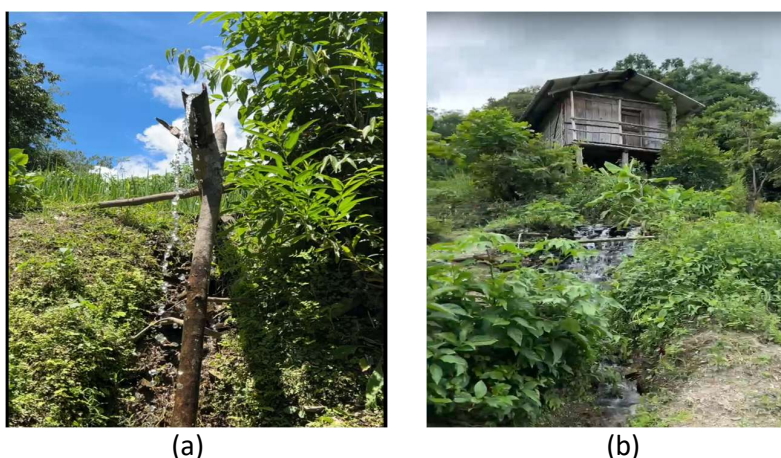


Fig. 1(a–b). Bamboo based locally built system using natural flow in Noklak district, Nagaland,
Source: Photographs taken by S. Niamkoi Khamniugan, CAEPHT (2026).

Challenges of Water Scarcity in Nagaland

Nagaland is one of the states in India that faces issues related to scarcity of water. The state has especially serious problems related to managing water from springs and not having a properly working rainwater harvesting system in place (Lairenjam & Hangshing, 2023). Not having an awareness of water-related issues has made the effect of insufficient water management worse by the citizens of Nagaland. The 2011 Census of India states that only 29% of the households of Nagaland have access to a source of water inside the home; 29% of households rely on a source of water that is further away than 100 meters and travelling to that source may involve going over hilly or difficult terrain. Areas that are so far away from water sources, such as Kiphire district, primarily receive their water from springs; with the loss of the drying up of many of the springs the discharge from the spring is declining resulting in water scarcity increasing.

Water Harvesting Systems for the Water-Scarce Mountains

Water scarcity has made use of traditional water harvesting systems critical in ensuring that communities can continue growing crops and making a living from agriculture. One traditional form of water harvesting, called the Ruza system, used by an indigenous people in Kikruma (village located in the Phek district of Nagaland), involves creating ponds at higher elevations above the village that collect runoff water, and then using slender gravity-fed drains to connect those ponds to the farmlands below in order to supply water to the fields. This model has provided the community of Kikruma with a way to combat the effects of climate change and to produce abundant crops for many generations. Another traditional water harvesting system, called the Jalkund, can be found in Wokha. A Jalkund is a shallow pond or tank built to be filled with rain water and used for irrigation during the dry season (Pandey *et al.*, 2003; Sharma & Goswami, 2018).

Integration of Traditional Practices with Modern Innovations

To combat water shortages through better management of the resource, it is increasingly important to combine both traditional and new water-saving techniques, such as Ruza and Jalkund, with modern technologies. In the Wokha district of India, efforts are underway to develop new technologies, including water-efficient irrigation systems and methods for recharging groundwater and harvesting rainwater, while also using traditional water conservation practices. By integrating these methods, the efficiency of water use and the availability of water throughout the year (especially during dry months) will be improved (Tambe *et al.*, 2012).

Indigenous Water Conservation Methods and Emerging Water Technologies for Nagaland

Examples of traditional water savings methods used in rural Nagaland include the Ruza and Jalkund systems which have provided a reliable source of water for rural communities. These systems have also fostered an ethos of sustainability and collaboration, highlighting the importance of understanding local water cycles. However, because of the dual issues of aging water infrastructure and increasing demand for water, the use of new technology such as: The use of desalination plants, smart water metering systems, and efficient water distribution systems, which can all be used as components of the existing systems to enhance access to water and water quality, will be necessary to provide the population with access to reliable and potable water.

The integration of modern technologies into existing systems such as the RWH initiatives supported by non-profit organizations and the government is critical to providing the population

with sustainable and reliable access to potable water. Emerging technologies such as IoT-based monitoring systems will allow the collection of real-time information regarding water level, quality, and use, which will allow for improved water management and more rapid responses to water-related emergencies (Mukherjee & Shah, 2005).

Ageing Water Infrastructure

Nagaland faces a major obstacle to development due to its outdated infrastructure; this problem has only worsened due to the rapid growth of both the population and cities within the state. Water supply systems in most rural parts of Nagaland have deteriorated over time, thus causing wastage of water, and also delivering poor service levels to the communities served by such systems. By revitalizing existing services using newer materials and techniques, these inefficiencies can be lessened and access to potable water enhanced (Singh and Panda, 2012).

Conclusion

The water shortages in Nagaland are not because there isn't enough rain, but rather, they stem from inadequate storage capacities, bad distribution networks, eroding springs and old infrastructure. Community-based solutions like the Ruza and Jalkund offer many effective ways to utilize local resources, but they need to be modernized in order to meet current and future demands, as well as to adapt to climate changes. New technologies, such as IoT monitoring; GIS-based water management plan production, efficient irrigation systems and decentralized rainwater harvesting systems, have the potential to greatly impact Nagaland's water management. By integrating new technologies with traditional knowledge and local input from the community, it is possible to design and build a water system that is resilient, sustainable and capable of adapting to future climate changes. By creating such a water system in Nagaland, other objectives may also be achieved, such as providing a consistent water supply while maintaining ecological balance and preserving cultural heritage within Nagaland's sensitive mountain environment.

Reference

- Lairenjam, M., & Hangshing, L. (2023). Water scarcity and traditional water management practices in Nagaland. *Journal of Hill Agriculture*, 14(2), 145–152.
- Mukherjee, A., & Shah, T. (2005). Groundwater socio-ecology and management in India. *Hydrogeology Journal*, 13(1), 328–345.
- Pandey, D. N., Gupta, A. K., & Anderson, D. M. (2003). Rainwater harvesting as an adaptation to climate change. *Current Science*, 85(1), 46–59.
- Sharma, P., & Goswami, R. (2018). Traditional water harvesting systems in northeastern hill regions of India. *Indian Journal of Soil and Water Conservation*, 46(3), 210–216.
- Singh, R., & Panda, R. K. (2012). Role of watershed management in sustainable water resources development. *Agricultural Water Management*, 103, 1–10.
- Tambe, S., Kharel, G., & Arrawatia, M. (2012). Reviving dying springs: Climate change adaptation experiments from the Sikkim Himalaya. *Mountain Research and Development*, 32(1), 62–72.

RECENT ADVANCES IN BIOFORTIFICATION OF FRUIT CROPS: A SUSTAINABLE APPROACH TO NUTRITIONAL SECURITY

Parul Bhopal¹ and Kripal Chand^{2*}

¹Phd Scholar, Fruit Science, Dr YSPUHF, Nauni

²Phd Scholar, Fruit Science, PAU, Ludhiana

*Corresponding Email: kripalchand3@gmail.com

Abstract

Micronutrient malnutrition, referred as hidden hunger, remains a major public health challenge, particularly in developing countries like India. Although, fruits are rich sources of vitamins, antioxidants and bioactive compounds, their micronutrient levels are often insufficient to meet daily dietary requirements. Biofortification has emerged as a sustainable, cost-effective and scalable approach to enhance the nutritional quality of fruit crops by increasing essential nutrient concentrations through agronomic practices, conventional breeding, modern biotechnology and nanotechnology. Recent advances have significantly enhanced the levels of iron, zinc, vitamin A, selenium and antioxidants in various fruit crops. Agronomic and nano-biofortification provide immediate nutritional benefits, while conventional breeding and genome-editing technologies offer long-term solutions for developing nutrient-dense fruit varieties. Despite constraints, related to regulation, public acceptance and awareness, biofortification shows strong potential for improving nutritional security and public health. Persistent research integration, policy support and farmer outreach will be crucial for widespread adoption of biofortified fruit crops.

Keywords: Micronutrient malnutrition, Biofortification, Nutritional security

Introduction

Exposure to rural and resource-constrained communities reveals a distressing reality-children suffering from poor growth, low immunity and visible signs of malnutrition. Such observations reflect the widespread burden of 'hidden hunger', a condition caused by deficiencies of essential micronutrients despite adequate caloric intake. Hidden hunger, remains a serious public health concern, particularly in developing countries like India. According to the Global Hunger Index (2025), India ranks 102nd out of 127 countries, indicating a 'serious' level of hunger. While fruits offer valuable vitamins and antioxidants, their micronutrient content is frequently insufficient to fulfil daily dietary requirements. Biofortification has emerged as a sustainable, cost-effective and scalable approach to strengthen the nutritional quality of fruit crops. It is the process of enhancing the concentration of essential nutrients in crops using agronomic practices, conventional breeding, modern biotechnology and nanotechnology. Unlike food fortification, biofortification delivers nutrients directly through the food system, ensuring regular intake even among low-income populations. Biofortifications ensures regular intake of essential nutrients through routine diets, offering a sustainable benefit for low-income and rural populations (Azeem *et al.*, 2025).

Why Biofortification is Essential in Fruit Crops?

Broadly prevalent deficiencies of iron, zinc, vitamin A and selenium continue to affect large sections of the population, leading to anemia, weakened immunity and developmental disorders. Biofortification is particularly important in fruit crops because fruits are consumed fresh and

regularly, nutrient enhancement improves both health value and market appeal, complements germplasm diversity and supports sustainable nutrition without changing food habits (Banerjee *et al.*, 2023).

Key Nutrients Targeted

Major nutrients targeted through fruit crop biofortification include:

Nutrient	Dietary Role	Deficiency symptoms in Human
Iron (Fe)	Hemoglobin formation, oxygen transport	Anemia, Dizziness, Fatigue, impaired cognitive development
Pro-vitamin A (β carotene)	Vision immunity, epithelial health	Night blindness, dry skin
Zinc (Zn)	Enzyme activation, immune function growth	Growth retardation, hair loss
Vitamin C	Collagen synthesis, antioxidant activity	Scurvy, bleeding gums, wound healing delayed
Selenium (Se)	Thyroid metabolism, antioxidant defense	Keshan disease, muscle weakness
Antioxidants and phenolic compounds	Oxidative stress reduction	Increased oxidative damage, higher risk of chronic diseases

These nutrients play a crucial role in human health, particularly in preventing micronutrient-related disorders (Ye *et al.*, 2020; Gupta *et al.*, 2022).

Global and National Initiatives

International programs such as Harvest Plus have played a pioneering role in promoting biofortified crops worldwide. International institutions like **International Institute of Tropical Agriculture (IITA)**, Cornell University and Queensland University of Technology (QUT), Australia are actively engaged in biofortification research in fruits such as banana, papaya, citrus and mango. In India, ICAR institutes have developed biofortified fruit varieties such as 'Solapur Lal' pomegranate and nutrient-dense bananas (Imran *et al.*, 2025).

Approaches to Biofortification

1. Agronomic Biofortification

Agronomic biofortification refers to nutrient enrichment of crops by applying mineral fertilizers, foliar sprays, soil amendments or other practices to increase the uptake and accumulation of essential micronutrients such as zinc, iron, and selenium in the edible portions. Techniques include:

- i. **Soil application**
- ii. **Foliar spray**
- iii. **Trunk injection**
- iv. **Soilless cultivation systems**

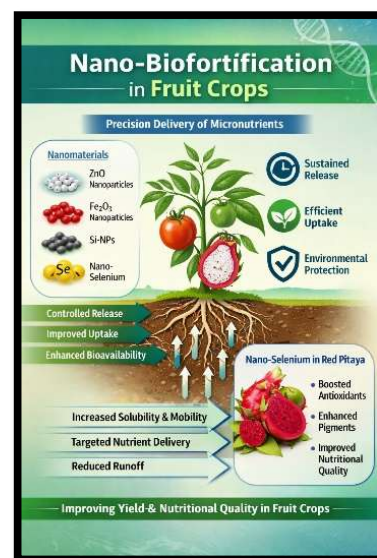
Recent studies have demonstrated successful enhancement of silicon, selenium and zinc content in fruit crops such as strawberries, apples and berries without compromising yield or quality.

2. Nano-Biofortification

Nanotechnology has revolutionized nutrient management in fruit crops by introducing precision and efficiency into nutrient delivery. Nano-engineered particles such as zinc oxide (ZnO), iron oxide (Fe₂O₃), silicon nanoparticles (Si-NPs) and nano-selenium serve as highly effective carriers for essential micronutrients. These nanoparticles enhance nutrient solubility, mobility and bioavailability, ensuring that plants receive targeted doses at the right time, reducing nutrient losses and environmental run off. (Carmona, 2024; Gupta *et al.*, 2022).

- Controlled and sustained nutrient release
- Improved nutrient uptake efficiency
- Enhanced bioavailability

Nano-selenium biofortification in red pitaya has shown significant improvement in antioxidant activity, pigment synthesis and nutritional quality, highlighting its future potential in fruit crops.



3. Conventional Breeding Approaches

Crop	Method	Variety	Enhanced Nutritional Traits
Banana	Hybridization	Kaveri Kanchan	Pro-vitamin A enriched (β-carotene)
Pomegranate	Hybridization	Solapur Lal	Higher iron, zinc, vitamin C and anthocyanin content
Grape	Hybridization	Pusa Navrang	Antioxidant rich and early maturing variety
Banana	Selection	Apantu, Bira	Pro-vitamin A enriched

Traditional breeding continues to be the most widely preferred strategy for improving fruit crops due to its cost-effectiveness and relative ease of regulatory approval. This method encompasses several techniques aimed at enhancing desirable traits.

Clonal selection entails identification and propagation of superior plants with favorable traits. Hybridization permits the combination of desirable traits from two different parent plants to produce improved offspring. Polyploidy breeding induces alteration in the number of chromosome sets, often resulting in larger fruits, higher yields or enhanced stress tolerance. Additionally, mutagenesis uses physical or chemical agents to induce genetic variations, providing new traits for selection. Collectively, these traditional methods continue to play a vital role in developing nutrient enriched, high-quality fruit varieties. Despite its achievements, conventional breeding is time intensive and often restricted by genetic variability.

4. Genetic Engineering and Genome Editing

Modern molecular tools have revolutionized biofortification by enabling precise nutrient enhancement. These include:

- Marker-assisted selection (MAS)

- ii. Quantitative Trait Loci mapping (QTL) and Genome Wide Association Studies (GWAS)
- iii. Transgenic approaches
- iv. CRISPR/Cas9 genome editing

A notable example of this achievement is the pro-vitamin A, biofortified banana (Banana-21) developed through genetic engineering at QUT, Australia. The project demonstrated stable enhancement of β -carotene without negative agronomic effects, though regulatory approval is still pending. Genome editing using CRISPR/Cas9 has further created new opportunities for targeted modification of nutrient-related genes, serving as a transgene-free alternative for future biofortification programs (Latif & Mustafa, 2025).

Challenges and Constraints

Despite its potential, the adoption of genetically modified (GM) crops faces several challenges. Regulatory hurdles and lengthy approval processes often delay the commercialization of GM technologies. Public perception and acceptance remain major concerns, largely due to misinformation and limited understanding of genetic modification. Biosafety issues related to environmental and food safety further influence regulatory decisions and consumer confidence. In addition, limited awareness among farmers and consumers restricts informed adoption and demand for GM crops. Addressing these limitations requires strong policy frameworks, institutional support and effective communication strategies to ensure the safe, responsible and socially acceptable use of GM technologies in agriculture.

Conclusion

Biofortification of fruit crops represents a sustainable and impactful solution to hidden hunger. Advances in agronomy, nanotechnology, breeding and biotechnology have significantly improved the nutritional quality of fruits. With supportive policies, public awareness and scientific innovation, biofortified fruits can play a pivotal role in ensuring nutritional security and improving public health, especially in developing nations like India.

References

- Azeem A, Khan S, Zia Ul, Haq M, Ahmad I and Ali S (2025). Biofortification strategies for enhancing crop nutritional value: A review of methods, challenges, and future directions. **Discover Plants** 2(1): 185.
- Banerjee S, Roy P, Nandi S and Roy S (2023). Advanced biotechnological strategies towards the development of crops with enhanced micronutrient content. **Plant Growth Regulation** 100: 355–371.
- Carmona ER (2024). Nanomaterial-based biofortification: Potential benefits and impacts on crops. **Journal of Agricultural and Food Chemistry** 72(43): 23645–23670.
- Gupta N, Jain SK, Tomar BS, Anand A, Singh J, Sagar V and Singh AK (2022). Impact of foliar application of ZnO and Fe₃O₄ nanoparticles on seed yield and physio-biochemical parameters of cucumber (*Cucumis sativus* L.). **Plants** 11(23): 3211.
- Imran GM, Nalini N, Banoth SK, Malek F and Lakshman B (2025). Nano-biofortification for improving nutrient status of crop plants. **Chronicle of Bioresource Management** 9(2).
- Latif M and Mustafa M (2025). CRISPR/Cas-mediated biofortification of crop plants: Advancing nutritional enhancement through precision genome editing. **Insights Journal of Life and Social Sciences** 3(2): 99–109.
- Ye Y, Qu J, Pu Y, Rao S, Xu F and Wu C (2020). Selenium biofortification of crop food by beneficial microorganisms. **Journal of Fungi** 6(2): 59.

MEDICINAL FLOWERS: NATURE'S HEALING BLOOMS**Arshi Sultanpuri^{1*}, Kritika Thakur² and Neha Rani²**¹Assistant Professor, Department of Seed Science and Technology,
Dr. Y.S. Parmar UHF, Nauni, Solan, Himachal Pradesh- 173230, India²Ph.D. Scholar, Department of Seed Science and Technology,
Dr. Y.S. Parmar UHF, Nauni, Solan, Himachal Pradesh- 173230, India*Corresponding Email: drarshisultanpuri@gmail.com**Abstract**

Flowers have been cherished for their beauty and fragrance throughout human history. However, their significance extends beyond aesthetics, as many of these blossoms possess remarkable healing properties. The utilization of medicinal flowers as a source of natural healing has been a fundamental practice across cultures and time periods. The extensive role that medicinal flowers play in maintaining human health and well-being can never be neglected. Medicinal flowers, often referred to as “nature’s pharmacy”, have been employed for their therapeutic properties for centuries. Medicinal flowers play a vital role in traditional and modern healing systems, offering natural remedies for both physical ailments and emotional well-being. Rich in bioactive compounds, they have been used for centuries to promote balance, resilience, and holistic health. Moreover, the essential oil extracted from these flowers also tend to possess anti-inflammatory properties and also serves as analgesics. This wide spectrum of healing attributes makes medicinal flowers a valuable resource in traditional and alternative medicine systems. Therefore, the current article highlights the medicinal properties of some of the most important medicinal flowers.

Keywords: medicinal flowers, pharmacy, analgesics**Introduction**

Angiospermous plants have a specific part called flower, which grows individually or in clusters, thus giving rise to an inflorescence. Flowers are of commercial importance due to their beautiful colors, fragrance and shapes. Flowers are used since ancient times in various religious offerings and flowers with intoxicating aroma and beauty are of commercial importance as well. Since, the beginning of human civilization, flowers have been one of the key sources of medicine and those flowers are called as medicinal flowers. Now, the trend is globally shifting towards the usage of ornamental flowers with medicinal properties. These are those flowers whose oils or flower extract possess the medicinal properties. Despite tremendous developments in allopathy during the 20th century, flowers continue to be a key source of medications in both the traditional and modern systems of medicine around the globe. The use of medicinal flowers continues to gain recognition and acceptance within contemporary healthcare systems and holistic wellness practices and the introduction to the world of medicinal flowers emphasizes their historical roots, diverse applications and their crucial role in promoting health and healing in the present day. The study of medicinal flowers offers an exciting and profound trip into the natural world of healing, whether you are a seasoned herbalist, a healthcare professional, or simply interested about the therapeutic potential of nature's blooms. Some flowers with medicinal properties are discussed below:

Chamomile

It is one of the oldest therapeutic flowers known to humans. It belongs to the Compositae/ daisy family with two common varieties Roman Chamomile (*Chamaemelum nobile*) and German Chamomile (*Chamomilla recutita*). Flower products are used for human ailments such as gastrointestinal problems, rheumatic pain, hemorrhoids, ulcers, wounds, inflammation, muscle spasms, menstruation problems, drowsiness and heavy fever and their constituents/ ingredients show antispasmodic, antiseptic, anti-cancer, anti-inflammatory properties.

Bio-active Constituents of Chamomile

Approximately 120 secondary metabolites, comprising 28 terpenoids and 36 flavonoids, have been identified in chamomile. The terpenoids α -bisabolol and its oxide, which include chamazulene and acetylene derivatives, are the main components of German chamomile. Roman Chamomile is primarily composed of angelic and tiglic acid esters, such as farnesene and α -pinene and contains less chamazulene. The primary bio-active components are α -bisabolol, bisabolol oxides A and B, chamazulene or azulenes, farnesene and spiro-ether quiterpene lactones, hydroxycoumarins, flavanoids (apigenin, luteolin, patuletin and quercetin), coumarins, terpenoids (Lemberkovics *et al.*, 1998) with flavonoids like apigenin, quercetin and patuletin as glucosides.

Lavender

Lavender, botanically known as *Lavendula* Linn., a member of family Lamiaceae, consists of approximately 25-30 species and is indigenous to many Asian regions, the Mediterranean region and to Tropical Africa. Three species of lavender which are extensively used for oil extraction are *Lavendula angustifolia*, *L. latifolia* and *L. intermedia*. Lavender oil finds its uses in various cosmetic and perfume industry. In addition, its essential oil is also known to cure issues like irritability, stress, anxiety, headaches, depression, cold, etc. Due to its microbicidal properties, it is becoming more and more popular in Europe as an aerosol for cleaning homes, offices and public spaces.

Bio-active Constituents of lavender

Some of the main bioactive constituents of lavender include linalyl acetate (73.53%), lavandulyl acetate (7.47%), trans-caryophyllene (3.69%), j-farnesene (1.99%), terpendiol (1.81%), t-cardinene (0.81%), j-pinene (35.91%), lavandulyl acetate (14.14%), geranyl acetate (7.39%), trans-caryophyllene (6.69%), trans-ocimen (4.8%), neryl acetate (3.89%), j-farnesene (3.44%), j-myrene (2.22%), linalyl acetate (2.21%), β - pinenoxide (2.18%), t-cardinene (1.42%), sabinaketon (1.30%), limonen (1.12%), cis-ocimen (0.95%), α -terpinolene (0.79%), linalool (0.71%), j-chamigren (0.53%).

Periwinkle

Periwinkle, botanically known as *Catharanthus roseus* is a member of Apocynaceae family. Being a native of the Madagascar region, it has now outspread to the regions of India, China, Indonesia, Philippines, Israel, USA, Africa, etc. Amongst the few medicinal plants as mentioned in folk medicinal literature, periwinkle finds a prime place and its mention is as early as 2nd BC. The height of the plant varies in between 20-80 cm, with different blossom colours like pink, white or purple. Nirmal and Dhawal are important white flowered cultivars. It has found its application also in the human disease management (Lawal *et al.*, 2015). It manages the high sugar levels in the human blood, used as an anti-oxidant, also possess wound healing capabilities. Also, it is known to be anti-cancerous.

Bio-active Constituents of periwinkle:

The chemical constituents of essential oil of periwinkle contain:

- **Flowers of pink-coloured cultivars:** Monoterpene hydrocarbons (39%), diterpenes (33.4%) and fat derivatives (15.3%). But on the contrary, its leaf oil contains fat derivatives of 76.1%.
- **Flowers of white-coloured cultivars:** Monoterpene hydrocarbons (41.6%), oxygenated counterpart (12.3%) and alkanes (22.3%).

Jasmine

Jasminum grandiflorum, belongs to Oleaceae family and is a highly valued plant due to its varied applications in various fields. The gentle fragrances present in the blossoms of jasmine are used in various perfume industry. *J. sambac* and *J. auriculatum* are other important oil yielding species of jasmine and Arka Surab, CO 1-Pitchi and CO 2-Pitchi are important varieties of *J. grandiflorum* for concrete production (concrete recovery 0.25 to 0.32%). It is used to calm the labor pains, used as an expectorant for sensitive skin, coughing, etc. Also, they are used as a food flavorant. Furthermore, the scent can be explained as exotic, fragrant and comforting. The liquid essential oils are typically distilled from different plant sections that contain potent aromatic components.

Bio-active constituents in jasmine Oil

The major constituents of *J. grandiflorum* oil are Benzyl acetate (37%), Benzyl benzoate (34.7%) and linalool (9.6%) (Galovicova *et al.*, 2022).

Tuberose

Polyanthes tuberosa belonging to the family Asparagaceae is an ornamental crop grown commercially for loose flowers and oil extraction due to its medicinal properties. Tuberose flowers are highly fragrant and contain 0.08 to 0.14% concrete which is extracted from single type cultivars on commercial scale. Tuberose essential oil is used in many medications for lowering sadness, anxiety and tension because of its remarkable properties. It also contains anti-inflammatory and anti-spasmodic properties.

Bio-active constituents in tuberose oil

Major compounds of enfleurage absolutes are methyl benzoate, methyle salicylate, indole, E-citral, methyl anthranilate, methyl isoeugenol, beta farnesene, 2,4-decandien-1-al, 1-tetradecene, nerolidol, 2-heptadecanone, benzyl benzoate, Z-3-hexenyl 2-oxopropanoate, methyl eugenol, E-methyl isoeugenol, 7-decen-5-olide, ecosanol, pentacosane, heptacosane, alpha-farnesol and (Rakthaworn *et al.*, 2009).

Calendula

Since time immemorial, *Calendula officinalis* has been utilized as a popular therapeutic herb (Patil *et al.*, 2022). It is also referred to as pot marigold or English marigold and a member of Daisy family. The Ayurvedic and Unani medical systems have documented the therapeutic properties of *Calendula officinalis*. Antioxidants are found abundantly in calendula petals. It has been demonstrated that calendula extract eliminates superoxide and hydroxyl radicals produced by photo reduction of riboflavin. Its extracts are having cytotoxic (Ashwlayan *et al.*, 2018), antihelminthic effects, genotoxic and antigenotoxic effects, neuroprotective effects, cardiovascular effect, anti-inflammatory effects, hepatoprotective, gastroprotective effects.

Bio-active constituents in calendula

It included a variety of chemical components, including as amino acids, polysaccharides, essential and volatile oils, tannin, quinines, coumarins, carotenoids, flavonoids, steroids, triterpenes,

triterpendiol esters, saponins and many more chemical groups. About 4.5% of amino acids are found in the flowers that were extracted from the ethanol extract of the flowers.

Conclusion

Medicinal flowers stand as a testament to the deep connection between nature and human well-being, bridging ancient wisdom with contemporary healing practices. Their therapeutic properties support physical health, emotional balance, and preventative care, while offering gentler, more sustainable alternatives to synthetic treatments. As interest in natural healing continues to grow, medicinal flowers remain an enduring and invaluable resource, encouraging a deeper respect for biodiversity and the healing potential of the natural world.

References

- Ashwlayan, VD, Kumar, A, Verma, M, Garg, VK and Gupta SK. (2018). Therapeutic potential of *calendula officinalis*. *Pharmacy & Pharmacology International Journal* 6(2): 149-155.
- Galovicova, L, Cmikova, N, Vukovic, N and Vukic, M. (2022). Chemical Composition, Antioxidant, Antimicrobial, Antibiofilm and Anti-Insect Activities of *Jasminum grandiflorum* Essential Oil. *Horticulturae* 8(10):95.
- Lawal, OA, Ogunwande, IA, Ibiroga, AE, Layode, OM and Opoku, AR. (2015). Chemical constituent of essential oils from *Catharanthus roseus* L. G. Don grown in Nigeria. *Journal of Essential Oil Bearing Plants* 18(1):57-63.
- Lemberkovics, E, Kery ,A, Marczal, G, Simándi, B and Szöke, E. (1998). Phytochemical evaluation of essential oils, medicinal plants and their preparations. *Acta Pharmaceutica Hungarica* 68:141-149.
- Patil, K, Sanjay, CJ, Doggalli, N, Renuka, DKR and Harshitha, N. (2022). A review of *Calendula officinalis* - Magic in Science. *Journal of Clinical and Diagnostic Research*. 16(2): 23-27.
- Rakthaworn, P, Dilokkunanant, U, Sukkatta, U, Vajrodya, S, Haruethaitanasan, V, Pitpiangchan, P and Punjee, P. (2009). Extraction methods for tuberose oil and their chemical components. *Kasetsart Journal-Natural Science* 43:204-211.

MICROBIAL SUCCESSION IN EARLY DEVELOPMENTAL STAGES OF *PENAEUS INDICUS*: A CRITICAL ANALYSIS**R. Gayathri, L. Vinoth Kumar*, G. Dhivagar, E. K. Devipriya,
M. Dhanu Pradeep and S. T. Dhivya Bharathi**

Department of Fish Processing Technology, TNJFU- Dr.MGR. Fisheries College and Research Institute, Ponneri, Thiruvallur District, Tamil Nadu 601204

*Corresponding Email : vinothkumar@tnfu.ac.in**Abstract**

Microbial communities play a crucial role in shrimp larval development, health, and disease resistance, particularly during early life stages when the immune system is not fully developed. In hatchery systems, changes in microbial communities can strongly influence larval performance, yet information on microbial succession in *Penaeus indicus* is still limited. This article explores how microbial communities change across the egg, nauplius, zoea, mysis, and postlarval stages of *P. indicus*. Early microbial communities are relatively simple and largely shaped by the surrounding environment, but they become more diverse and functionally specialized once feeding begins. Proteobacteria and Bacteroidetes remain dominant throughout development, while other bacterial groups vary in response to dietary shifts and physiological changes. The mysis stage stands out as a critical phase marked by major microbial reorganization and increased susceptibility to disease. By the post-larval stage, a more stable, host-associated microbiome is established, supporting digestion, immune function, and protection against opportunistic pathogens. Understanding these developmental microbial changes can help guide targeted microbial management strategies to improve hatchery performance and promote sustainable production of *Penaeus indicus*.

Keywords: *Penaeus indicus*, microbial succession, larval development, shrimp hatchery, microbiome, disease resistance

Introduction

Microbial communities are fundamental to shrimp larval development, influencing nutrition, immunity, and resistance to disease, particularly during early life stages when immune defenses are immature. In hatchery systems, imbalances in microbial populations often lead to poor survival and disease outbreaks, posing major challenges to the culture of *Penaeus indicus*. The early life cycle of *P. indicus* includes egg, nauplius, zoea, mysis, and post-larval stages, each associated with changes in feeding and physiology that influence microbial colonization. Environmental microbes dominate initial stages, while the onset of feeding promotes increased microbial diversity and functional specialization. Beneficial bacteria aid digestion and immune function, whereas opportunistic pathogens such as *Vibrio* spp. may proliferate under unfavorable conditions. Understanding microbial succession during early development is therefore essential for improving larval survival and sustainable hatchery management.

Early life stages of *Penaeus indicus*

The early life cycle of *P. indicus* includes the stages: egg, nauplius, zoea, mysis, and post-larva. Each stage is characterized by distinct morphological, physiological, and nutritional requirements,

which in turn influence microbial colonization patterns. During these stages, larvae are continuously exposed to microbes from seawater, broodstock-derived microbiota, live feeds, and hatchery systems. The absence of a fully developed immune system makes early larvae particularly vulnerable to opportunistic and pathogenic microorganisms.

Microbial changes during early development

Microbial communities during the egg and nauplius stages are relatively simple and mainly derived from the surrounding environment. Early colonizers are dominated by Proteobacteria and Bacteroidetes. Although diversity is low, the presence of opportunistic pathogens such as *Vibrio* spp. can adversely affect hatching success and larval quality. The external feeding during the zoea stage leads to a rapid increase in microbial diversity. Microalgal feed introduces new bacterial taxa, causing shifts in community structure. The mysis stage is a key transitional phase marked by increased microbial complexity and functional specialization. Bacteria involved in digestion and immune stimulation become prominent; however, stress and dietary changes make this stage highly susceptible to disease. In post larvae, the microbiome becomes more stable and host-associated, with the establishment of a core microbiota. Balanced microbial communities at this stage support efficient digestion, immune modulation, improved growth, and increased resistance to diseases such as vibriosis.

Role of beneficial bacteria

Beneficial bacteria play a vital role in the early development and overall health of *Penaeus indicus* by maintaining microbial balance in both the gut and rearing environment. During sensitive larval stages such as nauplius, zoea, mysis, and post-larvae, these bacteria help regulate microbial succession and prevent the overgrowth of pathogenic organisms, particularly *Vibrio* spp. Dominant beneficial bacterial groups including Proteobacteria, Bacteroidetes, Firmicutes, Actinobacteria, and Fusobacteria contribute to improved digestion and nutrient absorption through enzyme production, thereby enhancing growth and survival. Certain genera such as *Alteromonas* protect early stages from fungal infections, while *Roseobacter* in later stages supports protein utilization and exhibits probiotic effects. Beneficial bacteria also stimulate the immune system, increasing disease resistance, and improve water quality by decomposing organic matter and reducing toxic metabolites. Overall, a stable and beneficial microbiota is essential for healthy development, improved immunity, and successful hatchery production of *P. indicus*.

Harmful Microbes & Disease Risk

Harmful microbes pose a significant disease risk during the early developmental stages of *Penaeus indicus* due to the underdeveloped immune system of larvae and their continuous exposure to the rearing environment. Opportunistic and pathogenic bacteria, particularly *Vibrio* species such as *V. harveyi*, *V. parahaemolyticus*, and *V. alginolyticus*, are frequently associated with disease outbreaks in shrimp hatcheries. These bacteria proliferate rapidly under poor water quality, high organic load, and unstable microbial conditions. Disruption of the normal microbial balance (dysbiosis) allows pathogenic microbes to dominate the gut and surrounding water, leading to reduced feeding, poor growth, tissue damage, and mass mortalities, especially during sensitive stages like zoea and mysis. Although some *Vibrio* species are part of the natural microbiota, excessive abundance increases pathogenicity through toxin production and immune suppression. Therefore, effective management of harmful microbes and maintenance of a balanced microbial community are crucial to reduce disease risk and ensure healthy early development of *P. indicus*.

Management Practices

Since microbial composition varies with developmental stages, stage-specific management is essential, particularly during the critical zoea and mysis stages. Use of probiotics and beneficial microbial supplementation can help promote desirable bacteria and suppress opportunistic pathogens such as *Vibrio* spp. Maintaining good water quality, controlling organic load, and avoiding indiscriminate use of antibiotics are important to prevent microbial imbalance. Proper feed management, including nutritionally balanced formulated diets and possible inclusion of prebiotics, supports stable gut microbial communities. Overall, adopting microbiome-based management practices, aligned with natural microbial succession, can enhance larval health, disease resistance, survival rates, and sustainable production of *Penaeus indicus*.

Conclusion

The early developmental stages of *Penaeus indicus* involve dynamic changes in microbial communities that strongly influence larval health and survival. Microbial associations begin at the egg stage and become more complex with feeding and development. The mysis stage is a particularly sensitive period, marked by major microbial shifts and increased disease risk. By the postlarval stage, a stable and host-associated microbiome is established, supporting digestion, immunity, and disease resistance. Understanding these microbial changes can help improve hatchery management practices and promote healthy, sustainable shrimp production.

Reference

<https://scholar.archive.org/work/tve6ht5lr5fillh5gq5zcn4xwy/access/wayback/https://assets.researchsquare.com/files/rs-807775/v1/950d6675-a384-415b-8932-d72151ac951c.pdf?c=1628866974>
<https://link.springer.com/article/10.1007/s00438-022-01865-7>
<https://link.springer.com/article/10.1007/s10482-021-01658-9>

MODERNIZATION OF OLD PROCESSING TECHNIQUES IN THE FOOD INDUSTRY

Radha Lolge^{1*} and Vedprakash Surve²

¹Research Scholar, Dept. of Food Business Management,
College of Food Technology, VNMKV, Parbhani

²Head, Dept. of Food Business Management,
College of Food Technology, VNMKV, Parbhani

*Corresponding Email: radhalolge22@gmail.com

Abstract

The modernization of traditional food processing techniques represents a significant advancement in the food industry, combining centuries-old practices with modern science and technology. Traditional methods such as fermentation, drying, milling, salting, and smoking played a crucial role in preserving food, enhancing flavor and ensuring year-round availability. However, these methods often faced challenges related to hygiene, consistency, shelf life, and scalability. Modernization has addressed these limitations through mechanization, automation, controlled processing environments, advanced preservation technologies, and quality assurance systems. This review explores the transformation of traditional food processing techniques across key sectors, including dairy, grains, fruits and vegetables, and meat and fish. It highlights the impact of modernization on food safety, quality, nutritional retention, sustainability and economic viability. The review also discusses challenges such as high investment costs, technical skill requirements, and the need to preserve traditional food identity. By integrating traditional knowledge with modern technology, the food industry can achieve improved efficiency, global competitiveness, and consumer satisfaction while maintaining cultural heritage.

Keywords: Food industry, Modernization, Food safety, Quality, Food Processing

Introduction

Food processing is one of the oldest human activities, developed primarily to preserve food, improve its palatability, and ensure availability during periods of scarcity. Traditional food processing techniques such as drying, fermentation, salting, smoking, milling, and curing evolved through experience and cultural knowledge passed down across generations. These methods were closely linked to local resources, climate and dietary habits and played a vital role in sustaining early civilizations.

However, traditional food processing methods were often limited by poor hygiene, lack of standardization, high post-harvest losses, and restricted shelf life. With the rapid growth of population, urbanization, industrialization, and globalization of food markets, the demand for safe, nutritious, and long-lasting food products increased significantly. This necessitated the modernization of old processing techniques. Modern food processing integrates traditional methods with advances in food science, microbiology, biotechnology, and engineering to improve efficiency, safety, quality, and sustainability while preserving the essence of traditional foods.

Traditional Food Processing Techniques: An Overview

Traditional food processing methods were primarily designed to extend shelf life and reduce spoilage in the absence of refrigeration or chemical preservatives. Common techniques included sun drying, fermentation, smoking, salting, sugaring and manual grinding.

Sun drying was widely used for cereals, fruits, vegetables, fish, and meat. Fermentation relied on naturally occurring microorganisms to improve digestibility, flavour and nutritional value, as seen in products such as curd, yogurt, idli, dosa, sauerkraut and fermented fish. Smoking and salting were used mainly for meat and fish preservation; while milling and pounding were used to process grains.

Although these techniques were effective at a household or community level, they were highly dependent on environmental conditions and human skill. Variations in temperature, humidity and microbial activity often resulted in inconsistent quality and food safety risks. Additionally, traditional methods were labor-intensive and unsuitable for large-scale production, highlighting the need for modernization.

Need for Modernization in the Food Industry

The modernization of old processing techniques became essential due to several factors. Rapid population growth increased the demand for food, requiring higher productivity and reduced post-harvest losses. Urban lifestyles created a need for convenient, ready-to-eat and long-shelf-life food products. Global trade demanded uniform quality, safety compliance and extended storage stability.

Furthermore, increased awareness of foodborne illnesses and nutrition emphasized the importance of hygienic processing and quality control. Modernization addresses these challenges by introducing scientific control, mechanization, automation and standardized processing conditions while retaining traditional food characteristics.

Modernization of Traditional Techniques in Major Food Sectors**Dairy Industry**

Traditionally, dairy processing involved natural fermentation and manual operations. Milk was fermented into curd or yogurt using residual microorganisms, and butter was produced by hand churning. These processes were highly variable and prone to contamination. Modern dairy processing employs pasteurization to destroy harmful microorganisms, homogenization to improve texture and stability, and controlled fermentation using standardized starter cultures. Technologies such as Ultra-High Temperature (UHT) processing and aseptic packaging allow milk to be stored for several months without refrigeration. Automated milking, stainless-steel equipment, and cold-chain systems have significantly improved hygiene, productivity, and shelf life, making dairy products suitable for large-scale distribution.

Grain and Cereal Processing

Traditional grain processing involved sun drying, hand pounding, and stone grinding, which resulted in uneven particle size, nutrient losses, and low processing efficiency. Storage losses due to pests and moisture were also common.

Modern grain processing uses mechanical dryers, roller milling, and extrusion technology. Fortification of flour with vitamins and minerals helps address micronutrient deficiencies.

Advanced packaging materials protect cereals from moisture and pests, while automation ensures consistency and higher yield. Traditional grains are now transformed into breakfast cereals, instant flours, and ready-to-eat products.

Fruit and Vegetable Processing

Fruits and vegetables were traditionally preserved by sun drying, pickling, or using sugar and salt. These methods were weather-dependent and often resulted in nutrient degradation and microbial contamination.

Modern processing techniques such as freeze drying, vacuum drying, controlled atmosphere storage, canning, and aseptic processing have significantly improved shelf life and nutrient retention. Refrigeration and minimal processing technologies enable the availability of fresh-cut fruits and vegetables with extended shelf life. These advancements reduce post-harvest losses and support international trade.

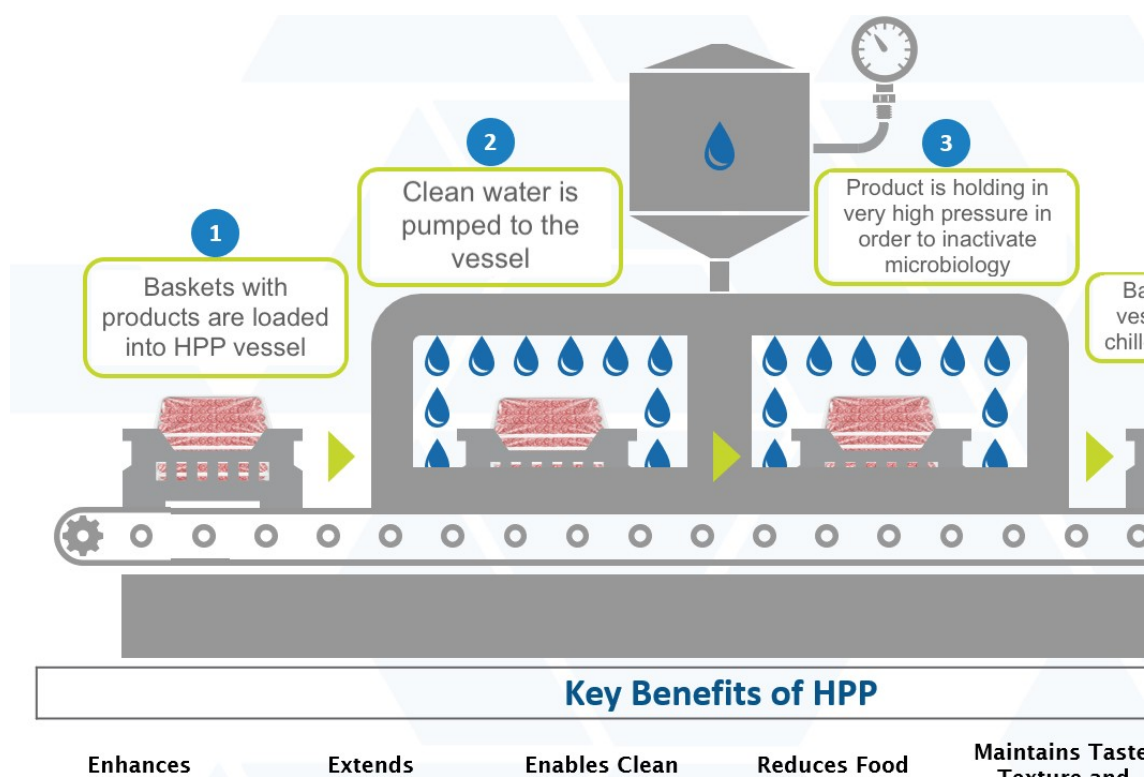


Meat and Fish Processing

Salting, smoking, and drying were the main traditional methods for preserving meat and fish. Although effective, these methods provided limited control over microbial growth and quality.

Modern meat and fish processing employs refrigeration, freezing, irradiation, high-pressure processing (HPP), and hygienic slaughtering systems. Modified atmosphere packaging extends shelf life and maintains sensory quality. These technologies ensure food safety, reduce spoilage, and meet stringent food safety regulations.





Role of Modern Technology in Food Processing

Technological advancements such as automation, sensors, computer-controlled systems, and non-thermal processing methods have revolutionized traditional food processing. Real-time monitoring of temperature, moisture, pH, and microbial activity ensures consistency and safety. Quality assurance systems like Good Manufacturing Practices (GMP) and Hazard Analysis and Critical Control Points (HACCP) are now integral to food processing industries worldwide.

Impact on Food Safety, Quality, and Nutrition

Modernization has significantly improved food safety by minimizing contamination and controlling critical processing parameters. Nutrient retention has improved through gentle processing techniques such as freeze drying and high-pressure processing. Consistency in texture, flavor, color, and nutritional value enhances consumer acceptance and trust.

Sustainability and Environmental Considerations

Modern food processing focuses on sustainability by improving energy efficiency, reducing water consumption, and minimizing waste. By-products from food processing are now used in animal feed, bioenergy production, and nutraceutical industries. Modernization also helps reduce food losses, contributing to global food security.

Challenges and Future Prospects

Despite its benefits, modernization faces challenges such as high capital investment, technical skill requirements, and potential loss of traditional food identity. Small-scale and rural producers often lack access to modern technologies. Future efforts should focus on affordable and adaptable technologies, training programs, and policies that support inclusive growth while preserving traditional knowledge.

Conclusion

The modernization of old processing techniques in the food industry represents a crucial step in meeting the demands of a growing global population. By integrating traditional knowledge with modern science and technology, the food industry has achieved improved safety, quality, efficiency, and sustainability. A balanced approach that respects cultural heritage while embracing innovation is essential for the continued evolution of the food processing sector.

References

- Fellows, P. J. (2017). *Food Processing Technology: Principles and Practice*. Woodhead Publishing.
- Potter, N. N., & Hotchkiss, J. H. (2012). *Food Science*. Springer.
- Toledo, R. T. (2007). *Fundamentals of Food Process Engineering*. Springer.
- Singh, R. P., & Heldman, D. R. (2014). *Introduction to Food Engineering*. Academic Press.

MOLECULAR AND METABOLIC MECHANISMS OF CAPSAICIN SUPPLEMENTATION IN ENHANCING TRANSITION COW HEALTH AND PRODUCTIVITY

Kiran Shinde¹, Suhana Parvin Muquit^{2*} and Chandrakant Kale³

¹Division of Animal Nutrition, ICAR-Indian Veterinary Research Institute, Bareilly, Uttar Pradesh.

²Physiology & Climatology Division, ICAR-Indian Veterinary Research Institute, Bareilly, Uttar Pradesh.

³Division of Veterinary Parasitology, Nagpur Veterinary College Nagpur

*Corresponding Email: muquit.suhana03@gmail.com

The transition period, extending from approximately three weeks prepartum to three weeks postpartum, represents one of the most metabolically demanding and physiologically unstable phases in the life of a dairy cow. During this time, the abrupt shift from a pregnant, non-lactating state to the onset of high milk production imposes profound endocrine, metabolic, and immunological adjustments. Reduced dry matter intake combined with the sudden increase in energy demand for lactogenesis leads to negative energy balance (NEB), excessive adipose tissue mobilization, elevated circulating non-esterified fatty acids (NEFA), hepatic lipid accumulation, oxidative stress, and systemic inflammation. These metabolic perturbations compromise immune competence, predispose cows to metabolic disorders such as ketosis and fatty liver, and impair reproductive performance and milk productivity.

Central to these adaptations is the coordinated regulation of nutrient partitioning, insulin sensitivity, inflammatory signaling, and oxidative balance. Therefore, nutritional interventions that target molecular pathways involved in energy sensing, immune modulation, and stress adaptation have gained increasing attention. Among emerging nutraceutical candidates, capsaicin the principal pungent component of *Capsicum* species has shown promise due to its capacity to influence key metabolic and cellular signaling pathways.

Capsaicin exerts its biological effects primarily through activation of the Transient Receptor Potential Vanilloid 1 (TRPV1) receptor, a non-selective cation channel expressed not only in sensory neurons but also in gastrointestinal epithelium, adipose tissue, pancreatic β -cells, vascular endothelium, and immune cells. TRPV1 activation induces Ca^{2+} influx, which serves as a second messenger to initiate downstream signaling cascades regulating inflammation, oxidative stress responses, insulin sensitivity, and mitochondrial function. Thus, capsaicin functions not merely as a sensory stimulant but as a metabolic modulator capable of influencing whole-body homeostasis.

Chemical Nature and Physicochemical Properties

Capsaicin is a lipophilic, crystalline, colorless, and odorless compound in its purified form. Chemically, it is classified as a phenolic protoalkaloid due to:

- A phenolic hydroxyl group on its aromatic ring, conferring antioxidant and vanilloid activity.
- A nitrogen-containing amide group in its acyclic side chain, distinguishing it from classical heterocyclic alkaloids.

- Its molecular formula is $C_{18}H_{27}NO_3$ with a molar mass of 305.42 g/mol. Owing to its hydrophobic nature, capsaicin is insoluble in water but readily soluble in organic solvents such as ethanol, methanol, and acetone. These physicochemical characteristics influence extraction efficiency, stability, and bioavailability when incorporated into animal feed formulations.

Sources and Extraction: Capsaicin is synthesized and predominantly accumulated in the placental tissues of chili fruits. Its concentration varies widely depending on species, cultivar, maturity stage, and environmental conditions. On a dry matter basis, capsaicin content typically ranges from approximately 0.1% in mild cultivars to over 6% in highly pungent varieties.

Several extraction techniques have been developed:

1. Conventional solvent extraction – simple and cost-effective but may leave solvent residues.
2. Soxhlet extraction – high yield but involves prolonged heating.
3. Ultrasound- and microwave-assisted extraction – improved efficiency and reduced processing time.
4. Supercritical CO_2 extraction – environmentally friendly and produces high-purity extracts but requires specialized equipment.
5. Extractable yields generally range between 2-6% on a dry matter basis, depending on the extraction method and plant genotype.

Mechanism of Action: TRPV1-Mediated Signaling

The biological effects of capsaicin are primarily mediated through activation of the Transient Receptor Potential Vanilloid 1 (TRPV1) receptor, a non-selective cation channel expressed in sensory neurons, gastrointestinal tissues, metabolic organs, vascular endothelium, and immune cells.

Upon binding, TRPV1 channels open, allowing influx of Ca^{2+} and Na^+ ions, which initiates intracellular signaling cascades. Acute activation induces nociceptive signaling, whereas prolonged stimulation leads to calcium-mediated desensitization of sensory neurons and suppression of action potential generation. This desensitization mechanism underlies many of capsaicin's analgesic and anti-inflammatory properties.

From a physiological perspective, capsaicin supplementation may enhance transition cow health through multiple interrelated mechanisms:

Regulation of Energy Metabolism and Insulin Sensitivity:

During the transition period, dairy cows experience negative energy balance characterized by increased lipolysis and reduced insulin responsiveness. Capsaicin enhances metabolic adaptation primarily through activation of AMP-activated protein kinase (AMPK), a key cellular energy sensor that promotes glucose uptake, fatty acid β -oxidation, and mitochondrial efficiency. In addition, stimulation of enteroendocrine TRPV1 receptors enhances glucagon-like peptide-1 (GLP-1) secretion, supporting insulin release and pancreatic β -cell function. These coordinated actions improve insulin sensitivity, optimize nutrient partitioning, and may reduce hepatic lipid accumulation, thereby lowering the risk of ketosis and fatty liver during early lactation.

Modulation of Lipid Mobilization and Adipose Tissue Function

Excessive adipose tissue lipolysis during early lactation elevates circulating NEFA and contributes to systemic inflammation and hepatic metabolic burden. Capsaicin modulates adipose tissue function by improving adipokine balance and enhancing lipid handling efficiency. Increased

adiponectin supports fatty acid oxidation and metabolic flexibility, while improved activity of lipid-metabolizing enzymes facilitates triglyceride hydrolysis and peripheral energy utilization. These effects collectively promote more controlled lipid mobilization and reduce metabolic overload.

Anti-Inflammatory Actions

Systemic low-grade inflammation is a hallmark of transition cow physiology. Capsaicin attenuates inflammatory signaling by suppressing NF- κ B-mediated transcription of pro-inflammatory cytokines, thereby limiting excessive immune activation. In addition to cellular modulation, neuronal TRPV1 desensitization reduces neurogenic inflammatory signaling associated with stress. This combined effect helps maintain immune balance and may lower the incidence of postpartum inflammatory disorders.

Antioxidant and Redox Regulation

Heightened metabolic activity during the periparturient period increases reactive oxygen species production. Capsaicin contributes to redox homeostasis through direct free radical scavenging and upregulation of endogenous antioxidant enzymes, including superoxide dismutase, catalase, and glutathione peroxidase. Reduced lipid peroxidation further supports cellular integrity and mitochondrial stability. By preserving oxidative balance, capsaicin enhances physiological resilience during metabolic stress.

Implications for Productivity and Reproductive Performance

The metabolic stabilization achieved through improved energy regulation, reduced inflammation, and enhanced antioxidant capacity translates into measurable productive benefits. Capsaicin supplementation has been associated with improved dry matter intake, enhanced milk yield and composition, and lower somatic cell counts. Improved metabolic and endocrine balance may also support ovarian function and corpus luteum development, contributing to better reproductive efficiency during the postpartum period.

Integrated Perspective

Capsaicin functions as a metabolic modulator influencing interconnected energy, immune, and redox pathways. By improving insulin sensitivity, regulating lipid mobilization, attenuating inflammatory signaling, and maintaining oxidative balance, it supports systemic adaptation during the transition phase. These coordinated physiological effects provide a mechanistic rationale for its inclusion in precision dairy nutrition strategies aimed at enhancing health, productivity, and reproductive performance.

Conclusion and Future Directions

Capsaicin represents a promising nutraceutical approach to improving transition cow health through targeted modulation of metabolic and inflammatory pathways. Future research should focus on dose optimization, long-term safety, bioavailability enhancement, and clarification of tissue-specific responses to maximize its practical application in dairy production systems.

References

- Abulaiti, A., Ma, Y., Ainiwaer, A., Yusup, A., Wang, H., & Zhang, X. (2023). Effect of capsaicin supplementation on lactational yield and lipoprotein esterase activity in lactating Holstein Friesian cows. *Journal of Dairy Science*, 106(4), 2451–2462.
- Fattori, V., Hohmann, M. S. N., Rossaneis, A. C., Manchope, M. F., Alves-Filho, J. C., Cunha, T. M., Cunha, F. Q., & Verri, W. A. (2018). TRPV1-mediated mechanisms involved in analgesic and anti-inflammatory actions of capsaicin. *Pharmacological Research*, 129, 246–255.

- Hangfan, L., Yujie, Z., Minghao, W., Qiang, L., & Xiaoyan, Z. (2025). Dietary capsaicin supplementation improves antioxidant status and attenuates inflammation in periparturient dairy cows. *Animal*, 19(2), Article 100923.
- Joonpyo, K., Eunjoong, K., Sungkyun, P., Hyunsoo, K., & Seongwon, S. (2015). Effects of rumen-protected capsicum supplementation on dry matter intake, milk yield, plasma GLP-1, and insulin in lactating dairy cows. *Journal of Animal Science*, 93(9), 4354–4363.
- Oh, J., Harper, M. T., Melgar, A., Räisänen, S., Chen, X., Nedelkov, K., Fetter, M., Ott, T., Wall, E. H., & Hristov, A. N. (2021). Dietary supplementation with rumen-protected capsicum during the transition period improves the metabolic status of dairy cows. *Journal of Dairy Science*, 104(11), 11609–11620.
- Wang, P., Yan, Z., Zhong, J., Chen, J., Ni, Y., Li, L., Ma, L., Zhao, Z., Liu, D., & Zhu, Z. (2012). Transient receptor potential vanilloid 1 activation enhances gut glucagon-like peptide-1 secretion and improves glucose homeostasis. *Diabetes*, 61(8), 2155–2165.

MOLECULAR TOOLS FOR ASSESSING GENETIC DIVERSITY

Tharringwon Marchang Ningshen¹, Pritam Das² and Pranab Dutta³

^{1,2}Ph.D. Scholar, School of Crop Protection, College of Postgraduate Studies in Agricultural Sciences, Central Agricultural University (Imphal), Umiam, Meghalaya, 793103.

³Professor, School of Crop Protection, College of Postgraduate Studies in Agricultural Sciences, Central Agricultural University (Imphal), Umiam, Meghalaya, 793103.

*Corresponding Email: tharringmcningshen@gmail.com

Abstract

Breeding resistant crop types and managing diseases effectively depend on an understanding of the genetic diversity of plant pathogens. The term "genetic diversity" describes the variance in the genetic composition of plant diseases caused by selection, migration, recombination, and mutation. Pathogens with high diversity, such as *Sclerotinia sclerotiorum*, can adapt to host defenses and environmental changes, making control measures more difficult. Methods including AFLP, SSR, ISSR, and RAPD markers are used to measure the diversity and population structure of pathogens. The effectiveness of fungicides and biocontrol is threatened by diverse pathogen populations because recombinants can circumvent resistance genes. Diversity studies provide valuable insights into integrated pest control and marker-assisted breeding, highlighting the importance of continuous crop observation. It is crucial for predicting disease outbreaks, developing long-lasting crop resistance, and implementing effective management strategies. It shows how pathogens evolve over time, adjust to limitations, and overcome host defenses.

Key words: Genetic diversity, host defenses, management strategies, markers.

Introduction

Genetic diversity is the total number of genetic characteristics in the genetic makeup of a population, species, or ecosystem, encompassing variations in allele frequencies, nucleotide sequences, and haplotypes within individuals of the same species. Plant pathogens may quickly adapt to new hosts, environmental stressors, and control strategies like fungicides or resistant crop varieties thanks to their genetic diversity. The probability of disease outbreaks is increased by diverse pathogen populations because subpopulations can take advantage of weaknesses in monoculture crops to cause epidemics like wheat rusts. Because of this diversity, it is more difficult to develop resistant plants; to match pathogen variability, crops must have a variety of genetic resources (Salgotra and Chauhan, 2023). Pathogens can quickly overcome crop resistance through mutations or gene exchange due to high genetic heterogeneity, which enables them to create new virulence factors. As a result, resistant cultivars fail and diseases adapt, creating boom-and-bust cycles (Treindl *et al.*, 2023).

Origins of genetic variation

Heterokaryosis, parasexualism, cytoplasmic adaptability, recombination, and mutation are some of the processes that cause variability in fungi. Bacteria exhibit variability because of conjugation, transformation, and transduction. Variability in viruses is caused by mutation and recombination (Singh. 2012)

Molecular tools for Studying/Assessing Genetic Diversity

RAPD, RFLP, AFLP, SSR, and ISSR are examples of molecular markers that exceed conventional phenotypic techniques in accurately characterizing pathogen populations.

SSRs (Simple Sequence Repeat) or STRs (Short tandem repeats)

Microsatellites, sometimes referred to as simple sequence repeats (SSRs) or short tandem repeats (STRs), carry a multitude of genetic information and function as unique markers in the genetic code. STR molecular are a perfect molecular marker technology because they are numerous, cover the entire genome, have a uniform distribution, high polymorphism, exhibit co-dominant inheritance, have good repeatability, and are simple to apply. By using measures like heterozygosity, allele richness, and fixation indices in pathogen populations, SSR markers measure genetic diversity as seen in *Sclerotinia sclerotiorum* and *Fusarium oxysporum*, they monitor host adaptation, regional spread, and fungicide resistance (Wang *et al.*, 2023).

SSR offers high reproducibility, genome-wide distribution, and transferability across related pathogens, outperforming other markers for fine-scale diversity.

RAPD (Random Amplified Polymorphic DNA)

RAPD are PCR-based methods that amplify arbitrary DNA segments using short, random primers to produce polymorphic banding patterns that show genetic variation in plant pathogens. By rating the presence or absence of bands, these prominent markers aid in the assessment of diversity and allow for the creation of dendrograms for population structure and cluster analysis. (JungehÜlsing and Tudzynski. 1997). RAPD is useful for evaluating genetic diversity in a variety of plant species. Hasan *et al.* (2023) investigated genetic diversity (GD) at the DNA level across seven types of eggplant (*Solanum melongena* L.) using the RAPD-markers-assisted PCR technique.

RFLP (Restriction Fragment Length Polymorphism)

Using Southern blotting and restriction enzyme digestion, RFLP examines genetic diversity in plant pathogen by identifying differences in DNA fragment lengths. These variations result from mutations that add or remove restriction sites, resulting in distinctive banding patterns that distinguish strains, populations, and isolates of pathogens. RFLP identifies clones, geographic origins, and virulence groups in fungal pathogens such as *Septoria tritici* and *Pseudomonas solanacearum* by evaluating diversity, population structure, and gene flow. It maps the evolution of pathogens and monitors epidemics throughout host ranges (Carder and Barbara 1991).

AFLP (Amplified Fragment Length Polymorphism)

Through selective PCR amplification of restriction enzyme-digested DNA fragments, AFLP markers produce genome-wide polymorphisms that reveal genetic diversity in plant diseases through intricate banding patterns that are examined for similarities. By evaluating the presence or absence of bands, these dominant markers evaluate population structure, clonality, and migration. Microsatellites, RAPD, and RFLP are inferior than AFLPs. According to Ajmone-Marsan *et al.* (2002), the AFLP method is widely used for the identification of genetic polymorphisms, assessment, and characterization of animal genetic resources, and it is an effective molecular tool for population genetics and genome typing.

ISSR (Inter-Simple Sequence Repeat)

ISSR (Inter-Simple Sequence Repeat) markers amplify DNA regions between microsatellite repeats using single primers, generating multilocus profiles to reveal polymorphisms in plant pathogens.

They provide high reproducibility and sensitivity, detecting genetic variation without prior sequence knowledge, ideal for fungal and bacterial strains (Luz *et al.*, 2020). In pathogens, ISSR identifies virulence shifts, gene flow, and adaptation, aiding surveillance in different crops (Haq and Ijaz. 2019). ISSR is more stable than RAPD and can be used in conjunction with SSR or AFLP for multi-locus profiles. It is also inexpensive, repeatable, and doesn't require genome sequence (Costa *et al.*, 2016).

Conclusion

Advancing plant pathology requires an understanding of the genetic diversity of plant pathogens using molecular techniques such as SSR, ISSR, AFLP, whole-genome sequencing. The population structures, recombination processes, and adaptive mutations that propel pathogen virulence and evolution are revealed by these tools. Targeted breeding of multi-gene resistant crops is made possible by molecular markers, which allow for accurate tracking of genetic shifts and pathogen propagation. Additionally, by identifying various pathogen strains susceptible to particular treatments, they develop biocontrol tactics such as *Trichoderma* formulations. Validation of virulence genes and predictive modeling will be accelerated by combining diversity data with CRISPR-based functional genomics. In the face of pathogen alterations brought on by climate change, persistent surveillance with these approaches promises resilient agriculture by reducing disease losses.

References

- Ajmone-Marsan P, Negrini R, Milanese E, Bozzi R, Nijman I.J, Buntjer J.B and Lenstra J.A (2002). Genetic distances within and across cattle breeds as indicated by biallelic AFLP markers. *Animal Genetics*, 33(4): 280-286.
- Biological online dictionary, genetic diversity (2019). Available via "https://en.wikipedia.org/wiki/Genetic_diversity definition and examples".
- Carder J.H and Barbara D.J (1991). Molecular variation and restriction fragment length polymorphisms (RFLPs) within and between six species of *Verticillium*. *Mycological Research* 95(8): 935-942.
- Costa R, Pereira G, Garrido I, Tavares-de-Sousa M.M and Espinosa F (2016). Comparison of RAPD, ISSR, and AFLP molecular markers to reveal and classify orchardgrass (*Dactylis glomerata* L.) germplasm variations. *PloS one* 11(4): e0152972.
- Haq I and Ijaz S. (2019). Assessment of genetic diversity based on ISSR markers in neopestalotiopsis species collected from Guava (*Psidium Guajava* L.) plants affected with canker disease in Pakistan. *Applied Ecology and Environmental Research* 17(5).
- Hasan R, Rahman M.A, Kabir A.H, Haydar F.A and Reza M.A (2023). RAPD-markers assisted genetic diversity analysis and Bt-Cry1Ac gene identification in eggplant (*Solanum melongena* L.). *Plant Trends* 1(1): 20-30.
- JungehÜlsing U and Tudzynski P (1997). Analysis of genetic diversity in *Claviceps purpurea* by RAPD markers. *Mycological Research* 101(1): 1-6.
- Li J, Zhang Y, Zhang Y, Yu P.L, Pan H and Rollins J.A (2018). Introduction of large sequence inserts by CRISPR-Cas9 to create pathogenicity mutants in the multinucleate filamentous pathogen, *Sclerotinia sclerotiorum*. *MBio* 9(3): 10-1128.
- Luz G.C, Strioto D.K, Mangolin C.A and Machado M.D.F.P (2020). ISSR markers to assess genetic diversity of cultivated populations from artificial selection of *Stevia rebaudiana* (Bert.) Bertoni. *Breeding Science* 70(4): 508-514.

- Meudt H.M and Clarke A. C (2007). Almost forgotten or latest practice? AFLP applications, analyses and advances. Trends in plant science 12(3): 106-117.
- Mueller U.G and Wolfenbarger L (1999). AFLP genotyping and fingerprinting. Trends in Ecology and Evolution 14: 389-394.
- Panwar V, Jordan M, McCallum B and Bakkeren G (2018). Host-induced silencing of essential genes in *Puccinia triticina* through transgenic expression of RNA i sequences reduces severity of leaf rust infection in wheat. Plant biotechnology journal 16(5): 1013-1023.
- Reshma R.S and Das D.N (2021). Molecular markers and its application in animal breeding. In Advances in animal genomics. Academic Press, pp. 123-140
- Singh R.S (2012). Introduction to principles of plant pathology, Oxford and IBH publishing CO, pp 200-208.
- Treindl A.D, Stapley J and Leuchtmann A (2023). Genetic diversity and population structure of *Epichloë* fungal pathogens of plants in natural ecosystems. Frontiers in Ecology and Evolution 11: 1129867.
- Wang F, Tang T, Mao T, Duan Y, Guo X and You J (2023). Development of EST-SSR primers and genetic diversity analysis of the southern blight pathogen *Sclerotium rolfsii* using transcriptome data. Frontiers in Microbiology 14: 1152865.

MOOD SWINGS – ARE THEY CONTROLLED BY GUT MICROBIOME?

Uthara S¹ and Ganga Nair²

¹Final year student, College of Agriculture, Vellanikkara, Thrissur, 6238791060,

²Final year student, College of Agriculture, Vellanikkara, Thrissur, 8848912317

Corresponding Email: uthara0063@gmail.com

Abstract

While mood swings are traditionally attributed to life experiences or hormonal cycles, emerging research indicates that the gut microbiota- a network of bacteria, viruses, and fungi – plays a major role in regulating mental health through the production of metabolites and neurotransmitters like Serotonin and GABA. Dysbiosis can trigger inflammation, compromise the gut barrier, and lead to various psychiatric and neurological conditions, including anxiety, depression, and bipolar disorder. Factors such as diet, lifestyle, and pharmacological stressors are identified as primary drivers of these microbial shifts. To counteract these effects several therapeutic interventions are suggested such as prebiotics and probiotics and advanced therapies such as faecal microbiota transplantation, phage therapy and synbiotics

Introduction to the concept of mood swings

Mood instability is characterised by frequent, sudden and unpredictable emotional changes. The symptoms of mood instability can be attributed as mood swings. People often correlate the occurrence of mood swings to various factors such as personality, living conditions, life experiences, and menstrual cycle in women. But, it is interesting to know that mood swings in our body are also controlled by the gut microbiome. Gut -brain connection is an involute relationship between digestive system and mental health. Through extensive research and observations it is now attributed that a balanced microbiome can lead to positive mood and an imbalanced microbiome can adversely affect the mental health. so let's dive deeper to the effects of gut microbiome on our mood swings.

The human gut microbiota

Human gastro-intestinal tract is an intricate biological network of microorganisms which are collectively termed as gut microbiota. It is dominated by bacteria and also includes viruses, fungi, archaea etc. These organisms affect the physiology, metabolism and the functioning of the host's body. They also affect the immune system of the host. They produce metabolites which can affect the host physiology. The composition of the gut microbiome is mainly influenced by diet, lifestyle, genetics and environmental exposure. Diets rich in plant-based foods and dietary fibre, such as fruits, vegetables, legumes and whole grains, have favourable outcomes on metabolic health. Diets low in fibre and high in refined sugars and saturated fats promotes dysbiosis and inflammation. Additionally, exposures during early life, including allergens, nutritional components can shape the gut microbiome. Apart from nutrition psychological and pharmacological stressors also modify microbial ecology. Antibiotic and non – Antibiotic drugs can also influence the microbial ecosystems. Physical activity can also affect the gut microbiota. Moderate exercise has beneficial effects. On the contrary, strenuous exercise can cause inflammation.

The gut microbial world

Now, let's understand about the different microbes in our gut and their effects. As bacteria constitute more percentage of gut microbiome it will be more convenient to study the different bacterial species in detail. *Enterococcus*, *Ruminococcus*, *Bacteriodes*, *Bifidobacterium*, *Prevotella*, *E.coli*, *Firmicutes* (including *Clostridium* and *Lactobacillus*) are the major bacterial species in the gut. *Bifidobacterium* is responsible for carbohydrate breakdown, vitamin production, immune support and digestion of dietary fibres. *Lactobacillus* as we all know ferments lactose to lactic acid, aids in lactose digestion, lowers gut PH, produces antimicrobials and reduces growth of harmful bacteria. On the contrary, bacterial species such as *E.coli* produce shiga toxin which causes haemolytic uremic syndrome. *Salmonella* causes food borne illness, diarrhoea, fever, abdominal cramps etc. Poor gut health can affect metabolic and cardiovascular conditions leading to obesity, type 2 diabetes, cardio-vascular diseases. It affects the inflammatory and immune related conditions causing inflammatory bowel disease, autoimmune diseases, allergies and respiratory infections and it can also lead to neuro-inflammation and cancer. Individuals with type 2 diabetes have distinct gut microbiota that is different from healthy persons. These microbial changes can affect glucose metabolism, insulin resistance and progresses the condition of diabetes. Dysbiosis, which is the imbalance in gut microbiota can lead to autoimmune diseases such as rheumatoid arthritis, multiple sclerosis, and IBD (inflammatory bowel disease). Beneficial microorganisms can produce immune tolerance. Certain gut microbes can also cause cancer progression causing colorectal cancer, inflammation, genotoxicity. On the other hand, some microorganisms in gut can cause protective effect by increasing immune response and inhibiting tumour growth. Increase in gut bacteria such as *Ruminococcus*, *Enterococcus* can accelerate chronic kidney disease and in such condition bacteria such as *clostridium* and *lactobacillus* are reduced.

Mood swings and gut microbiota

Now, it's time to discuss the main question under consideration 'Are mood swings controlled by gut microbiome? The relationship between gut microbiome and mental health was done by advanced sequencing techniques and computational tools. One such study was the Mendelian randomisation study which indicated that high tension and anxious feelings are related to gastroesophageal reflux diseases.

It uses genetic variation to explore causality. It makes use of single nucleotide polymorphism. The microbiome-mood links was studied by multi-omics technologies including 16S r RNA sequencing, shotgun metagenomics, metatranscriptomics, metaproteomics etc. These help in studying the taxonomic composition, gene expression, protein synthesis, and metabolic profiles of gut microbiota. The gut- brain axis is a bidirectional communication between gut microbiota and brain. Any alteration in the gut microbiota can cause depression, anxiety, autism spectrum disorder etc. Some gut bacteria can produce serotonin and gamma-aminobutyric acid which can affect the mood and anxiety levels. Serotonin production can drop if gut health is compromised, making a person more vulnerable to sadness, mood shifts, or anxiety. Certain metabolites produced by microbes such as SCFA's can modulate inflammation and affect the blood-brain barrier. Inflammation in the gut can trigger chemical changes that aggravate mental stress. Lipopolysaccharide is a toxic chemical produced by some gut bacteria and this can cause inflammation. In a healthy person, the gut barrier prevents liposaccharide from entering the

blood. But, in some people the barrier becomes leaky causing lipopolysaccharides to enter into blood. Microbial imbalances, especially dysbiosis, is attributed to disruption of sleep patterns and circadian rhythms, in turn amplifying symptoms of stress and anxiety. Additionally, dysbiosis within the gut-brain axis can be linked to a range of neurological and psychiatric disorders, including Alzheimer's disease Parkinson's disease, irritable bowel syndrome. Faecal microbiome analysis has identified decreased abundance of Firmicutes, in patients with bipolar disorder, which also indicates a potential link between gut microbiome composition and psychiatric symptoms. Targeting the microbiome may represent a novel approach for treating neurodevelopmental disorders such as autism. The relationship between gut microbiome and impulsive behaviour is an area of growing interest in the field of neuroscience and psychology. The gut microbiome has potential impact on cognitive functions, decision making and impulsive behaviours. The impact of gut microbiome on impulsive behaviour has implications on psychiatry, neurology etc. Several studies indicate that gut microbiome has significant influence on addiction behaviours through various pathways, including the modulation of the gut-brain axis, immune responses. These findings help in addiction treatment by microbiome mediated therapies.

Improving the gut health

Since it is clear that gut microbiome can affect mental health, consuming certain bacteria through food can improve mental health. Such bacteria are called psychobiotics and are broadly classified as probiotics and prebiotics. Prebiotics are plant fibres that are fermented by gut bacteria and affect mental health in the process. For example, a prebiotic called galacto-oligo-saccharide (GOS) is known to reduce levels of cortisol, the stress hormone in the body. Foods rich in prebiotic fibres include legumes, beans, peas, oats, bananas, berries, Jerusalem artichokes, asparagus, garlic, leeks, onions. Probiotic foods contain live, active microorganisms that support other gut microorganisms. Some common probiotic foods are buttermilk, cheese, kefir, yogurt with live active cultures, sauerkraut and tempeh. Probiotic products may contain one or more microbial strains. Human probiotic microorganisms belong mostly to genera such as *Lactobacillus*, *Bifidobacterium*, *Lactococcus*, *Streptococcus* and *Enterococcus*. Also, strains of gram-positive bacteria belonging to the genus *Saccharomyces* are commonly used in probiotic products. Consumption of prebiotic and probiotic foods can help increase helpful bacteria in your gut and decrease the amount of harmful and pathogenic bacteria. This can also improve digestion, decrease inflammation, support immune system, reduce gas and bloating, and help nutrient absorption.

Results of clinical studies confirm the positive effect of probiotics on gastrointestinal diseases. They are proven effective for the treatment of diseases such as obesity, insulin resistance, type 2 diabetes. The working of probiotics work may depend on the strain, dose, and components. Prebiotics may be used as an alternative to probiotics or as an additional support for them. Prebiotics have enormous potential for modifying the gut microbiota. In 1995, Gibson and Roberfroid introduced the term 'synbiotic' to describe a combination of synergistically acting probiotics and prebiotics. The principal purpose of that type of combination is the improvement of survival of probiotic microorganisms in the gastrointestinal tract. Appropriate combination of both components ensure a superior effect than the effect of single component. Another method for improving the gut microbiota is faecal microbiota transplantation (FMT) which is highly effective in treating the infections caused by *Clostridium difficile* by restoring microbial diversity.

Microbial consortia therapy is also used in treating recurrent bacterial infections. Dietary and nutritional interventions such as dietary modifications, microbiota – targeted dietary interventions and butyrate supplementation helps in managing symptoms of irritable bowel syndrome, obesity, and treating ulcerative colitis. Gut microbiota modulators are pharmaceuticals that target specific pathways or microbes within the gut and treats recurrent bacterial infections. Phage therapy is an alternative to antibiotics in treating infections. It makes use of bacteriophages to target harmful bacteria in the gut microbiota. Additionally, the use of post biotics are also coming under light for its potential in treating metabolic disorders. They are metabolites produced by probiotic bacteria and protects gut health. Apart from the above methods microbial ecosystem therapeutics are used in treating inflammatory diseases.

Conclusion

So, from the above discussion it is clear that there is a close relationship between gut microbiota and mental health and the gut – brain axis is a key mediator in mood regulation. Dysbiosis or microbial imbalance, is strongly associated with mood swings. Thus, restoring the balance of the gut microbiome is essential to cure the psychiatric symptoms. Probiotics containing microbes such as *Lactobacillus* helps in modulating the gut-brain axis and reduce inflammation. Prebiotics stimulate growth of beneficial bacteria and improves mental health. Dietary changes and FMT are also gaining popularity. Harnessing the therapeutic value of the gut-brain axis calls for integrated inputs from microbiology, nutrition, bioinformatics, and psychiatry. Incorporating microbiota – focused interventions into mental health care could transform the way mood disorders are managed.

Reference

(Source: Paul, J.K., Azmal,M., Haque, A.S.N.B, Meem, M., Talukder, O.F.& Ghosh, A.Unlocking the secrets of the human gut microbiota: Comprehensive review on its role in different diseases. World journal of Gastroenterology 31,99913(2025)
(<https://doi.org/10.3748/wjg.v31.i5.99913>)

Article ID : 06/III/92/0326

PREDICTION OF PRODUCTION PERFORMANCE IN DAIRY ANIMALS USING BODY MORPHOMETRIC TRAITS

Suryakant Sori^{1*} and Deeksha Pal²

¹Department of Livestock Production Management, College of Veterinary Science & Animal Husbandry, Anjora, Durg, Chhattisgarh, India

²Department of Livestock Production Management, College of Veterinary Science & Animal Husbandry, Navsari, Gujarat, India

*Corresponding Email: sibusori@gmail.com

Abstract

Efficient selection of dairy animals is essential for improving milk productivity and profitability in dairy farming systems. Body morphometric traits provide a simple, economical, and reliable approach for predicting production performance in dairy animals, especially under field conditions where milk recording systems are limited. Measurements such as heart girth, body length, height at withers, chest depth, and hip width are closely associated with body weight, feed intake capacity, and milk yield. These physical traits reflect structural development and physiological efficiency of animals. Prediction models based on morphometric parameters assist farmers and breeders in early identification of high-producing animals. Utilization of body measurements can significantly enhance genetic improvement programmes and herd management practices. Therefore, morphometric evaluation serves as an effective tool for estimating production potential in dairy cattle and buffaloes.

Keywords: Dairy cattle, Morphometry, Milk yield, Body measurements, Prediction

Introduction

Dairy farming plays an important role in strengthening rural economy and nutritional security. Selection of genetically superior animals is one of the major challenges faced by dairy farmers. Direct evaluation of milk production requires long-term performance recording, which is often unavailable in rural production systems. Body morphometric traits offer an alternative method for estimating productive potential through easily measurable external body dimensions. These traits represent growth pattern, skeletal development, and body capacity of dairy animals. Scientific evaluation of morphometric characteristics helps in predicting milk production performance at an early age.

Materials and Methods

Body morphometric measurements are recorded using a flexible measuring tape and measuring stick under standard field conditions. Measurements are taken when animals are standing on a level surface. Important parameters recorded include heart girth, body length, height at withers, chest depth, and hip width. Body weight can be estimated using standard formulae based on heart girth and body length. Statistical analysis such as correlation and regression analysis can be applied to establish relationships between morphometric traits and milk yield.

Table 1. Relationship between body morphometric traits and milk yield

Trait	Correlation with Milk Yield	Importance
Heart girth	High positive	Indicates feed intake capacity
Body length	Moderate positive	Reflects skeletal development
Height at withers	Moderate	Shows growth potential
Chest depth	High positive	Improves digestive efficiency
Hip width	Moderate positive	Associated with reproduction

Prediction Models

Production performance can be predicted through statistical regression models based on body measurements. Example prediction equation: $\text{Milk Yield} = a + b_1 (\text{Heart Girth}) + b_2 (\text{Body Length}) + b_3 (\text{Height at Withers})$. Such prediction models are particularly useful in areas where systematic milk recording is absent.

Discussion

Several studies have reported significant associations between body morphometric traits and milk production performance in dairy animals. Larger body frame and thoracic capacity allow greater feed consumption and efficient nutrient utilization, ultimately enhancing milk production. Morphometric evaluation is particularly useful for early selection of replacement heifers and genetic improvement programmes in organized as well as unorganized dairy sectors.

Practical Applications

Selection of replacement heifers, identification of superior dairy animals, breed improvement programmes, estimation of body weight without weighing balance, and scientific herd management.

Advantages

Low-cost and farmer-friendly method, applicable under field conditions, early prediction of productivity, supports genetic improvement strategies, and reduces selection errors.

Limitations

Morphometric traits may be influenced by nutrition, environment, age, and breed differences. Therefore, standardized measurement procedures must be followed for accurate prediction.

Conclusion

Body morphometric traits serve as reliable indicators for predicting production performance in dairy animals. Proper assessment of physical measurements enables early identification of high-yielding animals and supports efficient breeding decisions. Integration of morphometric evaluation with production and genetic information can significantly enhance dairy productivity and sustainability under field conditions.

References:

- Banerjee G.C. (2018). A Textbook of Animal Husbandry. Oxford & IBH Publishing Co., New Delhi.
- Brown B and Aaron M (2001). The politics of nature. In: Smith J (ed) The rise of modern genomics, 3rd edn. Wiley, New York, pp 230-257.
- ICAR (2013). Handbook of Animal Husbandry. Indian Council of Agricultural Research, New Delhi.
- Singh Y and Sharma R (2019). Relationship between body measurements and milk yield in dairy cattle. Indian Journal of Animal Production 54(2): 112-118.

MULCHING TECHNOLOGY FOR PEST SUPPRESSION

Ayushi Kumari and Radheshyam Ramkrishna Dhole*

Narayan Institute of Agricultural Sciences, Gopal Narayan Singh University,
Jamuahar, Sasaram, Rohtas – 821305

*Corresponding Email: nias.radheyshyam.dhole@gnsu.ac.in

Abstract

Mulching is an emerging smart pest control technique extensively used in modern sustainable agriculture to minimize pest attack, conserve soil health, and improve yield. It involves covering the soil surface using organic or inorganic materials such as straw, crop residues, plastic films, biochar, or synthetic sheets. Mulch acts as a protective shield, influencing soil microclimate, regulating temperature, improving moisture conservation, enhancing microbial activity, and acting as a physical barrier against weeds and pests. Integrated with advanced farming systems, mulching plays a crucial role within Integrated Pest Management (IPM) by reducing dependency on chemical pesticides. This paper discusses the methodology, materials, key benefits, pest suppression mechanisms, outcomes, and future strategies for adopting mulching technology in agricultural pest management.

Keywords : Mulching, Pest Suppression, Smart Agriculture, Integrated Pest Management (IPM), Soil Health, Plastic Mulch, Organic Mulch, Eco-friendly Farming.

Introduction

Pest management remains a significant challenge in agriculture. Conventional farming practices relied heavily on chemical pesticides for controlling pests, but overuse has led to environmental damage, pesticide resistance, residue concerns, and high input costs. Smart pest control strategies focus on sustainable approaches to minimize chemical dependency while protecting crop productivity.

Mulching technology has gained attention as a smart, eco-friendly, and cost-effective pest management tool. Its primary purpose is to protect soil and suppress weeds, but scientific studies show mulching also reduces pest population by altering pest behavior, interfering with egg-laying, enhancing natural predators, and creating unfavorable microenvironments for pest development.

In vegetable crops like tomato, capsicum, beans, cucumber, and cabbage, mulching effectively suppresses insect pests such as whiteflies, aphids, nematodes, borers, and leaf miners. With increased demand for residue-free agricultural produce, mulching is now an essential component of sustainable and precision farming.

Methodology

The methodology of implementing mulching technology is based on the following steps:

1. Crop and Pest Assessment

The first step is identifying crop type, pest history, weed infestation, and climatic conditions. This helps determine the most suitable type of mulch based on pest suppression requirements.

2. Soil Preparation

Land is prepared by tillage, leveling, and removal of existing weeds. Basal dose fertilizers can be applied before laying mulch.

3. Mulch Material Selection

Mulch selection depends on objectives such as moisture retention, pest suppression, weed control, soil temperature management, and cost. Common categories include:

- Organic mulches (straw, compost, dried leaves, sawdust)
- Inorganic mulches (plastic, rubber, landscape fabrics)
- Bio-mulches (biodegradable plastic, paper mulch, crop residue mulch)

4. Installation and Application

Mulch is laid on the soil surface in a uniform layer or sheet. For plastic mulch, holes are punched for planting. The thickness, placement, and anchoring depend on mulch type and climatic conditions.

5. Monitoring and Maintenance

Regular observation ensures no mulch deterioration or pest colonization occurs beneath the layer. Supplemental irrigation or mulching adjustments may be required.

6. Integration with IPM Tools

Mulching complements pest monitoring, biocontrol agents, trap crops, pheromone traps, and botanical pesticides for increased efficiency.

Types of Mulches Used in Pest Suppression

1. Organic Mulches

- Straw
- Grass clippings
- Compost
- Rice husk
- Groundnut shells

Organic mulch improves soil fertility and encourages beneficial organisms like spiders, predatory beetles, and nematodes that suppress pests naturally.

2. Plastic Mulches

- Silver-black mulch
- Black mulch
- Clear mulch
- Reflective mulch

Reflective mulches repel insects like aphids and whiteflies by disorienting their navigation system.

3. Bio-degradable Mulches

- Paper mulch
- Bio-plastic mulch
- Paddy straw mat

These breakdown naturally and reduce plastic waste concerns.

Key Features of Mulching for Pest Suppression

Mulching provides multiple benefits contributing to pest reduction:

1. Physical Barrier

Mulch forms a shield that prevents soil-dwelling pests such as nematodes, root maggots, and caterpillars from reaching plants.

2. Microclimate Modification

Mulch reduces soil temperature fluctuations, making the environment unsuitable for pest breeding.

3. Repelling Mechanism

Reflective mulches scatter sunlight and repel flying insects such as aphids, leafhoppers, thrips, whiteflies, and fruit flies.

4. Reduction of Weed Hosts

By suppressing weeds, mulch eliminates shelter and alternate food sources for pests.

5. Encouraging Natural Enemies

Mulching increases habitat diversity, supporting beneficial insects such as ladybird beetles, lacewings, parasitoid wasps, and spiders.

6. Moisture and Nutrient Management

Healthy and stress-free plants have higher resistance to pest attacks due to improved metabolism.

Outcomes and Benefits

1. Reduced Pest Infestation

Fields with mulching show significantly fewer pest populations compared to unmulched or chemically treated systems.

2. Lower Chemical Pesticide Dependence

Mulching reduces the frequency of pesticide application by 30–70%, improving environmental and economic sustainability.

3. Higher Yield and Quality

Crop yield increases by maintaining ideal growth conditions and minimizing pest stress.

4. Better Soil Health

Mulching improves soil structure, microbial activity, and nutrient cycling, making plants naturally more resilient.

5. Improved Water Use Efficiency

Water evaporation reduces by 50–70%, crucial for dry regions and climate-smart agriculture.

Future Strategy

Future developments in mulching will focus on:

- Developing biodegradable and low-cost mulching materials
- Integration with precision agriculture tools like sensors and AI-based monitoring
- Mulch recycling technologies to reduce waste
- Research on pest behavior and mulch color optimization
- Government subsidy programs for large-scale adoption

Innovations like nano-mulch films, solar-activated mulches, and microbial-enriched mulches show promising potential to boost mulching efficiency in pest suppression.

Conclusion

Mulching technology plays a vital role in modern pest management strategies by providing a multifunctional solution to improve crop health, reduce pest attack, conserve soil resources, and

lower chemical inputs. It supports ecological balance and enhances farm productivity, making it a suitable technology for small, medium, and large-scale farmers in sustainable farming systems. With increasing concerns about pesticide residues and climate change, mulching will continue to expand as a core component of Integrated Pest Management (IPM).

References

- Kader, M. A., "Mulching as a Sustainable Method of Controlling Soil Temperature and Insects", *Journal of Agricultural Technology*, 2021.
- Singh, R. & Thomas, T., *Integrated Pest Management Practices for Sustainable Agriculture*, ICAR Publication, New Delhi, 2022.
- FAO Report on Smart Agriculture and Mulching, Food and Agriculture Organization, 2023.
- Kumar, S., "Plastic and Organic Mulches: A Comparative Study", *Indian Journal of Agricultural Science*, 2022.
- Patel, M., *Advanced Mulching Techniques in Vegetable Farming*, National Horticulture Board, 2024.

MULTI-OMICS IN AGRICULTURE: THE NEXT FRONTIER FOR SMART CROP IMPROVEMENT

J. R. Patel* and P. J. Kandoriya

Department of Agricultural Microbiology, N. M. College of Agriculture,
NAU, Navsari, Gujarat, India

*Corresponding Email: jhanavipatel6629@gmail.com

Abstract

Agriculture is rapidly transitioning toward data-driven and molecular approaches to meet the growing global demand for food under changing climatic conditions. Multi-omics—integrating genomics, transcriptomics, proteomics, metabolomics, and metagenomics—has emerged as a powerful platform for comprehensive crop improvement. This article provides an in-depth overview of multi-omics applications in agriculture, emphasizing nano-induced gene expression, rhizosphere metagenomics, stress transcript profiling, and nutrient transporter gene regulation. Recent evidence indicates that multi-layer biological data can significantly enhance understanding of plant responses to abiotic stress, nutrient dynamics, and plant–microbe interactions. The article also discusses analytical tools, experimental workflows, data integration strategies, and challenges in field-level translation. Despite limitations such as high cost and computational complexity, multi-omics-guided agriculture is poised to revolutionize precision crop management and sustainable farming systems in the coming decade.

Introduction: Agriculture Enters the Omics Era

Global agriculture faces unprecedented pressure from climate change, soil degradation, nutrient inefficiency, and population growth. Conventional breeding and agronomic practices alone are no longer sufficient to achieve sustainable yield gains. In response, agricultural research is shifting toward systems biology approaches, where multi-omics technologies provide a comprehensive understanding of plant performance under real-world conditions.

Multi-omics enables researchers to move beyond single-gene or single-trait studies and instead analyze complex regulatory networks controlling growth, stress tolerance, and nutrient uptake. When integrated with nano-agriculture and digital farming tools, multi-omics forms the backbone of next-generation precision agriculture.

Concept and Framework of Multi-Omics

Multi-omics is the **simultaneous analysis and integration of multiple biological datasets** to understand organismal function at different molecular levels.

Core Omics Layers

Omics Layer	Molecule Studied	Key Purpose in Agriculture
Genomics	DNA	Identify genes and QTLs
Transcriptomics	RNA	Measure gene expression
Proteomics	Proteins	Understand functional pathways
Metabolomics	Metabolites	Reveal physiological status
Metagenomics	Microbial DNA	Analyze rhizosphere ecology

Systems Biology View

The power of multi-omics lies in linking:

Genotype → Gene expression → Protein function → Metabolic outcome → Phenotype

This integrated approach helps explain why plants with similar genes may perform differently under stress or nutrient limitation.

Detailed Emerging Research Directions**Nano-Induced Gene Expression**

Nanoparticles (NPs) such as Fe_3O_4 , ZnO , and TiO_2 are increasingly used as nano-fertilizers and nano-stimulants. Their small size (<100 nm) allows them to penetrate plant tissues and influence molecular pathways.

Mechanisms of Nano Action

Research suggests nanoparticles may:

- Enter roots via apoplastic and symplastic pathways
- Generate mild reactive oxygen species (ROS) signals
- Activate transcription factors
- Modify epigenetic regulation
- Enhance nutrient transporter expression

Molecular Evidence

Studies have reported:

- Up-regulation of ferritin (FER) genes with iron nanoparticles
- Increased expression of SOD, CAT, and POD antioxidant genes
- Modulation of IRT1 and FRO2 iron uptake genes
- Activation of stress signaling pathways (ABA-dependent)

Research Needs

- Long-term genomic stability
- Threshold toxicity levels
- Tissue-specific expression mapping
- Field validation studies

Rhizosphere Metagenomics

The rhizosphere contains one of the most complex microbial ecosystems on Earth. Metagenomics allows culture-independent profiling of this community.

Workflow of Rhizosphere Metagenomics

1. Soil/root sampling
2. DNA extraction
3. 16S rRNA / ITS sequencing
4. Shotgun metagenomics
5. Bioinformatics analysis
6. Functional annotation

Key Functional Groups Studied

- Plant growth-promoting rhizobacteria (PGPR)
- Nitrogen fixers

- Phosphate solubilizers
- Siderophore producers
- Mycorrhizal fungi

Nano–Microbiome Interaction

Recent findings indicate:

- Low NP doses may stimulate microbial diversity
- High NP concentrations can reduce fungal biomass
- Iron nanoparticles may enhance siderophore-producing bacteria
- Microbial functional genes shift under nano exposure

This area is highly relevant for soil health and sustainable nutrient management.

3. Stress Transcript Profiling

Transcriptomics (RNA-Seq) is widely used to identify differentially expressed genes (DEGs) under stress.

Typical RNA-Seq Pipeline

- RNA isolation
- Library preparation
- Sequencing (Illumina)
- Read mapping
- DEG analysis
- Pathway enrichment

Major Stress-Responsive Gene Categories

- Heat shock proteins (HSPs)
- Dehydration-responsive element binding (DREB)
- Late embryogenesis abundant (LEA)
- Aquaporins
- Antioxidant enzymes

Integration with Nano Treatments

Nano-priming studies show:

- Faster activation of defense genes
- Improved osmolyte biosynthesis
- Enhanced antioxidant transcript levels
- Better recovery after stress

This suggests nanoparticles may act as **molecular priming agents**.

4. Nutrient Transporter Gene Studies

Nutrient use efficiency (NUE) is a major sustainability goal. Multi-omics helps dissect transporter regulation at high resolution.

Major Transporter Families

Nutrient	Key Transporters	Function
Iron	IRT1, FRO2, FER	Fe uptake and storage
Zinc	ZIP family	Zn transport
Nitrogen	NRT1, NRT2	Nitrate transport
Phosphorus	PHT1 family	Phosphate uptake
Potassium	HAK/KUP/KT	K ⁺ transport

Nano Influence on Transporters

Evidence suggests nano-fertilizers may:

- Increase transporter gene expression
- Improve membrane permeability
- Enhance root surface area
- Reduce nutrient fixation losses

This has strong implications for biofortification and fertilizer efficiency.

Integrated Multi-Omics Workflow in Crop Research:

A typical advanced study follows:

1. Phenotyping (growth, yield, physiology)
2. Genomics/QTL mapping
3. Transcriptomics (RNA-Seq)
4. Proteomics validation
5. Metabolomics profiling
6. Rhizosphere metagenomics
7. Data integration using AI/bioinformatics

Opportunities for India

India has strong potential due to:

- National Nano Urea initiative
- Millet research focus
- Expanding genomics centers
- ICAR support for omics research
- Climate-resilient agriculture programs

High-priority crops: finger millet, rice, wheat, chickpea, groundnut.

Challenges and Limitations

Despite promise, key barriers remain:

- High cost of omics platforms
- Requirement of high-quality RNA/protein samples
- Massive data handling needs
- Lack of standardized nano safety protocols
- Limited long-term field validation
- Skill gap in bioinformatics

Bridging lab-to-land translation is the most critical need.

Future Outlook

The next decade will likely see convergence of:

- Multi-omics
- Artificial intelligence
- Nano-fertilizers
- Digital soil mapping
- Precision phenotyping

Future farms may use real-time molecular diagnostics to guide nutrient and stress management.

For young researchers, multi-omics agriculture offers very high novelty, funding potential, and publication impact.

Conclusion

Multi-omics technologies are fundamentally transforming agricultural research by enabling a comprehensive, systems-level understanding of plant biology, soil microbiomes, and nutrient dynamics. The integration of genomics, transcriptomics, proteomics, metabolomics, and metagenomics—particularly in conjunction with nano-enabled inputs—provides unprecedented opportunities to enhance crop productivity, stress resilience, and nutrient use efficiency. Emerging domains such as nano-induced gene regulation, rhizosphere metagenomics, stress transcript profiling, and nutrient transporter analysis are rapidly advancing precision crop improvement strategies. However, widespread adoption will require overcoming challenges related to cost, data integration, bioinformatics capacity, and field validation. With continued technological progress and interdisciplinary collaboration, multi-omics-guided agriculture is expected to become a central pillar of sustainable and climate-smart farming systems worldwide.

References

- Gupta, A.; Rico-Medina, A. and Caño-Delgado, A. I. (2020). The physiology of plant responses to drought. *Science*, 368(6488), 266–269.
- Kumar, V.; Guleria, P.; Kumar, V. and Yadav, S. K. (2021). Nanotechnology in agriculture: Current status and future prospects. *Journal of Plant Nutrition*, 44(2), 300–315.
- Ranjan, R.; Sinha, R. and Prasad, M. (2022). Advances in plant transcriptomics for abiotic stress tolerance. *Frontiers in Plant Science*, 13, 845678.
- Trivedi, P.; Leach, J. E.; Tringe, S. G.; Sa, T. M. and Singh, B. K. (2020). Plant–microbiome interactions: From community assembly to plant health. *Nature Reviews Microbiology*, 18(11), 607–621.
- Khan, I.; Saeed, K. and Khan, I. (2023). Impact of engineered nanoparticles on plant gene expression and physiology. *Environmental Nanotechnology, Monitoring & Management*, 20, 100780.
- Wang, P.; Lombi, E.; Zhao, F. J. and Kopittke, P. M. (2016). Nanotechnology: A new opportunity in plant sciences. *Trends in Plant Science*, 21(8), 699–712.
- Chen, H.; Teng, Y.; Lu, S.; Wang, Y. and Wang, J. (2018). Contamination features and health risk of soil heavy metals in China. *Science of the Total Environment*, 512–513, 143–153.
- Zhang, H.; Xie, X.; Kim, M. S.; Korniyev, D. A.; Holaday, S. and Paré, P. W. (2007). Soil bacteria augment Arabidopsis photosynthesis. *Plant Journal*, 50(3), 1–12.

NANO ENCAPSULATED BIO PESTICIDES

Ayushi Kumari and Radheshyam Ramkrishna Dhole*

Narayan Institute of Agricultural Sciences, Gopal Narayan Singh University,
Jamuahar, Sasaram, Rohtas – 821305

*Corresponding Email: nias.radheyshyam.dhole@gnsu.ac.in

Abstract

Sustainable agriculture demands eco-friendly, efficient, and residue-free pest management approaches. Traditional chemical pesticides, though effective, have caused long-term environmental and health challenges, including pesticide resistance, soil toxicity, and contamination of food chains. Nano-encapsulated bio-pesticides have emerged as an advanced smart pest control strategy, offering controlled release, enhanced stability, target specificity, and minimal ecological impact. This article discusses the concept, methodology, applications, key features, outcomes, and future strategies related to nano-encapsulated bio-pesticides. It highlights how nanotechnology strengthens biological pest control materials and supports precision agriculture. With growing global emphasis on climate-smart farming, nano-encapsulated bio-pesticides are expected to play a major role in sustainable pest management.

Introduction

Agriculture is continuously challenged by crop pests including insects, pathogens, nematodes, and weeds. For decades, farmers relied heavily on chemical pesticides for immediate control. However, overuse has resulted in pesticide-resistant pests, groundwater contamination, food residue concerns, and loss of beneficial organisms. The increasing demand for organic and residue-free farming has encouraged researchers to shift toward biological pest control methods.

Bio-pesticides—derived from microorganisms, plant extracts, and natural biomolecules—offer a safer alternative. Despite their potential, conventional bio-pesticides face limitations such as short shelf life, lower stability, rapid degradation under field conditions, and reduced effectiveness compared to synthetic chemicals.

Nanotechnology provides a breakthrough solution through nano-encapsulation, where active biological ingredients are enclosed in a nano-scale protective carrier. The carrier shields bio-pesticides from environmental degradation and enables slow and targeted release. This innovation significantly enhances the efficiency and commercial viability of natural pest control agents.

Thus, nano-encapsulated bio-pesticides are increasingly recognized as a smart, sustainable, and technologically advanced solution aligned with modern precision agriculture and climate-smart farming.

Methodology: Development and Working Mechanism

Nano-encapsulated bio-pesticides are produced through controlled scientific processes involving nanoparticles and biological active agents. The general methodology includes the following steps:

1. Selection of Bio-Pesticide Material

Bio-active compounds used may include:

- Microbial extracts (e.g., *Bacillus thuringiensis*, *Beauveria bassiana*)
- Plant extracts or essential oils (neem, eucalyptus, garlic)
- Biochemical compounds (pheromones, peptides, enzymes, microbial toxins)

2. Selection of Nano-Carrier Material

Nano-carriers may be:

- Polymeric nanoparticles: chitosan, cellulose, gelatin
- Lipid nanoparticles: liposomes, solid lipid carriers
- Inorganic nanoparticles: silica, clay, carbon-based materials

Nano-carriers must be biodegradable, non-toxic, and compatible with the bio-ingredient.

3. Encapsulation Process

Common encapsulation techniques include:

- Nano-emulsification
- Spray drying
- Coacervation
- Self-assembly nano-formation
- Sol-gel techniques

These processes ensure uniform size ranging from 20–500 nanometers, which enhances mobility and interaction with pests.

4. Controlled Release Mechanism

Once applied to the field, the nano-capsules release bio-pesticides through:

- Moisture-triggered release
- pH-responsive release
- Enzyme-activated release
- Temperature-dependent release

This controlled release improves effectiveness, reduces wastage, and minimizes repeated applications.

Uses and Applications

Nano-encapsulated bio-pesticides can be used in diverse agricultural environments. Common uses include:

- Insect pest management (e.g., stem borers, aphids, whiteflies)
- Plant disease suppression (fungal, bacterial, and viral pathogens)
- Nematode control
- Stored grain protection
- Weed and invasive species management
- Seed treatment and root-zone pest protection

They are applicable through:

- Foliar spray
- Soil drenching
- Seed coating
- Trunk injection in orchards
- Post-harvest grain treatment

- Nano-encapsulated biological repellents are also used in pheromone-based mating disruption and mosquito control programs.

Key Features of Nano-Encapsulated Bio-Pesticides

Nano-encapsulated bio-pesticides have several distinguishing characteristics that make them superior to conventional biological and chemical pesticide formulations:

1. Higher Stability

Nano encapsulation protects bio-compounds from:

- Sunlight degradation
- Oxidation
- Volatilization
- Temperature damage

This improves formulation lifespan and field performance.

2. Controlled and Slow Release

The gradual release of the active ingredient ensures long-term pest protection and minimizes repeated spraying.

3. Target Specificity

Nano-particles can be designed to interact only with specific pests or pathogens, reducing harm to beneficial organisms like pollinators and earthworms.

4. Reduced Dosage and Wastage

A lower amount of active ingredient delivers higher effectiveness due to high penetration efficiency and stability.

5. Eco-Friendly and Safe

Since the components are biodegradable and naturally sourced, nano-bio-pesticides reduce environmental pollution and toxic residues.

6. Compatibility with Smart Agriculture Systems

These formulations can integrate with:

- Drone-based spraying
- IoT-assisted pest monitoring
- Precision farming tools

This positions nano-bio-pesticides as a key component of future farming systems.

Outcome and Benefits

Field trials and laboratory studies indicate significant benefits of nano-encapsulated bio-pesticides:

- 30–70% reduction in chemical pesticide usage
- Improved pest mortality rates
- Extended residual activity (up to 4–10 times longer than conventional bio-pesticides)
- Reduced pest resistance development
- Better crop health and yield
- Enhanced economic returns for farmers
- Safer production for organic and export-oriented farming

They also contribute to biodiversity protection by safeguarding natural enemies such as ladybirds, parasitic wasps, spiders, and microbial decomposers.

Conclusion

Nano-encapsulated bio-pesticides represent a revolutionary step in pest management. Their ability to enhance the efficiency, longevity, and reliability of biological compounds makes them a promising replacement for hazardous chemical pesticides. By minimizing environmental pollution, reducing residue levels, and supporting eco-friendly farming, they align with the goals of sustainable agriculture and global food security. Adoption in large-scale farming systems can significantly reduce dependence on toxic chemicals and improve soil and ecosystem health.

Future Strategy and Research Needs

Although promising, nano-encapsulated bio-pesticides are still developing. Future strategies include:

- Establishing regulatory frameworks and safety guidelines
- Optimizing cost-effective production techniques
- Developing farmer awareness and training programs
- Expanding research on nano-bio-pesticide interactions with soil and ecosystems
- Commercialization partnerships between industries and agricultural institutions
- Integration with AI-based monitoring and drone-based precision spray technology

Further innovation may lead to smart nano-capsules capable of sensing pest presence and releasing bio-agents only when needed—transforming pest control into a fully automated and intelligent system.

References

- FAO (2024). Nanotechnology and biological pest control strategies in modern farming systems.
- Khalid, S., Ali, S., & Babar, M. (2020). Role of nanotechnology in sustainable agriculture and pest management. *International Journal of Biological Sciences*.
- Khot, L. R., Sankaran, S., Maja, J. M., et al. (2012). Applications of nanomaterials in agricultural production and crop protection: A review. *Crop Protection*.
- Kumar, S., Mohan, R., & Awasthi, A. (2021). Nano-encapsulation of bio-pesticides for improved pest management: Trends and future scope. *Journal of Nanotechnology in Agriculture*.
- Singh, P., & Prasad, R. (2023). Smart nano-pesticides: A future approach for eco-friendly pest control. *Agricultural Nanoscience Review*.

NUTRITIONAL EVALUATION OF *SILLAGO SIHAMA*: A COMPARATIVE STUDY WITH OTHER MARINE FISHES

G. Dhivagar, L. Vinoth Kumar*, E. K. Devipriya, M. Dhanu Pradeep, R. Gayathri and S. T. Dhivya Bharathi

Department of Fish Processing Technology, TNJFU- Dr.MGR. Fisheries College and Research Institute, Ponneri, Thiruvallur District, Tamil Nadu 601204

*Corresponding Email: vinothkumar@tnfu.ac.in

Abstract

Sillago sihama (silver whiting) is a commonly consumed marine fish along the Indian coast, valued for its taste, affordability, and availability. Despite its regular presence in local markets, its nutritional importance has received less attention when compared with commercially popular oily fishes such as sardine, mackerel, and hilsa. This article presents a concise evaluation of the nutritional composition of *S. sihama* based on Indian studies and compares its proximate and fatty acid profile with selected marine fishes. Silver whiting is characterized by high moisture and protein content (approximately 18–20%), low lipid levels (2–4%), and moderate mineral concentration. Although its omega-3 fatty acid content is lower than that of oily fishes, its lean nature and high-quality protein make it suitable for regular consumption. Highlighting the nutritional value of *S. sihama* can support dietary diversity and encourage the sustainable utilization of underexploited marine resources.

Keywords: *Sillago sihama*, Silver whiting, Proximate composition, Lean marine fish, Nutritional evaluation, Omega-3 fatty acids, Indian marine fishes, Dietary significance.

Introduction

Marine fishes are an important source of high-quality protein, essential fatty acids, vitamins, and minerals in particularly in coastal regions. Nutritional research has largely focused on oily fishes such as Indian oil sardine (*Sardinella longiceps*), Indian mackerel (*Rastrelliger kanagurta*), and hilsa (*Tenualosa ilisha*), due to their high lipid and omega-3 fatty acid content. However, lean marine fishes, which also contribute significantly to human nutrition, have received comparatively less attention.

Sillago sihama (silver whiting) is a widely distributed and commonly consumed lean marine fish. preferred for its mild flavour, soft texture, and ease of preparation. Despite its market importance and consumer acceptance, information on its nutritional composition remains limited. nutritional profile of *S. sihama* compares it with selected commercially important marine fishes, highlighting its role as a protein-rich, low-fat dietary resource.

Proximate composition of *Sillago sihama*

proximate composition of *Sillago sihama* exhibits biochemical characteristics typical of lean marine fishes. Analysis of muscle tissue shows a high moisture content, generally exceeding 70% on a wet weight basis, approximately 55% to 78%. Such variations are largely influenced by seasonal changes, reproductive stage, and physiological condition of the fish. Water is the major constituent of fish muscle and plays a critical role in determining texture, freshness, and caloric

value. Consequently, the elevated moisture content of *S. sihama* contributes to its soft flesh and comparatively low energy density.

Protein is the dominant nutritional component of silver whiting, contributing roughly 17–23% of the edible flesh and underscoring its importance as a rich and reliable source of dietary protein. Fish proteins are recognized for their high biological value, as they contain all essential amino acids and exhibit good digestibility. The substantial protein content of *S. sihama* therefore emphasizes its importance as a reliable dietary protein source supporting growth, tissue repair, and metabolic functions.

The lipid content of *S. sihama* is relatively low, typically ranging between 2% and 4%, confirming its classification as a lean fish. Lipids are the most variable component of fish muscle and are strongly influenced by factors such as feeding intensity, spawning activity, and season. Lean fishes generally store limited fat within muscle tissue, a characteristic clearly evident in silver whiting. This low lipid level enhances its suitability for low-fat and health conscious diets.

Ash content in *S. sihama* muscle usually ranges from about 1% to 1.5%, indicating the presence of essential minerals such as calcium, phosphorus, potassium, and iron. Although present in smaller quantities, these minerals are vital for skeletal development, enzymatic reactions, and physiological regulation.

Omega-3 Fatty Acids

Although *S. sihama* is a lean fish, it contains measurable amounts of omega-3 polyunsaturated fatty acids, particularly EPA and DHA. approximately 90–100 mg per 100 g of edible muscle. These levels are considerably lower than those observed in oily fishes such as sardine and hilsa. Therefore, while silver whiting contributes to omega-3 intake, it should not be considered a primary source of these fatty acids.

Comparative Nutritional Evaluation

The nutritional composition of *Sillago sihama* differs distinctly from that of commercially important marine fishes such as hilsa (*Tenualosa ilisha*), Indian mackerel (*Rastrelliger kanagurta*), and Indian oil sardine (*Sardinella longiceps*). While all these species provide good-quality of protein, they vary considerably in lipid content and energy value.

Silver whiting contains protein levels (approximately 17–20%) comparable to those of sardine, mackerel, and hilsa, indicating that it is an efficient source of dietary protein. However, *S. sihama* has a much lower lipid content (about 2–4%), classifying it as a lean fish. In contrast, hilsa and Indian oil sardine are high-fat fishes, with lipid levels often exceeding 10–18%, which contribute to their high energy density and rich omega-3 fatty acid content. Indian mackerel occupies an intermediate position, with moderate fat levels and balanced nutritional composition.

Due to its low fat content, silver whiting provides fewer calories and is easier to digest, making it suitable for regular consumption and low-fat diets. Oily fishes such as hilsa and sardine are nutritionally valuable for their omega-3 fatty acids, which are associated with cardiovascular and neurological health benefits. Mackerel offers a balance between protein and fat and serves as a moderate-energy food.

Overall, this comparison demonstrates that no single fish species fulfills all nutritional requirements. Lean fishes like *S. sihama* provide high-quality protein with low energy, whereas

oily fishes provide essential fatty acids and higher caloric value. Therefore, a balanced diet incorporating both lean and oily marine fishes is essential for optimal nutrition and health.

Conclusion

Sillago sihama (silver whiting) is a nutritionally valuable lean fish : it supplies high-quality, easily digestible protein, moderate minerals, and low fat. Compared with oily species (hilsa, sardine, mackerel), it has much lower lipids and omega-3 but offers a low-calorie, heart-friendly alternative for regular consumption. Including both lean and oily fishes in the diet provides complementary benefits—protein from *S. sihama* and essential fatty acids from oily species-while promoting dietary diversity and sustainable use of marine resources.

References

- Ahmed, I., Jan, K., Fatma, S., & Dawood, M. A. O. (2022). Muscle proximate composition of various food fish species and their nutritional significance: A review. *Journal of Animal Physiology and Animal Nutrition*
- Gopakumar, K. (1997). *Biochemical composition of fish and shellfish*.
- Mohanty, B. P., et al. (2015). Nutritional composition of important food fishes in India. *Indian Journal of Fisheries*,
- Nair, P. G. V. Biochemical composition of fish.
- Palani, K., et al. (2014). Proximate composition of marine fishes along the Indian coast. *Indian Journal of Geo-Marine Sciences*,

Article ID : 06/III/97/0326

AN OVERVIEW OF MICROPLASTICS IN FOOD: ENVIRONMENTAL PATHWAYS, DETECTION, AND HEALTH IMPACTS

Ayna Inayat

Department of Food Technology, Islamic University of Science and Technology (IUST),
Awantipora, Jammu and Kashmir, India.

*Corresponding Email: ayna3442@gmail.com

Microplastics are plastic particles smaller than 5 mm formed either intentionally (primary microplastics) or through degradation of larger plastic materials (secondary microplastics). Due to the persistent and non-biodegradable nature of plastics, these particles accumulate extensively in the environment, including water, soil, and air, and have become unavoidable contaminants in the human food chain. Even smaller particles known as nanoplastics (<1 µm) pose additional concern due to their ability to penetrate biological tissues more easily. Microplastics have now been detected in a wide range of foods, including seafood, drinking water, salt, fruits, vegetables, honey, sugar, and processed foods, raising significant food safety and public health concerns.

Sources and Types of Microplastics

Microplastics originate from two main sources. **Primary microplastics** are manufactured at microscopic sizes and include cosmetic microbeads, industrial plastic pellets, and synthetic textile fibers released during washing. **Secondary microplastics** result from the breakdown of larger plastic items such as bottles, bags, fishing nets, and food packaging due to sunlight (photodegradation), mechanical forces, and chemical reactions. Continuous fragmentation leads to the formation of nanoplastics, which are more mobile and biologically active.

Globally, plastic production has increased dramatically, with a substantial proportion used in food packaging. Exposure to heat, friction, pressure, and long storage durations causes plastics to shed microplastic particles and leach chemical additives such as bisphenol A (BPA) and phthalates into food.



Figure: Microplastics in different foods.

Pathways of Microplastics into Food

Microplastics enter food through environmental contamination, food processing, and packaging interactions.

Environmental Contamination

Oceans and freshwater bodies are heavily polluted with plastic waste. Marine organisms such as fish, shellfish, and crustaceans ingest microplastics directly from water or sediments. Filter-feeding shellfish accumulate particularly high levels, and since they are consumed whole, they represent a major dietary exposure route. Edible seaweeds can also trap microplastic particles.

Soil contamination arises from plastic mulch degradation, landfill waste, and sewage sludge used as fertilizer. Nanoplastics can be absorbed through plant roots and transported to edible plant tissues, while larger microplastics adhere to the surface of fruits and vegetables. Airborne microplastics settle on food during cultivation, harvesting, processing, and storage, especially in indoor environments with high plastic usage.

Food Processing Contamination

During food manufacturing, friction and wear of plastic machinery components (conveyors, pipes, containers) release microplastics into products. Foods such as sugar, flour, bread, dairy products, and honey are particularly susceptible due to extensive handling and mechanical processing.

Food Packaging Contamination

Plastic bottles, containers, wrappers, and pouches shed microplastics during storage and transport. Bottled water is among the most contaminated products due to bottle degradation and cap abrasion. Heating food in plastic containers accelerates the release of microplastics, nanoplastics, and chemical additives. Oily and acidic foods enhance migration of plastic-associated chemicals.

Foods Most Affected by Microplastic Contamination

Seafood shows the highest contamination levels due to polluted aquatic environments. Microplastics are found in fish digestive tracts, gills, and occasionally muscle tissue, while shellfish accumulate them extensively.

Drinking water, both bottled and tap, contains microplastics from plastic bottles, caps, pipes, and incomplete filtration processes.

Table salt, especially sea salt, contains microplastics trapped during crystallization from contaminated water.

Fruits and vegetables accumulate microplastics through soil, irrigation water, and atmospheric deposition. Nanoplastics can enter plant tissues and are difficult to remove by washing.

Honey, sugar, and natural sweeteners mainly acquire contamination from airborne fibers and processing equipment.

Processed and packaged foods, including snacks, bakery items, instant noodles, and beverages, are exposed during processing and packaging. Plastic-based tea bags release large numbers of microplastics when steeped in boiling water.

Formation and Transfer Mechanism

Microplastic formation involves environmental degradation of plastics through UV radiation, mechanical abrasion, and chemical oxidation. Primary microplastics are released directly from consumer and industrial products. Once present in the environment, microplastics are transported via water, air, and soil and enter food through ingestion by organisms, absorption by plants, or direct contamination during processing and packaging.

The scientific principles governing microplastic behaviour include bioaccumulation and biomagnification, environmental transport, and chemical leaching of additives and adsorbed pollutants.

Health Effects of Microplastics

Microplastics pose potential physical, chemical, microbiological, and long-term health risks, although definitive human epidemiological data are still limited.

Physical Effects

Ingested microplastics can cause irritation and inflammation in the gastrointestinal tract. Nanoplastics may cross intestinal barriers, enter circulation, and accumulate in organs such as the liver, kidneys, and spleen. Cellular studies indicate oxidative stress and tissue damage.

Chemical Effects

Microplastics release toxic additives like BPA and phthalates, known endocrine disruptors. They also act as carriers for environmental pollutants, including heavy metals and persistent organic pollutants, increasing toxic exposure in the body.

Microbiological Effects

Microplastics provide surfaces for microbial attachment and may introduce pathogens into the digestive system. They may also disrupt gut microbiota balance, affecting digestion, immunity, and metabolism.

Long-Term and Vulnerable Populations

Chronic exposure may contribute to hormonal disruption, immune dysfunction, organ toxicity, and developmental effects. Children, pregnant women, frequent seafood consumers, and immunocompromised individuals are particularly vulnerable.

Detection and Analysis Techniques

Microplastic detection in food involves complex laboratory procedures. Sampling methods include filtration, density separation, and chemical digestion to isolate particles. Analytical techniques such as FTIR spectroscopy, Raman spectroscopy, optical and electron microscopy, and thermal analysis (DSC/TGA) are used to identify polymer type, size, shape, and concentration. However, lack of standardized methods remains a major challenge.

Mitigation and Prevention Strategies

Exposure to microplastics can be reduced through coordinated efforts:

- **Consumers** should avoid heating food in plastic, limit bottled water, prefer glass or steel containers, choose loose or minimally packaged foods, and avoid plastic-based tea bags.
- **Food industries** should replace easily worn plastic components, improve maintenance, control airborne contamination, and adopt safer packaging materials.
- **Governments and regulators** should strengthen plastic waste management, restrict single-use plastics, promote biodegradable alternatives, and support standardized analytical methods and monitoring programs.

Conclusion

Microplastics in food represent a pervasive and emerging food safety issue with complex environmental, technological, and health dimensions. While their presence in a wide range of foods is well documented, uncertainties remain regarding long-term human health effects.

Applying precautionary principles through improved industry practices, regulatory frameworks, consumer awareness, and continued scientific research is essential. Addressing microplastic contamination offers significant opportunities for food technologists to innovate safer materials, improve detection techniques, and contribute to sustainable food systems and public health protection.

IMPORTANCE OF PHOSPHATE-SOLUBILIZING BACTERIA IN SUSTAINABLE FRUIT CULTIVATION

**Shahil Reza^{1*}, Prerna Baraily², Rakesh Yonzon³, Barnita Adhikary⁴,
Dipankar Barai⁴, Sudipto Mahata⁴ and Hasina Begam¹**

¹ Ph.D. Research Scholar, Department of Pomology and Post Harvest Technology, Uttar Banga Krishi Viswavidyalaya, West Bengal, 736165

² Assistant Professor, Department of Pomology and Post Harvest Technology, College of Agriculture, (Extended Campus), Uttar Banga Krishi Vishwavidyalaya, Majhian, Dakshin Dinajpur, West Bengal, 733133

³ Assistant Professor, Department of Plant Pathology, College of Agriculture, (Extended Campus), Uttar Banga Krishi Vishwavidyalaya, Majhian, Dakshin Dinajpur, West Bengal, 733133

⁴ Ph.D. Research Scholar, Department of Plant Pathology, Uttar Banga Krishi Vishwavidyalaya, West-Bengal, 736165

*Corresponding Email: shahilrezahorti@gmail.com

Abstract

Phosphorus (P) is an essential macronutrient required for optimal plant growth and productivity; however, its availability in soil is often limited due to fixation and low use efficiency of chemical fertilizers. Continuous and imbalanced application of synthetic fertilizers has resulted in soil nutrient depletion, rising input costs, and environmental degradation. Phosphate solubilizing bacteria (PSB), a key group of plant growth promoting rhizobacteria, play a vital role in enhancing phosphorus availability through organic acid production, enzymatic mineralization of organic P, and chelation of metal-bound phosphates. In addition to P solubilization, PSB promote plant growth through multiple mechanisms, including phytohormone production, nitrogen fixation, siderophore synthesis, biocontrol activity, stress alleviation, and bioremediation. Thus, the integration of PSB or PSB-based bioinoculants in fruit cultivation offers a sustainable, eco-friendly, and cost-effective approach for improving soil health, nutrient use efficiency, and crop productivity.

Keywords: PSB, P solubilization, Fruit, Plant Growth Promotion, Bacillus

Introduction

One of the most crucial macronutrients for plant growth and development is phosphorus (Vinuthana *et al.*, 2024). If phosphorus is not present in the soil or in sufficient amounts in fertilizers, it might hinder regular plant growth. Thus, crop output can be significantly reduced (up to 15%) by P shortage. P application is still one of the primary agricultural techniques used to meet plant needs. By increasing soil P availability and improving soil mineral fertility, the use of water-soluble P fertilizers increases plant uptake of P, which raises plant productivity and yield (Meyer *et al.*, 2018). Plant growth promoting rhizobacteria (PGPR) are diverse bacteria with higher P solubilizing abilities, promoting plant growth and yield. They include *Alcaligenes*, *Pseudomonas*, *Azospirillum*, *Bacillus*, *Klebsiella*, *Rhodococcus*, *Phyllo bacterium*, *Azotobacter*, *Xanthomonas*, *Enterobacter*, *Burkholderia*, *Arthrobacter* and *Serratia*, which aid in plant growth through various

mechanisms (Yasmeen, 2019). *Pseudomonas*, *Bacillus* and *Rhizobium* are dominant phosphate solubilizers, acting as biofertilizers and promoting plant nutrient recycling, Phyto stimulation and phytoremediation (Zhang *et al.*, 2018). Imbalanced and continuous use of chemical fertilizers leads to nutrient depletion, soil imbalance, rising input costs, and environmental problems such as nitrate leaching and low fertilizer use efficiency. These challenges have encouraged the search for sustainable nutrient management alternatives (Khandare *et al.*, 2020). Biofertilizers, particularly phosphate-solubilizing bacteria (PSB), are cost-effective and eco-friendly inputs that enhance nitrogen and phosphorus availability while reducing reliance on synthetic fertilizers. Studies show that PSB, alone or combined with organic fertilizers, can significantly improve crop productivity (Shukla *et al.*, 2013; Kumar *et al.*, 2014).

Mechanism of P solubilization through Phosphate Solubilizing Bacteria:

Phosphate-solubilizing microorganisms (PSMs) mobilize fixed and unavailable soil phosphorus through multiple biochemical mechanisms. The primary mechanism involves the secretion of low-molecular-weight organic acids (such as gluconic, oxalic, tartaric, and lactic acids), which lower soil pH, chelate metal cations (Ca^{2+} , Fe^{3+} , Al^{3+}), and compete with phosphate for adsorption sites. Acidification favors the transformation of poorly soluble di- and trivalent phosphate forms into the more soluble monovalent phosphate (H_2PO_4^-), thereby increasing P availability to plants (Othman and Panhwar, 2014). In addition to acidification, PSB enhance phosphorus availability through enzymatic mineralization of organic P. They secrete phosphatases, phytases, and C-P lyases that hydrolyze organic phosphorus compounds, including phytate, releasing inorganic phosphate that plants can readily absorb. Since plants cannot directly utilize phytate-bound P, microbial degradation of these compounds plays a crucial role in P nutrition (Seshachala and Tallapragada, 2012). The efficiency of microbial phosphate solubilization is influenced by soil pH, organic matter content, physicochemical soil properties, vegetation type, environmental conditions, agronomic practices, and interactions between phosphate-solubilizing microorganisms and the native soil microbial community (Richardson and Simpson, 2011).

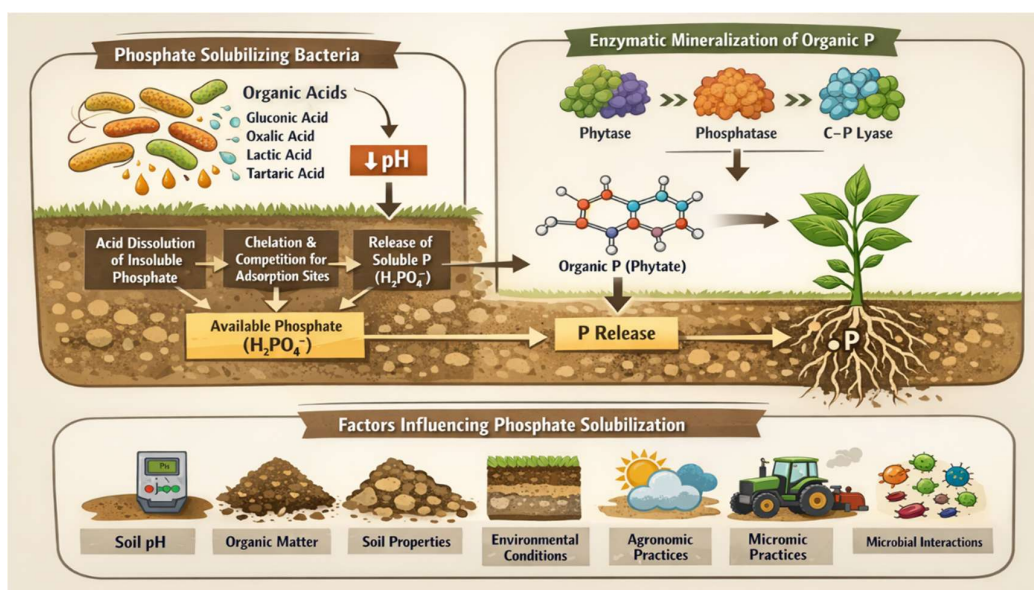
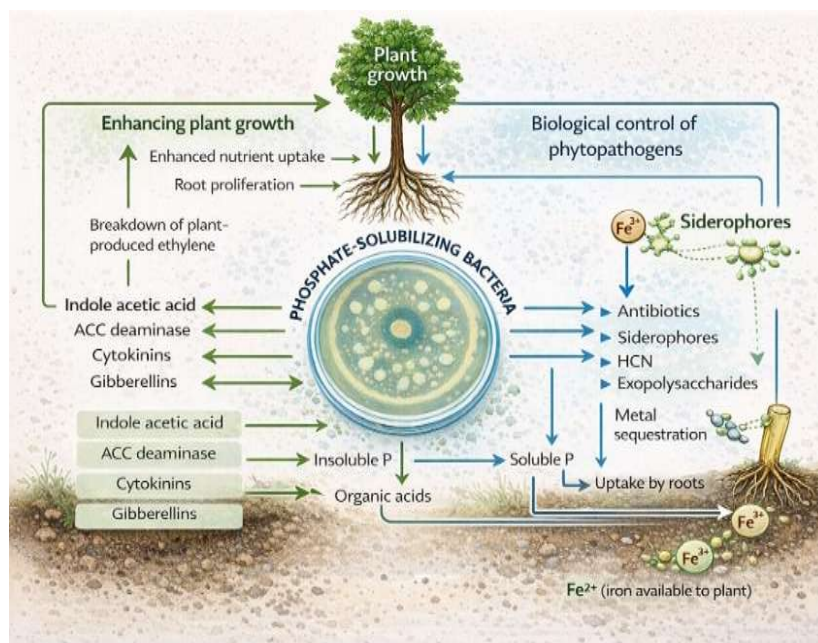


FIG -1: Mechanism of P solubilization through Phosphate Solubilizing Bacteria

Mechanism of Plant Growth Promotion by Phosphate Solubilizing Bacteria:

PSB are well known for making soluble P accessible for uptake by plants. They can also facilitate growth and development of plants by producing essential nutrients or by changing the concentration of plant growth promoting substances including phytohormones such as indoleacetic acid, through asymbiotic or symbiotic N_2 fixation, soil conditioning, exhibiting bio-control activity, by synthesizing siderophores, antibiotics and cyanide, by synthesizing an ACC deaminase that can modulate plant ethylene levels and by solubilizing or reducing the toxicity of metals (bioremediation). These mechanisms can probably be active simultaneously or sequentially at different stages of plant growth. However, the intrinsic ability of PSB for synthesizing the growth-promoting substances varies considerably under different ecological niches (Zaidi *et al.*, 2009).

**FIG -2: Mechanism of Plant Growth Promotion by Phosphate Solubilizing Bacteria****Role of PSB in Sustainable Fruit Cultivation:**

Phosphate-solubilizing bacteria enhance phosphorus availability and nutrient use efficiency in fruit crops while promoting growth through organic acid and phytohormone production. Their use reduces reliance on chemical fertilizers, lowers costs and minimizes environmental pollution. Overall, PSB support sustainable fruit cultivation by improving yield, soil fertility, and long-term agroecosystem. Table 1 and Table 2 shows the findings that PSB either by themselves or conjunction with other fertilizer boosts plant growth and promotion.

Table-1

Bacteria	Crops	Findings
<i>Bacillus megaterium</i> , <i>Pseudomonas fluorescens</i>	Banana	Increase bunch weight and length (Billah <i>et al.</i> , 2019)
<i>Bacillus circulans</i>	Apple	Field Reduced P-fertilizer uses (Mehta <i>et al.</i> , 2010)

Bacteria	Crops	Findings
<i>Burkholderia</i> sp	Peach	Reducing chemical fertilizer dependency in orchard ecosystems through microbiome-driven strategies (Li <i>et al.</i> , 2025)
<i>Bacillus</i> sp	Strawberry	Increase yield in P-deficient calcareous soils of Turkey (Gunes <i>et al.</i> , 2009)

Table-2:

Crop	Dose	Results
Mango cv. Himsagar	75% RDF + Azospirillum and Azotobacter @250g +PSB @ 250g+ K-mobilizers@250g	High leaf supplement status (Kundu and Mishra, 2018)
Mango plants cv. Dashehari	Azotobacter 50g per plant + PSB 50g per plant	High-rate expansion in plant height, number of shoots per plant and the number of nodes per shoot (Poonia <i>et al.</i> , 2018)
Strawberry cv. Chandler	vermicompost(250g/plant) and PSB(2g/plant)	More increased plant height, leaves per plant, primary branches per plant, auxiliary branches per plant (Kumar <i>et al.</i> , 2015)
Sweet Orange	80ml Azotobacter + 80ml PSB + RDF 800:400:400g NPK + 50kg FYM	The maximum expansion in tree height (Jugnake, 2017)
Guava	Azotobacter + PSB + FYM + RDF 100%	Maximum plant height (Sharma <i>et al.</i> , 2018)
Plum	12.5% nitrogen acquired by FYM + 12.5% nitrogen from Vermicompost + 75% of N + PSB + Azotobacter	The best yield (Kamatyanatti <i>et al.</i> , 2019)

Kumar *et al.*, 2024**Conclusion**

Phosphate-solubilizing bacteria (PSB) offer an effective biological approach to alleviate phosphorus deficiency in soils while reducing dependence on chemical fertilizers. By improving phosphorus availability and supporting plant growth and stress tolerance, PSB enhance crop performance and soil fertility. Studies in fruit crops demonstrate that PSB, applied alone or with organic and inorganic inputs, significantly improve growth and yield. Their use is especially important given increasing fertilizer costs, soil degradation, and environmental challenges, making PSB-based biofertilizers a key component of sustainable and resilient fruit production systems.

References

Billah M, Khan M, Bano A, Hassan T U, Munir A and Gurmani A R (2019) Phosphorus and phosphate solubilizing bacteria: Keys for sustainable agriculture. *Geomicrobiology Journal* 36:10: 904-916, DOI: 10.1080/01490451.2019.1654043

- Güneş, A, Ataoğlu N, Turan M, Eşitken, A and Ketterings Q M (2009) Effects of phosphate-solubilizing microorganisms on strawberry yield and nutrient concentrations. *Journal of Plant nutrition and soil science* 172(3): 385-392.
- Khandare R N, Chandra R, Pareek N and Raverkar K P (2020) Carrier-based and liquid bioinoculants of Azotobacter and PSB saved chemical fertilizers in wheat (*Triticum aestivum* L.) and enhanced soil biological properties in Mollisols. *Journal of Plant Nutrition* 43(1) :36-50.
- Kumar K P, L., Ravi K. UK S, Saran M R and Lakshmi A C (2024) Enhancing Fruit Crop Performance: The Role of Phosphate-Solubilizing Bacteria in Growth, Yield and Quality Improvement. *International Journal of Plant & Soil Science* 36(7): 670-684.
- Kumar P, Kumar R, Mohan B, Yadav S K, Singh S and Singh B (2017) Effect of foliar and soil application of micro nutrients and use of PSB on productivity and water use efficiency of chickpea under rainfed condition. *International Journal of Current Microbiology and Applied Sciences* 6(8): 3074-3080.
- Kumar S K, Bauddh S C Barman and R and Singh R P (2014) Amendments of microbial bio-fertilizers and organic substances reduce requirement of urea and DAP with enhanced nutrient availability and productivity of wheat (*Triticum aestivum* L.). *Ecological Engineering* 71:432-7.
- Li, Z, Li J, Liu G, Li Y, Wu X, Liang J and Peng, F (2025). Isolation, Characterization and Growth-Promoting Properties of Phosphate-Solubilizing Bacteria (PSBs) Derived from Peach Tree Rhizosphere. *Microorganisms* 13(4): 718.
- Mehta P, Chauhan A, Mahajan R, Mahajan P K and Shirkot C K (2010) Strain of Bacillus circulans isolated from apple rhizosphere showing plant growth promoting potential. *Curr Sci* 98:538–542.
- Meyer G, Frossard E, Mäder P, Nanzer S, Randall D G and Udert K M (2018) Water soluble phosphate fertilizers for crops grown in calcareous soils – an outdated paradigm for recycled phosphorus fertilizers. *Plant Soil* 424:367–88.
- Othman R and Panhwar Q A (2014) Phosphate-solubilizing bacteria improves nutrient uptake in aerobic rice. In: Phosphate Solubilizing Microorganisms. Cham, Switzerland: *Springer* pp:207–224.
- Richardson A E and Simpson R J (2011) Soil microorganisms mediating phosphorus availability update on microbial phosphorus. *Plant Physiol* 156:989–996.
- Seshachala U and Tallapragada P (2012) Phosphate solubilizers from the rhizosphere of piper nigrum l. in Karnataka. *India. Chilean J Agric Res* 72:397.
- Shukla L, Tyagi S P, Manjunath R and Saxena A (2013) Effect of vermicompost and microbial inoculants on soil health, growth, and yield of HD 2687 wheat (*Triticum aestivum*). *Indian Journal of Agricultural Sciences* 83 (3):340–3.
- Vinuthana V H, Yallappa M and Savita A S (2024) Exploring the Hidden Treasures: Isolation, Characterization and Screening of Phosphate Solubilizing Bacteria (PSB) for Plant Growth-Promoting Traits from Chilli Field Weeds Rhizosphere. *Microbiology Research Journal International* 34(7): 32-44.
- Yasmeen T (2019) Ameliorative capability of plant growth promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF) against salt stress in plant. In: Plant abiotic stress tolerance. *Springer: Cham, Germany* pp: 409–448
- Zaidi A., Khan M. S, Ahemad M, Oves, M and Wani P. A. (2009) Recent advances in plant growth promotion by phosphate-solubilizing microbes. *Microbial strategies for crop improvement* pp:23-50.
- Zhang S, Fan C, Wang Y, Xia Y, Xiao W and Cui X (2018) Salt-tolerant and plantgrowth- promoting bacteria isolated from high-yield paddy soil. *Can J Microbiol* 64:968–978

PROPAGATION STRUCTURES FOR EFFICIENT PLANT MULTIPLICATION

Koyya Unnathi Madhuri^{1*} and Boddu Aruna²

¹PhD scholar, Department of Fruit Science, Dr. YSR Horticultural University, Anantharaju peta, Andhra Pradesh

²PhD scholar, Department of Plant Breeding and Genetics, Kerala Agricultural University, Vellanikkara, Kerala

*Corresponding Email: unnathimadhurik@gmail.com

Abstract

Propagation structures such as mist chambers, greenhouses, plastic tunnels, cold frames, hot beds, bottom heat boxes, net houses, and phytotrons provide controlled environmental conditions essential for successful plant propagation. They regulate temperature, humidity, light, and moisture, enhancing rooting, germination, and seedling growth, thereby improving propagation efficiency, survival rate, and nursery plant production quality.

Keywords: Propagation, Multiplication, Plants, Nursery, Chambers

Propagation Structures

Propagation structures are specialized facilities designed to create controlled environmental conditions for the successful multiplication of plants. These structures help regulate temperature, humidity, light, and moisture to enhance seed germination, rooting of cuttings, grafting success, and early seedling growth. Common propagation structures include greenhouses, shade houses, mist chambers, polyhouses, and growth chambers. By providing protection from adverse weather, pests, and diseases, these structures improve propagation efficiency, ensure uniform plant growth, and support large-scale production of quality planting material in horticultural crops.

Mist Chamber

Mist propagation is a widely adopted technique for rooting softwood leafy cuttings under spray or mist conditions (Whitecomb, 1985). The primary objective is to maintain a continuous thin film of water on the leaves, reducing transpiration and keeping cuttings turgid until roots develop. High humidity allows full exposure to light without damage, while only minimal water should be applied to prevent nutrient leaching. Fine mist nozzles are essential for efficient operation. Small units are commonly used by farmers, whereas advanced intermittent systems are employed in commercial nurseries, particularly for propagating difficult-to-root cuttings.



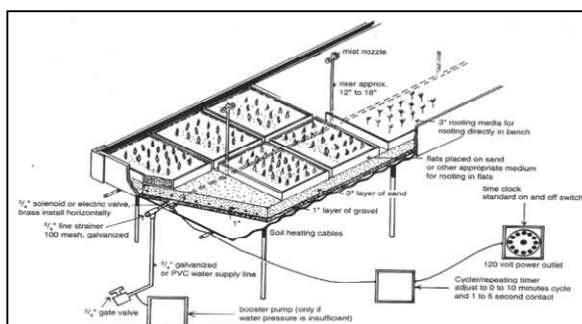
Construction of Mist Propagation Unit

Mist beds are generally constructed within a greenhouse, glasshouse, or polyethene tunnel, where a fine mist is sprayed intermittently over the cuttings at regular intervals during both day and night. The system is controlled by a time clock operating a magnetic solenoid valve. Mist units may operate through various control mechanisms such as timers, electronic leaf systems,

thermostats, screen balance devices, and photoelectric cells that regulate misting based on moisture, temperature, or light intensity. Proper water supply with adequate pressure and a pH of 5.5–6.5 is essential, while hard or alkaline water should be avoided to prevent nozzle blockage and leaf deposits.

Greenhouses

A greenhouse greatly extends the scope and efficiency of plant propagation by providing controlled environmental conditions. The most suitable greenhouse is one that allows maximum light penetration, which is essential for strong and healthy seedling growth, especially during late winter and early spring. Large panes and slender framework supports made of steel or aluminium are preferred as they minimize light obstruction while ensuring structural stability. Greenhouses oriented in an east–west direction receive better light exposure, and they should be located away from shade, although protection from strong north to northeast winds is beneficial. Greenhouses may be covered with glass, polyethylene, or fiberglass; glasshouses are durable but expensive, while polyhouses and fiberglass houses are lightweight and economical. Plastic-covered greenhouses may have high humidity, which can be controlled through proper ventilation. In India, low-cost polyhouses covered with UV-resistant polyethylene sheets are widely used for raising nursery plants in the off-season. Modern greenhouses are equipped with systems such as thermostats, coolers, air conditioners, and humidifiers for precise control of temperature and humidity. Seedlings in greenhouses can be grown on ground beds, raised beds, or bench-type beds depending on propagation needs.



Plastic Tunnels

Plastic tunnels are a simple and effective method for protecting cuttings and propagating material, developed by the Greenhouse Crops Research Institute, Littlehampton, England, and widely adopted by nurserymen worldwide. These tunnels consist of wire hoops about three feet wide, made from 0.2-inch diameter wire and spaced at 30-inch intervals, which support a white translucent polyethylene sheet stretched over them and secured firmly. Seeds, cuttings, or other propagating materials are planted inside the tunnels, especially during winter, to provide protection and favourable conditions for growth. Currently, perforated polyethylene tunnels are preferred over non-perforated ones, as they help regulate temperature and humidity and prevent excessive heat and moisture buildup, which can negatively affect rooting and plant development.



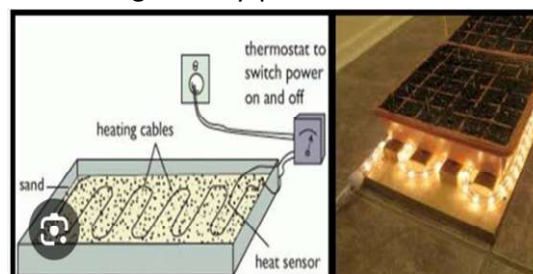
Cold Frame

Cold frames are simple and useful propagation structures that offer many advantages for raising plants under natural conditions. They are suitable for propagating softwood cuttings of herbaceous plants and shrubs during warmer months, and semi-mature or hardwood cuttings during autumn. Cold frames are also used for starting early vegetable crops and raising seedlings from seeds, as well as for conditioning and hardening rooted cuttings, young seedlings, and container-grown plants. Unlike hot beds, cold frames do not have artificial bottom heat and rely entirely on solar energy, so they must be placed in sunny, wind-protected locations. They are usually covered with glass, polyethylene, or fiberglass to retain heat and humidity, and the covering should fit tightly and slope from north to south for maximum sunlight exposure. Proper ventilation, shading, and winter protection are essential for achieving successful propagation results in cold frames (Hartmann *et al.*, 2011).



Hot Beds

Hot beds are small, low propagation structures used for raising nursery plants under controlled environmental conditions. They consist of a frame made of wood, steel, or aluminium, covered with glass or plastic, and include a heating system that provides artificial heat below the propagating medium through hot air or water. The temperature is automatically regulated by a thermostat to ensure optimal conditions for plant growth. Hot beds are widely used in western countries for efficient propagation, but their use in India is limited due to high construction costs (Singh, 2015). Proper management of shading, ventilation, temperature, and humidity is essential for successful propagation. For best results, hot beds should be placed in sunny, protected, and well-drained locations, and they can be used year-round except in regions with extremely severe winters.



Bottom Heat Box

The bottom heat box is a simple device designed to promote rooting in difficult-to-root fruit plants such as mango and guava. It consists of two galvanized iron chambers, with the outer chamber measuring about 70 cm in height and 46 cm in width, and the inner chamber slightly smaller. The space between them is filled with glass wool for insulation. Inside, a smaller chamber fitted with two 100-watt electric bulbs at the base provides uniform bottom heat to the rooting medium, which is filled with soil mixture or other suitable propagation media. A thermostat automatically regulates the temperature, maintaining an ideal range of $30 \pm 2^\circ\text{C}$ for



optimal rooting (Radha and Mathew, 2007). Under these conditions, cuttings generally initiate roots within 1–2 months, depending on the species.

Net House

A net house is a widely used propagation structure in tropical regions where artificial heating is unnecessary and cooling is costly. It is constructed with a roof covered by glass or plastic film and sides enclosed with wire netting, allowing proper ventilation while maintaining a favourable temperature for seed germination and seedling growth. To reduce excessive solar radiation and keep the structure cool, the roof may be covered with gunny cloth or live creepers. Net houses can be built in different sizes and designs depending on the requirements of the propagator, making them a flexible and economical option for nursery production (Bose *et al.*, 2001).

Phytotrons

Phytotrons are highly advanced controlled-environment facilities designed to study plant growth under precisely regulated conditions. They consist of artificially and naturally illuminated rooms, growth chambers, incubators, germination chambers, photoperiod rooms, and refrigerated greenhouses, allowing researchers to create and maintain a wide range of environmental conditions. Unlike simple growth chambers, phytotrons enable the simultaneous study of multiple environmental factors such as temperature, light, and humidity.



Conclusion

Propagation structures play a vital role in modern nursery management by creating favourable environmental conditions for rooting, germination, and plant growth. They improve propagation success, ensure healthy plant development, and enable year-round nursery production. Adoption of suitable structures enhances efficiency, plant survival, and overall quality of planting material in horticulture.

References

- Bose, T.K., Mitra, S.K., Sadhu, M.K. & Das, P., 2001. *Propagation of Tropical and Subtropical Horticultural Crops*. Naya Prokash, Calcutta.
- Hartmann, H.T., Kester, D.E., Davies, F.T. & Geneve, R.L., 2011. *Plant Propagation: Principles and Practices*. 8th ed. Boston: Prentice Hall.
- Radha, T. and Mathew, L., 2007. *Fruit Crops*. New Delhi: New India Publishing Agency.
- Singh, R., 2015. *Propagation of Fruit Crops*. New Delhi: Kalyani Publishers.
- Whitcomb, C.E., 1985. High light with moderated temperatures aids the rooting of softwood cuttings. *Proceedings of the International Plant Propagators Society*. 35: 567–571.

FIBRE EXTRACTION FROM DIFFERENT ORNAMENTAL FLOWERS

C. Nagamallika^{1*} and Jassica Keren Puli²

Department of Floriculture and Landscaping

Dr. YSRHU-College of Horticulture, Anantharajupeta, Andhra Pradesh

*Corresponding Email: nagamallikahimavarsha@gmail.com

Abstract

Fibre extraction from ornamental plant biomass offers a sustainable solution for managing post-harvest floriculture waste while creating value-added products. Ornamental species such as *Hibiscus rosa-sinensis*, *Canna indica*, *Helianthus annuus*, *Tagetes erecta* and *Chrysanthemum morifolium* contain fibrous tissues suitable for fibre production. Using methods such as retting, mechanical, and chemical treatments, these residues can be converted into natural fibres for paper, packaging, eco-textiles and biodegradable composites. This approach supports sustainable waste management, promotes a circular bioeconomy and provides additional income opportunities for flower growers.

Introduction

Ornamental horticulture is primarily focused on the aesthetic production of flowers, foliage, and landscape plants. However, large quantities of vegetative biomass such as stems, stalks, leaves, and spent floral parts are generated after harvest and pruning. In commercial floriculture systems, this biomass is often discarded as waste, leading to disposal challenges and environmental concerns. With the growing emphasis on sustainable agriculture and circular bioeconomy, attention is now shifting toward the valorisation of ornamental plant residues. Natural fibres derived from plant sources are biodegradable, renewable and environmentally friendly alternatives to synthetic fibres. While traditional fibre crops such as cotton and jute are widely utilized, several ornamental species also possess fibrous tissues rich in cellulose, hemicellulose and lignin. Plants such as *Hibiscus rosa-sinensis*, *Canna indica*, *Helianthus annuus*, *Tagetes erecta* and *Chrysanthemum morifolium* contain fibrous stems and stalks that can be explored for fibre extraction. The concept of extracting fibres from ornamental flowers and their associated biomass represents an innovative waste-to-wealth approach. It integrates sustainable waste management with value addition in floriculture, thereby enhancing the overall profitability and environmental responsibility of ornamental crop production systems.

Importance of the Study

- 1. Sustainable waste management:** Floriculture industries generate substantial plant residues. Fibre extraction provides a productive method to recycle this biomass, reducing environmental pollution and landfill accumulation.
- 2. Promotion of circular bioeconomy:** Utilizing ornamental plant waste for fibre production supports circular production systems where waste materials are converted into valuable secondary products such as paper, packaging, ropes, and biodegradable composites.
- 3. Additional income for growers:** Flower growers can obtain supplementary income from post-harvest residues. This diversification improves economic stability, particularly for small-scale farmers.

4. Eco-Friendly alternative to synthetic fibres: Plant-based fibres are biodegradable and reduce dependence on petroleum-based synthetic fibres, thereby lowering carbon footprint and environmental impact.

5. Scope for research and innovation: There is limited research on fibre quality, yield, and processing methods in ornamental species. This creates opportunities for scientific studies in:

- Fibre characterisation
- Mechanical strength analysis
- Improvement through breeding
- Development of eco-products

6. Contribution to sustainable floriculture: Incorporating fibre extraction into ornamental production systems enhances sustainability, resource-use efficiency, and environmental stewardship.

Why Explore Fibre from Ornamental Plants: The demand for biodegradable and sustainable raw materials is growing worldwide. Natural fibres are renewable, environmentally safe, and decompose easily without harming the ecosystem. While fibre crops like jute and cotton are well known, many ornamental plants also contain fibrous tissues in their stems, leaves, or floral stalks that can be utilised for handicrafts, textiles, ropes, and decorative items.

Fibre-Yielding Ornamental Species

Hibiscus rosa-sinensis

- Bast fibres present in stem cortex
- Suitable for cordage, handicrafts, and paper pulp

Canna indica

- Strong fibrous leaf sheaths
- Potential for fibre boards and eco-products

Helianthus annuus

- Fibrous stalks rich in cellulose
- Used in pulp and biodegradable composites

Tagetes spp.

- Abundant floral waste biomass
- Potential raw material for paper and packaging

Chrysanthemum morifolium

- Stem residues after flower harvest
- Scope for fibre-based biodegradable materials

Agave americana

- Leaf fibres (similar to sisal-type fibre)
- Strong and durable
- Suitable for ropes, mats, and handicrafts

Sansevieria trifasciata

- Leaf fibres with high tensile strength
- Traditionally used for bowstrings and cordage

Musa ornata

- Pseudo stem fibres
- Used in textiles and eco-friendly product

Dracaena reflexa

- Fibrous stems
- Potential for decorative fibre crafts

Cosmos sulphureus

- Stem fibres can be used for paper pulp
- Suitable for biomass utilization studies

Hibiscus sabdariffa

- Decorative calyces and foliage
- Stem bast fibres suitable for cordage

Yucca filamentosa

- Strong leaf fibres
- Used traditionally for ropes and mats

Phormium tenax

- Long, strong leaf fibres
- Suitable for textiles and handicrafts

Abutilon indicum

- Fibrous stems
- Used for coarse ropes and twine

Tithonia diversifolia

- High biomass production
- Potential for paper pulp fibre

Thespesia populnea

- Ornamental coastal tree
- Bark fibres used in cordage

Cordyline fruticosa

- Leaf fibres suitable for weaving
- Used in traditional crafts

Bougainvillea spectabilis

- Woody stems contain fibrous tissue
- Potential for pulp and handmade paper

Lantana camara

- Abundant woody biomass
- Explored for fibre boards and pulp

Saccharum spontaneum

- Ornamental grass in landscapes
- Fibrous stalks used for thatching and pulp

Miscanthus sinensis

- High cellulose ornamental grass
- Suitable for bio-fibre composites

Fibre Extraction Techniques

Water retting: Traditional soaking method to separate fibres through microbial degradation.

Enzymatic retting: Environment-friendly method using pectinase and cellulase enzymes to improve fibre quality.

Mechanical decortication: Mechanical separation of fibre bundles from stems

Chemical treatment: Alkali treatment (NaOH) to enhance fibre strength and surface properties.

Fibre Properties and Industrial Applications

- Cellulose content and tensile strength
- Biodegradability and eco-compatibility
- Use in handmade paper production
- Natural fibre composites
- Eco-textiles and packaging materials

Economic and Environmental Implications

- Waste-to-wealth approach in floriculture
- Additional income source for flower growers
- Reduction in environmental pollution
- Promotion of circular bioeconomy in horticulture

Conclusion

Fibre extraction from ornamental plant biomass offers a promising pathway toward sustainable floriculture and efficient biomass utilization. Many ornamental species generate substantial post-harvest residues that can be transformed into valuable natural fibres instead of being discarded as waste. The study highlights that ornamental plants with fibrous stems, leaves and pseudo stems can serve as alternative fibre resources comparable to traditional fibre crops. Adoption of appropriate extraction techniques can improve fibre quality, strength and industrial applicability. Integrating fibre recovery into ornamental production systems contributes to waste reduction, environmental protection and circular bioeconomy development. In addition, this approach creates opportunities for innovation in eco-products, biodegradable materials and natural fibre composites while providing supplementary income to growers. Therefore, exploring fibre extraction from ornamental flowers and associated biomass can significantly enhance the sustainability, profitability and environmental responsibility of modern floriculture systems.

Article ID : 06/III/101/0326

THE “BIO-GLUE” ECONOMY: MICROBES AS ARCHITECTS OF THE PLANT–SOIL INTERFACE

P. J. Kandoriya* and J. R. Patel

Department of Agricultural Microbiology, N. M. College of Agriculture,
NAU, Navsari, Gujarat, India

*Corresponding Email: pjkandoriya12@gmail.com

Abstract

The plant–soil interface represents one of the most complex and biologically active environments in terrestrial ecosystems. Recent advances in rhizosphere biology have revealed that microorganisms function not merely as nutrient transformers but as physical engineers of soil structure through the production of extracellular polymeric substances (EPS). These microbial biopolymers, together with plant root mucilage, act as natural “bio-glues” that bind soil particles, stabilize aggregates, retain water, and create protective niches for both microbes and roots. The emerging concept of the “bio-glue economy” highlights a paradigm shift from chemically driven soil management toward biologically mediated soil functionality. This review-style magazine article synthesizes current understanding of EPS composition, mechanisms of soil aggregation, interactions with plant roots, implications for nutrient cycling, stress tolerance, and disease suppression, and explores emerging applications in sustainable and climate-smart agriculture. Research gaps and future prospects for precision rhizosphere engineering are also discussed. Harnessing microbial bio-glue systems offers a powerful pathway to enhance soil resilience, crop productivity, and environmental sustainability in the face of global agricultural challenges.

Keywords: Rhizosphere, extracellular polymeric substances, soil aggregation, rhizosheath, plant–microbe interaction, biofilm, sustainable agriculture

Introduction: From Chemical Inputs to Biological Intelligence

For decades, agricultural productivity has relied heavily on chemical fertilizers, irrigation, and mechanical soil management. While these approaches increased yields, they also contributed to soil degradation, declining organic matter, reduced microbial diversity, and increased vulnerability to drought and climate stress. Modern soil science is now undergoing a conceptual transformation: soil is increasingly viewed as a self-organizing biological system rather than an inert substrate.

At the heart of this transformation lies the rhizosphere—the narrow zone of soil influenced by plant roots. Within millimeters of the root surface, intense biochemical exchanges occur among plants, microorganisms, and soil minerals. Among the most important discoveries of the past two decades is that many rhizosphere microbes secrete sticky extracellular polymeric substances (EPS) that physically restructure soil around roots.

This insight has given rise to the idea of the “bio-glue economy,” a framework that recognizes microbial biopolymers as foundational drivers of soil architecture, water dynamics, and nutrient efficiency. Rather than relying solely on external inputs, future agriculture may increasingly depend on managing these living adhesive networks.

The Rhizosphere: A Dynamic Biological Marketplace**Definition and Spatial Scale**

The rhizosphere is typically defined as the soil region directly influenced by root exudates and microbial activity, usually extending 1–5 mm from the root surface. Despite its small spatial extent, it is one of the most biologically active zones in soil.

Microbial populations in the rhizosphere are often:

- 10–100 times higher than bulk soil
- metabolically more active
- compositionally distinct
- strongly influenced by plant species

This high activity is driven by continuous release of root exudates.

Root Exudation: Fuel for the Bio-Glue Economy

Plants release 5–40% of their photosynthetically fixed carbon into the rhizosphere. Major components include:

- simple sugars (glucose, fructose)
- amino acids
- organic acids
- phenolics
- root mucilage
- sloughed root cap cells

These compounds serve as energy sources that stimulate microbial proliferation and EPS production.

Key concept

Where carbon flows, microbes grow; where microbes grow, EPS accumulates.

Rhizosphere as a Self-Organizing System

The rhizosphere behaves like a microscale ecosystem characterized by:

- steep nutrient gradients
- fluctuating moisture
- intense microbial competition
- rapid chemical signaling
- localized oxygen variation

EPS production is a microbial survival strategy under such fluctuating conditions.

Extracellular Polymeric Substances (EPS): Chemistry and Biology**What Are EPS?**

EPS are high-molecular-weight extracellular biopolymers secreted by bacteria, fungi, and algae. In soil biofilms, EPS may constitute up to 90% of the total organic matrix.

Molecular Composition**Polysaccharides (40–95%)**

- Glucose, galactose, mannose polymers
- Provide viscosity and adhesion
- Major structural component

Proteins and Glycoproteins

- Enzymatic functions
- structural reinforcement
- signaling roles

Extracellular DNA (eDNA)

- biofilm stability
- horizontal gene transfer
- structural scaffolding

Lipids and Humic-like substances

- hydrophobic interactions
- surface attachment

Physicochemical Properties

EPS exhibits several unique traits:

- highly hydrated gel structure
- strong adhesive capacity
- high cation exchange capacity
- metal chelation ability
- viscoelastic behavior
- protection against desiccation

These properties make EPS an ideal natural soil conditioner.

Mechanisms of Soil Aggregation by Bio-Glue

Soil aggregation is central to soil health. EPS contributes through multiple interacting pathways.

Physical Adhesion

Sticky polysaccharides coat mineral particles and bind:

- clay
- silt
- organic matter

into microaggregates (<250 µm).

Biological Enmeshment

Filamentous organisms provide mechanical reinforcement:

- fungal hyphae
- actinomycete filaments
- root hairs

These act like biological threads stitching aggregates together.

Cation Bridging

EPS contains negatively charged groups that interact with multivalent cations such as:

- Ca^{2+}
- Mg^{2+}
- Fe^{3+}

This creates strong electrochemical bridges between particles.

Hydration–Dehydration Cycling

EPS gels swell when wet and shrink when dry, which:

- stabilizes pore geometry
- reduces aggregate breakdown
- improves resilience to wetting events

Resulting Soil Improvements

EPS-mediated aggregation leads to:

- improved soil structure
- enhanced porosity
- better aeration
- reduced crusting
- lower erosion risk
- improved root penetration

Root Mucilage: The Plant's Contribution to Bio-Glue**Nature of Root Mucilage**

Root mucilage is a polysaccharide-rich gelatinous secretion produced by root cap and border cells. It forms a hydrated sheath around growing roots.

Functions of Mucilage

Root mucilage:

- lubricates root movement
- maintains moisture near root tips
- binds soil particles
- serves as microbial substrate
- modifies rhizosphere viscosity

Synergy Between EPS and Mucilage

The interaction between plant mucilage and microbial EPS creates a **composite biogel**.

Synergistic effects:

- stronger soil adhesion
- improved microbial colonization
- enhanced rhizosheath formation
- better drought buffering
- increased nutrient retention

This cooperation is central to the bio-glue economy.

Rhizosheath Formation and Its Agricultural Importance**What Is the Rhizosheath?**

The rhizosheath is the soil layer tightly adhering to roots after gentle shaking. Its formation depends on:

- root hair density
- mucilage production
- EPS-producing microbes
- soil texture
- moisture

Crops Known for Strong Rhizosheaths

- finger millet
- wheat
- barley
- sorghum
- maize

Finger millet is especially noted for exceptional rhizosheath development under dry conditions.

Benefits of Rhizosheath

- improved root–soil contact
- enhanced phosphorus acquisition
- better drought tolerance
- reduced nutrient diffusion distance
- microbial habitat stabilization

Role of Bio-Glue in Plant Nutrition**Nitrogen Dynamics**

EPS matrices:

- retain ammonium
- reduce nitrate leaching
- support nitrogen-fixing bacteria
- create microsites for mineralization

Phosphorus Availability

EPS and organic acids:

- solubilize bound phosphates
- reduce P fixation
- maintain P near root surface

This is particularly important in Indian soils with high P fixation capacity.

Micronutrient Cycling

EPS binds and mobilizes:

- iron
- zinc
- copper
- manganese

Siderophore-producing microbes embedded in EPS further enhance Fe availability.

Stress Mitigation Functions**Drought Stress**

EPS improves plant drought tolerance through:

- increased soil water retention
- hydraulic continuity
- reduced evaporation
- osmotic buffering
- microbial survival protection

Plants with EPS-rich rhizospheres often show higher relative water content and delayed wilting.

Salinity Stress

EPS can:

- bind Na⁺ ions
- improve soil structure under saline conditions
- protect microbial cells
- maintain root membrane stability

Heavy Metal and Nanoparticle Interactions

EPS functional groups (–COOH, –OH, –NH₂):

- chelate heavy metals
- immobilize toxic ions
- interact with iron nanoparticles
- modify nanoparticle mobility

This area is especially relevant for nano-enabled agriculture.

Disease Suppression and Plant Protection

Bio-glue systems enhance biological control.

Mechanisms

- biofilm barrier formation
- competitive exclusion
- antibiotic production
- induced systemic resistance
- quorum sensing interference

Disease-suppressive soils often show high EPS-producing microbial populations.

Applications in the Emerging Bio-Glue Economy**Advanced Biofertilizers**

Next-generation products focus on:

- EPS-rich strains
- biofilm-forming consortia
- stress-tolerant PGPR
- rhizosphere-competent microbes

Soil Structure Engineering

Potential uses include:

- erosion control
- mine spoil rehabilitation
- desert soil stabilization
- crust prevention
- degraded land restoration

Climate-Smart Agriculture

EPS contributes to:

- carbon sequestration in aggregates
- improved water-use efficiency
- reduced irrigation demand
- enhanced soil organic matter protection

Integration with Nanotechnology

Emerging research areas:

- EPS–nanoparticle interactions
- nano-biofertilizer delivery systems
- controlled nutrient release
- nano-enabled rhizosphere engineering

Research Gaps and Future Directions

Despite rapid progress, key questions remain:

- field-scale quantification of EPS
- crop-specific microbial consortia design
- long-term stability of bio-glue effects
- interaction with climate extremes
- standard methods for EPS measurement
- integration with precision agriculture
- regulatory frameworks for microbial products

Future research will likely move toward precision rhizosphere engineering using multi-omics tools.

Conclusion

The “bio-glue economy” represents a transformative shift in our understanding of soil–plant–microbe interactions. Microbial extracellular polymeric substances, working in concert with root mucilage, form a living adhesive network that structures the rhizosphere, stabilizes soil aggregates, enhances nutrient retention, and protects plants from environmental stresses and pathogens. These biological processes underpin soil resilience and crop productivity in ways that chemical inputs alone cannot achieve. As agriculture faces the dual challenges of climate change and soil degradation, harnessing EPS-producing microbes offers a promising pathway toward sustainable, biology-intensive farming systems. Continued interdisciplinary research combining soil microbiology, plant physiology, soil physics, and nanotechnology will be essential to fully realize the potential of microbial bio-glue systems in future agriculture.

Reference

- Ahmed, M. A.; Kroener, E.; Holz, M.; Zarebanadkouki, M. and Carminati, A. (2014). Mucilage exudation facilitates root water uptake in dry soils. *Functional Plant Biology*, 41 (11): 1129–1137.
- Carminati, A. and Vetterlein, D. (2013). Plasticity of rhizosphere hydraulic properties as a key for efficient utilization of scarce resources. *Annals of Botany*, 112 (2): 277–290.
- Chenu, C. (1995). Extracellular polysaccharides: An interface between microorganisms and soil constituents. *Environmental Pollution*, 87 (3): 281–287.
- Costa, O. Y. A.; Raaijmakers, J. M. and Kuramae, E. E. (2018). Microbial extracellular polymeric substances: Ecological function and impact on soil aggregation. *Frontiers in Microbiology*, 9: 1636.
- Flemming, H.-C. and Wingender, J. (2010). The biofilm matrix. *Nature Reviews Microbiology*, 8 (9): 623–633.
- Jones, D. L.; Nguyen, C. and Finlay, R. D. (2009). Carbon flow in the rhizosphere: Carbon trading at the soil–root interface. *Plant and Soil*, 321: 5–33.

- Lehmann, J. and Kleber, M. (2015). The contentious nature of soil organic matter. *Nature*, 528: 60–68.
- Nunan, N.; Young, I. M.; Crawford, J. W. and Ritz, K. (2003). Spatial distribution of bacterial communities and their relationships with the micro-architecture of soil. *FEMS Microbiology Ecology*, 44 (2): 203–215.
- Oades, J. M. (1984). Soil organic matter and structural stability: Mechanisms and implications for management. *Plant and Soil*, 76: 319–337.
- Or, D.; Phutane, S. and Dechesne, A. (2007). Extracellular polymeric substances affecting pore-scale hydrologic conditions for bacterial activity in unsaturated soils. *Vadose Zone Journal*, 6 (2): 298–305.
- Ramey, B. E.; Koutsoudis, M.; von Bodman, S. B. and Fuqua, C. (2004). Biofilm formation in plant–microbe associations. *Current Opinion in Microbiology*, 7 (6): 602–609.
- Rillig, M. C.; Muller, L. A. H. and Lehmann, A. (2017). Soil aggregates as massively concurrent evolutionary incubators. *The ISME Journal*, 11: 1943–1948.
- Sandhya, V. and Ali, S. Z. (2015). The production of exopolysaccharide by *Pseudomonas putida* GAP-P45 under various abiotic stress conditions and its role in soil aggregation. *Microbiological Research*, 170: 18–26.
- Tisdall, J. M. and Oades, J. M. (1982). Organic matter and water-stable aggregates in soils. *Journal of Soil Science*, 33 (2): 141–163.
- Vessey, J. K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and Soil*, 255: 571–586.

PROXIMATE COMPOSITION OF *ETROPLUS SURATENSIS*: INSIGHT INTO PROTEIN, LIPID AND MINERALS

**M. Dhanu Pradeep, L.Vinoth Kumar*, G. Dhivagar, E. K. Devipriya,
R. Gayathri and S.T. Dhivya Bharathi**

Department of Fish Processing Technology, TNJFU- Dr.MGR. Fisheries College and Research
Institute, Ponneri, Thiruvallur District, Tamil Nadu 601204
Corresponding Email: vinothkumar@tnfu.ac.in

Abstract

The Indian pearlspot (*Etroplus suratensis*) is an important edible fish valued for its nutritional quality. Proximate composition analysis indicates that its muscle is dominated by high moisture (75–83%) and protein (18–20%), with low lipid content (0.5–3%) and minimal carbohydrates, classifying it as a lean fish. The protein fraction is nutritionally superior, providing all essential amino acids with high digestibility, making it suitable for all age groups. Although total lipid levels are low, the presence of beneficial unsaturated fatty acids enhances its health value. The ash content (1–2%) reflects a valuable mineral profile, including calcium, iron, zinc, and trace elements such as selenium. Variations in proximate composition are influenced by environmental conditions, diet, season, and biological factors. Overall, *E. suratensis* represents a protein-rich, low-fat, and mineral-balanced fish, supporting its dietary importance and potential in sustainable fisheries and aquaculture.

Keywords: *Etroplus suratensis*, Proximate composition, Fish protein quality, Lean fish, Lipid profile, Unsaturated fatty acids, Mineral composition, Micronutrients, Nutritional value, Fisheries nutrition.

What is Proximate Composition?

Proximate composition refers to the quantitative estimation of the major nutritional components of food, namely moisture, crude protein, lipid, ash (minerals), and carbohydrates. In fish muscle, moisture, protein, fat, and minerals are the dominant components, while carbohydrates occur in negligible amounts. Proximate analysis is widely used in fisheries and nutrition studies because it provides a simple and reliable assessment of the nutritional quality of fish. It helps evaluate the food value of fish for human consumption and is also useful for comparing wild and cultured populations.

Proximate Composition of *Etroplus suratensis*

The Indian pearlspot (*Etroplus suratensis*) shows a typical fish muscle composition dominated by moisture and protein. Moisture content ranging from approximately 75 to 83%, indicating high water content in the flesh. Crude protein generally varies between 18–20%. Lipid content remains low, usually between 0.5–3%, while carbohydrates are present only in trace amounts (around 0.6–0.7%). Ash content, representing total minerals, ranges from about 1.4 to 1.8%. This composition confirms that *E. suratensis* is a lean fish with high protein and low fat, a characteristic commonly observed in many edible tropical fishes.

Protein Content of *Etroplus suratensis*

Protein is the most nutritionally important component of pearlspot muscle. The crude protein content of *E. suratensis* averages around 18–20% of fresh weight. Fish proteins are considered

high-quality proteins because they contain all essential amino acids required for human nutrition, including lysine, methionine, threonine, and tryptophan. In dietary terms, a 100 g serving of pearlspot flesh can provide nearly one-fifth of the daily protein requirement for an adult. Fish muscle proteins are also highly digestible, making them especially suitable for children, the elderly, and people with compromised digestion. The high protein quality of *E. suratensis* contributes significantly to its importance as a food fish in southern India.

Lipid Profile and Its Nutritional Role

Etroplus suratensis is classified as a lean fish due to its low lipid content, which generally remains below 5%. Fat levels between 0.5 and 3%, depending on habitat and season. Fish lipids are rich in unsaturated fatty acids, including polyunsaturated fatty acids that are beneficial for human health. In pearlspot, fatty acid analyses have identified palmitic, stearic, oleic, linoleic, and arachidonic acids. Brackish-water populations often show slightly higher lipid levels than freshwater populations, but overall fat content remains low. These unsaturated fatty acids contribute to cardiovascular health, reduce inflammation, and support brain function. The low saturated fat content further enhances the nutritional value of pearlspot, making it a healthy choice for regular consumption.

Mineral Composition and Micronutrient Value

The ash content of *E. suratensis* muscle represents its mineral fraction and accounts for about 1–2% of the total weight. Although quantitatively small, this fraction contains essential macro- and micro-minerals. Pearlspot provides appreciable amounts of calcium, iron, and zinc in that calcium and phosphorus are important for bone formation and maintenance, iron is essential for hemoglobin synthesis and oxygen transport, and zinc plays a key role in immune function and enzymatic activity. Trace elements such as selenium are also present and contribute to antioxidant defense mechanisms. Thus, the mineral composition of pearlspot complements its protein and lipid content and enhances its overall nutritional value.

Factors Influencing Proximate Composition of *Etroplus suratensis*

The proximate composition of *E. suratensis* is not constant and varies with several factors. Environmental conditions such as salinity, temperature, water quality, and pollution levels significantly influence moisture and lipid content. Diet is one of the most important factors affecting composition. Pearlspot is omnivorous and feeds on algae, detritus, and small invertebrates. Diets rich in algae are often associated with higher lipid deposition, while low-energy diets result in leaner flesh. Biological factors such as age, size, growth rate, and maturity stage also influence nutrient composition. Seasonal variations, especially those linked to feeding intensity and spawning cycles, can cause fluctuations in fat and moisture levels. Understanding these factors is essential for fisheries management and aquaculture practices aimed at improving flesh quality.

Conclusion

The Indian pearlspot (*Etroplus suratensis*) possesses a nutritionally balanced proximate composition characterized by high moisture, high-quality protein, low lipid content, and valuable minerals. Its protein content provides essential amino acids with high digestibility, while its low-fat level is dominated by beneficial unsaturated fatty acids. The presence of important minerals such as calcium, iron, and zinc further enhances its dietary value. Although environmental and

biological factors influence its composition, *E. suratensis* consistently remains a lean, protein-rich fish. These nutritional attributes justify its importance in Indian diets and support its potential for sustainable fisheries and aquaculture development.

References

- Antony, M. M. (2016). Comparative Evaluation of Proximate Composition of *Etroplus suratensis* from Ecologically Different Areas of Ashtamudi Lake, Kerala.
- Imtiaz Ahmed, Kousar Jan, Shabihul Fatma, Mahmoud A. O. Dawood (2022). Muscle proximate composition of various food fish species and their nutritional significance
- Jayaprakash, V., & Sunil Kumar, S. (1999). Dietary Protein Requirement for Optimising Growth Responses of Asian Cichlid, *Etroplus suratensis* (Bloch).
- Gopakumar, K. (1997). *Biochemical composition of fish and shellfish*.
- Nair, P. G., & Nair, K. G. (1987). Proximate composition and nutritive value of pearl spot *Etroplus suratensis* from Kerala waters.

RISING CO₂ AND CROP RESILIENCE: OPPORTUNITIES AND RISKS FOR GLOBAL AGRICULTURE

Vijay Gahlaut^{1*}, Vandana Jaiswal^{2,3} and Sundeep Kumar⁴

¹Department of Biotechnology, University Center for Research and Development, Chandigarh University, Mohali-140413, Punjab, India

²Biotechnology Division, CSIR-Institute of Himalayan Bioresource Technology, Palampur, India.

³Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India

⁴ICAR-National Bureau of Plant Genetic Resources, New Delhi, 110012, India

*Corresponding Email: zone4vijay@gmail.com

As the global climate changes, one of the most widely discussed aspects of environmental shifts is the increase in atmospheric carbon dioxide (CO₂) levels. The concentration of CO₂ in the atmosphere has been rising steadily. Because of intensified human activities, atmospheric CO₂ has risen by about 50% since the pre-industrial period (~1750), increasing from 277 parts per million (ppm) to 416 ppm by 2023. This increase is having a profound impact on agricultural productivity. Elevated CO₂ has direct effects on plant growth and crop production. It is a complex mechanism, but less understood. This article explores how elevated CO₂ affects crop growth, development, and stress resilience, and also discusses the understanding that the multifaceted CO₂–climate–crop nexus is essential to harness potential benefits while safeguarding yield quality and long-term global food security.

The Role of CO₂ in Photosynthesis

CO₂ is a key ingredient in photosynthesis, the process by which plants convert light energy into chemical energy. During photosynthesis, plants absorb CO₂ from the air and use it, along with water and sunlight, to produce sugars that fuel their growth. So, it may seem intuitive that higher CO₂ levels would benefit plants by boosting their ability to produce food. In fact, experiments and studies showed that elevated CO₂ can enhance photosynthesis, leading to faster plant growth and increased biomass, especially in C3 plants, which include many important crops like wheat, rice, soybeans, and potatoes. This phenomenon is called the "CO₂ fertilization effect". Under optimal conditions, increased CO₂ can result in higher yields and improved crop productivity. In fact, research has shown that CO₂ enrichment can increase crop yields by anywhere from 10% to 30%, depending on the species, growing conditions, and other environmental factors.

The Impact of Elevated CO₂ on Crop Water Use

In addition to promoting photosynthesis, higher CO₂ levels can also reduce the amount of water that crops lose through transpiration. Transpiration occurs when plants release water vapor from small pores on their leaves called stomata. Under higher CO₂ conditions, the stomata tend to close more tightly, reducing water loss. This effect can be especially beneficial in regions that are facing water scarcity or are prone to drought. Reduced water use in crops could lead to more efficient irrigation and better resilience to water stress, helping farmers in some parts of the world grow crops with less water.

However, this water-saving effect isn't always straightforward. While reduced transpiration can conserve water, it can also lead to changes in the microclimate around plants, such as increased

leaf temperature. If these changes are not balanced by other factors, they could lead to negative effects on crop performance, especially in regions where temperatures are already high.

Nutrient Quality and Composition

While elevated CO₂ can enhance crop growth and yield in some cases, there is growing concern about its effects on the nutritional quality of the food. Research suggests that higher CO₂ levels may reduce the concentrations of key nutrients like protein, iron, zinc, and other essential minerals in many staple crops. For example, studies on wheat, rice, and soybeans have shown that crops grown under elevated CO₂ tend to have lower protein content. This is partly because the extra carbon encourages the production of carbohydrates (like starches and sugars) at the expense of proteins and other micronutrients. As a result, even though yield may increase, the nutritional value of these crops could be compromised, which could have serious implications for food security.

Interactions with other Climate Change Factors

While elevated CO₂ alone can have certain benefits for crops, climate change is a multi-faceted phenomenon, and other factors, such as higher temperatures, changing precipitation patterns, and more frequent extreme weather events, are also in play. The interactions between CO₂ levels and these other stressors are complex and can lead to unpredictable outcomes.

Rising Temperatures: Warmer temperatures can accelerate plant growth, but excessive heat can also stress crops, particularly during key stages like flowering and grain filling. Heat stress can lead to reduced yields and lower-quality crops, potentially offsetting any gains from increased CO₂.

Shifting Precipitation Patterns: Climate change is expected to bring more erratic rainfall patterns, including both periods of intense rainfall and prolonged droughts. While elevated CO₂ may help crops cope with drought stress to some extent, an overall lack of water or flooding could still hinder crop growth and development.

Pests and Diseases: Warmer temperatures and higher CO₂ levels could also affect the prevalence and behavior of pests and pathogens that target crops. Some studies suggest that elevated CO₂ could make certain plants more susceptible to certain types of insects, diseases, or weeds, potentially reducing crop yields or requiring more intensive pest management strategies.

Regional Variability in CO₂ Effects

The effects of elevated CO₂ on crops will not be uniform across the globe. Geographic and environmental factors such as soil fertility, water availability, temperature, and the specific crop variety also play significant roles in determining how crops respond to higher CO₂ levels. For instance, crops grown in cooler climates may benefit more from increased CO₂, as the photosynthesis process is often limited by lower concentrations of carbon in the air. Conversely, crops in already hot regions may face challenges from excessive heat stress, which could counteract the positive effects of CO₂ fertilization. In regions where rainfall is inconsistent, the potential water-saving benefits of elevated CO₂ might be particularly valuable.

Looking Ahead: What Can Farmers Expect?

As CO₂ levels continue to rise, scientists and farmers are working to better understand how to maximize the benefits of CO₂ fertilization while mitigating potential downsides. Key areas of research include- (i) Developing new crop varieties that are more resilient to heat stress, drought,

and nutrient imbalances could help ensure that the benefits of elevated CO₂ are fully realized, (ii) Implementing smarter farming techniques such as precision agriculture, improved irrigation methods, and integrated pest management, can help farmers adapt to the changing climate and mitigate the negative effects of other climate stressors, (iii) Soil health should be maintained and enhanced through practices like crop rotation, cover cropping, and reduced tillage could help maximize the benefits of CO₂ fertilization and improve overall crop productivity.

Conclusion

In conclusion, while elevated CO₂ may offer promising benefits for crop growth, especially increased photosynthesis and water-use efficiency, the full impact on global food production remains uncertain. The benefits of CO₂ fertilization need to be weighed against the broader challenges posed by climate change, such as rising temperatures, changing precipitation patterns, and the potential decline in nutritional quality of crops (Figure 1). Adaptation strategies that combine technological innovation, sustainable farming practices, and regional adaptation will be essential to ensure that crops can thrive in a future with higher CO₂ levels and a changing climate.

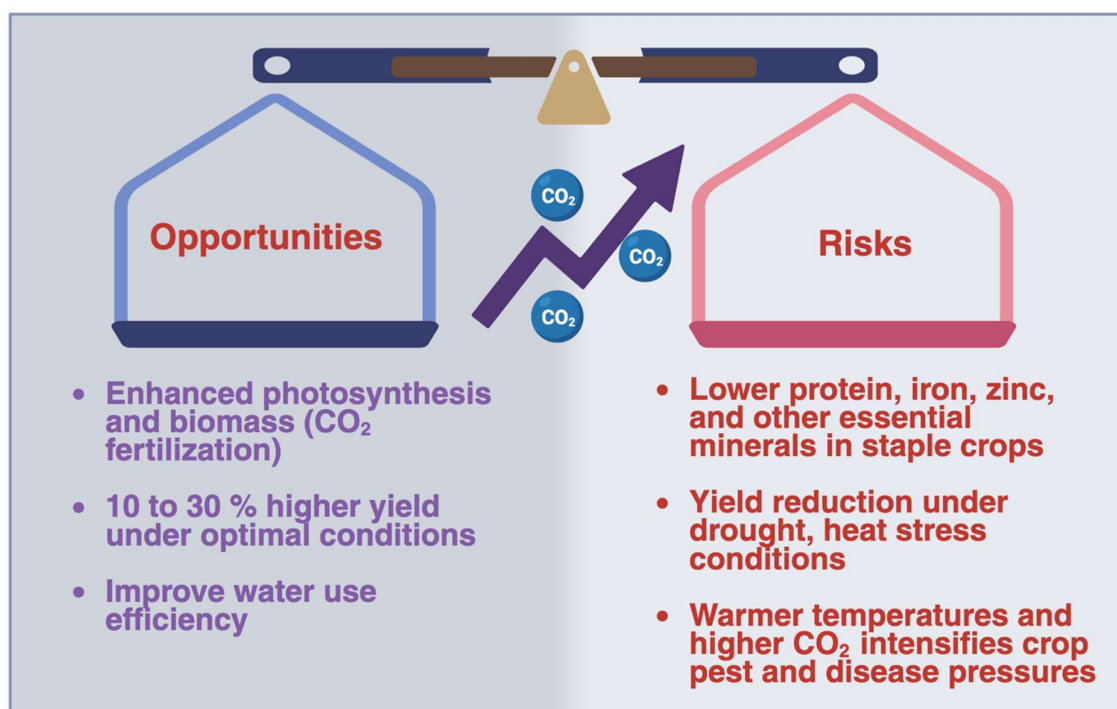


Figure 1. Opportunities and risks of rising CO₂ for crops. Figure created with BioRender.

Article ID : 06/III/104/0326

ROLE OF GENETICS AND PLANT BREEDING IN IMPROVING CROP QUALITY

Aprajita Singh* and Radheshyam Ramkrishna Dhole

Department of Genetics and Plant Breeding, Narayan Institute of Agricultural Sciences,
Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas (Bihar) – 821305, India

*Corresponding Email: aprajita0504@gmail.com

Abstract

Genetics and plant breeding play a crucial role in improving crop quality traits, including nutritional composition, processing characteristics, stress tolerance, and consumer acceptability. With increasing global food demand, changing dietary preferences, climate variability, and widespread nutritional insecurity, enhancement of crop quality has become as important as yield improvement. Advances in classical and molecular genetics have enabled the identification of genes and quantitative trait loci governing complex quality attributes, while modern breeding approaches have facilitated their efficient incorporation into elite cultivars. Technologies such as marker-assisted selection, genomic selection, and genome editing have significantly accelerated quality-oriented breeding programs. This paper provides a comprehensive overview of the role of genetics in crop quality improvement, highlighting key characteristics, essential components, stepwise breeding workflows, major applications, advantages, and future strategies. The integration of genetics-driven breeding approaches is essential for developing high-quality, resilient, and market-oriented crop varieties that support sustainable agricultural systems.

Keywords: Crop quality, Genetics, Plant breeding, Molecular markers, Genomic selection.

Introduction

A primary goal of contemporary agriculture is the improvement of agricultural quality, which is fueled by growing consumer awareness, dietary needs, industrial demands, and international market standards. Although yield augmentation was the main focus of previous plant breeding projects, it is now clear that this is not enough to address issues with food security, hunger, and sustainability. Crop quality characteristics that directly affect human health, economic value, and farmer profitability include protein and micronutrient content, flavour, texture, shelf life, and processing adaptability. Because it explains how quality qualities are inherited and expressed, genetics serves as the scientific basis for plant breeding. Simple trait inheritance was explained by early developments in Mendelian genetics, while complex traits governed by several genes and their interactions with the environment could be studied thanks to quantitative genetics. By making it possible to precisely identify, select, and manipulate genes linked to quality qualities, molecular genetics and genomics have transformed plant breeding in recent decades. A methodical and effective route to long-term crop quality enhancement is provided by genetics-driven plant breeding, as seen in other agricultural systems where focused, knowledge-driven techniques produce sustainable results.

Key Characteristics of Crop Quality Improvement

Genetic Variability

Genetic variability is the cornerstone of crop quality improvement. Diverse germplasm resources, including landraces, traditional cultivars, and wild relatives, serve as reservoirs of valuable alleles

governing nutritional, biochemical, and processing traits. Effective utilization of this variability enables breeders to broaden the genetic base and introduce superior quality traits into cultivated crops.

Heritability of Quality Traits

Understanding the heritability of quality traits is essential for predicting selection response. Traits with high heritability, such as grain size, color, or oil composition, respond effectively to direct selection, whereas complex traits like protein quality or micronutrient density require advanced breeding strategies and molecular tools.

Genotype × Environment Interaction

Crop quality traits are often influenced by environmental conditions such as temperature, soil fertility, and water availability. Therefore, breeding programs must account for genotype × environment interactions to ensure stable expression of quality traits across locations and seasons.

Integration of Molecular Tools

The integration of molecular genetics with conventional breeding allows precise identification and manipulation of genes controlling quality traits. This integration enhances selection efficiency and reduces reliance on time-consuming phenotypic evaluations.

Important Components of Genetics-Based Quality Improvement

Germplasm Evaluation

Systematic evaluation of germplasm for nutritional, biochemical, sensory, and processing traits provides the initial basis for crop quality improvement. Reliable phenotyping is essential for identifying suitable donor parents.

Breeding Methods

Conventional breeding methods such as pedigree, backcross, and recurrent selection remain important for quality improvement. These approaches are increasingly complemented by molecular breeding strategies to accelerate trait introgression.

Molecular Markers

DNA markers linked to quality-related genes and QTLs enable early and accurate selection of superior genotypes. Marker-assisted selection reduces breeding cycles and improves selection precision.

Genomic Resources

Advances in genome sequencing, transcriptomics, and QTL mapping have facilitated the identification of candidate genes associated with quality attributes, enabling targeted genetic improvement.

Breeding Workflow for Crop Quality Improvement

Trait Identification

Priority quality traits are identified based on nutritional needs, industrial requirements, market demand, and consumer preferences.

Germplasm Screening

Diverse genetic resources are screened to identify donor parents possessing superior quality traits.

Crossing Programme

Hybridization is carried out between elite cultivars and donor parents to combine high yield potential with improved quality attributes.

Selection

Phenotypic selection is integrated with molecular marker-based selection to identify desirable progenies at early stages.

Advanced Evaluation

Selected lines are evaluated through multi-location trials to assess quality, stability, and adaptability under diverse environmental conditions.

Applications of Genetics in Crop Quality Improvement

There are numerous uses for genetics-driven quality enhancement in the agriculture industry. In staple crops, genetic biofortification improves micronutrients including iron, zinc, and provitamin A, hence promoting nutritional security. Breeding for baking qualities, oil composition, and starch quality benefits the agro-industrial and food processing industries. Increased stress tolerance guarantees quality preservation in the face of heat, salinity, and drought stress. Additionally, in export-oriented agriculture, consistent grain quality, color, and shelf life boost competitiveness.

Advantages

Genetics-based breeding methods allow breeders to develop specific quality traits in crops without harming their overall genetic makeup. Molecular and genomic tools help breeding programs to shorten their duration because these tools speed up the process of discovering and securing advantageous genetic traits. The methods used in these approaches boost the nutritional properties of crops while making them more appealing to markets and improving their ability to survive in different climate conditions. Genetic-based solutions provide agricultural systems with sustainable solutions because they decrease the need for chemical pesticides and help create robust farming practices.

Future Strategies

Future crop quality improvement programs should emphasise the integration of artificial intelligence with genomics to analyse large-scale genetic and phenotypic datasets and improve prediction accuracy. The expanded application of wild crop relatives demonstrates their necessity for discovering new alleles that enhance crop quality and stress resistance. Genome editing technologies provide scientists with exact instruments that allow them to develop nutritional and processing characteristics through specific modifications. Climate-smart and participatory breeding approaches should be strengthened to ensure that improved varieties align with local farming systems, market demands, and consumer preferences.

Conclusion

Genetics and plant breeding work together as essential tools that agricultural scientists need to enhance crop quality. The combination of traditional breeding methods with modern genomic and molecular techniques enables scientists to create crop varieties that have superior nutritional value, product quality and exceptional durability. The systematic, genetics-driven method provides an effective and environmentally sustainable solution for future crop quality improvements, which support food security, economic stability, and environmental protection.

Reference

Application of CRISPR/Cas9 in Crop Quality Improvement.

Genomic Selection and Its Impact on Crop Improvement Programs (2024).

J. Environ. Agric. Agroecosyst. Manag. Applications of Genomic Tools in Plant Breeding: Crop Biofortification (2021).

Sun, L., et al. (2024). Modern Plant Breeding Techniques in Crop Improvement and Genetic Diversity: From Molecular Markers and Gene Editing to Artificial Intelligence—A Critical Review. *Plants*, 13(19), 2676.

The Role of Genetics and Plant Breeding for Crop Improvement: Current Progress and Future Prospects. (2023). *Int. J. Plant Soil Sci.* 35(20):190–202.

SEAWEED EXTRACTS – PLANT RESILIENCE BOOSTERS

K.G. Shilpa Shree^{1*}, T.R. Rupa², M.D. Prathibha³ and T. Anupa⁴

^{1 & 4} Senior Scientists, ICAR- Indian Institute of Horticultural Research, Bengaluru.

² Principal Scientist, ICAR- Indian Institute of Horticultural Research, Bengaluru.

³ Scientist, ICAR- Indian Institute of Horticultural Research, Bengaluru.

*Corresponding Email – shilpa.kgs@gmail.com

Introduction

Seaweeds are the abundant renewable resources of marine and coastal ecosystem. Seaweeds include nearly 10,000 species and contribute to approximately 10% of the total global marine productivity (D. Battacharyya *et al.*, 2015). Among these, large biomass species exist as free-floating, but majority are benthic, attached to hard bedrocks. Biochemicals extracted from seaweeds belonging to phyla Ochrophyta (brown seaweed), Rhodophyta (red seaweed) and Chlorophyta (green seaweed) are being utilized commercially in agriculture as plant biostimulants. Extracts of brown seaweeds are well known for their plant growth promoting properties and to improve crop tolerance to many abiotic stresses like salinity, temperature stress and water deficit conditions.

Seaweed extracts have been reported to contain an array of bioactive compounds *viz.*, terpenes, polysaccharides, polyphenols, phlorotannins, amino acid derivatives, lipids, growth promoting hormones such as auxins, gibberellins, cytokinins, ethylene etc (R.J. Mughunth *et al.*, 2024). Presence of such diverse biochemical compounds enable seaweed extracts to stimulate growth and defence response when applied to the plant. In abiotic stress conditions, the physiological effect caused by seaweed extracts in plants is linked to growth promoting compounds and elicitors.

Seaweed Extracts-Methods of Preparation

Seaweed extracts can be prepared by both physical and chemical methods. In physical method of extraction heat, pressure and microwaves are used and in chemical method of extraction solvents, acids and alkali are used. The choice of extraction method depends on factors like seaweed species being used, extraction efficiency and environmental impact.

Conventionally, seaweed extracts were prepared by using hot water which could be considered as most eco-friendly as no solvents were used. But hot water extraction has many limitations such as break down of heat sensitive bioactive compounds, molecular degradation and formation of undesirable compounds which leads to reduced quality and bioactivity of the extract. Alkaline extraction at high pressure (using potassium hydroxide/calcium hydroxide/sodium hydroxide) is the most widely used extraction process. Some advanced chromatographic methods are also being used to extract specific pigments and to isolate bioactive compounds from seaweeds. But during solvent extraction, large quantities of organic solvents are used which produces hazardous waste. Therefore, environmentally friendly and efficient extraction methods like microwave-assisted extraction, ultrasound-assisted extraction and reactive extrusion are becoming popular as commercial extraction methods.

Chemical composition of seaweed extracts largely depends on the method adopted for extraction and on the chemicals used during the extraction process. Therefore, the biological activity of extracts of the same seaweed raw material prepared by different extraction methods could be markedly different.

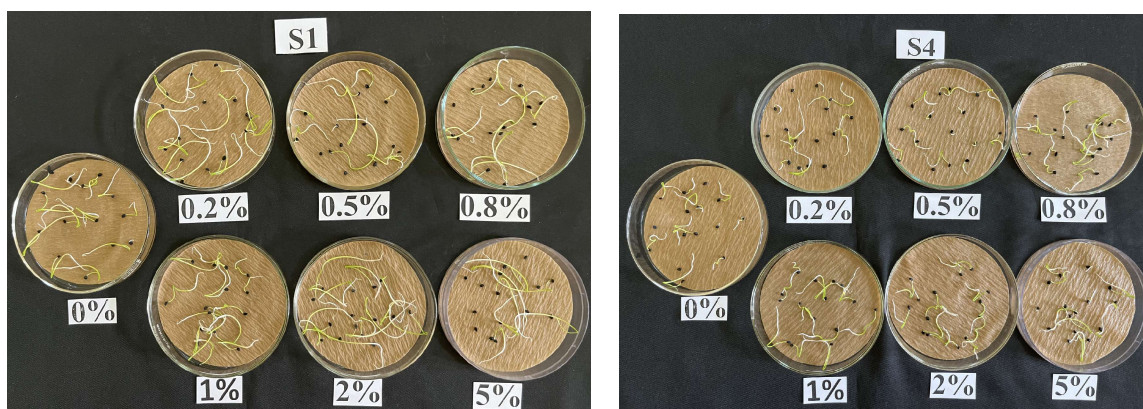
Mode of Application

In market, seaweed liquid extracts and seaweed soluble powder are commonly available and plant response depends on mode of seaweed extracts application. Seaweed extracts are suitable for foliar application and for soil application through fertigation or drenching. Foliar applications are reported to be more effective in inducing plant response against abiotic and biotic stresses than fertigation and drenching. To harness the maximum effectiveness of foliar application, seaweed extracts have to be applied in the morning when leaf stomata are open.

Seaweed Extracts- Effect on Plant Growth

Seaweed extracts influence plant growth similar to the activity of phytohormones. The phytohormone like activity of the seaweed extracts depends on many factors like the type of seaweed used for extraction, seaweed handling conditions after harvesting it from sea, solvent and method used for extraction. Phytohormones such as auxins present in seaweed extracts have been reported to improve root architecture and result in improved seed germination rate and seedling vigour by increasing root volume and density. Enhancement in root growth is highly beneficial in vegetatively propagated plants. Increased root and shoot growth in plants treated with seaweed extract were associated with enhanced uptake and accumulation of nutrients. Betaines like glycine betaine and laminine commonly present in extract of brown seaweeds inhibit chlorophyll degradation in leaves. Researchers have reported improved nutrient concentration and plant growth in crops like tomato, cucumber, lettuce, grape due to seaweed extracts application.

Enhanced crop tolerance to abiotic stresses due to seaweed extracts application has been attributed to the presence of bioactive compounds in seaweed extracts. Among the abiotic stresses, salinity significantly affects crop yield in irrigated areas worldwide. Irrigating with saline groundwater severely affects growth and yield of salt sensitive vegetable crops like french bean and onion. Seaweed extracts have been shown to improve plant tolerance to salinity by improving germination and seedling vigour in french bean and onion. Onion seeds (Arka Bheem) pre-soaked in 0.8% and 1% extracts of seaweeds *Kappaphycus* and *Sargassum* showed better germination and improved root growth at higher salt stress levels as compared to seeds that did not receive seaweed extract treatment. Also, french bean seeds (Arka Suvidha) pre-soaked in 0.2% and 0.8% extracts of seaweeds *Kappaphycus* and *Sargassum* showed good germination, improved root growth and lower sodium absorption at higher salt stress levels.



Improved germination observed in onion seeds (Arka Bheem) due to seaweed extracts soaking treatments under non-saline (left) and salt stress conditions of 7.5 dS/m (right)



Improved germination observed in french bean seeds (Arka Suvidha) due to seaweed extracts soaking treatments under non-saline (left) and salt stress conditions of 7.5 dS/m (right)

Conclusion

Seaweed extracts have received a greater acceptance in agriculture as plant biostimulants. Extracts prepared from different seaweed species and by different extraction methods are attributed with number of beneficial effects such as increased root growth, better nutrient uptake and improved crop performance under abiotic stresses. Seaweed extracts with their plant response stimulating and phytoeliciting properties have the potential to become a promising abiotic stress management practice in agriculture.

References

- Dhriti Battacharyya, Mahbobeh Zamani Babgohari, Pramod Rathor and Balakrishnan Prithiviraj (2015). Seaweed extracts as biostimulants in horticulture, *Scientia Horticulturae*, 196: 39-48.
- R.J Mughunth, S Velmurugan, M Mohanalakshmi and K Vanitha, (2024). A review of seaweed extract's potential as a biostimulant to enhance growth and mitigate stress in horticulture crops, *Scientia Horticulturae*, 334: 113-312

HOW TO CONSTRUCT A HISTOGRAM USING FREQUENCY DISTRIBUTION IN MICROSOFT EXCEL

Suwetha P¹, Surulivel L² and Aruna S³

¹Ph.D. scholar, Department of Aquatic Environment Management,
Dr. M.G.R. Fisheries College and Research Institute, Ponneri, Tamil Nadu - 601 204, India

²Assistant Professor, Department of Fisheries Extension, Economics and Statistics,
Dr. MGR. Fisheries College and Research Institute, Ponneri, Tamil Nadu -601 204, India

³Assistant Professor, Department of Aquatic Environment Management,
Dr. MGR. Fisheries College and Research Institute, Ponneri, Tamil Nadu -601 204, India

*Corresponding Email: suwethap0410@gmail.com

Abstract

Two essential statistical tools for summarizing and visualizing quantitative data are the frequency distribution and the histogram. This article offers a straightforward and useful introduction to using Microsoft Excel to create frequency distributions and histograms. It describes how unprocessed numerical data can be categorized into class intervals and graphically displayed using histograms for simple comprehension. Because of its ease of use, accessibility, and graphical features, Microsoft Excel is a useful tool for professionals, researchers, and students to evaluate and convey data in an understandable and significant manner.

Keywords: Quantitative data, MS Excel, Frequency Distribution, Histogram, Data visualization

What is Frequency Distribution?

After data collection, the next step is to organize the data systematically to identify underlying patterns and trends. Frequency distribution is a widely used method for summarizing quantitative data. It represents the number of observations within each class or category of the measurement scale in tabular or graphical form. This approach allows researchers to quickly assess whether values are high or low and to determine whether observations are uniformly distributed or concentrated within specific ranges. Hence, frequency distribution provides a clear picture of how individual observations are distributed across the measurement scale.

Features of Frequency Distribution

Four key features of frequency distribution are identified. They are as follows:

- Central tendency and location metrics (mean, median, mode)
- Dispersion metrics (standard deviation, variance, and range)
- The degree of skewness, or symmetry or asymmetry
- Kurtosis is the degree of flatness or peakedness.

Frequency distribution graphs

A frequency distribution graph is a diagrammatic illustration of the information in the frequency table which are,

- Histogram
- Frequency Polygon
- Cumulative Frequency Curve (Ogive)
- Box-and-Whisker Plot (Box Plot)

What is a Histogram?

A frequency distribution is represented graphically by a histogram. Class intervals are shown on the horizontal axis, while the vertical axis shows the frequencies that correspond to them. Histograms aid in visualizing the symmetry, skewness, and value concentration of a data distribution.

Why do we use a histogram to illustrate frequency distribution?

Histograms in Microsoft Excel illustrate the continuous character of the data by utilizing neighboring bars to show class intervals and their frequency. Compared to numerical tables alone, they facilitate comprehension and aid in the rapid identification of patterns such data concentration, dispersion, and skewness.

Data Arrangement in Excel

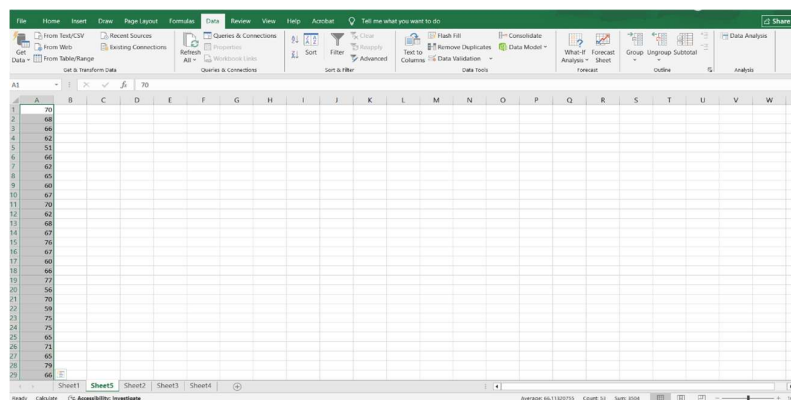
To construct a frequency distribution and histogram in Excel, quantitative data should be arranged properly:

- One column containing raw numerical data
- Another column specifying class intervals (bins)

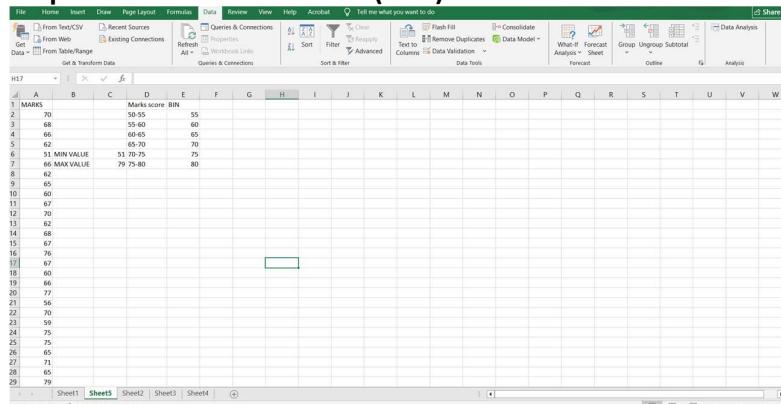
Proper data organization ensures accurate calculation and graphical representation.

Steps to Create a Frequency Distribution in MS-Excel

Step 1: Enter data into the Excel worksheet

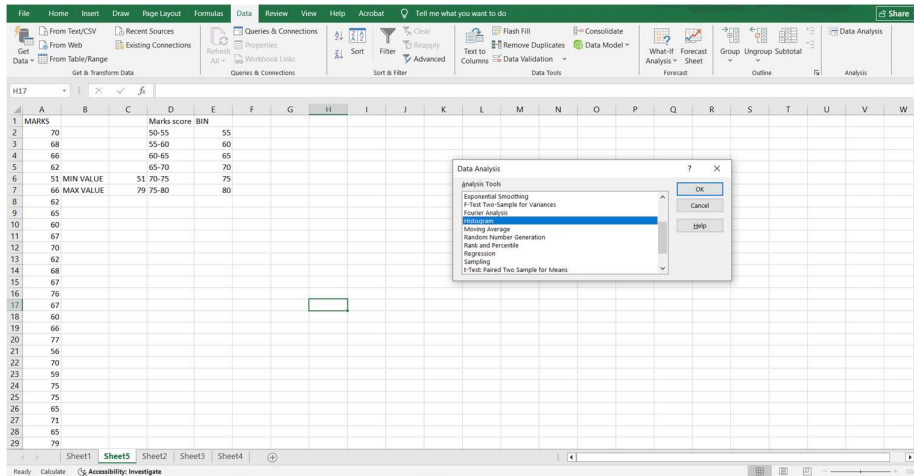


Step 2: Define class intervals (Bins)

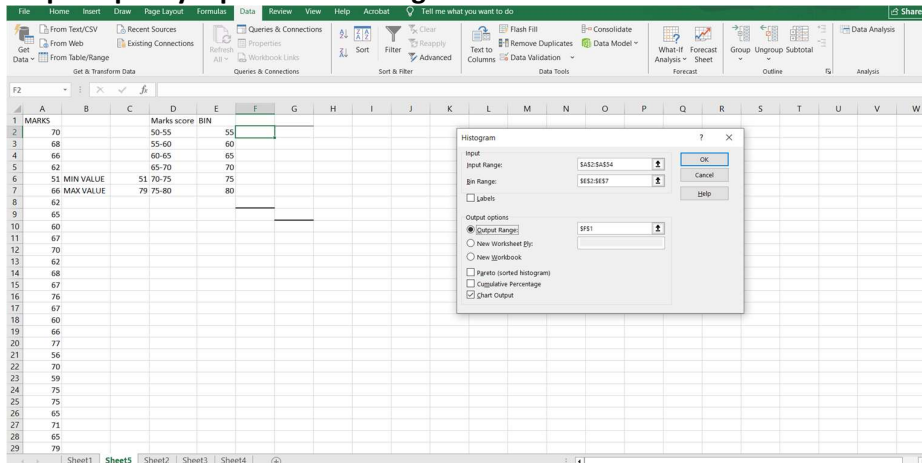


Based on the range of the data, determine suitable class intervals. Enter the upper limits of each class in a separate column, which will serve as the bin range for frequency calculation.

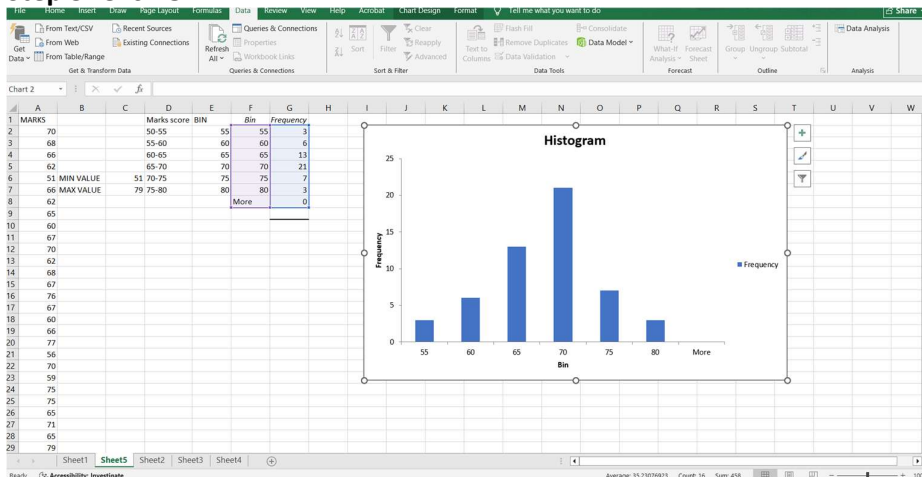
Step 3: Click on the Data Analysis command button and click histogram option



Step 4: Specify input and bin ranges



Step 5: Click OK



Understanding the Output

The Excel output contains two main components:

1. Frequency Distribution Table

- Displays the number of observations falling within each class interval

2. Histogram

- Graphically represents class intervals on the X-axis and frequencies on the Y-axis
- Adjacent bars indicate the continuous nature of quantitative data

Conclusion

A simple and efficient method for summarizing and visualizing quantitative data is the creation of a frequency distribution and histogram in Microsoft Excel. Excel facilitates the rapid discovery of data patterns, spread, and distributional characteristics by grouping raw data into class intervals and graphically portraying them. MS-Excel is a useful tool for professionals, researchers, and students because of its accessibility and usability, especially for popular science communication and beginning analysis.

TALAROMYCES: THE EMERGING FUNGAL WARRIOR AGAINST PLANT DISEASES

Heyram S.P.

PhD Scholar, Department of Plant Pathology, Tamil Nadu Agricultural University,
Lawley Road, Coimbatore, Tamil Nadu - 641003, India.
Corresponding Email: heyrampalanivel1102@gmail.com

Abstract

Antagonistic fungi play an important role in sustainable agriculture by promoting plant growth and reducing the impact of plant diseases. Among these, *Talaromyces* species have gained attention as effective biological control agents due to their natural presence in soil and the plant rhizosphere. These fungi protect crops by suppressing a wide range of fungal and bacterial pathogens through mechanisms such as antibiosis, competition, mycoparasitism and stimulation of plant defense responses. In addition to disease control, *Talaromyces* improves nutrient availability and supports overall plant vigor, contributing to healthier and more resilient cropping systems. Their wide distribution, ecological adaptability and ability to coexist with beneficial soil microorganisms make them well suited for eco-friendly disease management. With rising concerns over chemical residues, fungicide resistance and environmental sustainability, *Talaromyces* species represent a promising biological alternative for long-term and environmentally responsible crop protection.

Keywords: *Talaromyces*, biological control, antagonistic fungi, sustainable agriculture, plant disease management

Introduction

Antagonistic fungi are increasingly recognised for their dual role in supporting plant health and productivity. Some of these beneficial fungi directly stimulate plant growth by releasing metabolites that make essential nutrients more available to plants. Others contribute indirectly by suppressing plant diseases, which reduces stress on crops and allows them to grow more vigorously. This disease-suppressing ability forms the basis of biological control, an environmentally friendly approach that offers a safer and more sustainable alternative to chemicals. In recent years, species of *Talaromyces* have attracted growing attention as effective biocontrol agents against a wide range of plant diseases. Naturally present in soil and the plant rhizosphere, these fungi interact closely with plant roots and surrounding microorganisms. Their value in sustainable agriculture lies in their ability to control harmful fungal and bacterial pathogens through natural biological processes. At a time when concerns about fungicide resistance, chemical residues and ecological imbalance are increasing, *Talaromyces* species are emerging as promising allies for eco-friendly and long-term plant disease management.

General characteristics

Talaromyces is a group of ascomycetous fungi that was first reported from paddy field soils of West Bengal, India by C. R. Benjamin in 1955 with *Talaromyces vermiculatus* designated as the type species. Taxonomically, it is placed in the class Ascomycetes, order Eurotiales and family Trichocomaceae. The asexual stage of *Talaromyces* is commonly associated with *Penicillium*,

particularly members of the biverticillate–symmetrical group. Morphologically, *Talaromyces* species form soft, globose fruiting bodies that range in colour from white and yellow to red. Their asci are short-lived and typically contain eight spores arranged in chains, while the ascospores themselves vary in shape from globose to slightly ellipsoidal and may be smooth or ornamented. Members of *Talaromyces* are widely distributed across diverse habitats, including soil, plant debris, manure, agricultural and industrial wastes, dung and food materials. To date, several species and varieties have been recorded worldwide. Among them, *Talaromyces flavus* is the most frequently isolated soil species and is well known for its strong antagonistic activity against important plant pathogens such as *Alternaria alternata*, *Fusarium moniliforme*, *Magnaporthe grisea*, *Sclerotium rolfsii* and *Verticillium albo-atrum*. Many *Talaromyces* species are efficient colonizers of the rhizosphere and plant tissues, displaying remarkable adaptability to soil environments and tolerance to abiotic stresses such as nutrient limitation and pH fluctuations. These traits make them particularly attractive for applications in sustainable plant disease management.

Distribution and habitat

Talaromyces species are widely distributed across the globe and occur in diverse climatic regions ranging from temperate to tropical zones. They are particularly prevalent in tropical and subtropical ecosystems, where warm conditions and abundant organic matter support rich fungal communities. Numerous studies have identified *Talaromyces* as a regular component of soil fungal populations, where they play an important role in organic matter breakdown and nutrient recycling. Their broad geographic spread highlights a high degree of ecological flexibility, allowing them to survive and thrive under different moisture regimes, temperature ranges and soil pH levels. These fungi are commonly isolated from a variety of habitats, including agricultural and forest soils, composts, decaying plant material and stored agricultural products. Many *Talaromyces* species are well suited to life in the rhizosphere, forming close associations with plant roots and actively interacting with other soil microorganisms. In addition, several species exist as endophytes, residing within plant tissues without causing visible disease symptoms. This endophytic lifestyle enhances their survival and strengthens their role in suppressing plant pathogens. Beyond typical soil-based environments, *Talaromyces* has also been reported from unusual and specialised habitats such as acidic soils, indoor settings, insect-associated niches and food-related substrates. The ability of certain species to tolerate environmental stresses, including nutrient scarcity and elevated temperatures, further extends their ecological reach. This remarkable adaptability and habitat diversity form the foundation for the growing interest in *Talaromyces* as a robust and reliable genus with strong potential for use in sustainable agriculture and biological disease control.

Mechanism and mode of action

Talaromyces species control plant diseases through several interconnected mechanisms, making them highly effective across different cropping systems. One of their key strategies is antibiosis, in which these fungi produce a variety of natural compounds, such as secondary metabolites and volatile substances, that suppress the growth, reproduction or survival of plant-pathogenic fungi and bacteria. Many *Talaromyces* species also release enzymes capable of breaking down pathogen cell walls, weakening them and ultimately leading to their destruction. Another important mode of action is competition. *Talaromyces* are strong colonizers of soil and root

surfaces, particularly in the rhizosphere. By rapidly occupying space and efficiently utilizing available nutrients, they limit the resources needed by pathogens to establish and cause disease. In some cases, *Talaromyces* species directly attack harmful fungi through mycoparasitism, where they grow over pathogen hyphae, penetrate them and cause structural damage through enzymatic activity. These direct interactions play a major role in suppressing soil-borne diseases.

Beyond directly targeting pathogens, *Talaromyces* can also strengthen plant defenses. When they colonize roots or internal plant tissues as endophytes, they trigger the plant's own defense system, a phenomenon known as induced systemic resistance. This priming effect enables plants to respond faster and more effectively to pathogen invasion, often providing broad and long-lasting protection. In addition to these well-known mechanisms, *Talaromyces* species can modify the rhizosphere environment itself. Through the release of organic acids and other metabolites, they influence soil pH and nutrient availability, creating conditions that are less favourable for pathogens while supporting beneficial microorganisms. Over time, these changes can contribute to the formation of disease-suppressive soils. *Talaromyces* also promote plant growth by improving nutrient availability, particularly phosphorus and essential micronutrients. Healthier, more vigorous plants are naturally better equipped to tolerate and resist disease.

Biocontrol potential

Talaromyces species have shown remarkable potential as biological control agents against a wide range of plant pathogens that threaten economically important crops. Numerous studies have documented their antagonistic activity against major soil and air-borne fungal pathogens, including *Fusarium*, *Rhizoctonia*, *Pythium*, *Phytophthora*, *Sclerotium*, *Alternaria* and *Colletotrichum*. Among them, *Talaromyces flavus* is one of the most extensively studied species and has consistently demonstrated strong suppression of *Verticillium dahliae*, the causal agent of Verticillium wilt in crops such as cotton, potato, tomato and brinjal. *Talaromyces flavus* is recognized as an important antagonistic fungus involved in the natural suppression of several destructive diseases of herbaceous crops. It commonly inhabits the rhizosphere, where it utilizes root exudates and produces hydrogen peroxide through the activity of glucose oxidase enzymes. Hydrogen peroxide is highly toxic to many fungi and pathogenic bacteria, contributing directly to pathogen inhibition. In addition, this fungus suppresses pathogens through multiple mechanisms, including mycoparasitism mediated by enzymes such as chitinases and pectinases, the production of volatile compounds like alcohols and aldehydes, and the release of non-volatile inhibitory substances generated by enzymes such as glucose oxidase and related glycosidases.

In cereal and pulse crops, *Talaromyces* species have been reported to effectively reduce root rot and wilt diseases caused by *Fusarium oxysporum* and *F. solani*. Antagonistic strains isolated from the rhizosphere have significantly lowered Fusarium wilt severity in crops such as chickpea, tomato and cucumber under both greenhouse and field conditions. Similarly, suppression of *Rhizoctonia solani*, the pathogen responsible for damping-off and root rot in rice, vegetables and legumes, has been associated with reduced hyphal growth and sclerotial formation. In rice and maize production systems, *Talaromyces* isolates have also shown the ability to limit *Pythium*-induced seedling mortality. Other studies report inhibition of *Colletotrichum* species causing anthracnose in chilli, mango and strawberry, as well as *Alternaria* species responsible for leaf blight in tomato and brassica crops. Some *Talaromyces* strains have even demonstrated activity against post-harvest pathogens, helping to reduce fruit rot and extend shelf life. A summary of the

antagonistic activity of different *Talaromyces* species against major plant pathogens and their associated crop diseases is provided in Table 1.

Table 1. Antagonistic activity of *Talaromyces* spp. against plant pathogens

Species	Target pathogen	Disease	Crop	Mode of action
<i>Talaromyces flavus</i>	<i>Verticillium dahliae</i>	Verticillium wilt	Cotton, tomato, potato and brinjal	Strong reduction of microsclerotia, disease suppression
<i>Talaromyces flavus</i>	<i>Fusarium oxysporum</i>	Fusarium wilt	Tomato, chickpea	Inhibition of mycelial growth and pathogen survival
<i>Talaromyces flavus</i>	<i>Rhizoctonia solani</i>	Root rot, damping-off	Vegetables, legumes	Suppression of hyphal growth and sclerotia
<i>Talaromyces pinophilus</i>	<i>Fusarium spp.</i>	Root rot, wilt	Cereals, vegetables	Antifungal metabolites and enzyme activity
<i>Talaromyces pinophilus</i>	<i>Pythium spp.</i>	Damping-off	Vegetables	Rhizosphere competition and antibiosis
<i>Talaromyces purpurogenus</i>	<i>Colletotrichum spp.</i>	Anthrachnose	Chilli, fruits	Inhibition of spore germination
<i>Talaromyces purpurogenus</i>	<i>Alternaria spp.</i>	Leaf blight	Tomato, brassicas	Growth suppression via secondary metabolites

Conclusion

Talaromyces species are emerging as valuable partners in the shift toward sustainable plant disease management. By naturally suppressing harmful pathogens while supporting plant growth and soil health, these fungi offer a practical alternative to heavy reliance on chemical fungicides. Their ability to function through multiple biological mechanisms, adapt to diverse environments and coexist harmoniously with crops makes them particularly well suited for eco-friendly agriculture. As concerns over fungicide resistance, environmental safety and long-term soil productivity continue to grow, harnessing the potential of *Talaromyces* can help build more resilient cropping systems. With continued research and field-level application, these beneficial fungi may play an important role in shaping the future of sustainable and environmentally responsible crop protection.

References

- Alloway, B. J. (2008). *Zinc in soils and crop nutrition*. International Zinc Association.
- Duo-Chuan, L. I., Chen, S., & Jing, L. U. (2005). Purification and partial characterization of two chitinases from the mycoparasitic fungus *Talaromyces flavus*. *Mycopathologia*, 159, 223–229.

- Heredia, G., Reyes, M., Arias, R. M., & Bills, G. F. (2001). *Talaromyces ocotl* sp. nov. and observations on *T. rotundus* from conifer forest soils of Veracruz State, Mexico. *Mycologia*, 93, 528–540.
- Houbraken, J., & Samson, R. A. (2011). Phylogeny of *Penicillium* and the segregation of Trichocomaceae into three families. *Studies in Mycology*, 70, 1–51.
- Inglis, G. D., & Kawchuk, L. M. (2002). Comparative degradation of oomycete, ascomycete, and basidiomycete cell walls by mycoparasitic and biocontrol fungi. *Canadian Journal of Microbiology*, 48, 60–70.
- Kirk, P. M., Cannon, P. F., David, J. C., & Stalpers, J. A. (2001). *Dictionary of the fungi* (9th ed.). CAB International.
- Le Floch, G., Rey, P., Benizri, E., Benhamou, N., & Tirilly, Y. (2003). Impact of auxin-compounds produced by the antagonistic fungus *Pythium oligandrum* or the minor pathogen *Pythium* group F on plant growth. *Plant and Soil*, 275, 459–470.
- Marois, J. J., Johnston, S. A., Dunn, M. T., & Papavizas, G. C. (1982). Biological control of Verticillium wilt of eggplant by *Talaromyces flavus*. *Phytopathology*, 72, 370–374.
- Naraghi, L., Heydari, A., Rezaee, S., Razavi, M., & Afshari-Azad, H. (2010). Biological control of *Verticillium dahliae* by *Talaromyces flavus* in greenhouse and field conditions. *Plant Pathology*, 59, 970–977.
- Naraghi, L., Heydari, A., Rezaee, S., Razavi, M., & Jahanifer, H. (2010). Study on antagonistic effects of *Talaromyces flavus* on *Verticillium albo-atrum*, the causal agent of potato wilt disease. *Crop Protection*, 29, 658–662.
- Nicoletti, R., & Varese, G. C. (2018). Mycobiota of plants: Endophytic fungi and their role in plant health. *Fungal Ecology*, 35, 1–3.
- Pitt, J. I., Samson, R. A., & Frisvad, J. C. (2000). List of accepted species and their synonyms in the family Trichocomaceae (pp. 9–49). In R. A. Samson & J. I. Pitt (Eds.), *Integration of modern taxonomic methods for Penicillium and Aspergillus classification*. Harwood Academic Publishers.
- Samson, R. A., Yilmaz, N., Houbraken, J., Spierenburg, H., Seifert, K. A., Peterson, S. W., Varga, J., & Frisvad, J. C. (2011). Phylogeny and nomenclature of the genus *Talaromyces* and taxa accommodated in *Penicillium* subgenus *Biverticillium*. *Studies in Mycology*, 70, 159–183.
- Stolk, A. C., & Samson, R. A. (1972). *The genus Talaromyces: Studies on Talaromyces and related genera II*. CBS.
- Sundaramoorthy, S., & Balabaskar, P. (2013). Biocontrol efficacy of *Talaromyces* spp. against soil-borne plant pathogens. *Journal of Plant Protection Research*, 53, 285–293.
- Visagie, C. M., Houbraken, J., Frisvad, J. C., Hong, S. B., Klaassen, C. H. W., Perrone, G., Seifert, K. A., Varga, J., Yaguchi, T., & Samson, R. A. (2014). Identification and nomenclature of the genus *Penicillium*. *Studies in Mycology*, 78, 343–371.

WHAT AILS THE DOMESTIC EDIBLE OIL ECONOMY-WHETHER STAGNATION ON PRODUCTION FRONT OR WEAK FARMER, PRO-CONSUMER HEALTH SUPPORTIVE POLICY INTERVENTIONS?

Ranga Rao Veerapaneni

Formerly Director (Retd), erstwhile integrated Oilseed Research (ICAR-DOR)

&it's All India Co-ordinated Oilseeds Research Project (AICORPO)

Rajendranagar, Hyderabad.

Corresponding Email: ranga.v40@gmail.com

The progressive slippage of domestic edible oil economy from it's much hyped yellow revolution of early 90s post country's 1st ever technology mission on oilseeds (TMO) into an unending trap of rapidly rising demand-supply gaps, (2024-25=16Mt), burgeoning import burden (2024-25=Rs1,61000 crores) and unsustainable chronic import dependency (2024-25 close to 60%) is indeed a matter of grave concern. This is more so, given the availability of seven annual edible oil yielding crops as well as diverse range of crop growing situations and the huge opportunities the latter offer as sole/ sequence/relay/intercrops for yearround cultivation. What then propelled the country into such humongous, unsustainable and chronic import dependency?

Trends in Production, Productivity and Domestic Availability of Edible Oils

Contrary to the widespread misconceptions from different quarters in the country, overall production as well as productivity of oilseeds in the country witnessed 115 & 42% improvement, respectively since the days of yellow revolution. As a result domestic availability of edible oils also touched as high as 12 Mt by 2024-25 though still short of 15.87Mt demand projection of Niti Ayog for 2030 based on the per capita dietary limits set by NIN/ICMR.

Interestingly, despite such impressive improvements on the domestic edible oil supply front and the huge untapped potential the latter offers for further stepping up prevailing production and per hectare yields of oilseed crops, the country's import dependency is likely to continue unabated even beyond 2030 unless appropriate corrective measures are taken. This indeed calls not only for serious introspection but warrants a critical re-appraisal of the very basis of not only our current demand projections of edible oils but farmer support systems as well as import policies being pursued currently.

Permissible Per Capita Consumption Levels of NIN/ICMR Vis a Vis those of Today

As per NIN/ICMR's dietary guidelines (2024), a moderate adult male with energy requirement of 2730kcal/day requires 30 grams visible oil and fat/day which works out to around 11 kg /year. According to Niti Ayog's (2024) own demand projections based on dietary guidelines of NIN/ICMR, the country 's total demand of edible oils for even 2030 (=15.87 MT) and 2047 (=17.35Mt) were well within it's realisable limits. What is of serious concern, our per capita consumption level in the country as per latest data is already close to double the permissible threshold limit of NIN/ICMR.

Niti Ayog's Latest Projections of Country's Demand of Visible Oils For 2030 And 2047

According to the latest Niti Ayog's report (2024) "pathways and strategies for accelerating growth in edible oils towards the goal of atma nirbharata ", the country needs as much as 38.9 and 41.9 MT of total visible oil by 2030 and 2047, respectively if it follows per capita consumption level of

developed countries. What is more, the above requirements are reported to touch staggering levels of 45.5 MT(2030) to as high as 66.8 MT(2047) with the adoption of current USA 's level as a benchmark(=45 kg)..Not surprisingly, a switchover from western standards to the dietary guidelines of NIN/ICMR is reported to have brought down the above demand projections of visible oils to as low as 15.87 MT (2030) to 17.35 MT (2047)(Niti Ayog, 2024). Quite obviously, the current system of computing future demand projections of total edible oil requirements based on past CAGRs of per capita consumption (which has already breached NIN/ICMR benchmark long back) as well as the liberalised and open import policy regime followed post WTO agreement warrants a critical re-appraisal if the country is to scale down not only the current runaway imports and the associated burden but discourage excessive consumption of oils.

What Should Therefore, be The Criteria for Country's Future Demand Projections, Whether Developed West or NIN/ICMR'S Pro-Health Benchmark?

Excessive intake of visible fats and oils beyond permissible level are known to have adverse effect on health and increase incidence of fatty liver, high triglycerides as well as LDL, cholesterol and pose high risk of cardiovascular diseases including stroke. Neither the country can take such a risk and endanger its public health nor would it be able to sustain such humongous demand levels in view of continued inherent limitations of domestic oilseed production system such as predominant cultivation under rainfed conditions with poor management, little or no success of conventional breeding approaches in tackling major stumbling blocks to productivity and stability of performance namely biotic, abiotic stresses and nutritional quality, in-access to state of art non- transgenic/ non-GM genome editing technologies on account of strong opposition from within the country to not only GM crops but to the latter as well which are critical for breaking current yield barriers in oilseed crops coupled with stability and superior nutritional quality

A Pro-Farmer and Pro-Consumer Wayforward Towards Sustainable Self Reliance In Domestic Edible Oil Economy

As already highlighted elsewhere, the country does not need to be in a rat race with developed countries of west and adopt their excessively very high per capita consumption levels to our situations. Keeping in view the overall realisable production levels *vis a vis* realities on the ground, larger public health, progressive decline in the acreage of a number of otherwise potential oil crops such as sesame, Niger, safflower, sunflower, groundnut and the urgent need to free the country from its chronic import dependency and the associated huge and recurring drain on our foreign exchange reserves, the domestic edible oil economy calls for a host of key policy interventions which are not only pro-farmer but pro-consumer health if the country is to achieve speedily its goal of durable and sustainable self reliance in the crucial sector. These inter alia are:

Adoption of NIN/ICMR dietary guidelines in respect of visible oils as a basis for all future demand projections instead of past CAGR of per capita annual consumption and Immediate freezing of current per capita consumption level of visible oils at either 150-160% of recommended intake or at 2020-21 level i.e 18.2 kg or even lower.

Dispense forthwith with the current open and liberalised import regime with zero & 12.5% basic duty (refined oils) as the country has the option under WTO agreement to raise import duties upto 45% in soy oil and 300% (other oils). Restriction of such low duty structure only to bridge the demand-supply gap based on NIN/ICMR 's dietary guidelines or as per revised benchmark

suggested under 5.1 above and adoption of calibrated and flexible duty structure thereafter as a deliberate disincentive measure

Diversion of huge savings in foreign exchange outgo accruing from import cuts to all oilseed farmers as a special bonus / quintal so as to encourage farmers switch to oilseed crops in all their potential niche areas and situations and adopt cost intensive improved technologies without fear of losing

As part of self reliance drive and make oilseed cultivation more attractive to farmers in the face of rising costs, offer remunerative MSPs to oilseed farmers, preferably based on C2 costs rather than current A2+fl costs backed up with guaranteed procurement as in case of rice and wheat

Launching of a nationwide aggressive educational drive thru regional multimedia for creating awareness on adverse effects of excessive consumption of visible oils on health as well as safe consumption levels per family and choice of edible oils vis a vis culinary usage, dos and don'ts

Distribution of edible oil requirements of marginalised sections of society thru public distribution to avert hardships if any on account of import restrictions beyond permissible levels and possible inflationary pressures

As part of promotion of conjunctive use of scarce water resources, discourage indiscriminate and excessive use of water even in drylands and thru it promote expansion of acreage under oilseeds, limit free electricity for only less water intensive crops like pulses, oilseeds, vegetable and fruit crops.



Official Address :

Peshok Tea Estate
P.O.- Peshok, Dist.- Darjeeling
West Bengal, India
PIN-734312

Contact No : +91 9635231406

email : agriindiatoday@gmail.com

Disclaimer : All the articles included in this issue are the views expressed by the authors and their own interpretations, in which Agri-India TODAY e-Newsletter has no responsibility. So, the author is fully responsible for his articles.