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SOIL DEGRADATION AND ITS IMPACT ON GLOBAL FOOD SECURITY

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Introduction

Soil is the foundation of life on Earth, supporting plant growth, regulating water cycles, and storing carbon. Yet, despite its crucial role, soil is being degraded at an alarming rate due to unsustainable agricultural practices, deforestation, industrial pollution, and climate change. Soil degradation defined as the decline in soil quality caused by human activities poses a significant threat to global food security. As fertile land becomes barren, the ability to produce sufficient, nutritious food for a growing population is severely compromised. Addressing soil degradation is not just an environmental concern; it is a pressing global challenge that requires immediate action.

The Causes of Soil Degradation

Several interconnected factors contribute to soil degradation, with agriculture being one of the primary drivers. Intensive farming practices, such as excessive tillage, monocropping, and overuse of synthetic fertilizers and pesticides, strip the soil of its organic matter and essential nutrients. Continuous cropping without replenishing soil fertility depletes its natural ability to support plant growth. Overgrazing by livestock further exacerbates the problem by compacting the soil and reducing vegetation cover, making it more susceptible to erosion.

Soil erosion caused by wind, water, and human activities is another major contributor to degradation. When topsoil, which contains the highest concentration of organic matter and nutrients, is removed, crop yields decline, and land productivity diminishes. Deforestation accelerates erosion by eliminating trees and plant roots that hold soil together, leading to desertification in many parts of the world.

Pollution from industrial activities, mining, and improper waste disposal also severely impacts soil health. Heavy metals, plastics, and chemical residues accumulate in the soil, altering its composition and harming beneficial microbes. Similarly, salinization often a result of excessive irrigation and poor drainage—renders soil infertile, particularly in arid and semi-arid regions.

Climate change further intensifies soil degradation through increased temperatures, erratic rainfall patterns, and extreme weather events. Rising global temperatures accelerate the decomposition of organic matter, reducing soil carbon storage. Prolonged droughts and heatwaves lead to soil desiccation, while intense storms and flooding wash away fertile topsoil, leaving behind degraded land unsuitable for cultivation.

Impact on Global Food Security

The loss of productive soil directly threatens food security by reducing agricultural output. As soil health declines, crop yields shrink, leading to food shortages, higher prices, and increased dependency on food imports. According to the United Nations, 33% of the world's soils are already degraded, and if current trends continue, food production may struggle to keep pace with global population growth. Nutrient depletion in degraded soils also affects food quality. Crops grown in poor soils contain lower levels of essential vitamins and minerals, contributing to malnutrition and health issues in vulnerable populations. In developing countries, where smallholder farmers rely on local soils for sustenance, degradation leads to poverty and food insecurity, forcing communities to migrate in search of arable land. Water scarcity is another consequence of soil degradation. Healthy soils act like a sponge, absorbing and storing water for plant use. However, degraded soils with low organic matter content lose this capacity, leading to increased water runoff, reduced groundwater recharge, and lower crop resilience to drought. Without adequate soil conservation measures, regions already experiencing water stress will face worsening agricultural conditions.

Solutions to Combat Soil Degradation

Reversing soil degradation requires a combination of sustainable agricultural practices, policy interventions, and global cooperation. One of the most effective approaches is conservation agriculture, which emphasizes minimal soil disturbance, permanent soil cover, and diversified crop rotations. No-till farming helps preserve soil structure, while cover cropping prevents erosion and improves soil organic matter. Crop diversification and agroforestry integrate trees and multiple plant species into farming systems, enhancing soil resilience and biodiversity. Organic amendments such as compost, manure, and biochar can restore soil fertility by replenishing nutrients and increasing microbial activity. Biochar, in particular, has been shown to improve soil structure, enhance water retention, and sequester carbon, making it a valuable tool in regenerative agriculture.

Integrated soil fertility management combines organic and inorganic nutrient sources to optimize soil productivity while maintaining long-term soil health. Farmers can adopt precision agriculture techniques, using soil testing and remote sensing technologies to apply fertilizers and water more efficiently. Policy support and financial incentives are essential to encourage farmers to adopt soil-friendly practices. Governments and international organizations must invest in soil conservation programs, provide subsidies for sustainable farming inputs, and implement regulations to prevent land degradation. Land tenure security also plays a crucial role, as farmers are more likely to invest in soil health if they have long-term ownership of their land. Public awareness and education are equally important. Farmers, policymakers, and consumers need to understand the consequences of soil degradation and the benefits of soil conservation. Schools and agricultural extension programs should incorporate soil health education to foster a culture of sustainability.

Conclusion

Soil degradation is one of the greatest challenges facing global food security, with severe implications for agriculture, water resources, and human livelihoods. If left unaddressed, the continued loss of fertile soil will threaten food production and exacerbate hunger and poverty worldwide. However, by adopting sustainable land management practices, restoring degraded soils, and implementing strong policies, we can protect this vital resource for future generations. Healthy soils are the foundation of a food-secure and climate-resilient world, and their preservation must be a global priority.

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ENHANCING PRODUCTIVITY IN PLANTATION AND SPICE CROPS THROUGH PRECISION TECHNIQUES

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Abstract
Precision farming, or precision agriculture, is an innovative management approach that leverages information technology, geospatial data, and advanced tools to enhance resource efficiency in agriculture. This method is particularly vital for the cultivation of plantation and spice crops, which require meticulous management due to their sensitivity to environmental changes. Key techniques such as remote sensing, Geographic Information Systems (GIS), soil health monitoring, Variable Rate Technology (VRT), automated irrigation systems, and targeted pest management are employed to optimize resource use and enhance productivity. The benefits of precision farming encompass increased yields, cost efficiency, sustainability, improved crop quality, and data-driven decision-making. However, challenges such as high initial investment, the need for technical expertise, and effective data management can hinder its implementation. Despite these obstacles, the potential of precision farming to revolutionize agricultural practices for plantation and spice crops is significant, promising a future of smarter and more sustainable farming.

Keywords: Precision Farming, Plantation Crops, Spice Crops, Remote Sensing, Geographic Information Systems (GIS).

Introduction

Precision farming, also known as precision agriculture, is a modern farming management concept that uses information technology, geospatial data, and advanced tools to optimize the use of resources like water, nutrients, pesticides, and labour. Precision agriculture has become a significant trend and direction in the current development of modern agriculture in the world. The goal is to improve crop yields, reduce costs, and minimize environmental impact. Plant phenotypic analysis, developmental stage observation, crop yield estimation, and plant density estimation all rely on it. In agricultural production, it is frequently employed to address real-world issues. In addition to helping farmers make appropriate economic and management decisions, accurate yield estimates can also help prevent famine. This method has shown great potential in the cultivation of plantation and spices crops, which require specific and careful management to ensure optimal growth and productivity. In this assignment, we explore the importance, techniques, and benefits of precision farming in the cultivation of plantation and spice crops.

Precision Farming

Precision farming, also known as precision agriculture, is an advanced farm management approach that utilizes information technology, geospatial data, and data-driven decision-making tools to optimize resource use and improve crop productivity while minimizing environmental impacts. It involves technologies such as remote sensing, Geographic Information Systems (GIS), Variable Rate Technology (VRT), automated irrigation, and real-time monitoring systems to enhance efficiency and sustainability in agricultural practices.

Precision Farming Techniques for Plantation and Spices Crops

- Remote Sensing and Drones
- Geographic Information System (GIS) and Global Positioning System (GPS)
- Soil Health Monitoring
- Variable Rate Technology (VRT)
- Automated Irrigation Systems
- Pest and Disease Management

1. Remote Sensing and Drones : Remote sensing technology and drones are vital tools in precision farming. These tools collect high-resolution images and data on crop health, moisture content, soil condition, and pest infestations. Drones equipped with sensors can provide real-time monitoring and mapping of plantation fields and spice crops. This data helps farmers make informed decisions on irrigation, fertilization, and pest control.

- **In Plantation Crops**: For crops like tea and coffee, drones can be used to monitor growth patterns and detect stress caused by weather or diseases.
- **In Spices**: Drones help in detecting early signs of pest damage or disease outbreaks, such as in pepper or cardamom plantations.

2. Geographic Information System (GIS) and Global Positioning System (GPS) : GIS and GPS are essential tools for mapping, monitoring, and managing agricultural lands. By integrating data from various sources, such as soil quality, moisture levels, and topography, GIS allows farmers to create detailed maps of their fields. These maps help in identifying areas of the plantation or spice farm that require specific attention, such as uneven soil quality or varying water needs.

- **In Plantation Crops**: GIS helps manage large-scale plantations (e.g., rubber and cocoa), optimizing land use by segmenting fields based on varying growth conditions and input requirements.
- **In Spices**: Spices like turmeric and pepper require careful planning due to their sensitivity to environment changes. GIS tools help identify micro-zones that may need different irrigation or fertilization strategies.

3. Soil Health Monitoring : Soil is the foundation of any agricultural activity. Regular monitoring of soil health is crucial in precision farming. Sensors and soil testing kits can analyse soil fertility, pH, moisture, and nutrient levels. This data helps farmers make precise decisions about fertilization and irrigation.

- **In Plantation Crops**: For crops like tea, soil acidity and nutrient levels play a vital role in quality and yield. Precision soil monitoring helps farmers apply specific nutrients to improve plant growth.
- **In Spices**: Spices such as black pepper require specific soil conditions. Monitoring pH and nutrient content helps farmers optimize soil health for better yield and quality.

4. Variable Rate Technology (VRT) : Variable Rate Technology (VRT) allows farmers to apply inputs like water, fertilizers, and pesticides at varying rates across the field based on specific requirements.

This technology uses data from sensors and GPS systems to adjust input levels automatically. This results in more efficient use of resources and minimizes waste.

- **In Plantation Crops**: VRT is especially useful in large plantations such as tea and coffee, where variations in soil and climate can result in differing needs across the field. VRT ensures that each area receives the right amount of fertilizer and water.
- **In Spices**: For spices like cardamom and turmeric, VRT helps apply fertilizers in the exact quantities required, preventing over-application that could damage the crops.

5. Automated Irrigation Systems : Efficient water management is essential for plantation and spice crops, which often require precise amounts of water at different growth stages. Automated irrigation systems, integrated with sensors and weather data, ensure that water is applied only when needed and in the required amounts. Drip irrigation and sprinkler systems are examples of technologies used in precision farming.

- **In Plantation Crops**: Plantation crops like coffee and rubber require consistent moisture. Automated systems optimize irrigation, reducing water wastage while ensuring proper hydration for healthy growth.
- **In Spices**: Crops like pepper and turmeric benefit from consistent moisture levels. Automated irrigation ensures that the crops receive adequate water during critical stages of growth.

6. Pest and Disease Management : Precision farming uses technology to detect pests and diseases early. This includes the use of sensors, cameras, and drones that identify areas affected by pests. Automated pest management systems can apply pesticides only to affected areas, reducing the overall chemical use and minimizing environmental harm.

- **In Plantation Crops**: Pests like tea mosquitoes and coffee borer beetles can damage large plantations. Precision pest management ensures early detection and targeted control measures.
- **In Spices**: Spices like cardamom and black pepper are susceptible to fungal diseases and insect pests. Precision farming helps in precise pest and disease control.

Importance of Precision Farming in Plantation and Spices Crops

Plantation crops like tea, coffee, rubber, and cocoa, as well as spices such as pepper, cardamom, and turmeric, require specific attention to soil health, irrigation, pest control, and weather conditions. These crops are sensitive to environmental changes, and inefficiencies in management can lead to reduced yields and poor quality. Precision farming helps address these challenges by:

1. **Optimizing Resource Use**: By carefully monitoring soil conditions, water usage, and nutrient levels, precision farming ensures that inputs such as fertilizers and water are applied only when and where needed.
2. **Enhancing Crop Productivity**: Precision techniques help farmers track growth patterns, detect stress or disease early, and manage inputs to maximize yield and quality.
3. **Sustainability**: With the use of advanced technologies, precision farming minimizes the environmental impact, reducing the overuse of chemicals and conserving water and soil.
4. **Cost Reduction**: By using resources more efficiently, farmers can reduce their input costs, leading to higher profitability.

Benefits of Precision Farming in Plantation and Spices Crops

1. **Increased Yield**: By optimizing inputs like water, fertilizers, and pesticides, precision farming helps increase crop yields while maintaining quality.
2. **Cost Efficiency**: Precision farming reduces unnecessary inputs, lowering costs and increasing profitability for farmers.
3. **Sustainability**: Efficient use of resources reduces environmental impact, making farming practices more sustainable.
4. **Improved Quality**: The precise application of nutrients and water enhances the quality of crops, especially in high-value plantation and spice crops.
5. **Data-Driven Decision Making**: The availability of real-time data allows farmers to make informed decisions and adjust practices based on changing conditions.

Challenges in Implementing Precision Farming

While the benefits of precision farming are evident, there are challenges to its implementation in plantation and spice crops:

1. **High Initial Investment**: The setup costs for precision farming technologies such as drones, sensors, and automated systems can be high.
2. **Technical Expertise**: Farmers may need training to effectively use advanced technologies and interpret the data.
3. **Data Management**: Collecting, analysing, and acting on large amounts of data requires skilled labour and infrastructure.

Conclusion

Precision farming holds immense potential for improving the productivity, sustainability, and profitability of plantation and spice crops. Through advanced technologies like drones, GIS, automated irrigation, and soil monitoring systems, farmers can optimize their use of resources and enhance crop health. Despite the challenges of high initial costs and the need for technical expertise, the long-term benefits make precision farming a worthwhile investment. As technology continues to evolve, it is expected that more farmers will adopt precision farming techniques, leading to smarter, more sustainable agricultural practices in the future.

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WASTE FROM WEALTH IN BANANA PSEUDOSTEM

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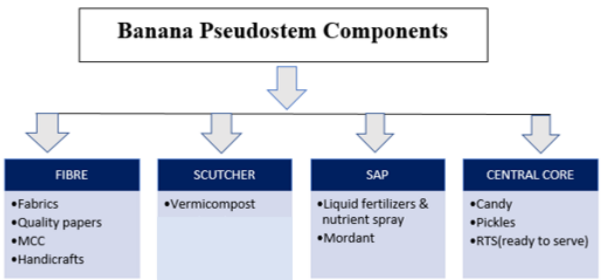
Abstract

Banana pseudostem, often considered agricultural waste, holds immense potential for value addition. India ranks third in banana cultivation area and first in production, generating significant pseudostem biomass. Traditionally discarded or burned, its disposal poses environmental and economic challenges for farmers. However, pseudostem can be processed into valuable products such as fiber for textiles and paper, vermicompost, liquid fertilizers, and edible items like candy and pickles. Mechanized fiber extraction enhances efficiency, fostering sustainable rural enterprises. Promoting awareness and skill development in pseudostem utilization can transform this byproduct into an economic asset, reducing waste and increasing farmer income.

Banana Pseudostem   Pseudostem Splitting   Raspador machine



Introduction

To a farmer dirt is not a waste, it is wealth likewise banana pseudostem is not a waste it is a wealth. India, with 8.4 lakh hectares under banana cultivation, ranks third in area and first in production (297 lakh MT). Beyond fruit, banana farming generates a large amount of biomass, particularly pseudostems, leaves, and suckers. However, in most states, pseudostems are treated as waste, with farmers spending ₹8,000–10,000/ha on disposal, leading to environmental concerns (Patil & Kolambe, 2011).

To harness this untapped potential, a World Bank-funded project, "A Value Chain on Utilization of Banana Pseudostem for Fiber and Other Value Products," was initiated under NAIP (ICAR), led by Navsari Agricultural University. Research at CIRCOT, Mumbai, resulted in the **Raspador machine**, which mechanizes fiber extraction. Additionally, Navsari Agricultural University (NAU) developed a **cutter machine** for efficient pseudostem splitting, making fiber processing faster and easier. These innovations aim to transform banana pseudostem into a valuable resource for fiber production (Desai *et al.,* 2016).

Banana pseudostem processing:
[MCC - Microcrystalline Cellulose powder, RTS - Ready to Serve (Beverage)]

Fibre based products

The textile grade fibre was extracted from banana pseudostem is obtained about 600 kg/ha. Using this fibre, the various byproduct was developed *viz.,* fabrics, quality papers, MCC and handicrafts (Patil and Kolambe, 2011).

1. Fabric
In fabric, the number of processes were followed for minimizing protruded fibres and making the fabrics smooth as well as soft. Banana fibre that produces synthetic leather can be used for sofa cover, car cover, school bags *etc..,* At CIRCOT, Mumbai woven and non-woven fabrics were prepared by using 100 per cent banana fibre. Modified version of yarn machine with 16 spindle, better quality yarn can be obtained. Subsequently, high value fabrics will be developed.

2. Quality papers
The variety of paper and board have been prepared using banana fibre in varying proportion. Using these paper and board, different articles like file cover, writing pad, art paper, printing paper, folder *etc.,* have been prepared. Paper prepared from fibre was found to have better quality than that from paper prepared from whole pseudostem. Process for developing quality grade papers *viz.,* anti-grease and cheque has been standardized.

3. MCC

The extracting microcrystalline cellulose (MCC) from banana fibre has been standardized. The quality of MCC extracted from banana fibre is comparable with commercially available MCC, the MCC from banana fibre is preferable in pharmaceutical industries.

4. Handicrafts
The various handicrafts items have been prepared using banana fibres and it includes decorative wall hangings, bags, dolls, key chains *etc.,*

Banana fibre articles

Painting made on banana fibre paper

Scutcher based products

Huge quantity of scutcher (about 30 to 35 t/ha) is generated during fibre extraction. The scutcher waste which is by-product obtained during fibre extraction from pseudostem using raspador machine is highly suitable for preparing good quality vermicompost (Patil and Kolambe, 2011).

1. Vermicompost

The vermicompost preparation can be done using pesudostem scutcher and dungs. The ratio of scutching waste and dung is 70:30 was found to be an ideal in terms of nutrient content. Scutcher based vemicomspost was pelleted and it also used as a fish feed. The vermicompost is blended with fish feed up to 30 per cent without any reduction in body weight of fish.

Sap based products

Banana pseudostem sap is obtained as a by-product during extraction of fibre. It is a rich source of plant nutrients like K, Fe and plant growth regulators. About 15,000 to 20,000 litres of sap can be extracted from one hectare of pseudostem (Patil and Kolambe, 2011).

Dyed fabric with sap

Dyed fabric without sap

1. Liquid fertilizer

Sap extracted from pseudostem as liquid fertilizer. Initially in different crops sap based liquid fertilizer can be apply through soil and foliar application. In response to its positive effect in enhancing the yields of the crops. Application of sap saves about 20 to 40 per cent RDF without affecting the yields. The enriched sap contains essential plant nutrient and also contains growth promoting substances *viz.,* giberallic acid and cytokinin.

2. Mordant

The sap are used as mordant in textile dying with natural dyes like *manjistha* and *annatto.* Textile dyes have good fastening properties when used with sap.

Central core-based products

Central core is inner most tender portion of the pseudostem which is edible. It is a by-product obtained from banana pseudostem during the process of fibre extraction. About 10 to 12 t/ha central core can be obtained from one hectare banana plantation. The various edible products can be developed using central core like candy, RTS and pickles (Patil and Kolambe, 2011).

1. Candy

The processing of central core into candy it makes delicious and palatable which is preferred by people and especially children. It contains digestible fibres, iron, vitamins B_3 and B_5 in appreciate amount.

2. Pickles

Pickle preparation can be done by blending central core with fruits and vegetables.

3. Ready to served drink

The soft drinks are being prepared from sugar syrup left out during candy preparation as well as directly from central core sap. Large quantity of sugar syrup generated during processing of banana central core candy is generally considered as waste material. The left-out syrup, with 70^{o} brix was flavored either artificially or naturally to improve its overall acceptability. The concentrated syrup is heated to 85ºC for 25 min followed by immediate cooling to room temperature. The prepared RTS drink is filled into pre-sterilized glass bottles and then hermitically sealed by crown corking machine. The bottles can be stored at ambient temperature for 6 months.

Conclusion

Hence, pseudostem can be used as a primary source for many values added products. A skill training program can be developed to raise knowledge on extraction of banana fibre and vermicompost preparation to the farming community and foster the rural enterprenuers in agriculture sector. Organizing training to women through SHG's on handicraft preparation from banana fibre. The major challenge among the small land holders is extraction of fibre from pseudostem due to the high cost of machinery. In order to overcome this problem, farmers can come together by any programs or group and extract the fibre from pseudostem which helps the land holders regardless of price and making them unite. In light of these banana pseudostem is a "Waste from Wealth".

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BIO-FUMIGATION: AN ORGANIC WAY OF REDUCING PLANT PARSITIC NEMATODES

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What is bio-fumigation?

It is a process where plants belonging to family Brassicaceae are incorporated in soil and release certain volatile organic compounds (VOCs) mainly glucosinolates (GSLs). These glucosinolates later gets hydrolyzed into isothiocyanates (ITCs), which are capable of suppressing various pest and diseases including Plant Parasitic Nematodes (PPNs). The damage caused by soil inhabiting PPNs is increasing day by day, causing considerable yield losses in most of the field crops. Their complete eradication is not possible, hence once introduced it becomes impossible to control them. Therefore management of nematodes is a difficult task and needs more and more reliable management tactics in order to minimize the increasing damage caused by them. Chemicals may effectively manage the incidence of pest and diseases to some extent but they simultaneously cause damage to the environment and other living beings. Hence bio-fumigation can be an alternative and eco-friendly approach to tackle the increasing incidence of soil pathogens including PPNs.

Common biofumigant crops:

Plants generally belonging to the Brassicaceae family such as broccoli, cauliflower, mustard and rapeseed containing volatile organic compound (Glucosinolates) are used for the process of bio-fumigation. The glucosinolates after going under enzyme mediated hydrolysis are converted into isothiocyanate, which act as biocide and kill the harmful disease causing soil inhibiting pathogens and nematodes. The isothiocyanate produced by mustard is called “Ally isothiocyanate” (AITC).

Raising and managing a biofumigant crop:

- Selection of the right variety.
- Soil testing in order to ensure the appropriate amount of required nutrients by the biofumigant crops.
- Sowing should be done at proper time.
- The incorporation of the biofumigant crop should be done at the time of mid flowering, where the GSL levels are highest.
- Proper tools and machinery should be available.
- A recommended seed rate should be taken.
- Maceration and incorporation should be done when soil moisture levels are optimum, otherwise soil structure may get damaged.
- Soil temperatures more than 12^0 C improves the formation of ITC.

Soil incorporation:

The incorporation of the mustard should be done before full bloom and before it starts to produce seeds i.e., about 2 weeks after flowering has started.

- Soil incorporation should be done before the full bloom stage of the mustard crop

- It should be done in the morning and evening
- Prior to incorporation proper soil moisture should be maintained.
- Before incorporating, the mustard crop should be properly chopped and crushed with the help of flail mower
- It should be immediately incorporated after mowing so that 80% of the fumigant gas will be released in first 20 minutes after mowing.
- Proper selection and usage of tool which can place as much plant material as possible into the top 15 to 20 centimetre and do not use plough.
- After the completion of the incorporation process leave the field undisturbed for 14 days so that all the plant material can break down. The partial or incomplete breakdown might cause crop injury to the next crop.

Fig. (A) Bio-fumigant crop is grown up to an optimal life stage; (B) incorporated to release glucosinolates (GSLs); and tilled to release GSLs and isothiocyanates.

The benefits of bio-fumigation:

The benefits offered by the process of bio-fumigation varies with the type of biofumigant crop, local climatic and soil conditions and management practices adopted. Proper and timely incorporation of biofumigant crops leads to an improved soil health.

1. **Weed suppression**
   The glucosinolates (GSLs) and isothiocyanates (ITCs) released from the incorporation of biofumigant crops act as biocidal chemicals which ultimately results in the suppression of the weeds. Apart from biocidal properties, soil incorporation of biofumigant crops leads to improved soil health, providing various essential nutrients to crops. This results in early and vigorous growth of the crops, suppressing the growth and development of weeds.
2. **Soil biology**
   Bio-fumigant crops after being incorporated in the soil, release certain biocidal chemicals which suppress the harmful disease causing insects and pests by disrupting their life cycle at various life stages. Apart from this they also enhance the populations of beneficial soil micro-organisms such as mycorrhizal fungi, nematophagous fungi, PGPRs etc.
3. **Soil organic matter**
   After the incorporation of biofumigant crops the organic matter of the soil is replenished. The micro-organisms break down organic matter and produce sticky substances that bind soil particles together to form soil aggregates. This further improves:
   - Overall microbial activity
   - Enhanced nutrient content
   - Root growth

- Increased water holding capacity
- Improved water and air holding capacity
- Improved soil structure

4. **Nutrient cycle**
   Bio-fumigation directly or indirectly leads to an increased population of beneficial soil micro-organisms, these further play an important role in breakdown and mineralisation of essential plant nutrients. Certain nitrogen fixing bacteria and others sulphur and phosphorus solubilising bacteria play a vital role in cycling these nutrients in the environment.
5. **Sustainable and Natural Control**
   Bio-fumigation can be integrated into Integrated Pest Management (IPM) systems, providing an organic method of nematode control that fits into broader sustainable farming practices. It works alongside crop rotation, natural predators, and other soil health-promoting techniques to suppress nematodes. Unlike chemical treatments, bio-fumigation is highly specific in targeting nematodes and doesn't generally harm other non-target organisms like beneficial insects and soil microorganisms.
6. **Natural Nematode Suppression**
   Effective Nematode Control: The release of isothiocyanates and other bioactive volatile organic compounds (VOCs) during bio-fumigation has been shown to effectively suppress or kill various species of plant parasitic nematodes, including root-knot nematodes, cyst nematodes, and others. This provides a natural and effective means of managing nematode populations. Bio-fumigation can provide long-lasting effects by reducing the nematode population in the soil. When used as part of a crop rotation system, it helps lower nematode populations over time, reducing the need for frequent reapplications of chemical treatments.

Conclusion

In conclusion, bio-fumigation presents a promising, environmentally friendly alternative to chemical treatments for managing plant parasitic nematodes. By utilizing naturally occurring bioactive compounds in plants, such as glucosinolates in brassicas, bio-fumigation can suppress nematode populations while minimizing ecological impact. Although further research is needed to optimize its effectiveness and application methods, bio-fumigation offers a sustainable strategy for integrated pest management, reducing dependency on harmful chemical nematicides and promoting soil health.

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BUILDING A SUSTAINABLE FUTURE FOR INDIAN AGRICULTURE: IFFCO'S STRATEGIES FOR REGENERATIVE AGRICULTURE

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Abstract
Farmers make everyday decisions related to farming such as how much fertilizer to be applied, time of application, the specific area to be applied, which resources are needed for plant protection, and related aspects based on limited information, traditional knowledge, and hearsay. This can lead to wastage of resources, greater costs, and unsustainable farming in the longer run. Precision agriculture involves the application of technologies and agronomic principles to manage all aspects of agricultural production to improve crop performance and minimize environmental impact. This paper aims at focussing the efforts of IFFCO- the largest cooperative in fertilizer sector in the world, to promote regenerative agriculture which would be essential and inevitable for climate resilient agriculture.

Introduction

As the world population approaches 10 billion by the end of this century, producing enough high-quality food to feed every hungry mouth will be paramount. On the other hand, while the population will increase, the availability of arable land and other natural resources will not increase. Ultimately, this demands efficient use and protection of existing resources to maintain their viability well into the future. This means the impact of farmers', agronomists', researchers', and other stakeholders' decisions will be magnified. Farmers' decisions will directly tie to their own profitability and viability as well as the sustainability of the world's population. Decision-making in agriculture can be supported by the vast amounts of agronomic data collected in modern agriculture to provide information and insight that support balanced decisions. With advancements in agriculture data systems, it's easier than ever for data to be a key support in making sustainable decisions. The outlook for farming in future under climate change scenario is uncertain and influenced by many factors including:

- Geopolitical outlook-The war in Ukraine and Israel is affecting the country's ability to produce and ship fertilizers and raw materials. A potential tariff war between the US and other countries could also impact farmers' margins.
- Climate change- Long-term climate change trends will continue to affect agricultural productivity. Warmer temperatures may lengthen growing seasons in northern regions, but negatively impact production in lower latitudes.
- Severe weather- Increased severe weather occurrences, including powerful tornadoes in the Great Plains and Southeast, and potentially worsening drought conditions in the Midwest.
- Inflation- Farmers are still experiencing historically high input costs due to inflation.

- Net farm income- Net farm income is expected to fall to its lowest level in nearly a decade, with a forecasted decline of 15%-20% from 2024 levels.

Some other factors that may impact farming in future include: labour shortages, low stock levels, and stalled-out farm policy. In future, data-driven solutions are expected to become integral to efficiency across the agricultural value chain. From accelerating product trials to optimizing precision crop nutrition protocols, these tools will deliver actionable insights, enhancing productivity and supporting regenerative practices in real-time.

Using precision ag-tech tools for precise nutrient management will be more important now than ever before. However, farmers and fertilizer industry will face the problem of higher fertilizer costs because in India, the prices of fertilizers depend on prices of raw materials like natural gas, phosphate rock, potash, phosphoric acid etc. in the global markets and also due to geo-political events (Ukraine, Israel wars). Because crop performance is dependent on so many factors, regenerative agriculture and data analysis can help farmers, agronomists and industry professionals better understand the impacts of technologies, production practices, or even the changing climate. Regenerative agriculture is the way forward to decarbonize the food system and make farming nature-positive and resilient to climate shocks. At IFFCO, we consider regenerative farming to be the future of farming. We see regenerative agriculture as a systematic, outcome-based approach to adopt the best sustainable farming practices that positively affect nature and climate across the world. This paper aims at focussing the efforts of IFFCO- the largest cooperative in fertilizer sector in the world, to promote regenerative agriculture which would be essential and inevitable for climate resilient agriculture.

Regenerative Agriculture

Our planet and humanity are basically supported by a 10-30 centimetre layer of soil, and it is our most precious resource. Healthy soil matters for our health – and the health of the planet. Just like us, soil is a living organism that needs air, water and essential nutrients to thrive. Healthy soil maintains water management, recycles nutrients, and plays a pivotal role in storing carbon, helping mitigate climate change. Soil health is the foundation for resilient crop production and sustainable farming. Balanced crop nutrition together with good agricultural practices are crucial for the regeneration of our soils. When fertilizers are applied to degraded soils and supported by a balanced crop nutrition program, the soil organic matter will increase. Analysis of more than a hundred long-term fertilizer trials shows that fertilized land has a higher soil organic matter content than unfertilized land. Land managed by supplying organic sources of nutrients, in addition to mineral sources, has the highest content of soil organic matter. Balanced crop nutrition combined with good agricultural practices are crucial for the regeneration of our soils. IFFCO provides farmers with crop nutrition solutions, tools, services and knowledge to preserve and improve soil, helping grow a nature-positive food future. Regenerative farming methods, including reduced tillage, cover cropping, and balanced crop nutrition are key to restoring and maintaining soil health. However, digital tools and data from soil analysis are crucial in optimizing nutrient use efficiency - an essential aspect for the transition to sustainable, nature-positive agriculture. With over 60 years' experience in research and commercial analytical services, IFFCO's Analytical Services analyses samples from all over the country, equipping farmers with precise scientific assessments and enabling tailored management practices. By now, it's clear how much technology is reshaping agriculture under the scenario with rising costs, climate challenges, and persistent uncertainties pushing many to embrace a "do more with less" mindset under tight deadlines.

IFFCO’s Solutions for Regenerative Agriculture

Solving the Greatest Food Challenges Together: With our agronomic expertise, IFFCO is well prepared to innovate and respond to the new challenges the agriculture industry is facing. However, we cannot do this alone. We call on all actors across the food value chain to transform our food system through regenerative agriculture. Let’s take action to feed the world and support the climate, nature and our farmers. Together, we can secure crop supply and produce more food while using less of the planet’s resources.

With our agronomic expertise, IFFCO is well prepared to innovate and respond to the new challenges the agriculture industry is facing. However, we cannot do this alone. We call on all actors across the food value chain to transform our food system through regenerative agriculture. Let’s take action to feed the world and support the climate, nature and our farmers. Together, we can secure crop supply and produce more food while using less of the planet’s resources.

Our approach to regenerative agriculture takes advantage of more than 60 years of agronomic expertise, to innovate and respond to new challenges. Our solutions can positively impact the five themes of regenerative agriculture in a measurable way.

Climate

To mitigate emissions and improve crop resilience*:* Our solutions can reduce field emissions and improve crop resilience to climate shocks. By applying advanced technology, we can reduce emissions, such as using low-carbon footprint fertilizers produced with renewable electricity.

Biodiversity:

To reduce pressure on land use change and to protect natural habitat: By adopting IFFCO’s regenerative agriculture practices, farmers can reduce land use changes and protect natural habitats. Our sustainable solutions can improve soil health and reduce emissions, thereby contributing to field biodiversity.

Soil health

To improve soil fertility, soil structure, biodiversity and prevent soil degradation: Ensuring soil health is essential for efficient farming. Our balanced and optimized crop nutrition solutions can help enhance soil, thereby preventing soil degradation.

Resource use

The efficient use of all necessary resources required for crop growth: Our digital tools and crop solutions can help produce more, with less, through water use efficiency and by applying the right nutrients, in the right amount, at the right time.

Prosperity

To improve farmer livelihoods: With our crop nutrition products, agronomic knowledge and digital solutions we can support farmers to reduce costs and increase crop yield, quality and resilience, all while impacting nature and climate positively.

Scaling Up Regenerative Agriculture

As stewards of the soil, farmers are at the core of the transition to regenerative farming. However, today, the main barrier to this is the lack of short-term commercial attractiveness for farmers. The risk and cost of the transition are key challenges that need to be addressed by all players across the food value chain.

The commitment and collaboration of all actors in the food system to create an environment that rewards and incentivizes farmers is crucial in order for the transition, and scaling up, of regenerative farming.

IFFCO's Approaches for Regenerative Agriculture

Today's farmers are faced with many challenges including feeding a growing population, providing a livelihood for themselves, and protecting the environment. Farmers make everyday decisions related to farming such as how much fertilizer to be applied, time of application, the specific area to be applied, which resources are needed for plant nutrition and related aspects based on limited information and traditional knowledge. This can lead to wastage of resources, greater costs, and unsustainable farming in the longer run. Precision agriculture involves the application of technologies and agronomic principles to manage all aspects of agricultural production to improve crop performance and minimize environmental impact. Our approaches to regenerative agriculture take advantages of more than over six decades of agronomic expertise, to innovate and respond to new challenges. Our solutions can positively impact the five themes of regenerative agriculture in a measurable way.

Crop nutrition

Crop and agronomy knowledge: Every day, our agronomists deliver the best crop nutrition recommendations and solutions to our farmers, giving valuable technical advice on how to produce efficiently and profitably in a sustainable way. Our agronomists and sales agronomists work actively in the field to help farmers implement solutions to efficiently grow high-yielding, top-quality crops while protecting the planet. Over the past 60 years, IFFCO has accumulated unrivalled knowledge in crop nutrition. Here's how:

- We are providing "Holistic Crop Nutrition solutions" through an array of inputs like conventional fertilizers, biofertilizers, bio stimulants, speciality fertilizers (water soluble fertilizers, secondary and micronutrients containing fertilizers apart from Nanofertilizers (Nano Urea Plus (20% N), Nano DAP (8% N and 16% P_2O_5), Nano Zn and Nano Cu).
- Our field executives and researchers have conducted thousands of trials on Nanofertilizers and collected over millions of soil samples and analysed for appraising soil fertility status in respect of macro, secondary and micronutrients to deepen our understanding of every farming environment, soil context, and crop type.
- We work with farmers on the ground and this allows us to learn lessons on the same crop grown in different agro-ecological/climatic zones of India, making our knowledge global and unique.
- We have very intensive promotional programmes (Field demos., Crop Harvest Days, crop seminars, Seminars and Workshops, Field Days, Farmers group meetings at their door steps, Agricultural Exhibitions etc.) to create greater awareness among farmers about our innovative products and their scientific use based on 4R principles (Right fertilizer, Right quantity, Right time and Right method of application) to ensure balanced and efficient use of nutrients to ensure "Maximum Economic Yield" in a cost effective and eco-friendly way under changing climate.
- We collaborate and build partnerships with the food chain and research communities. Our trials and projects are connected to leading R&D institutions and ICAR and State Agricultural Universities.

- While AgTech has continued to revolutionize traditional practices through data-driven solutions, advanced AI, and sustainable innovations, the challenges of the past years have tempered the speed and impact of some trends. Looking forward to future, AgTech promises to deliver not just innovative tools but actionable solutions that can be implemented and scaled to address pressing challenges. Our focus is on tackling resource scarcity, mitigating climate change impacts, and supporting resilient food systems. Key trends such as regenerative agriculture, AI-powered data insights, increased adoption of BioSolutions, and digital twin technology are expected to drive significant progress.

Data-Driven Regenerative Agriculture

Regenerative agriculture is transforming global farming by focusing on improving soil health, biodiversity, and sustainable crop production. In recent years, the application of AI in agriculture has empowered farmers to adopt regenerative methods more effectively by tailoring decisions to local conditions and ecological needs. The adoption of regenerative agriculture, indeed, accelerated, but with a broader focus than initially expected. However, motivations varied by region, with yield improvement driving adoption in India, Latin America, and North America, while European farmers were more motivated by additional revenue streams. The “nature positive” movement, which emphasizes net gains in biodiversity and ecosystem health, is gaining traction in agricultural circles. New focus areas will allow companies to implement practices that align with specific regional and ecological requirements. This shift supports practical ways to measure and assess the impact of regenerative agriculture on tangible aspects such as soil quality, biodiversity levels, and forest conservation efforts, thereby enhancing the resilience and sustainability of agricultural systems.

Regenerative Agriculture and Agriculture Analytics

Precision agriculture was a major innovation when it came about in the 1990s but on its own today, it’s simply not enough. In the world of modern applications, stand-alone data in silos is of little use to application developers and operators and cannot enable evidence-based decision-making. These silos and the manual processing required, limit the benefits of technology for the farmer. The future of agriculture is in precision agriculture analytics. These combined with interconnected regenerative agriculture systems provide for maximum efficiency, profitability, and sustainability. In computing, the term “silos” has also become a great visual analogy for many of the problems with IT and software development. Data silos occur naturally as each department in an organization collects and stores its own data for its own purposes. This type of disconnect is evident in agricultural data silos too. Related types of data are dumped into purpose-built databases with monitoring data in one place, financial in another, and crop information and inventory in a third. Vast quantities of data are stored in these so-called stand-alone agricultural data silos and because of their lack of interconnectivity, cannot maximize the benefits of 21st-century advances in agricultural technology. **The importance of breaking data silos-**one of the greatest challenges that crop growers and researchers face today is the fragmentation of data sources with valuable information being stored in these agricultural data silos.

Regenerative Agriculture AI: Unlocking New Data Potential

Generative AI, a critical aspect of AI in agriculture, is revolutionizing industries by enabling smarter decision-making through the analysis of complex data. Generative AI, a critical facet of AI in agriculture, is transforming industries by enabling smart decision-making through the analysis of complex data. In agriculture, this technology holds the potential to drive insights from vast datasets, allowing farmers, agronomists, and researchers to optimize productivity and sustainability. In future, Generative AI is set to become a cornerstone for agricultural companies to unlock real-time insights from vast datasets, empowering agronomists and researchers to optimize product performance and accelerate decision-making. By driving innovation and showcasing the role of AI in agriculture, these tools also help validate the efficacy of solutions like biologicals, which play a critical part in advancing sustainability.

Driving Product Development and Grower Success Through Data: Data-centric technologies are essential not only for optimizing field trial outcomes and enhancing decision-making but also for driving innovation in agricultural practices. Beyond streamlining operations, these technologies enable breakthroughs and pave the way for new approaches. By integrating data across the agricultural value chain, companies not only improve efficiency but also accelerate the pace of innovation, demonstrating the role of AI in agriculture. The adoption of digital tools would vary significantly across regions and farm sizes. In future, data-driven solutions are expected to become integral to efficiency across the agricultural value chain. From accelerating product trials to optimizing precision crop nutrition protocols, these tools will deliver actionable insights, enhancing productivity and supporting regenerative practices in real-time. As biodiversity gains prominence as a corporate priority, data tools will play a crucial role in measuring the impact of farming practices on local ecosystems, enabling companies to achieve both sustainability and productivity goals.

Meeting Resource Constraints with AI and Machine Learning : With finite resources and rising costs, the agricultural sector must innovate to meet the needs of a growing global population. BioSolutions, AI, machine learning in agriculture, and other sustainable practices are increasingly vital, allowing farmers to maintain productivity while reducing environmental impact. This technological integration is set to help address such resource constraints, further demonstrating the impact of artificial intelligence in agriculture.

Digital Twins : The Untapped Frontier in Agriculture-Digital twins create virtual replicas of real-world systems, allowing industries to simulate conditions and predict outcomes without physical testing. Although widespread in healthcare and manufacturing, digital twins represent a largely untapped resource in agriculture, promising enhanced precision and reduced costs in field trials. The sector faced challenges such as limited data integration, slower technology adoption rates, and the complexity of replicating dynamic environmental variables in virtual models. Despite these hurdles, interest in the potential of digital twins began to grow, setting the stage for future advancements. In future, digital twin technology is expected to gain traction in agriculture. By enabling virtual testing of factors like soil types and weather conditions, digital twins will reduce time and costs in product testing and support more precise innovation in agricultural practices. These models could also help agricultural stakeholders better understand and manage the ecological impact of various practices, contributing to nature-positive outcomes by simulating environmental effects. Moreover, the integration of synthetic data with digital twins is anticipated to transform field trials, enhancing their efficiency, accuracy, and safety. This combination allows researchers and agronomists to model scenarios that were previously impractical, supporting smarter resource use and adaptive management strategies. By empowering stakeholders with actionable insights, digital twins can accelerate innovation and pave the way for a more resilient and sustainable agricultural future.

Maximizing the transformation of big data into actionable insights

Having access to big data is great, but to benefit from it, this data needs to be transformed into something actionable. Several parameters influence agricultural growing practices including changes in the weather, temperature, rain, and soil pH which can all be accurately measured. When these are properly integrated, they enable the farmer to not only carry out sound precise agriculture but also to be able to make extemporaneous adjustments based on changes in weather and wind and make accurate calculations regarding fertilizer type and application rates.

Conclusion

As we look back and forward, it’s clear that the agricultural sector is rapidly evolving. For future, we anticipate even more significant advancements in data-driven agriculture, machine learning, and other innovative solutions allowing us to tackle resource constraints, along with the adoption of disruptive technologies like digital twins. It is also clear that the impact of artificial intelligence in agriculture will be a key driver in shaping a regenerative agricultural future. To fully leverage these technological advancements in future, agricultural stakeholders should prioritize data integration and interoperability, focus on developing user-friendly solutions, emphasize education and support for new technologies, foster collaboration between technology providers, research institutions, and agricultural stakeholders and adapt solutions to regional needs and farm sizes. By embracing these trends and focusing on practical implementation, agriculture can build a more resilient, productive, and sustainable future for food production. The commitment to biodiversity and nature-positive practices, alongside technology-driven advancements, will be key in shaping a truly sustainable agricultural future.

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ARTIFICIAL INTELLIGENCE: A REVOLUTIONARY APPROACH TO POSTHARVEST MANAGEMENT

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Summary

Artificial intelligence emergence revolutionized the enhancement of postharvest innovations or any improved storage technologies as it helps play a critical role in postharvest management, offering effective solutions to reduce losses, maintain quality, and extend the shelf life of agricultural produce. The adoption of these technologies can significantly contribute to food security, improve livelihoods, and promote sustainable agricultural practices. While challenges remain in terms of cost, technical expertise, and infrastructure, targeted interventions such as government subsidies, research and development, extension services, and public-private partnerships can promote the wider adoption of AI as improved postharvest technologies. By embracing this AI innovation and investing in effective postharvest management strategies such as this, farmers can be assured of reduce food losses, enhance food availability, and build a more sustainable and food-secure future.

Introduction

Postharvest losses (PHLs) remain a global challenge posing significant threats to agricultural sector and economy of countries, especially the developing countries such as Nigeria. An estimated 20-40% of food crops harvested in Nigeria were lost due to poor handling, inadequate storage, and inefficient processing. These losses impact all actors' across the value chain incomes, food security, and the nation's agricultural economy. However, the emergence of postharvest innovative technologies are bridging the gap and helping to reduce the much impact of these loss on the economy and livelihood of handlers (Ilahy, 2023). The major strategies in food crop loss reduction is the practice of effective handling management practices such as the use of artificial intelligence innovations are crucial in mitigating these losses. These practices encompass a range of activities, including proper harvesting techniques, storage conditions, transportation methods, and processing technologies, all aimed at preserving the quality and quantity of harvested crops from the point of harvest to consumption (Hodges et al., 2011).

Causes of postharvest loss in commodities

Postharvest loss in food crops occurs as a result of many factors which can be classified into two main categories: biotic factors (insect, pest, rodents, and fungi) and abiotic factors (temperature, humidity, rain). Moisture content and temperature are the most crucial factors affecting the storage life. Most of the storage molds grow rapidly at temperatures of 20–40 _C and relative humidity of more than 70% (Abedin, et al. 2012). Low moisture keeps the relative humidity levels below 70% and limits the mold growth. In the traditional storage structure, temperature fluctuations due to weather changes cause moisture accumulation either at the top or bottom of the grains' bulk depending on the direction of air convection (Kumar and Kalita, 2017). This can be avoided by minimizing the temperature difference of inside and outside the storage structure.

Technology in postharvest handling

The adoption of improved postharvest technologies has a significant positive impact on postharvest management. The Hermetic storage solutions, like Purdue Improved Crop Storage (PICS) bags, are airtight containers that prevent moisture, air, and pests from entering. Solar-Powered Cold Storage: Solar-powered cold storage solutions, such as ColdHubs, provide farmers with a reliable way to store perishable products like fruits, vegetables, and dairy without relying on the national grid. Reducing losses, maintaining quality, and enhancing food security is the major role of improved storage technologies. The following are reason of the technologies innovation in postharvest:

- Reducing Postharvest Losses: Improved storage technologies can reduce postharvest losses by up to 50-60% (Kumar and Kalita, 2017). Hermetic storage, for example, can reduce losses to as low as 1-2%. Proper storage conditions, such as temperature and humidity control, can also help reduce losses.
- Maintaining Quality: Improved storage technologies can help maintain the quality of agricultural produce by preventing spoilage and damage. Techniques such as modified atmosphere packaging and vacuum packaging can help preserve the quality of perishable crops. Improved storage facilities can also help reduce the risk of contamination and pest infestation.

The use of Artificial intelligence to enhance postharvest technologies becomes inevitable due to technological change.

Emergence of Artificial intelligence

The evolution of artificial intelligence (AI) has been propelled by the development of diverse machine learning algorithms, which have contributed to the refinement and advancement of the technology (Apell and Eriksson, 2023). Machine learning is a branch artificial intelligence thus, a techniques that encompasses the study of algorithms that enhance computer programs through experiential learning. This method uses data sets comprising examples of precise attributes or features manifested as numeric values or binary digits. The assessment of a machine learning model's performance in a specific task is gauged using a performance metric that refines with accumulated experience (Bharadiya, 2023). Deep learning is a type of machine learning that uses artificial neural networks to learn and make predictions from data. It uses a multi-level structure to interpret image properties, leading to improved image recognition accuracy. It is based on the principle that models should be able to interpret problems utilizing a hierarchical structure of concepts. In Postharvest management, several deep-learning models have been used for fruit quality assessment. However, one of the most used models is Convolutional Neural Networks (CNNs) (Dhiman *et al.,* 2022). CNNs are well suited for image classification tasks, including fruit quality assessment, as they can automatically learn features from images without requiring manual feature engineering. In the case of fruit quality assessment, CNNs can be trained to classify fruit based on various quality attributes such as color, size, shape, bruises, and other defects. There have been several studies that have used CNNs for fruit quality assessment. For example, Ganesh *et al.* (2019) used CNNs to assess the quality of apples, tomatoes, and bananas based on their appearance. One of the advantages of using CNNs for fruit quality assessment is that they can be easily retrained to recognize new fruit varieties or adapt to environmental conditions (Ganesh *et al.,* 2019).

Prospect and Advances of Artificial Intelligence in Postharvest Handlings: case study fruits

Thermal imaging is a non-intrusive technique that comprehensively assesses temperature variations across a sample. While traditional temperature measurement methods, such as thermocouples, thermometers, thermistors, and resistance temperature sensors, have been employed for monitoring food and agricultural products, thermal imaging offers the distinct advantage of simultaneous, real-time monitoring of large areas. This capability enables the detection of subtle temperature fluctuations that may indicate incipient quality defects or physiological changes. Additionally, thermal imaging provides rapid data acquisition, significantly reducing processing time compared to conventional methods. The following sub sections explored few applied AI-powered thermal imaging techniques in various post-harvest fruit handling operations.

1. Bruise detection

Bruising, the prevalent surface damage sustained by crops, particularly during post-harvest handling and transportation, manifests as thermal variations between bruised and non-bruised produce. Thermal imaging has emerged as a promising tool for detecting bruises, capitalizing on the differential thermal properties of bruised and sound tissues. Recent studies have further explored the applicability of thermal imaging in guava bruise evaluation, examining the impact of temperature variations on bruise detectability (Kuzy *et al.,* 2018). To address jujube fruit bruise detection Havens and Sharp (2016) have proposed a novel approach that integrates thermal imaging with a convolution neural network (CNN).

2. Maturity identification

Thermal imaging has emerged as a valuable tool for fruit maturity assessment, offering a non-destructive and efficient method to determine the ripening stage of various produce. This technique relies on detecting infrared radiation emitted by fruits, which varies in intensity based on their physiological and biochemical properties. As fruits mature, their metabolic activity increases, resulting in a rise in surface temperature. Thermal imaging captures this temperature variation, providing a reliable indicator of maturity level. Xu, *et al.* (2006) have successfully utilized thermal imaging to identify immature green citrus fruits, providing a non-destructive method for assessing citrus maturity.

3. Condition monitoring

This technique detects infrared radiation emitted by fruits, which varies in intensity based on their physiological and pathological states. In disease detection, thermal imaging has proven to be an effective tool for distinguishing between healthy and virus-infected tomatoes (Raza, *et al* 2015). Raza, *et al* (2015) observed a notable temperature drop in infected tomatoes compared to healthy ones, suggesting potential disease-induced alterations in metabolic processes. This paves the way for the development of thermal imaging-based disease detection systems for tomatoes and potentially other crops

4. Pest and disease detection

This method proves invaluable for early pest and disease detection, mitigating disease transmission, and reducing crop losses. In the realm of temperature monitoring Kuzy *et al*., (2018) have employed thermal imaging to accurately track the surface temperature of apples stored in both plastic and cardboard containers. The study achieved impressive estimated errors of 0.410 and 0.086 for plastic and cardboard containers, respectively, highlighting the effectiveness of thermal imaging for monitoring temperature variations under different packaging conditions. Thermal imaging has also proven its value in optimizing post-harvest treatment processes

Conclusion

The utilization and up-scaling of artificial intelligence (AI) for postharvest management in ensuring quality is gained significant traction in agricultural sector. Improved postharvest technologies play a critical role in advancing postharvest management by reducing losses, maintaining quality, and enhancing food security. The adoption of improved technologies can also help improve the livelihoods of farmers and reduce poverty. Furthermore, in fruits handling, The thermal imaging in AI is a versatile and powerful tool for fruit quality evaluation, it represents just one facet of the evolving spectrum of AI-based approaches. Machine learning algorithms can discern patterns and identify distinctive attributes signifying fruit quality by analyzing extensive spectral datasets. Hence, the use of technological innovations in Nigeria's agricultural sector is crucial to minimizing post-harvest losses, improving food security, and increasing farmer incomes. By adopting cold storage, mobile apps for market access, block chain, and mechanized harvesting tools, Nigerian farmers can better preserve their harvests and reduce waste.

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CREATING A FREQUENCY TABLE IN MS EXCEL: A STEP-BY-STEP GUIDE

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Abstract

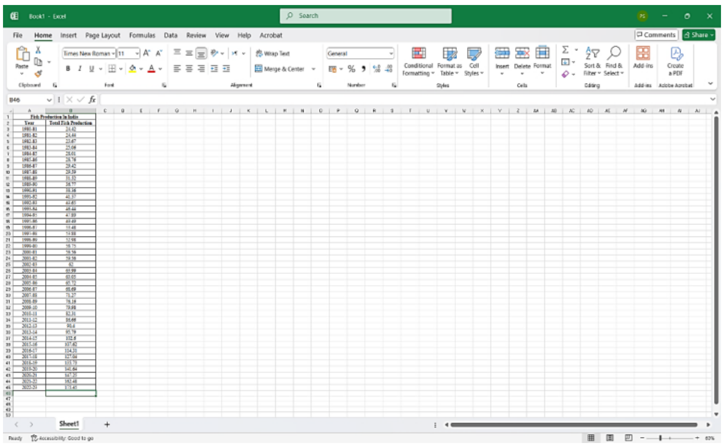
A frequency table is a statistical tool that groups data by listing values and their frequencies, facilitating the determination of common and unusual occurrences in a data set. Such tables, also referred to as frequency distributions, reveal information about data trends and patterns. Microsoft Excel contains pre-installed tools such as the Data Analysis ToolPak, which facilitates the generation of frequency tables. This article describes step-by-step the process of building a frequency table with Excel's Histogram function through an example taken from fish production data in India.

Keywords: Frequency Table, MS Excel, Data Analysis ToolPak, Histogram, Fish Production

Introduction

A frequency table is used to summarize or condense the large datasets by categorizing values into predefined intervals or groups. It is an important statistical tool for ascertaining trends and distributions in data. Microsoft Excel provides an easy way to generate frequency tables via the Histogram feature of the Data Analysis ToolPak. This article gives a step-by-step guide to making a frequency table, utilizing fish production in India from the Handbook of Fisheries 2023 as an illustration

Step 1 : Open a New MS- Excel Worksheet and enter the data as per your need
(Here Fish production data in India is taken from the Handbook of Fisheries 2023)



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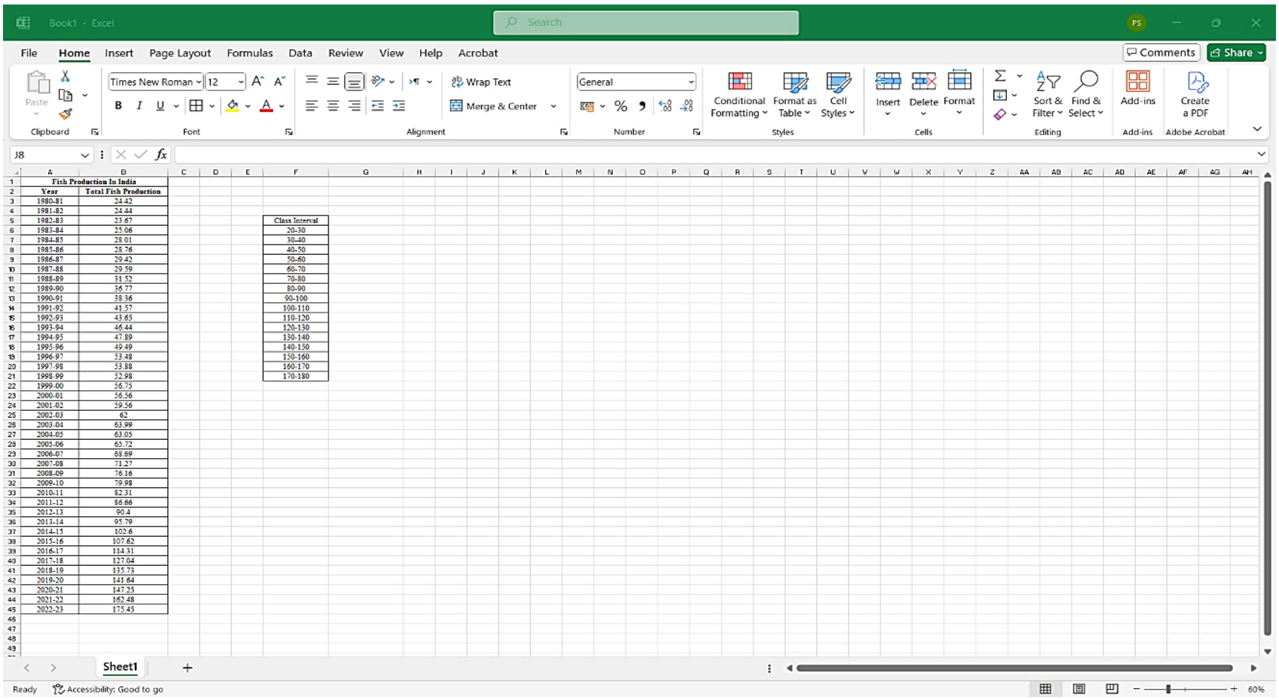
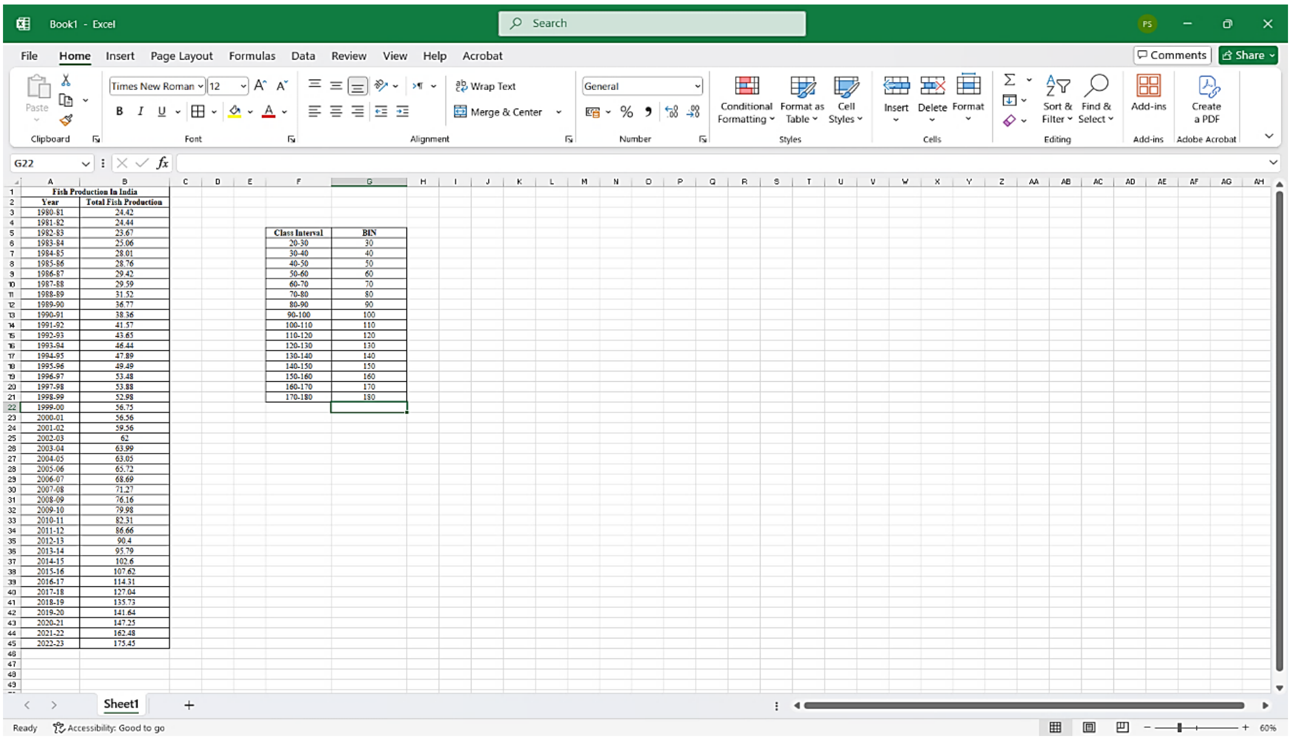
Step 2: Enter the Class Intervals in a separate column



Fish Production In India	
Year	Total Fish Production
1980-81	24.42
1981-82	24.44
1982-83	23.67
1983-84	25.06
1984-85	28.01
1985-86	28.76
1986-87	29.42
1987-88	29.59
1988-89	31.52
1989-90	36.77
1990-91	38.36
1991-92	41.57
1992-93	43.65
1993-94	46.44
1994-95	47.89
1995-96	49.49
1996-97	53.48
1997-98	53.88
1998-99	52.98
1999-00	56.75
2000-01	56.56
2001-02	59.56
2002-03	62
2003-04	63.99
2004-05	63.05
2005-06	65.72
2006-07	68.69
2007-08	71.27
2008-09	76.16
2009-10	79.98
2010-11	82.31
2011-12	86.66
2012-13	90.4
2013-14	95.79
2014-15	102.6
2015-16	107.62
2016-17	114.31
2017-18	127.04
2018-19	135.73
2019-20	141.64
2020-21	147.25
2021-22	162.48
2022-23	175.45

Class Interval
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140
140-150
150-160
160-170
170-180

Step 3 : Enter the BIN values in another column
(BIN values means the upper limits of each class interval)



Fish Production In India	
Year	Total Fish Production
1980-81	24.42
1981-82	24.44
1982-83	23.67
1983-84	25.06
1984-85	28.01
1985-86	28.76
1986-87	29.42
1987-88	29.59
1988-89	31.52
1989-90	36.77
1990-91	38.36
1991-92	41.57
1992-93	43.65
1993-94	46.44
1994-95	47.89
1995-96	49.49
1996-97	53.48
1997-98	53.88
1998-99	52.98
1999-00	56.75
2000-01	56.56
2001-02	59.56
2002-03	62
2003-04	63.99
2004-05	63.05
2005-06	65.72
2006-07	68.69
2007-08	71.27
2008-09	76.16
2009-10	79.98
2010-11	82.31
2011-12	86.66
2012-13	90.4
2013-14	95.79
2014-15	102.6
2015-16	107.62
2016-17	114.31
2017-18	127.04
2018-19	135.73
2019-20	141.64
2020-21	147.25
2021-22	162.48
2022-23	175.45

Class Interval	BIN
20-30	30
30-40	40
40-50	50
50-60	60
60-70	70
70-80	80
80-90	90
90-100	100
100-110	110
110-120	120
120-130	130
130-140	140
140-150	150
150-160	160
160-170	170
170-180	180

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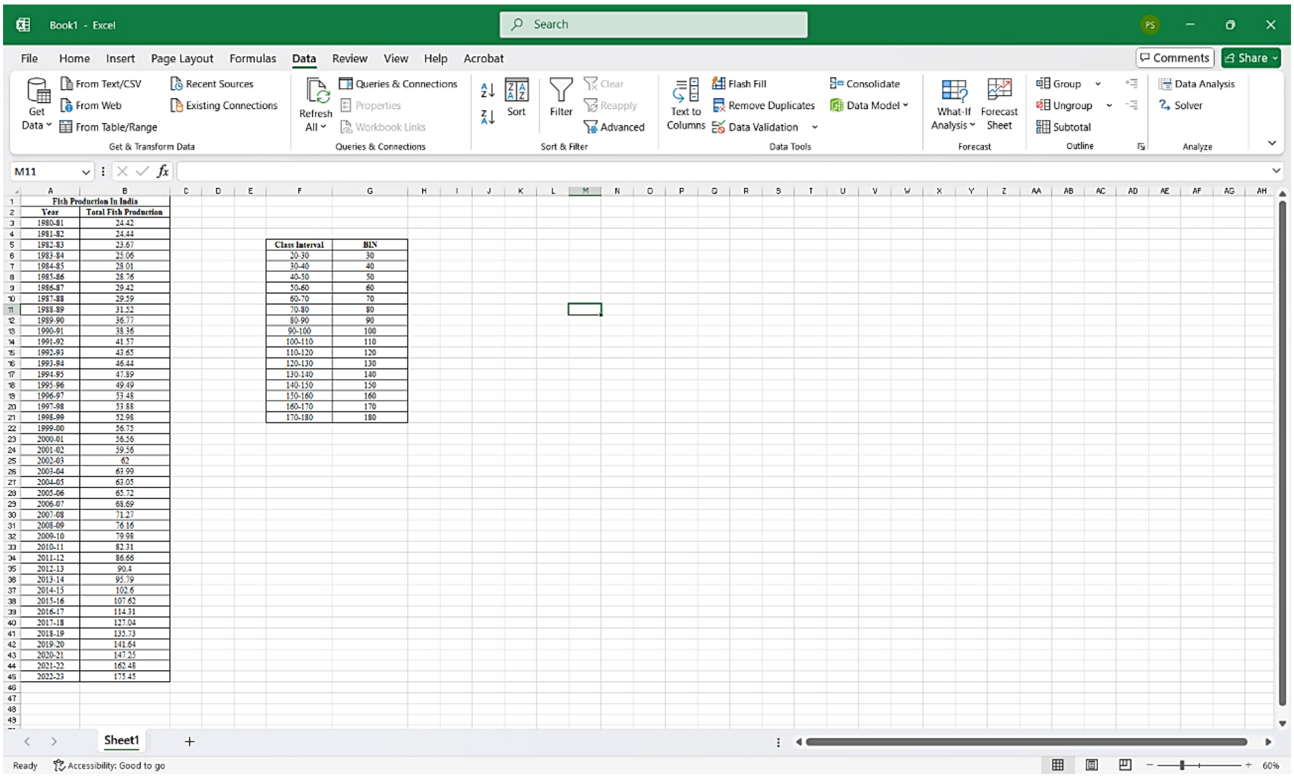
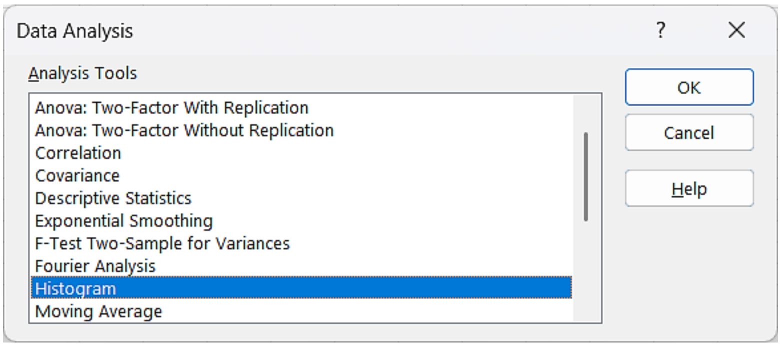
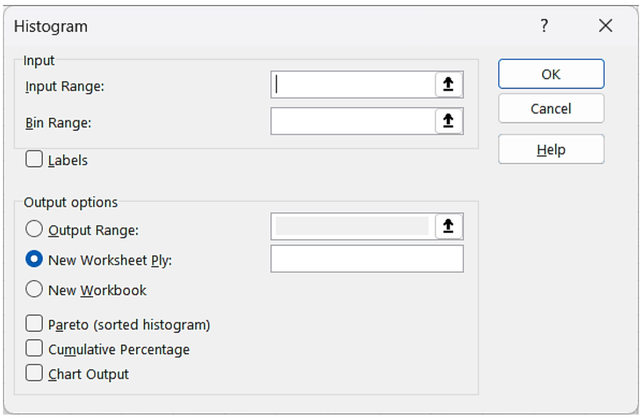
Step 4 : Go to Data tab and select Data Analysis



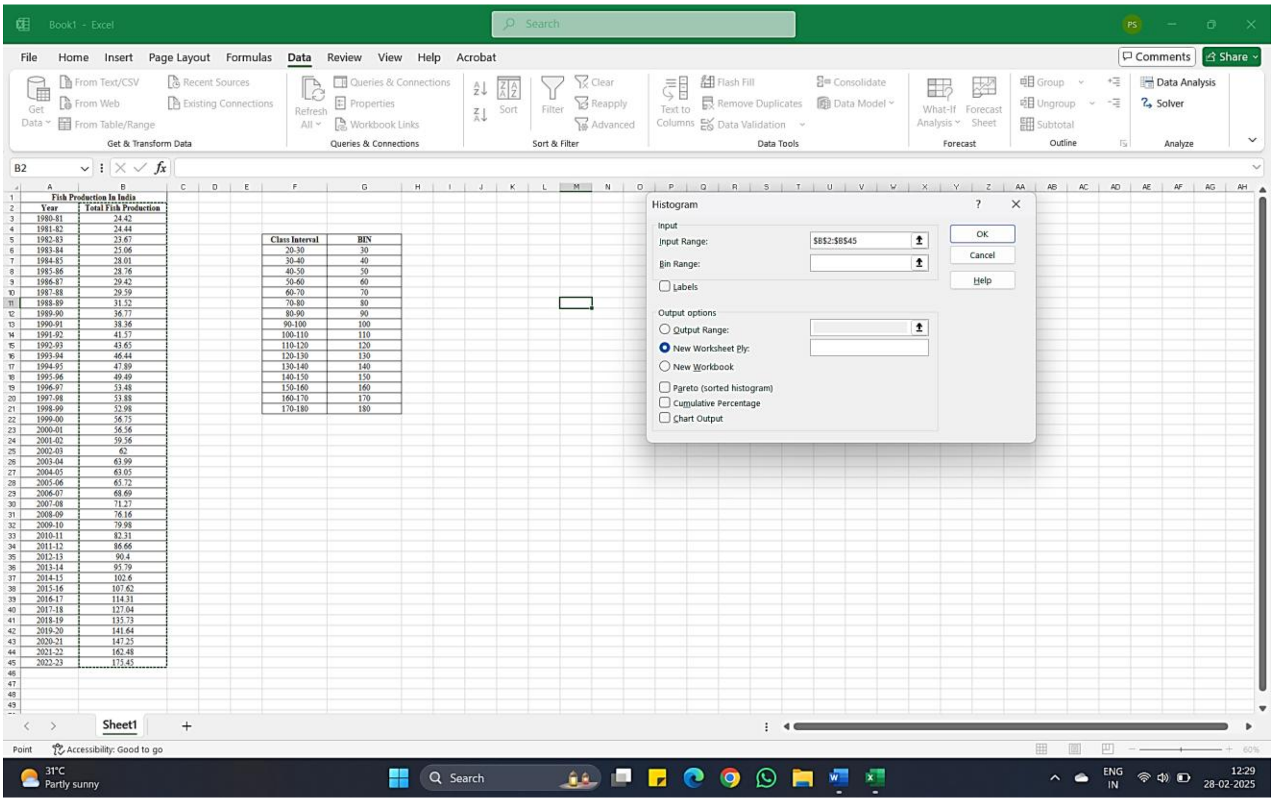
Step 5 : Choose Histogram from the list of analysis tools



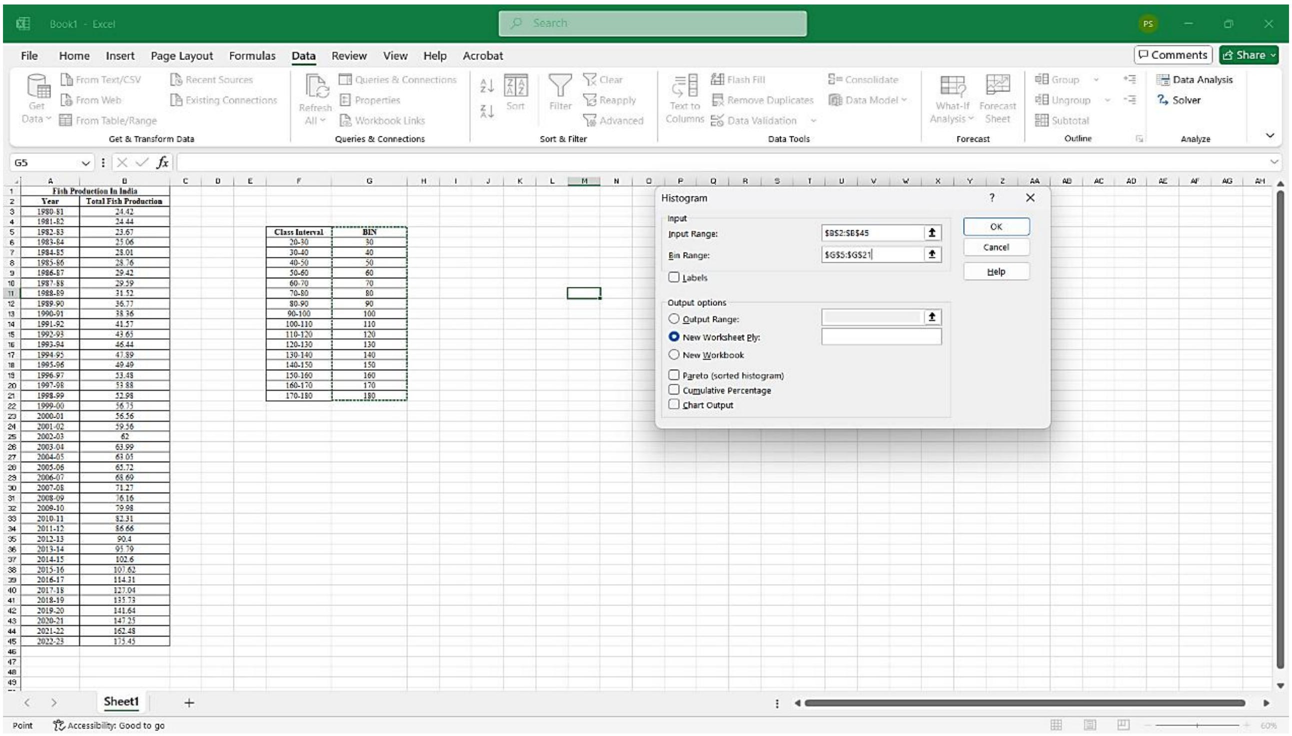
Step 6 : Histogram Dialog Box will popup



Step 7 : Select the input values (column containing the dataset)



Step 8 : Select the BIN values (column containing the BIN values)



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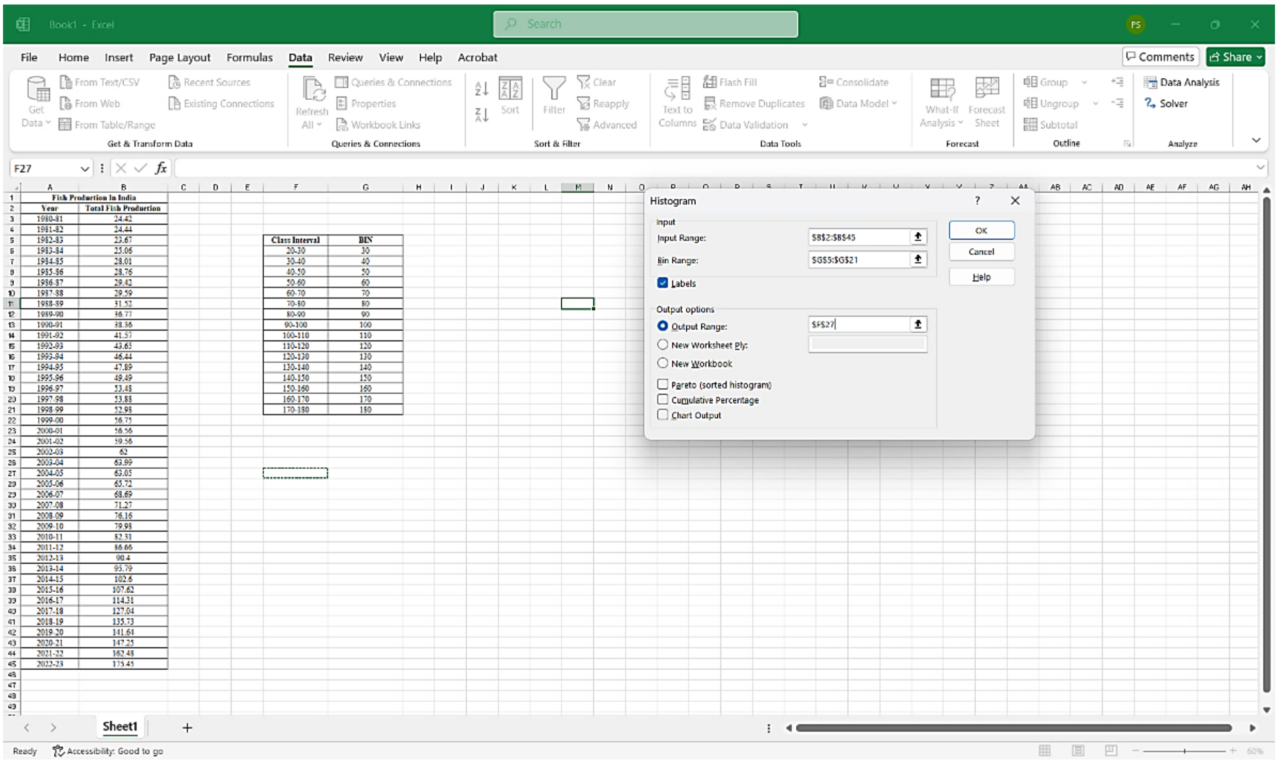
Step 9 : Choose the Output Range where the frequency table should be displayed (same Excel or in a new worksheet or in a new workbook)



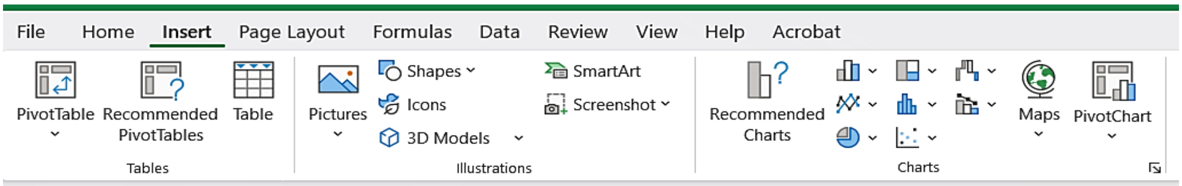
Step 10 : The BIN values and Frequency output will appear in the selected area

BIN	*Frequency*
30	8
40	3
50	5
60	6
70	5
80	3
90	2
100	2
110	2
120	1
130	1
140	1
150	2
160	0
170	1
180	1
More	0

Step 11 : Select and Copy the Class Interval and Frequency in the separate worksheet

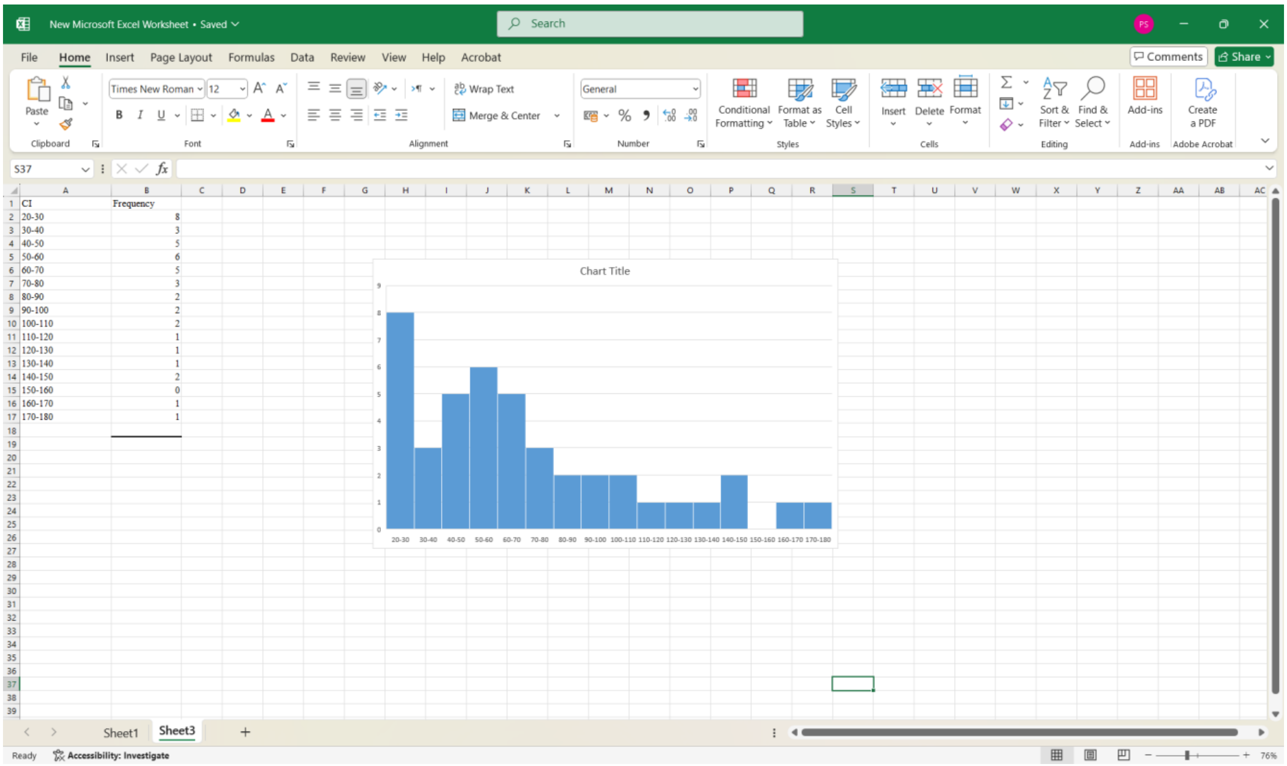
	A	B	C
1	**Class Interval**	***Frequency***	
2	20-30	8	
3	30-40	3	
4	40-50	5	
5	50-60	6	
6	60-70	5	
7	70-80	3	
8	80-90	2	
9	90-100	2	
10	100-110	2	
11	110-120	1	
12	120-130	1	
13	130-140	1	
14	140-150	2	
15	150-160	0	
16	160-170	1	
17	170-180	1	
18			

Step 11 : Select the Class Interval and Frequency, go to the Insert tab and select Histogram chart

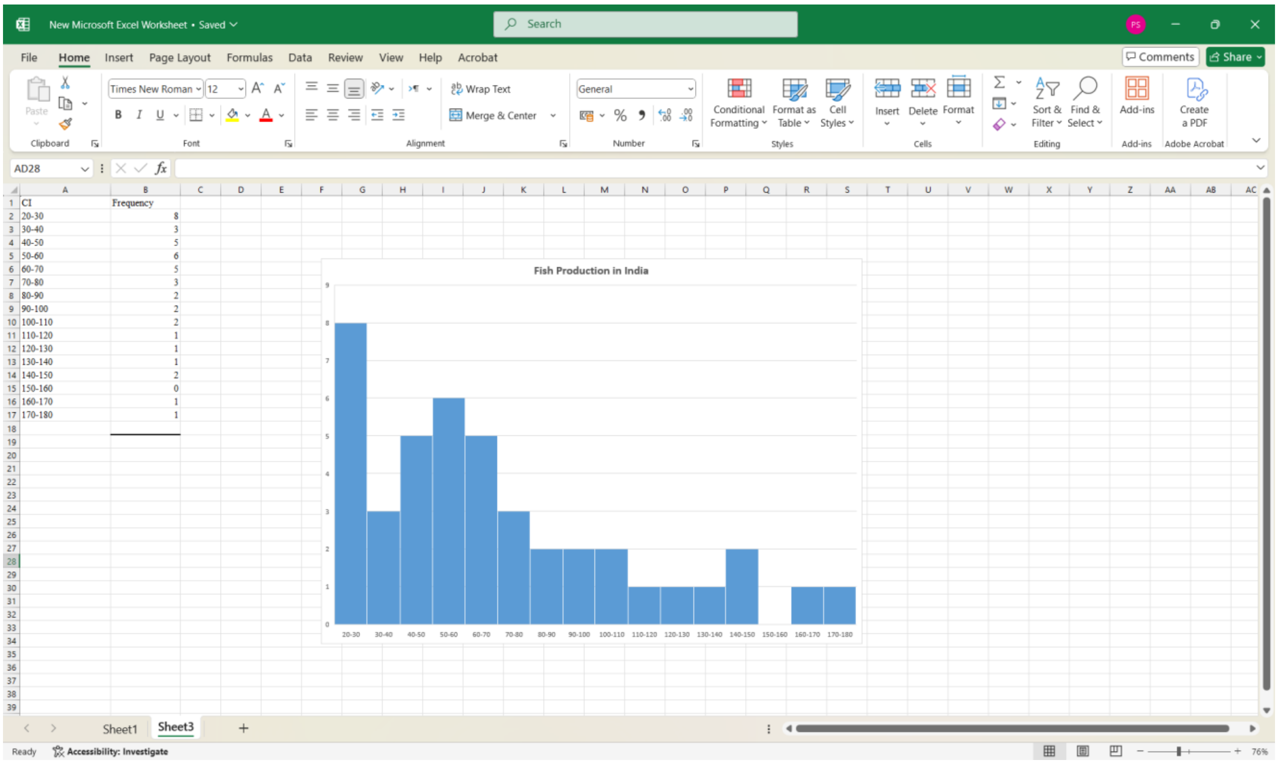


	A	B	C	D	E	F	G	H	I	J	K
1	**Class Interval**	***Frequency***									
2	20-30	8									
3	30-40	3									
4	40-50	5									
5	50-60	6									
5	60-70	5									
7	70-80	3									
3	80-90	2									
9	90-100	2									
0	100-110	2									
1	110-120	1									
2	120-130	1									
3	130-140	1									
4	140-150	2									
5	150-160	0									
6	160-170	1									
7	170-180	1									
8											
9											
0											
1											

Step 12 : After selecting the histogram, chart will appear



Step 13 : Change the required Chart title



Conclusion

Frequency tables are essential for summarizing and analyzing data patterns efficiently. Using the Data Analysis ToolPak in MS Excel allows users to quickly generate frequency tables and histograms, making data visualization and interpretation easier. This method is particularly useful in fields such as fisheries, agriculture, and business analytics, where handling large datasets is crucial for decision-making.

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https://statisticsbyjim.com/basics/frequency-table/

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TURNING STUBBLE INTO SUSTAINABILITY: CROP RESIDUE MANAGEMENT IN THE NORTHWESTERN PLAINS OF INDIA

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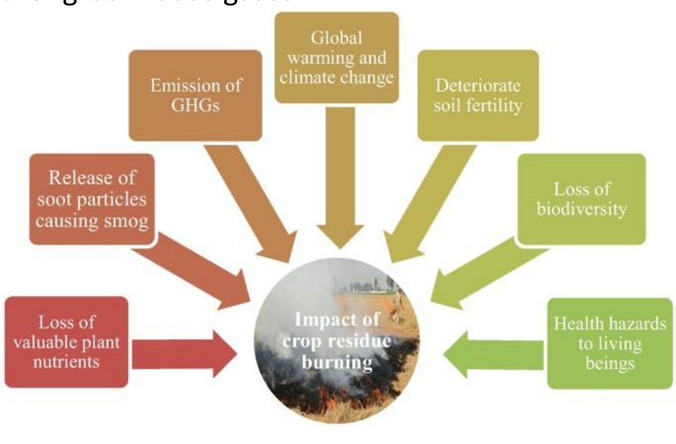
The north western plain of India, encompassing regions such as Punjab, Haryana, western Uttar Pradesh, and parts of Rajasthan, is one of the most agriculturally productive areas of the country. It is characterized by intensive cropping systems, particularly the cultivation of rice, wheat, and sugarcane. While these crops are essential for feeding the nation's growing population, their residue management has become a major environmental and agricultural challenge. Effective crop residue management (CRM) is crucial not only for maintaining soil health but also for ensuring the sustainability of agricultural practices in the region.

The Challenge of Crop Residue in the North western Plain

Each year, millions of tons of crop residue are produced in the north western plains of India. These residues, including straw from rice, wheat, and other crops, are often left in the fields after harvesting. Traditionally, farmers either burn the residue or leave it to decompose in the fields. However, burning crop residue has become a significant concern due to its environmental impact.

Environmental Impacts of Crop Residue Burning

1. **Air Pollution:** Burning crop residue is a major source of air pollution, especially in the winter months. The thick smoke from these fires leads to hazardous air quality, causing respiratory problems and other health issues in local communities. It also contributes to the formation of smog, which can have far-reaching effects on neighbouring regions.
2. **Loss of Soil Fertility:** Crop residues, when burned, release important nutrients such as carbon, nitrogen, phosphorus, and potassium into the atmosphere rather than returning them to the soil. This reduces the organic matter content of the soil and depletes its fertility over time, making it less conducive to healthy crop growth.
3. **Contribution to Climate Change:** The carbon released during the burning of crop residue contributes to greenhouse gas emissions, which exacerbate the global climate change crisis. In particular, the burning of rice straw, which is rich in carbon, releases large amounts of CO2, methane, and other greenhouse gases.



Alternatives to Burning: Strategies for Effective Crop Residue Management

To address the issue of crop residue burning, various innovative practices and technologies have been developed to help farmers manage crop residue in an environmentally friendly manner while still ensuring optimal crop production.

1. Crop Residue Recycling (In-Situ Management)

One of the most effective ways to manage crop residue is through in-situ management, which involves leaving the crop residue in the field to decompose naturally. This method has several benefits:

- **Enhancing Soil Organic Matter:** Crop residues left in the field enrich the soil with organic matter, improving its structure and fertility.
- **Moisture Conservation:** Decomposing crop residues act as mulch, which helps retain soil moisture and reduce evaporation, especially in areas with erratic rainfall.
- **Nutrient Recycling:** As residues decompose, they release essential nutrients back into the soil, promoting healthy plant growth for subsequent crops.

Farmers can use tools like **mulchers**, **choppers**, and **reapers** to chop and incorporate crop residues into the soil, speeding up the decomposition process.

2. Crop Residue as Animal Feed

In the north western plains of India, livestock farming is an important agricultural activity. Crop residues, especially from wheat and rice, can be used as animal feed. While rice straw is often considered less nutritious, it can be supplemented with additives like urea, molasses, or other nutrients to improve its digestibility.

By utilizing crop residues for livestock feeding, farmers can reduce the reliance on commercial feed, decrease waste, and increase the sustainability of both crop and livestock systems.

3. Bioenergy Production

Crop residues are a valuable source of biomass that can be converted into bioenergy. Technologies like **biogas production** and **biochar generation** are being promoted in the region to convert crop residues into useful energy. Biogas plants, which use organic material like crop residue to produce methane gas, can be a source of renewable energy, while biochar can improve soil health by increasing its carbon content.

4. Composting and Vermiculture

Another promising option for crop residue management is composting or vermiculture (using earthworms to break down organic matter). This process transforms crop residues into nutrient-rich compost that can be used to improve soil fertility. Farmers can set up small-scale composting units on their farms or partner with local cooperatives to compost crop residues efficiently.

Composting and vermiculture also reduce the need for chemical fertilizers, which are expensive and can degrade soil health in the long run.

5. Use of Technology for Efficient Management

Advancements in technology have provided farmers with better tools to manage crop residues efficiently. The introduction of **super straw management systems (SMS)** attached to combine harvesters has allowed for direct incorporation of crop residues into the soil, avoiding the need for burning. The SMS technology chops and spreads the residue evenly across the field, ensuring quicker decomposition and enhancing soil health.

Government Policies and Support

The Indian government has recognized the importance of crop residue management in tackling environmental pollution and ensuring sustainable agriculture. Several initiatives and schemes have been introduced to encourage farmers to adopt eco-friendly residue management practices:

- **Subsidies for Farm Machinery:** The government has introduced subsidies for the purchase of machinery like mulchers, choppers, and SMS systems, which help in the proper management of crop residues.
- **Awareness Campaigns:** State governments, along with environmental organizations, have been conducting awareness campaigns to educate farmers about the harmful effects of residue burning and the benefits of alternative management practices.
- **Promoting Biomass Power Plants:** The government is encouraging the establishment of biomass power plants that can use crop residues as raw material for generating energy.

Conclusion

Crop residue management is a critical issue for farmers in the north western plain of India. Effective residue management practices are essential for improving soil health, reducing air pollution, and mitigating climate change. While challenges exist, the adoption of sustainable alternatives to residue burning, such as recycling, bioenergy production, and the use of technology, holds the potential to transform agricultural practices in the region.

For a sustainable future, it is imperative that both the government and farmers collaborate to develop and implement solutions that balance agricultural productivity with environmental responsibility. By embracing these practices, the north western plain of India can continue to be a key agricultural hub while contributing to the global fight against climate change.

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ECOSYSTEM BASED FISHERY MANAGEMENT

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Abstract
A significant portion of the world's fish stocks are overexploited, and the ecosystems that support them have deteriorated. Traditional fisheries management has often fallen short; it tends to emphasize maximizing harvests of individual target species while neglecting habitats, predator-prey relationships, and other key components of the ecosystem. This narrow focus can lead to considerable indirect social and economic consequences. Recognizing the need for a more effective, holistic management strategy, numerous advisory bodies have recommended incorporating ecosystem considerations into fisheries management in a comprehensive and consistent manner. Ecosystem-Based Fisheries Management (EBFM) offers a more integrated approach that focuses on maintaining the overall health of marine ecosystems to sustain the benefits they provide. Achieving the diverse goods and services expected from marine environments requires a wide-ranging, interdisciplinary strategy. EBFM implementation generally follows a three-step process: establishing clear goals, developing measurement systems, and applying management strategies. The core aim of ecosystem-based management is to ensure that ecosystems remain healthy, productive, and resilient, so they can continue delivering the services humans depend upon. However, there is often a limited perspective—relying mainly on indicators tied to economic outcomes from fishing—that can restrict the capacity to fully measure EBFM progress. To truly align with EBFM principles, it is essential to acknowledge that ecological and human factors are interdependent.

Introduction
Since the introduction of the FAO Code of Conduct for Responsible Fisheries, a persistent challenge has been the effective application of Ecosystem-Based Fisheries Management (EBFM). Although the concept of EBFM has evolved with varying interpretations, consensus is emerging around its fundamental principles. These emphasize that fisheries management should be grounded in scientific understanding, account for ecosystem linkages across different scales, incorporate precautionary and adaptive strategies to manage uncertainty, prioritize long-term socio-ecological sustainability, encourage collaboration and interdisciplinary input, and effectively pursue management objectives. These core principles are in alignment with FAO guidelines and have broad relevance across various fisheries management contexts.

EBFM presents a comprehensive framework that integrates all ecosystem components connected to fisheries, including fish populations, marine habitats, social benefits, and cultural values. It highlights the complex interconnections within these systems by:

- Assessing the social and economic benefits provided by fisheries, such as food security, employment opportunities, and preservation of cultural traditions.
- Evaluating the wide array of ecological factors that may be affected—positively or negatively—by management decisions.

- Striking a balance between maintaining socio-economic advantages and taking proactive steps to minimize potential harm to fish populations and the broader marine ecosystem.

By accounting for these interconnected factors, managers can design strategies that are more effective in meeting environmental, social, and economic goals. For example, a management agency overseeing fisheries along a coastline important for both tourism and offshore wind energy development must consider how these industries impact fishing operations and the health of marine ecosystems.

With EBFM, managers can adopt a holistic strategy, using predictive models to evaluate how different management scenarios might achieve sustainable fisheries while addressing the broader dynamics of human activity and ecosystem health. This enables the establishment of catch limits that support the long-term viability of fish stocks while protecting associated species and habitats.

Objectives of EBFM

The primary objective of Ecosystem-Based Fisheries Management (EBFM) is to sustain healthy marine ecosystems, ensuring that the fisheries they support remain viable. Specifically, EBFM seeks to:

- Prevent ecosystem degradation by monitoring environmental health and key ecological indicators.
- Minimize the risk of irreversible alterations to species diversity and ecosystem processes.
- Ensure the long-term delivery of socio-economic benefits while maintaining ecosystem integrity.
- Expand understanding of ecosystem functions to better anticipate and manage the impacts of human activities.

How is EBFM different from other approaches to fisheries management?

The earliest formal fisheries management method—the Single-Species Approach—focuses solely on regulating target species, often based on biological data, catch rates, and stock assessments. While it remains common, this approach has been criticized for ignoring broader ecosystem interactions, such as predator-prey relationships, habitat shifts, and environmental changes.

In response to these limitations, the Ecosystem Approach to Fisheries Management (EAFM) was introduced. EAFM incorporates ecological considerations into the management of one or more species and emphasizes precautionary actions. However, it often excludes social and economic concerns from scientific assessments, leaving these factors to be addressed at the policy level.

Ecosystem-Based Fisheries Management (EBFM) takes this further by explicitly including social and economic dimensions—both within the fishery and in external sectors—as integral to management decision-making. While some institutions use EAFM and EBFM interchangeably, EBFM offers a more comprehensive and holistic framework. It aims to balance ecological sustainability with socio-economic objectives, providing a more integrated and effective fisheries management strategy.

What are the benefits of ecosystem-based fisheries management?

EBFM improves decision-making by offering better predictions of how management actions will affect ecosystems and human communities. It is designed to be flexible, cost-efficient, and responsive to changing environmental and social conditions. Key benefits of EBFM include:

- Balancing ecological, social, and economic objectives through informed trade-offs among competing stakeholder interests.

- Enhancing the ability to forecast environmental pressures and their potential impacts on individual species and entire ecosystems, offering a comprehensive understanding of ecosystem responses to multiple stressors.
- Supporting long-term sustainability by stabilizing ecosystem-level indicators. NOAA Fisheries has adopted an agency-wide EBFM Policy that outlines guiding principles for incorporating EBFM into resource management. This policy reflects an ongoing commitment to sustainable fisheries and the health of marine ecosystems.

Human indicators in relation to EBFM goals and objectives

Human indicators are primarily used to evaluate progress toward the EBFM goal of sustaining a profitable fishing economy, accounting for 31% (93 mentions) of all indicator references. These typically assess catch volumes, operational costs, and profitability metrics.

The aim of maintaining an economically viable fishing sector is closely linked to the broader EBFM goal of preserving ecosystem structure and functions that support human needs. This linkage may explain why these indicators are frequently referenced. In fact, they appear three times more often than indicators focused on minimizing environmental impacts, and at least seven times more frequently than those associated with precautionary management and sustainable supply chains.

Conclusion

Ecosystem-Based Fisheries Management (EBFM) represents a fundamental shift in fisheries governance, placing ecosystem health at the center of management decisions rather than focusing exclusively on target species. While general agreement on EBFM principles is growing, its operational goals and implementation frameworks remain less clearly defined. As a result, management agencies tend to adapt EBFM to suit their unique circumstances, leading to diverse practices rather than a single, standardized model. A critical challenge is ensuring that current practices align with EBFM principles to achieve its overarching goal: maintaining the structure and function of ecosystems to support human well-being. EBFM promotes holistic ecosystem management that safeguards essential ecological processes and services, whether or not they are directly tied to market value. Furthermore, EBFM plays a vital role in reducing fisheries-related impacts on threatened and protected species by managing essential ecosystem processes that are crucial for their recovery.

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ENHANCING NUTRITIONAL VALUE OF CROPS THROUGH GENETIC APPROACH

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Abstract
This article discusses the genetic approaches aimed at improving nutritional crops to provide food security and solve malnutrition on the global platform. The basic strategies include modification of genes, gene editing, and traditional breeding to increase the vital nutrients such as vitamins, minerals, and proteins in staple crops. It highlights its ability to deal with micronutrient deficiencies across developing regions along with the difficulties faced in issues like regulatory approvals, public acceptability, and ecological effects. This review draws attention to the requirement of constant biotechnology research on plants, thus making possible more nutritious crops with higher global demands for healthier foods.

Keywords : genetic modification, gene editing, biotechnology, vitamins, minerals, and proteins

Introduction
Increasing population sizes in the globe, along with malnutrition rates, has a great necessity to introduce an advanced method toward upgrading the crop quality nutrition. Current conventional cultivation lacks adequate micronutrient supplies, leaving massive populations susceptible to severe inadequacies of the vitamins and minerals. Various genetic techniques like genetic manipulation, gene edition, and biotechnology combined with other omics such as genomics, transcriptomics, and proteomics contribute significant strengths towards developing nutrition levels of staple food crops. Scientists can pinpoint and amplify significant genes for those crucial nutrients- vitamins, minerals, and proteins-through the employment of these novel technologies. This report examines the prospect and the hurdle in using genetics and omics-based strategies in producing healthier crops with improved nutritional quality.

Biofortification : Boosting essential nutrients
Biofortification is a strategy to increase the nutritional content of crops through genetic approaches to address deficiencies in essential nutrients. This process is aimed at improving the levels of vitamins, minerals, and proteins in staple crops, thus enhancing public health, especially in regions with limited access to diverse diets. Traditional biofortification methods include conventional breeding, while modern techniques involve genetic modification and gene editing to precisely introduce beneficial traits. Success stories abound in combating micronutrient deficiencies using biofortified crops such as golden rice, which provides vitamin A through enriched content in beans. Biofortification directly enhances nutrient density in crops, which makes it an ideal approach in the fight against malnutrition without changes in diet. Challenges still linger with issues facing the regulatory approval, consumer acceptance, and environmental impact. Continued research into biofortification techniques has the potential to significantly reduce malnutrition worldwide.

Genetic Editing: Precision nutrient enhancement

Genetic editing specifically with CRISPR-Cas9 technology affords the development of precise technologies to enhance nutrition in crops. It involves making direct changes at the genetic locus controlling the nutrient biosynthesis by introducing or changing specific genes into crops that elevate the content of essential vitamins, minerals, and proteins without having to introduce exogenous DNA. For instance, it has been applied to increase the provitamin A levels in rice (Zhai *et al*., 2020) or enhance the bioavailability of iron in wheat (Yang *et al*., 2019). Genetic editing is a more targeted approach than traditional breeding. It is faster and more precise for biofortification. Although genetic editing is promising for solving malnutrition issues, it also presents regulatory and ethical challenges. However, the technology offers a sustainable solution toward combating micronutrient deficiencies in crops and eventually improving global food security with research and technological developments (Jinek *et al*., 2012).

RNA interference: Reducing anti-nutritional factors

RNA interference (RNAi) is a powerful genetic tool used to decrease anti-nutritional factors in crops, thereby enhancing the nutritional quality of crops. Anti-nutritional factors, including lectins, phytates, and protease inhibitors, can interfere with nutrient absorption and digestion, which reduces food quality. Specific genes responsible for producing these compounds can be silenced or downregulated through RNAi, thereby minimizing their negative impact. For instance, the levels of harmful lectins in beans (Mikami *et al*., 2017) and phytates in cereals (Tiwari *et al*., 2019) have been successfully reduced using RNAi. This will enhance the availability of important nutrients from them. RNAi allows for the precise targeting of undesirable traits by not affecting the gross genetic structure of the crop. This approach provides a promising avenue to improve the nutritional content of staple foods, which would be more advantageous for human consumption while ensuring food security (Wang *et al*., 2018).

Crop Name	Character of Crop Enhanced	References
Golden Rice	Increased provitamin A (beta-carotene) content	Potrykus, I., & Al-Babili, S. (1997). "Golden Rice: Introduction of a Novel Gene into Rice Genome." *Science*, 276(5311), 1985-1989.
Biofortified Maize	Increased lysine and tryptophan content	Pixley, K. V., *et al*. (2007). "Breeding for Increased Levels of Tryptophan and Lysine in Maize." *Field Crops Research*, 102(2), 118-129.
Iron-Biofortified Wheat	Increased iron content	Reddy, M. S., *et al*. (2009). "Genetic Biofortification of Wheat: Improving Iron Content." *Plant Breeding*, 128(3), 240-245.
Zinc-Biofortified Rice	Increased zinc content	Howarth, A. J., *et al*. (2017). "Zinc Biofortification of Rice through Agronomic Practices." *Plant and Soil*, 411(1), 73-87.

Crop Name	Character of Crop Enhanced	References
High-Oleic Soybean	Increased oleic acid content (enhancing nutritional fats)	McGarvey, B. D., *et al*. (1995). "Modification of Soybean Oil Composition via Genetic Engineering." *Plant Physiology*, 107(1), 1-9.

Omics approaches

Omics approaches that include genomics, transcriptomics, proteomics, and metabolomics offer highly integrative approaches for understanding the mechanisms to be employed in nutritional value enhancement in crops. This would enable researchers to probe deep into the nutrient biosynthesis and metabolism biological networks that are typically very complex. Genomics informs about the genetics underlying traits correlated with nutrient content. Transcriptomics measures gene expression patterns and may uncover key regulators of nutrient pathways. Proteomics and metabolomics further delve into our understanding by identifying proteins and metabolites involved in nutrient production and storage. Through integration of these omics data, researchers can pinpoint specific genes or pathways for targeted improvement through genetic modification or breeding. Omics approaches also enable the identification of novel biomarkers for biofortification, which facilitates the development of crops with improved nutritional profiles. This holistic approach accelerates crop improvement and helps design more efficient strategies for addressing global malnutrition (Borrill *et al*., 2015).

Omics approaches

- **Metabolomics**
- **Proteomics**
- **Transcriptomics**
- **Genomics**
- **Ionomics**

Metabolomics and its role in nutritional improvement

Metabolomics, the study of metabolites and their pathways, plays a crucial role in the nutritional improvement of crops. It is through analysing the metabolic profiles of plants that scientists identify the key metabolites contributing to nutrient quality, such as vitamins, minerals, and antioxidants. This helps in understanding how various metabolic pathways are influenced by environmental factors, genetics, and breeding practices. Metabolomics can, therefore, allow for the identification of biomarkers to nutritional traits with increased precision when selecting in the breeding programs. For instance, in fruits and vegetables, metabolomics profiling has successfully been used for enhancing the accumulation of health-promoting compounds such as carotenoids and flavonoids (Zhao *et al*., 2018). Additionally, through the combined use of various omics strategies, scientists might better understand more of plant biology, thus achieving the production of crops with greater nutritional content profiles. Metabolomics, therefore, provides interesting information on the improvement of crop quality for healthier human life (Dixon *et al*., 2017; Zhang *et al*., 2019).

Proteomics and its role in nutritional improvement

Consequently, proteomics becomes quite important in optimizing crop nutritional value through its understanding of the proteins that are involved in biosynthesis, storage, and transport functions related to nutrient production. Knowledge of the proteome of plants helps determine key proteins responsible for the nutritional difference in crops such as enzymes that form essential amino acids, vitamins, and antioxidants. Environmental stressors and genetic modifications can be understood in the nutritional quality of crops with the help of proteomics. For instance, proteomic analysis has been applied to enhance the protein quality in grains (Wu *et al*., 2018) and elevate the contents of health-promoting compounds such as antioxidants in fruits (Sharma *et al*., 2019). In addition, proteomics assists in identifying biomarkers for biofortification, which accelerates the development of crops with enhanced nutrient content. Proteomics, which is a significant part of multi-omics research, has proven to be critically important for sustainable crop nutrition improvement (Liu *et al*., 2020).

Transcriptomics and its role in nutritional improvement

Transcriptomics refers to the study of gene expression patterns, thus greatly contributing to nutritional enhancement in crops. It determines which genes participate in nutrient metabolism and biosynthesis, thereby offering knowledge on the ways in which the genes are controlling the synthesis of essential vitamins, minerals, and proteins and which metabolic pathways will ultimately affect nutrient content. Such a method can reveal some of the primary transcription factors and regulatory networks governing nutrient accumulation so that targeted genetic modifications may improve nutrient levels. For example, transcriptomics was applied to optimize carotenoids synthesis in maize (Zhu *et al*., 2018) and rice for increasing its iron and zinc content (Gonzalez-Guerrero *et al*., 2017). Scientists can develop crops with optimized nutritional profiles by integrating transcriptomic data with other omics technologies, promising a solution to global malnutrition (Zhang *et al*., 2020).

Genomics and its role in nutritional improvement

Genomics is involved in improving nutritional crops by describing comprehensive genetic factors, such as nutrient contents and metabolism, governing the food quality. Genomic study has the advantage of identifying or characterizing nutrients genes, vitamins, minerals, or proteins production, which enhances nutritional crop content and development, and this development may be accomplished either through genetically modifying or via classical breeding practices. For instance, genomics has been applied in identifying genes that enhance the bioavailability of iron in rice (Gao *et al*., 2017) and enhance the levels of vitamin A in golden rice (Ye *et al*., 2000). Furthermore, genomics yields an understanding of genetic variations among crop species, showing the potential of crossbreeding different varieties to arrive at nutrient content optimization. Genomic tools would enable scientists to expedite breeding for nutrient-dense crops as a long-term solution for malnutrition at the global level (Bouis & Saltzman, 2017).

Ionomics and its role in nutritional improvement

Ionomics is the study of the distribution and function of minerals and trace elements in plants. This field of study plays a significant role in improving the nutritional value of crops. It is an approach to understanding the uptake, transport, and accumulation of essential minerals like iron, zinc, calcium, and magnesium, which are very important for human health. Ionomics allows identification of the genes and pathways regulating mineral nutrient concentrations in crops and hence in crop varieties having more bioavailable micronutrient levels. In particular, such an ionomic analysis has already improved iron and zinc concentrations in rice (Johnson *et al*., 2013) as well as improved the calcium levels in vegetables (Wang *et al*., 2016). Breeding or genetically engineering crops to nutritional goals is the hope of integrating ionomic data with genomics and other omics technologies to reduce micronutrient deficiencies worldwide, according to a study by Baxter *et al*., 2008.

Conclusion

Genetic improvement in crop plants should therefore be given adequate attention to have them produce optimal nutrients. Key techniques include biofortification, editing by genetic machinery, and the utilization of the phenomenon of interfering RNA. Besides this, key tools in revealing intricate biological networking patterns involved with the production or regulation of plant nutrient content can be found among genomics, transcriptomics, proteomics, metabolomics, and ionomics. These tools help identify the key genes, proteins, and metabolites involved in improving crop nutrition, allowing for the production of more nutrient-dense varieties. By combining these advanced technologies, scientists can better overcome the challenges of malnutrition, improving food security and public health. As research in genetic and omics-based approaches continues to evolve, we are coming closer to making crops that not only are resilient but also nutritionally optimized, hence providing a sustainable solution to the global nutritional deficiencies.

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EXPLORATION OF YIELD PREDICTION USING STATISTICAL AND MACHINE LEARNING TECHNIQUES ACROSS VARIOUS AGRICULTURAL SECTORS

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Abstract

Crop yield prediction is a cornerstone of modern agriculture, enabling farmers, policymakers, and stakeholders to optimize resource use, enhance food security, and adapt to challenges like climate variability and population growth. Crop yield prediction is pivotal for sustainable agriculture, informing resource allocation, food security, and climate adaptation strategies. This paper explores the application of statistical and machine learning (ML) techniques in predicting yields across diverse agricultural sectors, including cereals, oilseeds, horticulture, and cash crops. Statistical methods like regression and time-series analysis offer interpretability and simplicity, while ML approaches viz. random forests, neural networks, and deep learning excel in handling complex, non-linear data. Findings suggest ML outperforms in data-rich scenarios, yet statistical methods remain valuable for transparency and smaller datasets. Hybrid models combining both approaches show promise for balancing accuracy and interpretability.

Keywords: Crop yield, Machine learning, Random forests, Neural networks, Deep learning

Introduction

Agriculture is a cornerstone of global food security and economic stability, with crop yield prediction playing a pivotal role in optimizing resource allocation, reducing losses, and ensuring sustainable practices. The integration of statistical and machine learning techniques has revolutionized crop yield prediction, enabling farmers and policymakers to make data-driven decisions. This response explores the advancements, methodologies, and applications of these techniques across various agricultural sectors, drawing insights from recent research papers.

Statistical Techniques in Crop Yield Prediction

Statistical methods, such as linear regression, multiple linear regression (MLR), and time-series analysis, have been foundational in yield prediction. These techniques rely on assumptions of linearity and independence among variables, using factors like temperature, rainfall, and soil properties to model crop outcomes. For instance, MLR has been widely applied to predict yields in staple crops like wheat and maize by correlating historical weather data with production records. In horticulture, statistical models have helped estimate fruit yields based on variables like irrigation levels and pest incidence. Similarly, in plantation sectors (e.g., palm oil), regression models incorporate long-term climate trends to forecast output.

The strength of statistical methods lies in their simplicity and interpretability, making them accessible for small-scale farmers and regions with limited data infrastructure. However, their reliance on predefined assumptions limits their ability to capture complex interactions, such as those influenced by erratic climate patterns or genetic variability, often resulting in lower predictive accuracy under dynamic conditions.

Machine Learning Techniques in Crop Yield Prediction

Machine learning has emerged as a powerful tool for crop yield prediction, offering superior accuracy and the ability to handle high-dimensional data. Various algorithms have been explored, including:

1. Random Forest

Random Forest, an ensemble learning method, has consistently demonstrated high accuracy in crop yield prediction. Studies have shown that it outperforms other models, achieving accuracy levels of up to 99.13% (Bogireddy & Murari, 2024; Mimenbayeva *et al.*, 2024). Its ability to handle high-dimensional data and prevent overfitting makes it particularly suitable for agricultural datasets (Mehla *et al.*, 2024).

2. Gradient-Boosting Algorithms

Gradient-boosting algorithms, includes XGBoost, LightGBM, and CatBoost. CatBoost achieved an accuracy rate of 99.123% in predicting rice yields, outperforming other algorithms (Mahesh & Soundrapandiyan, 2024). These models are effective in handling complex, non-linear relationships and are widely adopted in agricultural prediction tasks (Nuser *et al.*, 2024).

3. Deep Learning Models

Deep learning models, such as Long Short-Term Memory (LSTM) networks, have been employed to enhance predictive capabilities. These models are particularly effective in analyzing time-series data, such as weather patterns and historical yields, to provide accurate forecasts (Nitin *et al.*, 2024).

4. Support Vector Machines (SVM) and Ensemble Methods

Support Vector Machines (SVM) and ensemble methods combine the strengths of individual models to improve prediction accuracy. For instance, ensemble methods have been shown to outperform single-model predictions, providing more reliable and precise yield forecasts (Bhati *et al.*, 2024).

Challenges and Future Directions

Despite the advancements in crop yield prediction, several challenges remain:

- **Data Quality and Availability:** Machine learning models require large, high-quality datasets. Ensuring data accuracy and availability is crucial for reliable predictions.
- **Model Complexity:** The complexity of agricultural systems poses challenges in developing accurate models. Simplifying models while maintaining accuracy is an ongoing research focus.
- **Sustainability:** Future research should focus on developing models that promote sustainable agricultural practices, reducing environmental impact while optimizing yields.

Comparative Analysis

Statistical methods are computationally efficient and interpretable but struggle with non-linear dynamics and scalability across sectors. ML techniques, while more accurate and flexible, demand extensive data preprocessing and expertise, limiting their adoption in less-developed agricultural systems. Hybrid approaches combining statistical rigor with ML's predictive power are gaining traction, offering a balanced solution. For example, integrating MLR with ANN has improved yield forecasts in mixed cropping systems by blending statistical baselines with adaptive learning.

Table: Comparison of Machine Learning Models for Crop Yield Prediction

Model	Key Features	Accuracy/Performance Metrics	Citation
Random Forest	Ensemble learning, handles high-dimensional data, prevents overfitting	Accuracy: 99.13%, R-Squared: 0.95	(Bogireddy & Murari, 2024) (Mehla *et al*., 2024)
CatBoost	Gradient-boosting, handles categorical data	Accuracy: 99.123%, RMSE: 0.24	(Mahesh & Soundrapandiyan, 2024)
LSTM Networks	Deep learning, time-series analysis	High predictive accuracy for crop damage and yield prediction	(Nitin *et al*., 2024)
XGBoost	Gradient-boosting, handles large datasets	Low mean squared error: 0.023	(Nuser *et al*., 2024)
Support Vector Machine	Robust for non-linear relationships	High accuracy in crop yield prediction	(Bhati *et al*., 2024)

This table highlights the key features and performance metrics of various machine learning models used in crop yield prediction, providing a concise overview of their strengths and applicability.

Conclusion

The integration of statistical and machine learning techniques has significantly advanced crop yield prediction, enabling farmers and policymakers to make informed decisions. Random Forest, gradient-boosting algorithms, and deep learning models have emerged as powerful tools, with Random Forest consistently demonstrating high accuracy. The inclusion of environmental, economic, and management factors, along with the integration of IoT and remote sensing, has further enhanced predictive capabilities. Addressing challenges such as data quality and model complexity will be essential for future advancements in this field.

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GENE CLONING: AN OVERVIEW OF TECHNIQUES AND APPLICATIONS

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Abstract

Gene cloning is a basic molecular biology technique through which particular genes are replicated and manipulated. Gene cloning includes the isolation of an interest gene, its insertion into a proper vector, and its introduction into host cells for replication and expression. Gene cloning has transformed medicine, agriculture, and biotechnology through the production of therapeutic proteins, gene therapy, genetically modified organisms (GMOs), and vaccine production. Although it has benefits, including enhanced crop resistance and biomedical research breakthroughs, gene cloning raises ethical issues, health risks, and ecological problems. The emergence of recombinant DNA technology and CRISPR-based genome editing further broadened the uses of gene cloning. The article discusses the methods, applications, advantages, and disadvantages of gene cloning while touching on its importance in scientific research.

Keywords: Gene cloning, recombinant DNA technology, gene therapy, genetically modified organisms (GMOs), biotechnology.

Introduction

Gene cloning is a core molecular biology technique that allows scientists to produce an exact replica of a given DNA sequence. The process entails purifying a target gene, transferring it into a vector (plasmid), and introducing the vector into a host cell where it can replicate. Through the years, different methods of cloning have been established, such as restriction enzyme-based cloning, polymerase chain reaction (PCR) cloning, and recombination-based cloning (Sambrook & Russell, 2001). These processes have transformed biotechnology, facilitating growth in genetic engineering, medicine, and agriculture. Gene cloning is commonly used for producing recombinant proteins, gene therapy, and producing genetically modified organisms (Watson *et al*., 2017). With continued development through innovations like CRISPR-based cloning, its uses are bound to increase even more, with our capabilities to edit genetic material for therapeutic and industrial applications.

Steps in Gene Cloning

Gene cloning is a multi-step process of precise isolation, replication, and expression of a target gene of interest. The major steps of gene cloning are described below:

Isolation of DNA

The initial step is the isolation of the target gene from the source organism. This can be achieved through restriction enzymes, which cleave DNA at specific sequences, or by polymerase chain reaction (PCR) amplification (Sambrook & Russell, 2001).

Insertion into a Vector

The gene is then inserted into a cloning vector, for example, a plasmid, with the help of DNA ligase enzymes. The vector is a carrier that aids in replication within a host cell (Watson *et al*., 2017).

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Transformation into Host Cells
The recombinant DNA is then transformed into competent host cells, typically bacteria such as Escherichia coli, via transformation methods such as heat shock or electroporation (Brown, 2016).

Selection and Screening
Successfully transformed cells are isolated on the basis of antibiotic resistance markers or reporter genes. Screening methods such as blue-white screening or PCR are applied to verify the existence of the cloned gene (Lodish *et al*., 2021).

Expression and Analysis
The gene can be expressed to create the target protein after cloning, or it can be analyzed further for functional studies. Expression can be controlled based on specific promoters in expression vectors (Alberts *et al*., 2014).

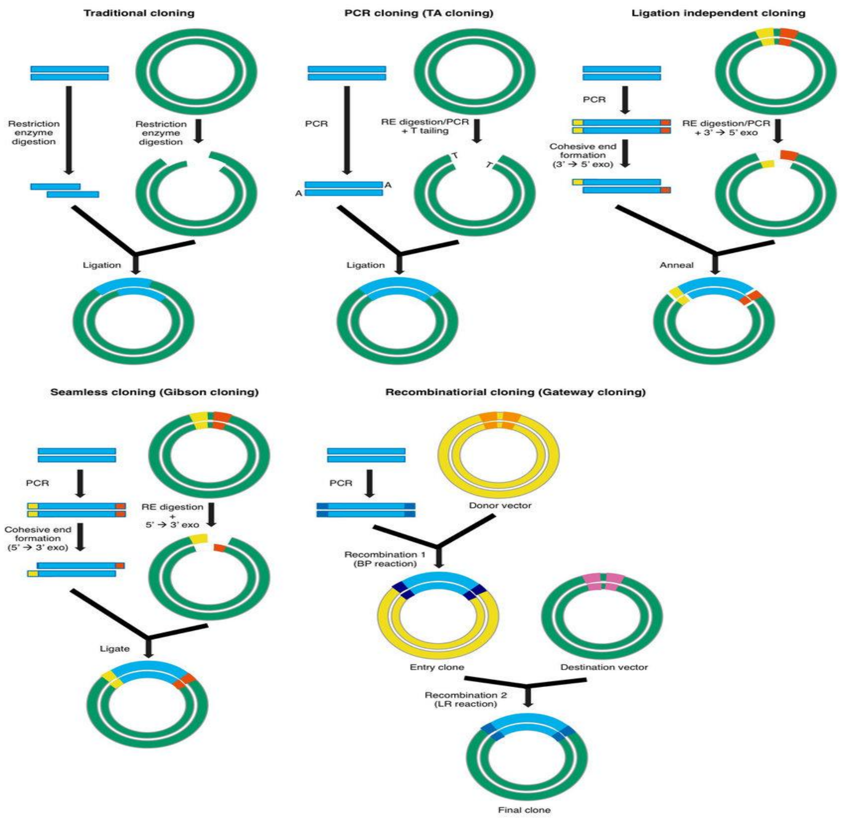

Figure 1. Overview of the main molecular cloning methodologies. Schematic examples of cloning approaches. Refer to the text for detailed explanations.

Applications of Gene Cloning
Gene cloning has revolutionized several scientific and industrial applications by making it possible to manipulate genetic material with precision. Some of its significant applications are:

Recombinant Protein Production
Gene cloning is extensively applied in the manufacture of therapeutic proteins, including insulin, growth hormones, and clotting factors. Through the introduction of human genes into bacterial or mammalian cell expression systems, large amounts of biologically active proteins can be produced (Watson *et al*., 2017).

Gene Therapy

Gene therapy uses cloning in a significant way in which defective genes are repaired or replaced to treat genetic diseases such as sickle cell anemia and cystic fibrosis. The developments of viral vectors and CRISPR gene editing have improved the efficiency and specificity of these therapies (Lodish *et al*., 2021).

Production of Genetically Modified Organisms (GMOs)

Gene cloning has resulted in the development of genetically modified crops with enhanced resistance to pests, diseases, and environmental stress. It is also applied in livestock to improve desirable traits like disease resistance and increased productivity (Brown, 2016).

Biomedical Research

Cloned genes assist scientists in gene function, regulation, and expression research. Gene cloning is employed to produce model organisms like transgenic mice to research human diseases and evaluate possible treatments (Alberts *et al*., 2014).

Vaccine Development

Recombinant DNA technology, enabled by gene cloning, is applied to construct vaccines. The manufacturing of hepatitis B and COVID-19 vaccines depends on cloned genes that encode viral proteins to elicit immune reactions without resorting to live pathogens (Sambrook & Russell, 2001).

Forensic Science and Paternity Testing

Gene cloning methods, including polymerase chain reaction (PCR), are applied in criminal investigations to examine DNA evidence collected at crime scenes. In addition, DNA fingerprinting is used to identify biological relationships during paternity testing (Watson *et al*., 2017).

These uses demonstrate the immense application of gene cloning in medicine, agriculture, and biotechnology to unlock new solutions to worldwide problems.

Genetically Modified Crops Through Gene Cloning and Their Improvements

Crop	Gene Modification	Improvement
Corn (Maize)	*Bacillus thuringiensis* (Bt) gene insertion	Resistance to pests (e.g., corn borers), reduced pesticide use
Soybean	Herbicide-resistant gene (*CP4 EPSPS* from *Agrobacterium tumefaciens*)	Tolerance to glyphosate herbicide (Roundup Ready)
Rice	*Phytoene synthase (psy)* and *crtI* genes from *daffodil* and *bacteria*	Increased vitamin A content (*Golden Rice*) to prevent deficiency
Tomato	*Polygalacturonase* gene suppression	Delayed ripening (Flavr Savr), improved shelf life and texture
Cotton	*Bacillus thuringiensis* (Bt) gene insertion	Protection against bollworms, reduced pesticide application
Canola	Herbicide-resistant gene (*CP4 EPSPS*)	Tolerance to glyphosate for better weed control
Potato	*Potato leaf roll virus (PLRV)* resistance gene	Increased resistance to viral infections, improved yield
Papaya	*Papaya ringspot virus (PRSV)* coat protein gene	Resistance to PRSV, preventing crop loss

Crop	Gene Modification	Improvement
Sugar Beet	*CP4 EPSPS* gene insertion	Herbicide resistance, improved weed control
Apple	*Polyphenol oxidase (PPO)* gene silencing	Prevention of browning (Arctic Apple), improved shelf life
Banana	*RGA2* gene from wild banana	Resistance to *Fusarium wilt* (Panama disease)

Advantages of Gene Cloning

Gene cloning has many advantages in different scientific, medical, and industrial applications. Some of its major benefits are:

Production of Therapeutic Proteins

Gene cloning makes it possible to produce large quantities of vital proteins like insulin, human growth hormone, and clotting factors. This has greatly improved the therapy of diseases like diabetes and hemophilia, with increased accessibility and efficiency (Watson *et al*., 2017).

Advancement in Gene Therapy

Cloning methods enable the repair of genetic diseases by substituting faulty genes with functional ones. This has been critical in the management of diseases like severe combined immunodeficiency (SCID) and muscular dystrophy (Lodish *et al*., 2021).

Increased Agricultural Productivity

Gene cloning is also applied extensively to develop genetically altered crops with better resistance to pests, diseases, and environmental stresses. It also improves the nutritional content of food and boosts crop yield (Brown, 2016).

Accelerated Biomedical Research

Cloned genes enable scientists to examine gene function and regulation in depth. Transgenic animal models, for example, genetically altered mice, assist in comprehension of genetic illness and the development of new therapy (Alberts *et al*., 2014).

Improved Vaccine Development

Recombinant DNA technology, in conjunction with gene cloning, has been pivotal in the creation of safe and efficient vaccines, such as hepatitis B and COVID-19. This technique enables rapid vaccine design and mass production (Sambrook & Russell, 2001).

Forensic and Diagnostic Applications

Cloned DNA sequences are also utilized in forensic science for DNA fingerprinting, which assists in crime investigation and paternity testing. Gene cloning also assist in the diagnosis of genetic diseases early in life, enhancing patient treatment (Watson *et al*., 2017).

Industrial and Environmental Applications

Cloning technology is employed to bioengineer bacteria for bioremediation, decomposing pollutants like oil spills and plastic. It also helps produce biofuels and industrial enzymes for various purposes (Brown, 2016).

Disadvantages of Gene Cloning

Notwithstanding its valuable strengths, gene cloning has many technical, ethical, and biological pitfalls. Its following are the prominent disadvantages:

Ethical Issues

Gene cloning, particularly human genetic engineering, causes ethical concern that it will enhance the likelihood of eugenics, designer children, and changes in the genes of humans. The moral repercussions of gene cloning in the life sciences of reproduction and medicine have remained broadly contentious (Lodish *et al*., 2021).

High Cost and Technical Sophistication

Gene cloning demands costly machinery, expert skills, and sophisticated laboratory procedures. Technical complexity of cloning protocols, such as ensuring inserted gene stability, raises costs and reduces accessibility (Watson *et al*., 2017).

Risk of Genetic Mutations

Cloning procedures can bring about unwanted mutations, which may cause genetic instability. Such mutations can influence gene expression, protein function, and cellular processes, producing unforeseen effects in cloned animals (Alberts *et al*., 2014).

Low Efficiency and High Failure Rates

Cloning methods, particularly when used in the case of whole organisms, are of low efficiency. For most instances, a minute number of transformed cells properly integrate and express the cloned gene, and considerable screening and optimization are needed (Sambrook & Russell, 2001).

Unintended Ecological Consequences

The introduction of genetically modified organisms (GMOs) in the environment has the potential to upset natural environments. There exists the possibility of gene flow among the modified species and the wild ones, thus resulting in ecological unbalances and a decrease in biodiversity (Brown, 2016).

Possible Health Hazards

The long-term consequences of cloned genes on human health are unknown. There are fears regarding the safety of genetically modified food and the unforeseen immune reactions that may result from gene therapy uses (Lodish *et al*., 2021).

Misuse in Bioweapons and Genetic Manipulation

Gene cloning advances also increase concerns regarding the possibility of misuse of biotechnology for bioterrorism. The possibility of engineering deadly pathogens or playing with genetic material for unwarranted motives has security implications (Watson *et al*., 2017).

Even as gene cloning has unlocked new avenues in science and medicine, these issues point to the importance of responsible research, regulation, and ethical thinking to prevent abuse.

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HYDROPONIC TECHNOLOGY FOR HORTICULTURAL CROPS UNDER PROTECTED CULTIVATION

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Introduction

For survival, humans require food, water, and a place to live. Humans have a deep-seated obsession with biodiversity protection and land area optimization since these items do not occur in an endless supply and are caused by both biotic and abiotic factors. The number of people on Earth is expected to rise from 7.0 billion to 9.5 billion over the next 40 years. It will be necessary to double food production to keep up with the simultaneous rise in demand for food species. The concern with this becomes evident when one considers the output of current agricultural and freshwater harvesting systems despite our best efforts, 1.0 billion people suffer from malnutrition today, and 1.2 billion reside in areas with inadequate water supplies.

Soil is typically the most available and beneficial substrate for crop growth. For efficient crop growth, soil offers nutrients, air, water, and other elements. Some of the major obstacles to soil being suitable for crop growth are the existence of nematodes and microorganisms that cause illnesses, improper soil reaction, inadequate drainage, compaction, and degradation. Crops grown in towers could reduce the requirement for more land. Protected cultivation can increase output while using inputs (water, fertilizer, and herbicides) more effectively. Hydroponic greenhouse cultivation's primary benefit is its effective use of natural light. Fruit development is greatly influenced by light. Light enters the hydroponic greenhouse from both the upper and lower parts of the plants. According to RIRDC (2001), the most profitable crop kinds of cereal, green leafy vegetables, flowers, and fodder are growing well in hydroponic systems. Research on the benefits of hydroponic systems, including reduced pesticide use, higher yields, and water saving.

Hydroponic technology has emerged as a game-changer in the realm of agriculture, presenting a paradigm shift from conventional soil-based farming methods. By cultivating plants in a soilless environment, hydroponics unlocks a multitude of benefits and possibilities for agricultural production. This essay seeks to unravel the complexities of hydroponic systems, shedding light on their underlying principles, advantages, components, applications, challenges, and Future prospects. Hydroponics, at its core, involves the cultivation of plants without soil, where nutrient solutions serve as the primary source of nourishment. This method relies on the meticulous management of water, nutrients, and environmental conditions to foster optimal plant growth. Across various hydroponic systems, such as deep water culture, nutrient film technique, and aeroponics, plants thrive in nutrient-rich solutions, absorbing essential elements directly through their roots. The absence of soil not only eliminates the risk of soil-borne diseases but also allows for precise control over nutrient uptake, leading to accelerated growth rates and enhanced yields.In the near future, open-field agriculture will have to deal with a number of significant issues, including soil erosion, deforestation, and land availability and productivity. Furthermore, in certain regions with poor soil fertility, unsuitable topography, and unusable soil for crop cultivation such as urban areas, soil-less culture or protected farming can be effectively implemented. Hydroponics is a technique of growing plants in nutrient solutions (water-containing fertilizers) with or without the use of an inert medium (sand, gravel, vermiculite, rock wool, perlite, peat moss, coir or sawdust) to provide mechanical support (Sharma et al., 2018) [1]. Maharana and Koul (2011) [2] defined hydroponics as a technique of growing plants in soil-less conditions with their roots immersed in nutrient solution. The term 'hydroponics' is derived from two Greek words i.e. "Hydro" and "Ponos" means water and labour respectively. The first modern use of hydroponics was done by W.F. Gericke from the University of California during the 1930's. Most hydroponics systems operate automatically to control the amount of water, nutrients, and photoperiod based on the requirements of different plants. (Resh, 2013) [6]. Various commercial and special crops can be grown using hydroponics including leafy vegetables, tomatoes, cucumbers, peppers, strawberries, and many more.

Hydroponic cultivation offers several advantages over traditional soil-based farming. One major benefit is water efficiency, as hydroponic systems use significantly less water compared to conventional agriculture by recycling water and delivering nutrients directly to the roots. This makes hydroponics a sustainable option, especially in regions facing water scarcity or drought conditions. Another advantage of hydroponics is space efficiency. Vertical hydroponic systems, for example, allow for high-density planting, maximizing the use of limited space. This is particularly useful in urban areas where land is limited and expensive. Additionally, because hydroponic systems can be set up indoors or in greenhouses, growers have more control over environmental factors such as temperature, humidity, and light, leading to year-round production and consistent crop quality. Hydroponic cultivation also reduces the risk of soil-borne diseases and pests, as plants are not in contact with soil where pathogens and pests thrive. This can result in cleaner, healthier crops and lower reliance on pesticides and herbicides. Furthermore, because hydroponic systems are often automated and monitored closely, growers can more easily optimize growing conditions and nutrient levels, leading to faster growth and higher yields.

Hydroponic Technology

Hydroponic technology is the practice of protected cultivation to facilitate a favorable environment for the sustainable production of crops so as to exhibit maximum potential even in adverse climatic situations. Protected cultivation serves many advantages such as the production of various Vegetables, Flowers, and Hybrid Seeds with good quality irrespective of the vagaries of weather conditions, and ensures the effective management of resources. This technology is more pertinent to the farmers to produce more crops effectively with less area, specifically during the off-season when the price of the produce is very high. Thus the protection includes the use of mulches, barriers, glass, and other materials to supplement the suitable environment for sustainable growth of the crop plants. The main focus of this protected cultivation is to protect the crop plant from adverse climates viz., wind, rain, cold, high temperature, snow, and biotic and abiotic factors, and to set up a suitable condition that could increase the yield and quality of crop plants.

Hydroponic technology does not utilize the soil for food production. In this technique, the plants utilize natural or artificial substrates in which the roots extract nutrients very easily and in an effective manner from the nutrient solution or substrate. There are different types of hydroponic systems viz., Deep Water Culture (DWC), Drip System, Aeroponics, Nutrient Film Technique (NFT), Ebb and flow, and Aquaponics. In the Deepwater Culture system, the roots are immersed in the nutrient solution or medium and all other parts are placed above the nutrient film such as polystyrene wood or some other materials. In the Drip system of Hydroponics, the nutrients are supplemented directly to the root zone. This type of hydroponics is suitable for crops such as tomatoes and peppers. When using a closed system, the remaining nutrient solution is drained into the tank. In this method, the nutrients are supplied to the plants at prescribed time intervals. In an aeroponics system, the roots are hanging in the air and it retrieves the nutrients periodically from the sprinkler's irrigation system. The advantage of this system is that it does not require an oxygen supplement as the oxygen is supplied through the sprayed nutrient solution. In the Nutrient Film Technique (NFT) the roots are not fully immersed in the nutrient solution, but the nutrient liquid streams flow through the pipeline over the root. It requires a smaller amount of nutrients compared to the floating root system. In Ebb and flow, the plants are placed in the tray which is filled with water at a particular interval. The remaining nutrients are returned to the nutrient reservoir due to the gravity. The Aquaponics system utilizes both the flora and fauna to get effective outcomes regarding the nutrients in the solution. It is the combination microbial process of nitrification and denitrification that allows the recycling of water from the fish tank. In this method balanced micro-ecosystem is maintained.

Protected Structures for Hydroponic Cultivation Technology

Generally, the protected structures *viz.,* Greenhouse, Nethouse, Glasshouse, Walking tunnel are used with some modifications in a hydroponics system. Also, it requires some specialized structures and microclimates which can be controlled inside the protected structures. Specialized structures such as containers, chambers, pot stands, piping systems, grow bags, troughs, etc are used inside the protected structures. Inside the protected structures microclimates need to be supplemented with the use of additional systems viz., chillers, foggers, exhaust fans, cooling pad, heaters, and dehumidifiers. Protected structures used for the cultivation technology viz., rain shelters, shade houses, mulches, sand cover, cloths to greenhouse for effective control of the climate. The design of greenhouse is the foremost thing in practicing cultivation under the protected structures. Greenhouse ranges from a simple plastic-type, costing around Rs. 200 /m2 to saw tooth-type greenhouse with automated cooling and ventilation system, costing around Rs. 3000 / m2. The expectations, needs, experience, and most importantly, the greenhouse's cost-effectiveness in connection to the produce's market should all be taken into consideration when choosing a design for the greenhouse. Cost is undoubtedly crucial and can even take precedence over all other factors. The various forms of greenhouses are categorized according to their cost, ability to regulate the climate, and application in agricultural production. The gable, gambrel, skillion, raised arch, and sawtooth structural styles are frequently utilized and appropriate for hydroponic greenhouses.

Naturally Ventilated Greenhouse:

For Indian farmers, this is the most typical and well-liked variety of greenhouse. It is a greenhouse that uses no energy and has top and side natural ventilation. The sawtooth-type greenhouse design is the most efficient and well-suited for growing crops since it allows for the most airflow. Depending on the climate and location, this kind of greenhouse can produce crops for nine to twelve months. It is discovered that only a small number of locations with moderate climates are appropriate for hydroponic agriculture.

Semi Climate and Climate Controlled Greenhouse Design: The following design specifications are necessary for the semi-climate and climate controlled greenhouse, in addition to the fundamental requirements for naturally ventilated greenhouses as previously indicated. It has been determined to be quite appropriate for hydroponic farming. 1. Exhaust fan system for removal of heat air inside the greenhouse. 2. Cellulose pad for evaporating the cooling inside the greenhouse, 3. PVC Pipes for water supplies, 4. Stands, and 5. Sprinklers for cooling.

Plug Tray Nursery Technique in Hydroponics

The goal of plug-tray nursery rearing technology is to use a protected environment to generate seedlings that are strong, disease-free, and independent of season. Different kinds of covered buildings, including as greenhouses, net houses, and poly tunnels, are utilized, depending on the goal, to manage biotic and abiotic challenges during the period of producing seedlings. Plastic pro trays and sterilized soilless growth material are used to generate high-density seedlings free of root-borne illnesses. The size and volume of cells for various vegetable crops, as well as the kind and components of the soilless media used for nursery rearing, have all been standardized. The size and volume of cells for various vegetable crops, as well as the kind and components of the soilless media used for nursery rearing, have all been standardized. Schedules for fertigation and irrigation have also been established for the growth of vegetable seedlings in various seasons. Under this nursery-rearing approach, the roots develop so quickly that there is no mortality during the transplanting phase.

Adoption of this technology as an agro-enterprise assisting in the production of most horticultural crops has a very high potential. Depending on the local climate and operation scale, an appropriate protective structure is built. Every material needed for the process, including plastic trays, growing soil, nutrients, seeds, and so forth, is readily available in stores. The technology offers a set of procedures needed to develop healthy nursery animals in a certain amount of time.

Advantages of Plug Tray Nursery Technique

- It is an excellent scheme for producing high-density seedling
- Possible to produce disease-free nursery independent of season
- Off-seasonal crop production
- Adopted for self-employed enterprise for enhancing incomes.

Conclusion

This study provides a review of hydroponic greenhouse cultivation. Ecological answers to today's food needs are a great source of concern. Hydroponic greenhouse agriculture is one of the fastest-growing agricultural sectors in developing nations. In conclusion, hydroponic greenhouse farming technology is easily used, has the potential to significantly increase crop production and quality all year round, and offers a host of other advantages. It might not cause any pollution to the environment. Crops grown in towers can help address the issue of needing additional land. In protected agriculture, a higher yield can be attained by using inputs (pesticides, fertilizer, and water) more effectively. Hydroponic greenhouse farming's main benefit is its effective use of natural light. It may also be said that the majority of the hydroponically grown crops covered above are highly sensitive to environmental influences. Environmental influences alter a product's look in addition to its interior and external quality as well as physiological functions.

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INSECTS ON THE MENU: THE FUTURE OF INSECT-BASED NUTRITION

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Abstract

Entomophagy, the practice of consuming insects, is widely observed across the globe and has recently gained attention for its nutritional, environmental, and economic benefits. Insects serve as a vital protein source, particularly in regions affected by hunger, while also providing an alternative protein option in developed and developing nations. Edible insects are rich in essential nutrients, including vitamins, amino acids, minerals, and dietary fiber, contributing to human health and well-being. Additionally, their medicinal properties are being increasingly recognized. This article explores the various advantages of insect consumption, addressing its nutritional value, safety aspects, culinary applications, consumer acceptance, and strategies to enhance its adoption. Furthermore, the environmental sustainability of insect-based diets is discussed, highlighting their potential role in global food security and ecological balance.

Keywords: Insect, Nutrition, Environmental Stability, Human Health

Introduction

As the world faces increasing food insecurity, climate change, and the depletion of natural resources, the search for sustainable protein sources has gained importance. Edible insects have emerged as a solution due to their high nutritional value, environmental sustainability, and cultural significance in many parts of the world. In the world 5.5 million species of insects are available but only one million species have been described and approximately 2,100 species are edible (Jongema Y 2017). The edible insects includes dragonflies, termites, caterpillars, bugs, grasshoppers, beetles, wasps, ants, bees, and cockroaches. Those insects are caught from nature and some were farmed. Most of these insects have been eaten all over the globe (VanHuis et al. 2013). Consumption of insects "entomophagy" remains underutilized. Their nutritional compositions are similar to those of animal foods (Raubenheimer & Rothman 2013). Coleopteran species are consumed the most out of these edible insect species, accounting for roughly 34% of total consumption, followed by Orthopteran (24%) and Hemipteran (17%), Hymenoptera (10), and Odonata (8%), Lepidoptera (4%), Isoptera (2%), and Ephimeroptera (1%). This article gives the nutritional benefits of edible insects, their potential role in food security, environmental sustainability, their use as both food and feed and the challenges like consumer acceptance.

Nutritional Benefits of Edible Insects

Protein Content and Amino Acid Composition

Many insect species contain a protein content ranging from 19% to 77%, making them comparable to conventional meat and fish (Rumpold & Schlüter, 2013). For example, crickets (*Acheta* *domesticus*) contain about 65% protein and have essential amino acids similar to those found in soy and meat (van Huis et al., 2013). Mealworms (*Tenebrio molitor*) have 47-60% protein and provide an excellent balance of essential amino acids (Rumpold & Schlüter, 2013). Grasshoppers (*Schistocerca gregaria*) contain between 60-77% protein and have a high proportion of branched-chain amino acids, which are needed for muscle development and recovery (Rumpold & Schlüter, 2013). In India, species such as *Patanga succincta* (locusts) and *Gryllus bimaculatus* (field crickets) are consumed in tribal regions due to their high protein content (van Huis et al., 2013).

Fatty Acid Content

Edible insects are rich in unsaturated fatty acids, particularly omega-3 and omega-6 fatty acids, which are essential for cardiovascular health. For example, black soldier fly larvae (*Hermetia illucens*) contain significant amounts of lauric acid, which possesses antibacterial and anti-inflammatory properties (Surendra et al., 2016). Similarly, silkworm pupae (*Bombyx mori*), which are widely consumed in India, are rich in linoleic acid, which contributes to heart health by lowering cholesterol levels (Zhou & Han, 2006). The presence of these beneficial fatty acids prevents heart disease and improves overall well-being.

Mineral and Vitamin Content

Many edible insects are excellent sources of essential minerals such as iron, zinc, calcium, and magnesium, which plays crucial roles in immune function, bone health, and metabolism (Rumpold & Schlüter, 2013). For example, palm weevil larvae (*Rhynchophorus phoenicis*) contain high levels of iron, making them a beneficial food source for combating anemia (Ekpo, 2011). Grasshoppers and crickets provide abundant vitamin B12, which is vital for maintaining a healthy nervous system (van Huis et al., 2013). In India, the red weaver ant (*Oecophylla smaragdina*) is consumed for its rich protein and iron content (Chakravorty et al., 2014). Mopane worms (*Gonimbrasia belina*), widely consumed in Africa, are rich in zinc, which plays a crucial role in boosting immunity and promoting wound healing (Bauserman et al., 2015). Insects provides essential substances such as vitamins A, B1–12, C, D, E, and K, which are necessary for proper growth and well-being (Kouřimská & Adámková, 2016). For example, caterpillars are particularly rich in B1, B2, and B6, while bee brood pupae contain high amounts of vitamins A and D (Nowak et al., 2016). The red palm weevil (*Rhynchophorus ferrugineus*), often considered a pest, is also rich in vitamin E (Bukkens, 2005).

Medicinal Benefits of Edible Insects

Recent studies have explored the therapeutic potential of edible insects, revealing their promising health benefits. For instance, *Protaetia brevitaris seulensis* contains bioactive compounds that reduce platelet aggregation, improve blood circulation, and decrease the risk of cardiovascular diseases (Kim et al., 2020). Extracts from *Bombyx mori* have been found to lower blood glucose levels, suggesting their potential application in managing diabetes (Feng et al., 2018). *Gryllus bimaculatus* (field crickets) have demonstrated lipid-lowering effects, which may help prevent cardiovascular diseases (Jongema, 2017) Also , *Tenebrio molitor* flour has been found to support gut health by promoting the growth of beneficial bacteria (Mishyna et al., 2020). In northeastern India, traditional medicine has long used insects such as silkworms and ants for their anti-inflammatory and immune-boosting properties (Chakravorty, 2014).

Human Consumption of Edible Insects

Edible insects have been a part of human diets for centuries, particularly in Africa, Asia, and Latin America, where they are commonly eaten as nutritious and protein-rich foods. In Thailand, fried crickets and silkworm pupae are popular street food snacks. In Mexico, grasshoppers are a staple ingredient in traditional dishes, often seasoned with chilli and lime. In India, entomophagy is widely practiced among indigenous and tribal communities. In states like Arunachal Pradesh, Assam, Nagaland, and Manipur, insects such as red weaver ants, grasshoppers, and silkworm pupae are an integral part of traditional diets. Red weaver ants are often used to prepare chutneys, which are believed to have medicinal properties. In Maharashtra, the *Holotrichia* beetle larvae are sometimes consumed for their nutritional benefits.

Modern Innovations in Insect-Based Food

To expand the appeal of edible insects, food scientists and entrepreneurs are creating innovative insect-based products. Insect protein powders and flours are used in bakery items, pasta, protein bars, and snacks. Indian startups and research institutions are exploring insect protein integration into processed foods. Cricket flour is being tested in biscuits and energy bars. Insect-based protein shakes and meal replacements are gaining popularity among fitness enthusiasts for their high protein and amino acid content.

High Feed Conversion Efficiency

Insects require significantly fewer resources compared to traditional livestock, making them an efficient protein source. Crickets need six times less feed than cattle to produce the same amount of protein. Black soldier fly larvae can convert organic waste into high-quality protein, reducing food waste and contributing to a circular economy.

Culinary Applications and Cooking Methods

Edible insects are prepared using various cooking methods across cultures. In Indian cuisine, they are roasted, fried, or boiled with local spices for flavor. Grasshoppers, crickets, and locusts are commonly roasted or fried for crunchiness, while soft-bodied insects like silkworm pupae are boiled or steamed for curries and soups. Some communities ferment or pickle insects for preservation and enhanced flavor.

Environmental Sustainability

Insect farming has a much lower environmental impact than conventional livestock, producing significantly fewer greenhouse gases than cattle, pigs, and poultry. It requires minimal water quantity than livestock farming. It is highly land-efficient, utilizing vertical spaces to reduce deforestation and habitat destruction.

Insects as Animal Feed

The use of insects as animal feed has gained attention due to their nutritional benefits. Black soldier fly larvae can replace up to 50% of fishmeal in aquaculture feeds, making them a sustainable alternative. Housefly larvae (*Musca domestica*) have been successfully used to feed poultry and pigs, while mealworms have been incorporated into pet food and livestock diets with positive results.

State	Insects Consumed	Consumption Details
Jharkhand	Weaver ants	A delicacy in Panch Pargana; in Simdega district, villagers consume the ant's eggs.
Tamil Nadu	Asiatic honey bees, vulture bees, weaver ants, lesser banded hornets, termites, winged termites	Nilgiri tribes consume around 8 species of insects. Winged termites are eaten by many ethnic groups.

State	Insects Consumed	Consumption Details
Karnataka	Termites, Udonga Montana bugs	Native tribes in Mysore and surrounding regions consume termites. Udonga Bugs of Western Ghats, where they are traditionally collected and eaten.
Manipur	Water beetles, giant water bugs, water scorpions, diving beetles, scarlet skimmers	Over 41 species are consumed, with aquatic insects being a favoured group.
Arunachal Pradesh	Silkworm larvae, bamboo caterpillars, wasp broods, dragonflies, aquatic beetles, stink bugs, sand crickets, spiders	Nyishi and Galo tribes consume over 81 insect species, including honey bee broods and brown Anomala spiders.
Nagaland	Goat moths, carpenter worms, grasshoppers, crickets, red ants, silkworm larvae	Indigenous people cook larvae during festivals, ethnic groups in Phek, Dimapur, and Kohima consume these insects.
Assam	Giant wood spiders, paper wasps, weaver ants, water bugs, crickets, grasshoppers, praying mantis, termites, fire ant eggs, water beetle larvae	The Bodo tribe consumes over 23 species; the Karbi community consumes fire ants eggs and water beetles.
Maharashtra	Honey bee larvae	Consumed among the Dalit community.
Kerala & Telangana	Winged termites, Indian honey bees, rock bees, dwarf honey bees, weaver ants, locusts	Winged termites are a pre-monsoon delicacy; other edible insects are also consumed.
Madhya Pradesh	Swallowtail butterflies, weaver ants, red paper wasps, rock bees, Indian honey bees, silk moths, blister beetles, wheat termites, grasshoppers	10 species were recorded among tribal people in the Satpura Plateau. Canned silkworm pupae are used for pickles and as pizza toppings.
Odisha	Date palm weevils, roasted insects like date palm worms, weaver ants	Tribes in Kandhamal, Koraput, Sundergarh, Keonjhar, and Mayurbhanj consume these, often as snacks or with rice (weaver ant chutney).

Consumption details of insect's across various states of India

Consumer Acceptance and Challenges

Consumer acceptance remains a key challenge in promoting edible insects, mainly due to cultural and psychological barriers. In Western societies, insects are often seen as pests rather than food, leading to neophobia the fear of trying new foods. Their association with decay and a lack of awareness about preparation and safety further hinder their adoption.

How to Ensure Safe Consumption of Edible Insects

To ensure the safe consumption of edible insects, proper cooking methods like boiling, roasting, or frying eliminate bacteria and parasites. Hygienic farming with controlled conditions, clean feed, and water is essential. Government regulations should enforce quality control in farming, processing, and consumption. Wild-harvested insects should be avoided due to contamination risks. Individuals with shellfish or dust mite allergies should exercise caution when consuming insect-based foods.

Strategies to Improve Acceptance

Education campaigns can promote the benefits of edible insects and shift public perception. Incorporating insect-based ingredients like insect flour into familiar foods (e.g., bread, pasta, protein bars) can ease the transition. Endorsements from chefs, athletes, and celebrities help normalize consumption. Government regulations can support insect farming and trade, ensuring safety and accessibility. Culinary innovations that enhance visual appeal and taste can attract consumers and integrate insects into mainstream diets.

Food Security and Future Prospects

Now the world is in the trend of increasing human population and it is expected to reach 9.7 billion by 2050, ensuring food security is a pressing concern. Edible insects offer a sustainable alternative to conventional livestock production due to their high feed conversion efficiency and minimal environmental impact.

Conclusion

Edible insects present a promising solution to global food security, nutritional deficiencies, and environmental challenges. They offer a sustainable and nutrient-rich alternative to traditional protein sources, yet consumer reluctance remains a significant barrier. By promoting awareness, integrating insects into familiar food products, and implementing supportive policies, edible insects can become a mainstream food source in the future. The shift towards entomophagy is not just about innovation it's about necessity. The future of food may very well depend on embracing this overlooked yet highly beneficial food source.

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LEMON GRASS: A HEALTH REJUVENATING GRASS

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Introduction

About 55 species make up the genus Cymbopogon, which is native to tropical and semi-tropical regions of Asia and is grown in South and Central America, Africa, and other tropical nations. These are tuffted perennial C4 grasses that can be used fresh or dried and powdered. It is having following medicinal properties which can be added as culinary purpose in our daily cuisine.

Taxonomical Classification

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Poales
Family: Poaceae
Genus: Cymbopogon Spreng
Species: Citratus

Medicinal Purpose

Anti-amebic Effect

The broth culture's essential oil had an effect on amoebia sp. like *Entamoeba histolytica*. (Blasi *et al.,* 1990)

Antibacterial Activity

Salmonella paratyphi, *Shigella flexneri*, *Escherichia coli*, *Bacillus subtilis*, and *Staphylococcus aureus* were all susceptible to the essential oil's chromatographic fraction in an agar plate. Two of the three primary components of the oil identified by chromatographic and mass spectrometric techniques exhibit these actions. Gram-negative and gram-positive bacteria are susceptible to the antibacterial action of the α-citral (geranial) and β-citral (neral) components. (Syed *et al.,* 1990)

Antifungal Activity

Lemon grass oil is one of the most effective substances against human dermatophytes such as *Trichophyton mentagrophytes*, *T. rubrum*, *Epidermophyton floccosum*, and *Microsporum gypseum*. According to other research, lemon grass oil has antifungal properties against keratinophilic fungi, 32 ringworm fungus, and food storage fungi. Because of these inherent antibacterial properties, lemongrass oil also works well as a pesticide and herbicide. (Misrha *et al*., 1994).

Free Radical Scavengers and Antioxidant Effects

Measuring the bleaching of the 1,1-diphenyl-2-picrylhydrazyl radical, scavenging of the superoxide anion, and inhibition of the enzyme xanthine oxidase and lipid peroxidation in human erythrocytes demonstrated the free radical scavenging effects of methanol, MeOH/water extracts, and infusion and decoction of *Cymbopogon citratus*. (Cheel *et al.,* 2005)

Neurobehavioral Effect

Pentobarbital sleeping duration was used to assess the essential oil's sedative/hypnotic properties; elevated plus maze and light/dark box procedures were used to assess its anxiolytic properties; and seizures caused by pentylenetetrazole and maximum electroshock were used to assess its anticonvulsant properties. The amount of time spent sleeping, the time spent in the elevated plus maze's open arms, and the amount of time spent in the light compartment of the light/dark box were all increased by the essential oil. Furthermore, the essential oil prevented the tonic extensions brought on by maximum electroshock and postponed clonic seizures brought on by pentylenetetrazole, suggesting that the seizure threshold was raised and/or the seizure spread was halted. (Blanco *et al.,* 2007)

Anti-inflammatory activity

One of the major issues faced by world health is chronic inflammation, which has been connected to serious illnesses including cancer (Colotta *et al.,* 2009). Folk medicine has employed natural products to treat the resurgence of tissue inflammation in humans. Lemon grass is used as a herbal anti-inflammatory medication throughout Asia and Africa, according to ethnopharmacological research. In order to cure topical inflammation, citral, which is isolated from *C. citratus*, is used as an addition in lotions and ointments since it significantly inhibits inflammatory mediators.

Anti-obesity and antihypertensive activities

Drugs that are hypoglycemic and hypolipidemic have included lemon grass. Typically drunk as tea, it has been used in Ayurvedic and folk medicine to control blood serum levels of fat, cholesterol, and glucose, perhaps preventing obesity and hypertension. By secreting insulin, the plant has been utilized to maintain blood glucose levels (hyperinsulinemia). It lowers blood pressure, preventing hypertension. Citral, which was derived from *C. citratus*, functions as endothelium-independent vaso-relaxation by blocking the prostacyclin channel and Ca2+ influx. (Devi *et al.,* 2012)

Antidiabetic activity

One of the most deadly illnesses of the 20th century is diabetes. It hinders the pancreas' ability to produce enough insulin and may make blood sugar control impossible. Using molecular docking, the in-vivo antidiabetic efficacy of *C. citratus* was examined at 400 and 800 mg dosage rates. The levels of insulin, glucose and triglycerides are significantly reduced by the extracts. Using α-amylase and α-glucosidase inhibitory tests, the in vitro antidiabetic potential of *C. citratus* was examined in relation to Type II diabetes. The α-glucosidase and α-amylase were shown to have an EC50 of 0.31 mg/mL and 99.9% inhibition of 1 mg/mL, respectively. (Bouduo *et al.,* 2014)

How to add lemon grass in our daily food ?

As a common component in Thai salads like Yum Takrai, a spicy seafood salad with lemongrass and ginger, lemongrass can actually be consumed raw. It is important to always remove the outside woody stem and slice the lemongrass as thinly as possible because raw lemongrass can be difficult if not prepared properly.

Lemongrass can be used in cooking in two different ways. It can be steeped in liquids or cooked in with the rest of your ingredients. Because it holds the majority of the flavor, you should only utilize the bottom of the stem for both of these procedures, which is about 7 to 8 cm where the plant feels the most delicate. Remove the top portion of the stem, the bulb at the base, and any leaves.

The bottom stem's rough outer layers should also be peeled off for conventional cooking, leaving only the soft interior portion. Before adding to your dish, chop as small as you can or use a pestle and mortar to ground into a powder. This technique is effective for adding flavor to marinades, spice rubs, stews, and curries. If you want a stronger flavor, add lemongrass at the beginning with the other aromatics. Keep in mind that the longer you cook it, the more flavor it releases. However, you should add it later in the cooking process if you want something a little more understated.

Lemongrass infusions

Since you won't be eating the lemongrass, you don't need to remove the tough upper layers, which still have a lot of flavor, but you still need to use the lower part of the stem if you're using it as an infusion. Actually, you can save waste by reserving the upper layers that are taken off during normal cooking for use in infusions.

Use the side of a knife to crush the fragile section of the stem, similar to how you would a garlic bulb, and then chop into 3–5 cm pieces to add lemongrass to soups, herbal teas, or even your favorite alcoholic beverage. Steep for 5 to 10 minutes and then remove for hot infusions, such as soup or tea; leave for 4 to 5 days to infuse a bottle of vodka or gin. As with cooking, the flavor gets stronger the longer you keep it in.

Conclusion

By providing herbal medications free of side effects and reactions, medicinal herbs have significantly and remarkably improved the quality of the primary healthcare system. Antibacterial, antifungal, anti-inflammatory, anticancer, analgesic, antiseptic, antinociceptive, and antioxidant properties have all been employed in traditional medicine. In order to determine the therapeutic potency of secondary metabolites and increase the creation of new herbal medications, research into their pharmacology and phytochemical screening has recently drawn attention to medicinal plants. In an effort to enhance the phytochemical and pharmacological analyses of *C. citratus*, crucial elements including harvesting time, extraction techniques, and propagation mode should be tracked and addressed. These will improve the C. citratus extracts' physicochemical makeup and biological activity, raising their economic worth.

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PROTECTED CULTIVATION OF HIGH-VALUE VEGETABLE CROPS UNDER CHANGING CLIMATE

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Abstract
Protected cultivation is the most modern technique in the cultivation of vegetable crops in a controlled environment. In the last few decades for qualitatively and quantitatively production of vegetable crops requirement of greenhouse has increases rapidly. Currently faced with different challenges like, rapid urbanization, ever increasing population, limitations of land holdings, decreasing crop production etc. Protected cultivation is greater technology where plants grown in small piece of land or soilless culture system. Hydroponics is a recent technology where plants grow without soil and gives higher yield.

Introduction

Protected cultivation is a novel technique to modern agriculture that involves growing high-value vegetable crops in controlled environments like greenhouses, polyhouses, and net houses to protect them from harsh weather conditions. Given the growing problems provided by climate change, such as unexpected weather patterns, temperature extremes, and inconsistent rainfall, protected farming provides a long-term solution to assure constant crop production, increased yield, and improved quality. This strategy optimises resource utilisation, reduces pest and disease infestations, and extends the growing season, allowing for year-round cultivation of valuable commodities such as tomatoes, capsicum, and leafy greens. Protected agriculture is emerging as a crucial method for improving food security, increasing farmer income, and ensuring sustainable agricultural practices in the face of climate change.

What is protected cultivation?

Protected cultivation practices can be defined as cropping techniques where in the micro climate surrounding the plant body is partially or fully controlled during their growth period as per the requirement of the plant species grown. It is also known as Controlled Environment Agriculture (CEA). It is conservative of land and water, very productive and protective to the environment.

Why protected cultivation is necessary?

Protected cultivation offered a new dimension to produce more crops in a limited area of land as rapid urbanization, small land holdings, declining crop production and biodiversity, increasing population, demand for food especially vegetables are some constraints in agricultural production. It involves the cultivation of vegetables to attain maximum production in a controlled environment where temperature, humidity, light, soil, water, fertilizers etc. are manipulated even during off season.

Advantages of protected cultivation

1. Higher yield
2. Year-round cultivation
3. Off season production
4. Controlled pollination
5. Better quality
6. Weed free cultivation
7. Least pesticide residues
8. Assured production
9. Self-employment for the youth
10. Easier plant protection
11. Saving significant amounts of water
12. Allowing farmers to take advantage of market seasonality and higher prices.

Disadvantages:

1. High labour requirement.
2. Higher cost of production.
3. Initial capital investment is high.
4. Skilful knowledge is required.

Different production system under protected cultivation:

Green house and polyhouse

Greenhouse technology is suited to vegetable crops such as tomato, capsicum, cucumber French Bean, Cabbage, Chillies, Spinach, Cauliflower etc. The reason to grow vegetables in green house is to have crops when they can't be grown out side. Out of season tomatoes, cucumbers, peppers, lettuce and other vegetables command high prices in markets. Depending on location, greenhouse design varies. Minimal climatic control is provided by simpler greenhouses and provide economic yield of vegetables crops. In the temperate regions, the highly controlled greenhouses i.e. glass houses are used to grow vegetables as the freezing temperature outside cause problems in growing the crops.

Advantages

1. It minimizes environmental threats to the crops.
2. It helps in growing different type and variety of crops.
3. It helps to produce disease free and genetically superior transplants.
4. Hydroponics, aeroponics and nutrient film techniques are possible only under greenhouse gardening.

Disadvantages

1. It requires high operating expenses.
2. Poor pollination takes place under greenhouse cultivation.
3. It requires regular periodic inspection.
4. Lack of awareness among farmers.

Soil less culture

Growing of vegetables in media other than soil is called as soil less culture. It is an artificial mean of providing plants with support and reservoir for water and nutrient. Media used arecoco pit, vermiculite, perlite, saw dust, rock wool, peanut hulls, rice hulls or the mixtures. As compare to soil-based culture, soil less culture of plants involves a restricted root system and a reduced root zone.

Hydroponics

It is a type of horticulture and a subset of hydro culture. It is a method of growing plants in nutrient solution in water, without soil. The plants may be grown with their roots in the mineral solution only, or in an inert medium, such as perlite and gravel. As hydroponically grown plants dip their roots directly into nutrient rich solutions, they get all the nutrients they need. They have smaller root system so more plants can be grown in less area and get more yield.

Advantages

1. Crops can be grown where the soil is not suitable for growing plants.
2. Maximum yield is possible.
3. Cost of labour is mostly eliminated.
4. Conservation of water and nutrients.
5. Environment can be manipulated according to our choice.

Disadvantages

1. Construction cost is high.
2. Trained person must be required.
3. Consumption of electricity is high.

Aeroponics

It is an advance form of hydroponics. It involves growing plants in a trough or container in which the roots are suspended and sprayed with a nutrient mist. The rooted plants are placed in a special type of box with computer controlled humid atmosphere. This method results in healthier plants, more growth and higher yield in few resources. In this system, oxygen is surrounding the roots at all time.

Advantages

1. Unrestricted and natural growth
2. Reduces the incidence of disease
3. Disease free environment
4. Plants grow with higher density
5. Propagation from a single stem is possible

Disadvantages

1. It requires constant monitoring
2. It is highly susceptible to power outages
3. Requires technical knowledge

Conclusion

Protected agriculture is an important method for maintaining long-term and economic vegetable production in the face of climate change. By creating a controlled environment, it protects high-value crops from adverse weather, pests, and diseases while optimising resource consumption and improving yield quality. Despite obstacles such as high starting costs and technical skill, advances in automation, renewable energy integration, and precision farming are making this technology more accessible and efficient. As the demand for food security and resilient agricultural practices develops, protected cultivation emerges as a feasible strategy for maintaining productivity, improving farmers' livelihoods, and promoting a climate-resilient future for global agriculture.

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NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI) TO OPTIMIZE NITROGEN IN CROP PLANTS

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NDVI is primarily used to determine the health and density of vegetation in a given area. This index is widely used in agriculture, forestry, and ecology to monitor vegetation growth, assess plant stress levels, identify areas of drought or disease, and aid in crop management decisions. To read NDVI imagery, one can interpret the colour scale associated with the index values. Typically, healthy vegetation appears green, while less healthy or sparse vegetation appears yellow or red. Darker shades may indicate areas with high biomass, while lighter shades may suggest lower vegetation density or the presence of bare soil. Understanding the context of the area being analyze, such as the specific crop type or environmental conditions, can further assist in interpreting NDVI imagery and making informed decisions about agricultural practices.

Normalized Difference Vegetation Index (NDVI) is a commonly used metric to quantify the density and health of vegetation. Its values range from -1.00 to 1.00, with negative values indicating water or bare soil, values near zero indicating sparse vegetation, and higher values indicating denser and healthier vegetation.

What is Normalized Difference Vegetation Index (NDVI)?

It is a method that calculates the variation between the quantity of red light received by vegetation and the quantity of near-infrared light that is strenuously reflected by vegetation. The objective of this method is to provide a quantitative analysis of the state of plant life. There is no situation in which its value falls outside of the spectrum of -1.00 to +1.00. However, there is not a clear demarcation between the many types of land cover that may be found. If the sum of the figures comes out to be less than zero, it is quite probable that the substance in question is water. If you obtain an NDVI score that's quite near to a positive one, there's a good chance that it's just a bunch of tightly packed green leaves. This is especially true if the leaves are densely packed together. Green leaves have a greater value than yellow or light green leaves do, which is why this is the case. Imagine for a moment that it is very close to being equal to zero. In such a situation, there is hardly a snowball's chance in hell that any leaves of any type are still there, and the region may even be urbanized by this point. The Normalized Difference Vegetation Indicator is the index that is used by analysts in the area of remote sensing the majority of the time. The NDVI value of plant indicates its leaf greenness *i.e.* chlorophyll content of leaf tissues which shows healthiness and vigour of the plant. High NDVI value means healthier plants contain more chlorophyll content.

Why is Normalized Difference Vegetation Index useful?

There are a lot of different vegetation indices, and the vast majority are comparable to one another. However, it is the one that is used the most often and widely, and it also has an essential benefit, which is a high resolution of pictures that are derived from satellite data. In the circumstances like this, channels with a resolution of ten meters may be utilized to determine the NDVI. Remember that one pixel is equal to ten by ten meters. On the other hand, the index's resolution that uses extra light channels, namely red age, might be twenty meters, where one pixel is equal to twenty by twenty meters.

How is the NDVI calculated?

It may be determined using the following straight forward mathematical procedure, which converts raw satellite information into vegetation indices. The equation creates a single number that is representative and integrates the information that is accessible in the red and NIR (near-infrared) bands. The plant's health and vigor was evaluated using the Normalized Difference Vegetable Index (NDVI), which is computed by subtracting the visible red from near-infrared (NIR) reflectance of the plant and normalizing the result by the total of the reflectance's. The values of NDVI vary from 0.00 to 0.99 based on the intensity of leaf greenness due to presence of leaf N content. The equation for calculating NDVI is given below:

$$NDVI = \frac{\mathrm{FNIR} - \mathrm{FRed}}{\mathrm{FNIR} + \mathrm{FRed}}$$

Where, F_{NIR} and F_{Red} are the fractions of emitted NIR and red radiation reflected back from the sensed area.

The equation creates a single number that is representative and integrates the information that is accessible in the red and NIR (near-infrared) bands. To do this, it takes the reflectance throughout the red spectral band and subtracts it from the reflectance throughout the NIR band. After that, the result is divided by the total reflectance of the NIR and red wavelengths.

The assessment of the NDVI will never be more than a positive one and less than a negative one. In addition, a number between -1.00 and 0.00 denotes a plant that has died and inorganic items like stones, roads, and buildings. Simultaneously, its values for living plants may vary anywhere from 0.00 to 1.00, with 1 representing the healthiest plant and 0 representing the unhealthiest plant. It is possible to assign a single value to each pixel in a picture, whether that pixel represents a single leaf or a wheat field that spans 500 acres. For example, in mustard crop the NDVI values ranges from 0.74 to 0.81 under different treatments based on nitrogen management practices (Meena *et al*., 2024a).

NDVI reference values

NDVI values	Indication
-1.0 to 0.0	Indicates clouds and water
0.10 or less	Indicates barren rock, sand, or snow
0.20 to 0.50	Indicates sparse vegetation
0.60 to 0.90	Indicates dense vegetation
0.60 to 0.80	Indicates temperate and tropical rainforests

How do we use Normalized Difference Vegetation Index?

Justifiably, it is now being utilized in a number of different fields of research. For instance, it is leveraged in the field of agriculture for the objectives of precision farming and the evaluation of biomass. It is likewise employed by foresters in order to evaluate forest resources as well as the leaf area index (LAI). In addition, NASA believes it to be a reliable indication of the existence of drought conditions. The proportional NDVI and the concentration of vegetation are both lower in areas where water serves as a barrier to the establishment of vegetation. This is because water prevents the roots of plants from growing deeper into the soil. It, including other kinds of remote sensing, has the capability to be utilized in a wide variety of distinct ways in reality. The sensor based diagnostic tools GreenSeeker was used for optimizing nitrogen under field conditions by measuring NDVI values (Meena *et al*., 2024b)

What can NDVI tell us about plants?

It is essential to have a solid comprehension that the Normalized Difference Vegetation Index is only an indication of the healthiness of the plant and provides no information about the reasons behind ascertain condition. The vegetation index is more of an expression than a direct reflection of what is occurring on the field. Let's look at three applications of NDVI for field analysis:

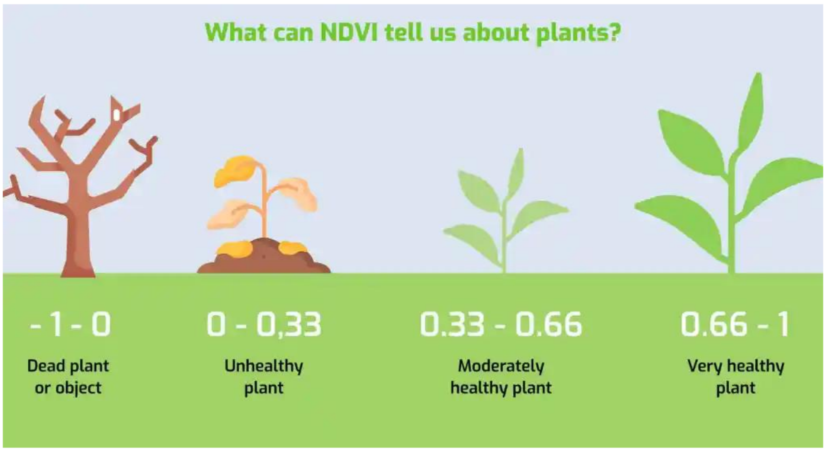
When a new season begins

It is beneficial for understanding the plant's winter hardiness and how it managed to survive.

If its value is less than 0.15, it is somewhat likely that all of the plants in this field section have perished. Typically, these numbers relate to the tilled soil without any plants. Another example of a low number is 0.15-0.2. It might suggest that the plants began preparing for winter during the early phenological period, before the tilling stage. A result in the range of 0.2 to 0.3 is satisfactory. The plants most likely progressed to the tilling stage and have regained their vegetative state.0.3-0.5 is a decent value. However, it is important to remember that higher NDVI readings suggest that plants overwintered at a later phenological stage. Suppose the satellite picture was captured before the vegetation resumed its normal state. In that case, analyzing the area after the vegetation continued its normal form is important. A number greater than 0.5 indicates an anomaly during the post-wintering phase. It is recommended that you check out this field zone. To recap, if you notice that the values obtained are significantly different from the norm, you need to conduct an inspection of the relevant portion of the field. A large departure from the norm is required

When the season is in the middle

Utilizing the index might be helpful in gaining a better understanding of how plants develop. Imagine that the readings fall between mild and high (0.50-0.85). It is highly likely that this particular part of the area does not face any major challenges at the present time. If the index remains lower than there may be issues such as a deficiency of soil water or nutrients. However, you need to do your own investigation into this particular area. Here, some of the pictorial images drawn for variable-rate application (VRA) of nitrogen by using the Normalized Difference Vegetation Index which identify regions with vegetation indices ranging from low to high.



To begin, it is a mathematical computation performed pixel-by-pixel on an image utilizing tools from a GIS (Geographic Information System). Calculated by contrasting the amounts of red and near-infrared light absorbed and reflected by the plant, it measures the plant's overall state of health. The NDVI may be used to study land all over the globe, making it ideal for focused field studies and national or global vegetation monitoring. By means of utilizing NDVI, we can get an immediate analysis of fields, enabling agriculturalists to optimize the production potential of areas, limit their influence on the environment, and modify their precision agricultural operations. Moreover, examining it in conjunction with other data streams, such as those about the weather, might provide further insight into recurring patterns of droughts, freezes, or floods and how they impact vegetation.

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PASHMINA: THE FINEST SPECIALTY FIBRE- PRODUCTION, STRUCTURE, ANNUAL CYCLICITY AND ITS SIGNIFICANCE

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Pashmina, derived from the undercoat of Changthangi goats in the Himalayan region, is one of the finest and most luxurious natural fibre known for its exceptional softness, warmth and lightweight properties. Pashmina has been an integral part of the rich textile tradition of India, particularly in Kashmir, where artisans have perfect art of weaving. It represents India's textile heritage and craftsmanship.

A herd of Pashmina goats grazing in the high-altitude regions of Ladakh, India

Keywords: Pashmina, luxury fiber, textile heritage, traditional craftsmanship, Geographical Indication (GI), aesthetic value.

Introduction

Pashmina, known as the "prince of specialty fibres," is among the finest animal fibres. On the scale of fineness Pashmina stands second to shahtoosh fibre (Chiru), an endangered species. It is the worlds' most desired fiber well known due to its warmth, softness, fineness and its aesthetic value. Besides adding softness to the product, it is having an alluring factor of being very rare. 'Pashmina' is the traditional name derived from a Persian word 'pashm' which means 'soft gold' (Shakyawar *et al*., 2013). It is also known as diamond fibre. It is specifically known for the fibre produced by goats living in some specific regions of Kashmir, especially at the high altitude of 11000-14000 feet. It is produced as an undercoat and shed annually. Their scarce production may be due to the harsh climatic conditions, light, temperature, nutrition or genetic factors. It is thinnest fibre with average fineness diameter of 12-15 µm (Shakyawar *et al*., 2013). India produces the best quality Pashmina wool in the world having excellent properties. Therefore, the products made from Indian Pashmina wool are of very high value with high export potential.

Earlier, Kashmir was the only region where there were craftsmen who were capable of spinning and weaving of such thin fibre just because of that it was named as Cashmere by Europeans. With time, to meet the growing demand of cashmere fiber these goats are also kept and reared in different regions of the world. However; to save the heritage value of Pashmina fibre, the traditional name 'Pashmina' is being used for the fibre obtained from goats located in Kashmir region (Leh and Ladhakh). The most significant difference between cashmere and Pashmina is the fibre diameter. Pashmina fibres are thinner and finer (12–15 µm) than cashmere fibre (15–19 µm) (Pashmina Technical Data – Department of Animal Husbandry, Govt of J&K).

Cashmere production in the world

The total Cashmere production throughout world is about 10000-15000 tons/annum from 200 million goats with an annual yield 750-1000 gm/year. The major contributing countries are China, Mongolia, Iran, Afghanistan, Pakistan, Nepal and India. China is the major producer of cashmere with 70% contribution followed by Mongolia with 20% contribution of total cashmere production. The rest 10% share is from other countries. India, contributes less than 1% of the total cashmere production. In India, there are two breeds of goat producing Pashmina i.e. Changthangi and Chegu. Changthangi breed is reared in Changthang region of district Leh, Kashmir and Chegu in some regions of Himachal Pradesh (Lahul and Spitti and Kinnaur) and Uttrakhand (Uttarkashi, Chamoli and Pithorgarh). The annual production of Changthangi breed is 45000 Kg from 1,60,000 goats and 1500 kg from 12000 Chegu goats. Annually India collectively produces 40-50 tons from nearly 2 lakh goats. The annual yield from Changthangi breed is 200-250 gm/animal/year (Singh, 2015; Beigh and Bashir, 2019) and about 50-100 gm from Chegu goats. Low yield may be due to some of the genetic factors making India a poor contributor towards the total production. Given the quality of Indian Pashmina, there is a huge demand of this specialized fibre in the textile industry.

Ultra structure of wool fibre and composition

Although, a lot of work has been done on human hair, wool fibre, angora fibre, yak fibre and alpacca fibre, yet major evidences are available mainly from human hair rather than from other animal fibres. Hair fibres from all the species share almost a common structure, except the presence or absence of innermost medulla. Pashmina fibre being the finest one, lacks inner medulla. Wool fibre consists of ~90-95% proteins with two major protein groups, α–keratins (KRTs) that constitute keratin intermediate filaments (KIFs) and the Keratin associated proteins (KAP or KRTAP) that form matrix part of hair fibre. The KRT proteins are further classified into two groups on the basis of their pI; type I acidic (40—50 kDa) and type II neutral/basic (55—65 kDa). KAPs/KRTAP or Matrix proteins are also classified into three classes on the basis of their sulfur content including high-sulfur (HS) and high Glycine-tyrosine (HGT) (6—9 kDa) proteins.

Pashmina Fibre and its biological significance

Pashmina fibre is produced from native goats domesticated in Ladakh region of Kashmir. The Pashmina fibre arises out of the most distinct engine, the hair follicle, which is the only exclusive organ that cycles throughout the life time of mammals' body. The hair shaft or fibre consists of terminally differentiated keratinocytes produced by hair follicle. Hair follicle is nature's most fascinating structures and its most obvious function is to produce a hair or fiber. It serves as an ideal system biology research model. Understanding of mammalian hair cycle actually depends on the progression of follicles through three phases: growth (Anagen), regression (Catagen) and resting (Telogen) phases. Cashmere goat is gaining the interest for studying the hair growth cycle because of the annual cyclicity of its hair fibre growth. Its secondary follicles give rise to cashmere fibre which sheds every year.

Annual cyclicity of Pashmina Fibre

Pashmina fibre undergoes annual growth cycle of synthesis and shedding. The hair follicles involved in the synthesis of Pashmina fibre present the most fascinating structures. Each hair follicle composed of two parts: upper permanent region and lower regenerating region. It is the lower region where hair matrix cells give rise to hair. Pashmina fibre synthesis progresses through three phases of follicle growth cycle, including Anagen, Catagen and Telogen. The study by Bhat *et al* (2019) suggests that primary follicles start growing before winters and regress after November.

Anagen Phase (growth): In the anagen phase, intense metabolic activity takes place. Follicle bulb stem cells which are known as dermal papilla cells produces several factors that induces hair matrix cells to undergo proliferation and differentiation into the hair shaft (HS) and the IRS. As the follicle progresses towards the end of anagen phase, proliferation and differentiation of HMCs slow down and the cells at the lower region of the hair follicle enter into an apoptosis phase, termed as catagen (Liu *et al*., 2015).

Catagen phase (regression): Quiescence of hair follicle marks the arrival of catagen phase. Hair follicle bulb undergo condensation and moves upward. Most of the cells HMCs undergo the apoptosis process (Liu *et al*., 2015). This phase is highly regulated phase with integrated cell differentiation and apoptosis, release of papilla from bulb, and cessation of cell growth and pigmentation process. Papilla shrinks due to the loss of extracellular matrix substance.

Telogen Phase (rest): The catagen is followed by telogen phase. In telogen, the hair follicle undergoes resting phase, the proliferation and differentiation of most of the cells stop, and the hair follicle becomes quiescent. By the end of telogen, hair follicle bulb regenerates and again begins their journey to enter anagen phase of the next hair cycle (Liu *et al*., 2015).

Economic significance of Pashmina fibre

'Pashmina', a specialty fibre, is the finest form of 'Cashmere' recognized for its superior quality, warmth, and aesthetic value. With the diameter of approximately 12-16 µm, it is the highly valued in global markets. Originating from goats residing at 11,000 – 14,000 feet, Pashmina is an undercoat fibre produced by secondary hair follicles and shed annual. The primary follicles in contrast, produce coarse guard hairs (50-100 µm) that form a protective layer against extreme Himalayan winters, where temperatures drop to -40^{o}C. Pashmina fibre has three times the insulating properties of regular wool.

Pashmina fibre length varies across body regions and between males and females. The traditional producers of Pashmina in Ladakh's Chanthang region are the Changpa nomads, who completely rely on Pashmina goats for their livelihood. Various programs have been launched to enhance Pashmina production, including improved nutrition, veterinary services, selective breeding and establishment of new Pashmina goat farms.

The Pashmina Promotion Programme (P-3) was launched by the Ministry of Textiles in the Leh and Ladakh regions to enhance Pashmina quality and yield. This initiative developed in collaboration with the Ladakh Autonomous Hill Development Council (LAHDC) and Pashmina rearer's aims to improve the economic conditions of nomads engaged in Pashmina production (12th Plan Highlights). Historically, between the 16th and 19th centuries, Kashmir was the sole hub for Pashmina craftsmanship, leading to the global adoption of the terms Cashmere. However, as the fibre gained popularity, cashmere-producing goats were reared worldwide. To safeguard the heritage of Indian Pashmina, the term 'Pashmina' is now exclusively used for fibre sourced from Kashmir and other regions of the Himalayan range.

Conclusion

Pashmina is the specialty fibre produced by native goat population in Changthang region (Leh & Ladakh). Despite of limited production, Indian Pashmina holds the strong export potential. Pashmina's Geographical Indication (GI) status recognizes its unique origin and traditional craftsmanship. Protecting its authenticity through technological innovation preserves its cultural significance, contributes to national pride, and supports India's textile heritage on the global stage.

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APPLICATION OF ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN NUTRIENT MANAGEMENT

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Abstract
Agriculture is undergoing a rapid transformation due to technological advancements, including AI and ML. Traditional nutrient management approaches rely on generalized recommendations, often leading to inefficiencies such as overuse of fertilizers, soil degradation, and environmental pollution. Hence nutrient management has become a crucial aspect of modern agriculture, impacting both crop yield and environmental sustainability. The application of Artificial Intelligence (AI) and Machine Learning (ML) in nutrient management has significantly improved decision-making processes, efficiency, and precision in agriculture. This review highlights the various AI and ML techniques used for optimizing nutrient application, predicting soil fertility, and enhancing sustainable farming practices.

Introduction

With the ever-growing population and the challenges that humankind is facing currently, such as climate change, poverty, and hunger, there is a need for highly efficient, productive and sustainable tech-based agriculture. Fertilizer plays a key role in food security and are used to increase global crop production and maintain soil fertility, which is essential and help increase food production. The application of artificial intelligence (AI) and machine learning (ML) techniques has revolutionized nutrient management in agriculture. These advanced technologies offer innovative solutions for predicting nutrient requirements and enhancing overall crop productivity (Kumar *et al*. 2023). AI-driven applications have been supported by a dataset for retrieving data/information, which helps in making vital decisions in terms of recommendations or commands to variable rate applicators.

Nutrients are one of the major inputs supplied to crop fields. Optimization of their application is the major aim for most of the agronomic practices, but due to the spatial and temporal variability within crop fields and lack of site-specific information in real time, there is a great hindrance to such optimized applications. ML-based nutrient management helps in assessing farm fields at their micro-climate levels and make efficient decisions, keeping in mind the crop needs and thus resulting in enhanced productivity levels and resource use efficiency, maximized returns and improved soil health (Olsen *et al*. 2021). ML algorithms have the potential to create mathematical models for decision-making. ML-based models can be used for the prediction of yield and amount of fertilizer required by the crop thus helping in the precise application of fertilizer and increasing the productivity.

Key concepts in ML for soil nutrient optimization include:

Supervised learning: Supervised learning is a type of machine learning algorithm that learns from labeled data eg. Optimum nutrient level, crop yield etc. to predict the outcomes for new unseen data.

Unsupervised learning: It is a type of machine learning that learns from unlabeled data. This means that the data does not have any pre-existing labels or categories such as identifying the cluster of soil sample with similar properties. It is more like exploration.

Reinforcement learning: Reinforcement machine learning is a machine learning model that is similar to supervised learning, but the algorithm isn't trained using sample data. The algorithm interacts with an environment (eg. farm field) and learn optimal actions (eg. Fertilizer application rates).

Machine learning based algorithms for nutrient prediction

With advances in machine learning algorithms even the most complicated regression and classification can be solved. Regression is a part of supervised learning that provides a prediction of an output variable as a function of an input variable that are usually known and available in these subcategories. Classification is also an important type of supervised learning that uses model to predict a discrete label instead of continuous output eg. Support vector machine (SVM) is commonly used to classify the soils according to the amount of nutrient present in them.

Decision tree-based algorithms are widely used in nutrient management to optimize fertilizer application, predict soil health, and improve crop yields. These models split data into decision nodes based on soil parameters, weather conditions, and crop requirements, leading to accurate and interpretable nutrient recommendations. The most common learning techniques in this category include classification and regression trees, along with automated chi-square detection. Random forest is a decision tree-based algorithm that is commonly used in nutrient management. Based on a set of decision rules that follow a tree-like architecture, it can make recommendations based on classified data.

Neural networks have revolutionized precision agriculture, particularly in nutrient management, by analyzing large datasets and optimizing nutrient applications for crops. Artificial neural networks (ANNs) are a type of supervised learning technique used for regression and classification. They are highly flexible and can model intricate patterns in the data, such as the interactions between multiple soil nutrients and their impact on crop health. Another deep learning algorithm employed for nutrient management is convolutional neural networks (CNNs). These have transformed nutrient management by enabling image-based analysis of soil health, crop nutrient deficiencies, and fertilizer optimization. CNNs process images from drones, satellites, and IoT sensors to detect patterns that indicate nutrient levels in soil and crops.

AI and ML based techniques nutrient management

Predictive Modelling: AI-powered prediction algorithms employ historical and real-time data to estimate soil nutrient levels, allowing farmers to apply fertilizers more effectively. These models include data from remote sensing, weather, soil testing and crop growth trends. Random forest, support vector machine (SVM) are popular machine learning techniques for predicting nutrient deficits and recommending site-specific fertilization options.

Precision Agriculture: ML algorithms analyze geographical and temporal variations in nutrient availability, allowing for more precise fertilizer delivery. AI powered technologies such as GPS-guided Variable Rate Technology (VRT) optimise fertilisation patterns, ensuring nutrients are supplied just where they are needed. This avoids waste, saves money, and mitigates the environmental effect of excessive fertiliser use. AI-powered precision agricultural solutions improve decision-making by giving farmers actionable insights based on real-time data.

Remote Sensing and Imaging: AI-based satellite and drone imaging technologies are commonly utilised to detect nutritional shortage in crops. Spectral analysis, hyperspectral imaging, and deep learning approaches evaluate plant health and highlight regions that require action. AI models perform accurate nutrient status evaluations using vegetation indicators such as the normalized difference vegetation index (NDVI), allowing for early remedial measures. The application of this technology is handy for large-scale farming when human monitoring is impracticable.

Soil Health Monitoring:
AI-enabled soil sensors continually monitor soil moisture, pH, and nutrient levels, giving farmers with real-time feedback. ML models analyse sensor data to determine the best nutrient delivery rates, resulting in balanced soil fertility. When combined with IoT and cloud computing, these sensors allow for automated nutrient management systems that dynamically change fertilisation schedules. AI-powered soil health monitoring improves sustainability by avoiding overfertilization and soil depletion.

Automated Decision Support Systems (DSS): AI-driven DSS combine numerous data sources to generate tailored nutrition management suggestions. These systems utilise reinforcement learning and AI-powered analytics to gradually increase accuracy. DSS systems use soil test results, climatic data, and crop models to create exact fertiliser application plans. Many current agricultural DSS are coupled with mobile applications, making them useful for farmers in remote places. These automated DSS save time, improve accuracy, and offer ideal soil conditions.

Crop Growth Simulation Models: AI and machine learning approaches improve crop growth models by adding real-time environmental and soil data. These models simulate nitrogen absorption dynamics and forecast crop responses to various fertiliser treatments. Farmers may experiment with different fertiliser delivery scenarios using AI-based simulations before adopting them in the field. AI-enhanced crop models increase yield projections and optimise fertiliser usage to maximise output.

Soil classification and mapping: This is an important aspect in precision agriculture one can classify the type of soils and indicate the spatial variability in agriculture fields, indicating site specific nutrient approach. Fields can be divided into homogenous zones and help to recognize the area for specific nutrient treatment by using various ML techniques like K means clustering and hierarchical clustering (Metwally *et al*. 2019). K-Means Clustering divides fields into zones based on soil properties, allowing farmers to apply variable fertilisation without wasting resources or contaminating the environment (Fard *et al*. 2023).

Variable rate technology
One of the major technologies used in site specific nutrient management is variable rate technology. In this system variable rate applicators are connected to a system based on decision support system that are connected to AI or computer-based program. For appropriate N management, over and under fertilized areas are identified on the bases of greenery of crop leaves. Once evaluated, N fertilizer (urea) can be applied according to the results of each particular zone.

Conclusion
As the global population grows and challenges like climate change and hunger intensify, tech-based agriculture becomes essential. AI and ML revolutionize nutrient management, optimizing crop productivity and resource use. These technologies predict nutrient needs, enabling precise fertilizer

application, reducing waste, and enhancing crop yield. This technology also helps monitor plant health, improving sustainability and resource efficiency while minimizing environmental impact. Data from sensors, drones, or remote sensing is processed through GIS-based software, generating recommendations for precise nutrient application, ensuring sustainable productivity.

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POTASSIUM DEFICIENCY IN VEGETABLES AND FRUITS

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Abstract
Potassium (K) deficiency is a problem in Indian soils due to inadequate K fertilization and imbalanced use of fertilizers. This can lead to smaller crop yields and soil fertility issues. The use of NPK fertilizers is often imbalanced, which can lead to K deficiency. The current fertilizer recommendations are outdated and need to be revised. This paper aims at creating awareness about potassium deficiency symptoms in vegetables and fruits to diagnose the deficiency and suggest corrective measures.

Introduction

In India, the removal of K is more or less equivalent to its uptake for field crops as their residues are mostly removed from the fields after harvesting. Crop residues and animal excreta (dung) generally find use as a source of energy for cooking and heating in rural areas, rather than recycling them back to the fields. Crop residues have plenty of other uses in rural households in India, prompting their removal from the crop fields or burning. On top of that, K fertilization is either nil or severely inadequate in many parts of the country, including the intensively cultivated areas.

Though local recommendations advocate proper balance among N, P, and K fertilizers, most farmers opt for N only or N and P with little or no K fertilizer. Surveys conducted in upper and trans-Gangetic Plains of India revealed that most of the farmers apply N at more than recommended rates, along with P at nearly recommended rates, but apply far more minor than recommended rates of K if applied at all. One of the primary reasons behind the neglect of K fertilization in India is the general belief that Indian soils are inherently abundant in K reserves owing to K-containing minerals and can support crops without K fertilization. Secondly, as India is almost 100% dependent on imports for K fertilizers, there has always been an attempt to curtail K fertilization to reduce the burden on the national exchequer. Next comes the rise in K fertilizer prices after decontrol in August 1992 after decontrol and the introduction of nutrient-based subsidy in April 2010 which further worsened the situation. These approaches of providing nutrients to the crops is responsible for mining of soils nutrient capital which created the problem of potassium deficiency in soils. Potassium deficiency is made worse by acidic soils (low pH), sandy or light soils (leaching), drought conditions, high rainfall (leaching) or heavy irrigation, heavy clay (illite) soils, soils with low K reserves, and magnesium rich soils. The purpose of this paper is to create awareness about potassium deficiency symptoms in fruits and vegetables to diagnose the deficiency and suggest corrective measures.

Deficiency Symptoms

Sugar beets: The first sign of K deficiency appears as tanning and leathering of the edges of recently matured leaves.When the soil solution is very low in Na, a severe interveinal leaf scorch and crinkling proceeds to the midrib **(Photo 1)**.Under high Na conditions, tanning and leaf scorch lead toa smooth leaf surface.

Photo 1. Potassium-deficiency symptoms in Sugar beets leaves (Left) and ground part (Right)

Potatoes: Upper leaves usuallysmaller, crinkled and darker greenthan normal with small necrotic patches, middle to lower leaves show marginal scorch and yellowing.Early indicator: dark green, crinkled leaves, though varieties differ in normal leaf colour and texture. Tuber size is much reduced and crop yield is low. The leaves of the plant appear dull and are often blue-green in colour with interveinal chlorosis. Leaves will also develop small, dark brown spots on the undersides and a bronzed appearance on the upper surfaces **(Photo2)**.

Photo 2. Early Potassium Deficiency symptoms (Left), Late Potassium deficiency symptoms in potato (Right) ana close view of the deficiency at early growth stage (Bottom)

Cucumber: Growth is stunted, internodes remain short and leaves small. Older leaves are bronzed and discolored yellowish green at the margins; the main veins are sunken. At a later stage interveinal chlorosis becomes more pronounced and extends towards the center of the leaf; it is followed by necrosis. Leaf margins desiccate but the veins remain green for some time. Symptoms spread from the base towards the top of the plant, the oldest leaves being worst affected **(Photo 3)**.

Photo 3. Potassium-deficiency symptoms in Cucumber

Tomato: In tomatoes, the stems are woody and growth is slow. Leaves are blue-green in colour, and the interveinal area often fades to a pale grey colour. Leaves may also have a bronzed appearance and yellow and orange patches may develop on some of the leaflets. Fruits often ripen unevenly and sometimes have green patches near the stalks **(Photo 4)**.

Photo 4. Early (Left) and Late (Middle) potassium-deficiency symptoms on leaves and on fruit (Right) of tomato

Brinjal: Potassium deficiency in brinjal, or eggplant, can cause leaves to turn yellow and brown, and the tips to curl. The deficiency usually affects older leaves first. Plants grow slowly and have poorly developed root systems. Stalks are weak and lodging is common. Fruit quality and yield are poor (**Photo 5**).

Photo 5. Potassium-deficiency symptoms in Brinjal

Grape: Intercostal chlorosis starts on the leaf margins and spreads to the internal area of mature leaves. At the margins, necrotic zones develop. The veins remain green for a certain time **(Photo 6)**. Potassium deficiency results in different symptoms, dependent on the date of appearance and the weather conditions.

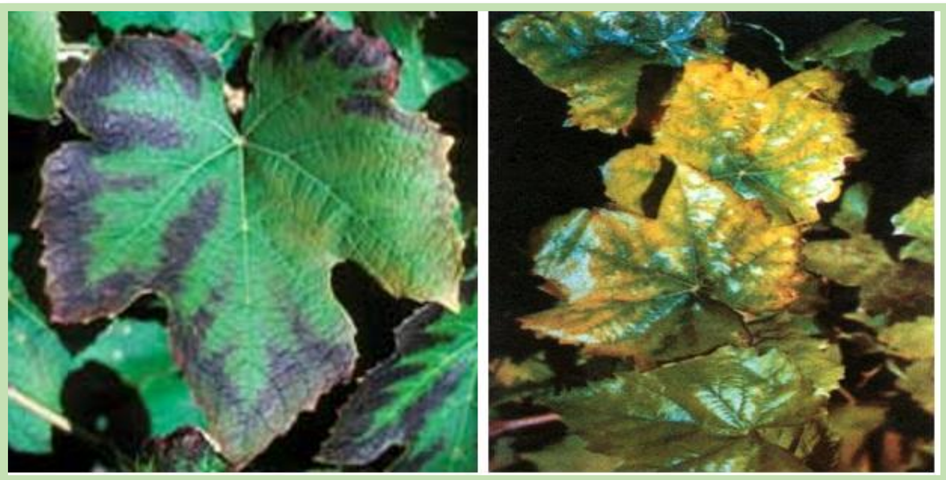

Photo 6. Early (Left) and Late (Right) deficiency symptoms of potassium in grapes

Apples: Potassium deficiency is characterized by a scorching of leaf margins often called "leaf scorch". The scorch and leaf rolling appears first on basal or spur leaves and progresses upward toward the younger leaves. Margins may first appear light green and later turn necrotic. Necrosis starts at the margin and progresses inward toward the midrib **(Photo 7)**. Leaves may appear tattered as necrotic areas fall off. Symptoms may also be accompanied by leaf abscission. Scorching is typically most severe on older basal leaves and becomes less apparent on the most apical leaves. Symptoms usually develop late in the season on slightly deficient trees or earlier if the shortage is acute. K deficiency may also reduce colour of fruit. Potassium deficient fruit will have a lower pressure test and poorer flavour. K deficient trees will be more prone to winter injury. Fruits often have a slightly acidic or woody taste, poor storage, shipping and canning qualities in fruit.

Photo 7. Potassium-deficiency symptoms in Apple

Potassium deficiency and plant disease

For many species, potassium-deficient plants are more susceptible to frost damage and certain diseases than plants with adequate potassium levels. Increased disease resistance associated with adequate potassium levels indicates that potassium has roles in providing disease resistance, and increasing the potassium levels of deficient plants have been shown to decrease the intensity of many diseases *(Defra 2010)*. However, increasing potassium concentration above the optimal level does not provide greater disease resistance (Datnoff et al. 2007). In agriculture, some cultivars are more efficient at K uptake due to genetic variations, and often these plants have increased disease resistance (Datnoff et al. 2007). The mechanisms involved with increased host resistance and potassium include a decreased cell permeability and decreased susceptibility to tissue penetration. Silica, which is accumulated in greater quantities when adequate potassium is present, is incorporated into cell walls, strengthening the epidermal layer which functions as a physical barrier to pathogens. Potassium has also been implicated to have a role in the proper thickening of cell walls (Datnoff et al.2007). To aid in potassium deficiency, farmers and many monoculture crop producers use vermiculite as a form of nutrition, soil aeration assistance as well as water retention to aid in nutrient poor environments (Wang et al. 2013).

Corrective Measures

Sources of potassium: There are a limited number of fertilizer materials that can supply K when needed. Potassium chloride (muriate of potash) has the highest K_2O equivalent at 60%. Other options include potassium sulphate (50%), potassium nitrate (44%), mono potassium phosphate (0:52:34), potassium magnesium sulphate (sul-po-mag) (22% K, 11% Mg) and poly-halite (Poly 4) dihydrated potassium, calcium, and magnesium sulphate ($K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$). Poly-halite has 19.2% S, 14% K_2O (11.6% K), 6% MgO (3.6% Mg) and 17% CaO (12.2% Ca), all in available form for plant uptake. Recently, a new fertilizer wherein the potash is derived from the molasses, a by-product of sugar mills named as Natural potash (14% K_2O) is also available in the market. Besides, a few fully water soluble NPK grades (18:18:18, 19:19:19) are available for foliar spray and fertigation. Wood ash also has high potassium content but must be used cautiously due its effect on pH level. Adequate moisture is necessary for effective K uptake; low soil water reduces K uptake by plant roots. Liming acidic soils can increase K retention in some soils by reducing leaching.

Rate of Potassium Application: Potassium deficiency in standing crops can be corrected quickly by foliar spray of 1% solution of high K containing fully water-soluble potassium sulphate (0:0:50). potassium nitrate (44%) or mono potassium phosphate (0:52:34) @ 10 gm/litre water to correct severe K deficiency. NPK grades (18:18:18, 19:19:19) can be used for foliar spray @ 10 gm/litre water to correct mild K deficiency. Soil application of muriate of potash, Poly halite (Poly 4), K– Mag etc. @ 40-60 kg K_2O/ha can help correcting K deficiency. There are several ways to naturally add K to the soil including composting, using green manure and wood ash to correct K deficiency in plants.

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PRESCRIBED FIRES

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Abstract

Prescribed fires are controlled burns that is applied usually to meet management objectives in a forest. It is designed to serve as management tool while also considering the safety of public in certain forested area. The successful implementation of prescribed burning is associated with the time of burning, frequency at which the burning occurs, combination of grazing and patch burning, control on invasive species and post fire rehabilitation techniques. It reduces the fuel loads accumulation, alters the plant communities living in a particular area, improves the habitat of wildlife and boosts soil health. It also performs ecological functions at multi-level scale. While it has its benefits, prescribed burning sometimes causes buildup of harmful chemicals viz particulate matter, PM2.5, carbon monoxide (CO), nitrogen oxides (NOx), and various volatile chemicals which causes adverse health effects such as low visibility. It also impacts the biological, chemical and physical soil properties. Although, prescribed fires are preferably applied for its beneficial effect, their potential use for optimal outcome is restricted by various social, operational and ecological factors.

Keywords: Prescribed fires, fuel loads, invasive species, particulate matter.

Introduction

Fire's origin is closely linked to the emergence of plants, as two of the three essential elements needed for fire viz oxygen and fuel is provided by the plants, while the heat source, third element readily available throughout earth's history is mainly through lightning (Oloo, 2024). Prescribed fires also referred to as "controlled burn" or "prescribed burn" are fires that is planned or intentionally ignited by fire experts to meet management objectives under controlled conditions (Hashida *et al.*, 2024). It simply follows the prescription of considering the safety of public and fire workers, weather and chances of fulfilling the burn objectives while removing the ground fuel for diversity in terrestrial ecosystem and reduction in spread of wildfires (Oloo, 2024).

According to US Forest Service, 1989, the intentional, controlled application of fire to a forest to accomplish the objectives of a landowner or land manager is known as prescribed burning. It is inclusive of fires designed for the purpose of site preparation and maintenance of understorey in forested area. These types of fires are applicable in even-aged or uneven-aged forests. It is frequently applied to limit woody plant invasion and restore herbaceous growth and diversity in grasslands and savannas around the world (Ansley *et al*., 2021). To assess the probability of a fire confined within the designated area once ignited and spreading with the required heat intensity to meet its objectives, it is vital to take into account fuel moisture levels, weather and soil conditions (Francos and Ubed, 2021).

Key aspects of prescribed fires (Valko *et al.,* 2014)

- **Burn time**: In growing season such as mid-July when the lightning season peaks, natural fire regimes are best simulated by conducting burns. Most effective method for reduction in accumulated litter is dormant season burning. For instance, in USA, most of the prescribed burns are applied in Spring.
- **Burn Frequency**: Regular burning is essential to mimic natural disturbance regimes, regeneration and for controlling invasive species. In grasslands, it is recommended to carry out burning every 2-3 years for biodiversity maintenance and prevention of invasive species and its re-colonization.
- **Mix of grazing and burning – patch-burning**: Fire and grazing interact through both positively and negatively. Free-ranging grazers prefer recently burned areas with high-quality forage and avoid areas that have gone without fire for several years, allowing for the accumulation of litter and biomass, which increases fuel loads and raises the likelihood of wildfires. Under such conditions, patch burning can be implemented as a conservation strategy. In this approach, areas are burned in patches periodically allowing sufficient time for regeneration.
- **Invasion control**: For invasion control, burning is a more natural approach as compared to herbicides application, which persist in the soil and impacts negatively on forest species. Fire can be effective when the species have different fire adaptations or when the phenology of invasive species differs from that of native species. It is also crucial to avoid applying the fires at wrong time, as it can promote invasive species, especially in arid and semi-arid ecosystems.
- **Rehabilitation methods post-fire**: This is done to accelerate forest recovery and reduce unwanted effects of burning. Mulching can be adopted to reduce soil erosion and target propagules of important species at a particular site. Additionally, sterile and non-persistent nurse crops can be seeded to improve soil quality.

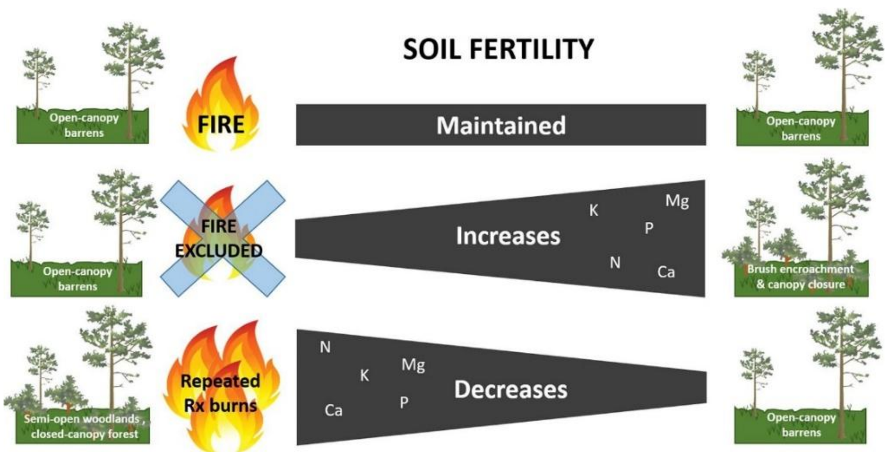

Figure 1: Graphical representation of prescribed burn frequency (Quigley *et al.,* 2020)

Effect of prescribed fires

- **Fuel reduction**: Common causes of wildfires includes arson, human negligence and lightning. Fuel loads such as dead vegetation, pine needles and brush when present in high amount inevitably ignites fire which sometimes turns into intense blazes damaging forest resources and property. Frequent prescribed burns help eliminate overloaded fuels, thereby lowering the severe wildfires risks. Prescribed burns are conducted when weather conditions are suitable for fire control. In contrary, wildfires usually occur when conditions are conducive to quick spread. Although prescribed fires may not significantly lower the number of fires, it helps reduce their severity (Oloo, 2024).
- **Alteration of vegetation**: Plant communities are in a state of constant change, though it may not be obvious immediately. For instance, a longleaf pine forest will eventually transition into a hardwood forest, and a prairie will eventually turn into a forest if kept unmanaged. To prevent such changes, it is crucial to put fires so as to maintain indigenous plant communities by limiting the invasive species growth and also promoting the growth of species like pines, grasses and various wildfires which are adapted to fire. Periodic fires are also crucial to maintain forest types such as the long leaf pine (*Pinus palustris*) forest type in Southern United States (Bruce, 1951). In addition, the structure and density of existing vegetation is altered by prescribed burning such as in case of pine forest, the number of young sweetgum trees is reduced so as to allow more sunlight to reach the ground and fostering the growth of grasses and other herbaceous plants (Oloo, 2024).
- **Improving wildlife habitat:** In grasslands and pine forests, prescribed burning is an effective tool for improving habitat. Shrubs and herbaceous plants often experience a surge of new growth, following a fire, which is more nutritious and palatable to grazing and browsing animals compared to the older, rough vegetation. Beneficial insects which are key food source for birds are abundant post fire. In addition, fire stimulates flowers, seeds and fruit production, making more food available for wildlife. Periodic prescribed burning is crucial for maintaining habitat of most wildlife species (Oloo, 2024).
- **Ecosystem multifunctionality:** When assessing the need to safeguard forests from both natural and anthropogenic disturbances, ecosystem multifunctionality is a key concept highlighting the importance of fire prevention methods. Forest treatments such as prescribed burns with the objective of decreasing density of trees and surface fuels limits the wildfire risks. For instance, in mediterranean forests, prescribed burnings are effectively used as fire prevention technique to reduce the severity of wildfires, which may also noticeably alter its ecosystem functionality (Plaza-Alvarez *et al*., 2024)
- **Build-up of combustion products:** Although prescribed burns are essential for land planning, there are still some drawbacks that needs careful attention before they are applied for large-scale management. Prescribed burns emit combustion products which gets concentrated into the atmosphere and affects the local air quality. Particulate matter measuring 2.5 µm in diameter, known as PM2.5 is one of the most prevalent and significant emissions with the potential for adverse health effects such as low visibility.

  Other significant emissions from fires include carbon monoxide (CO), nitrogen oxides (NOx), and various volatile chemicals. It is frequently linked to wildland fires, particularly in the western United States (Petralia and Potosnak, 2024).

- **Alteration in soil**: The severity of burning impacts the biological, chemical and physical soil properties. There is an increase in pH values, total organic carbon (TOC), and total phosphorus (TP) contents after a low-severity prescribed burn. Also, soil structure stability decreases due to the high temperatures from the burning, which disrupt aggregate cementing, leading to cracks and the disaggregation of soil peds (Moreno-Roso *et al*., 2023)

Limitations of prescribed fires

The soundness of prescribed fires is constrained by a number of factors. In forest area, the accumulation of fuels reduces the effectiveness of prescribed burning for a certain period. In areas where the landscapes are not heterogeneous and where weather conditions are extreme, it is difficult to apply prescribed burnings. Lack of clearly defined, measurable objectives inducive of operational, social and ecological issues contributes to inadequate treatment efforts in terms of fire protection. Furthermore, negligence on research, optimisation of fire application on spatial pattern and overlooking practical management guidelines restricts the potential use of prescribed fires.

Conclusion

Prescribed fires are increasingly adopted as a management tool to mitigate wildfire hazards, promotion of regeneration in forested area and also for improving soil conditions. There are instances of successful implementation of prescribed burning for invasion control, changes in plant communities on long term, influence on endangered plant species, role in wildlife populations and alterations in soil conditions. Despite its success, the efficacy of its application still remains a debate. While science has its role in fire management, the socio-political constraints inclusive of acceptance by the public, aversion to risk and lack of funding act as barriers to implement prescribed fires. Also, it is difficult to generalised the hazard-reduction potential of prescribed fires and depends entirely on the efficiency of fire management process. To achieve ecological objectives, prescribed fires as a management tool should incorporate adaptive risk management framework in combination with strengthened collaboration between scientists and fire-management agencies.

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REMOTE SENSING IN AGRICULTURE: REVOLUTIONIZING FARMING PRACTICES

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Abstract

Remote sensing offers numerous advantages in research by providing valuable insights into agricultural crop canopies and related parameters. It plays a crucial role in crop classification, monitoring and yield assessment, particularly due to the high sensitivity of crops to variations in soil, climate and other physio-chemical factors. To ensure sustainable agricultural management, all influencing factors must be analyzed across spatial and temporal scales. When integrated with advanced technologies like Global Positioning Systems (GPS) and Geographic Information Systems (GIS), remote sensing significantly enhances the assessment and management of agricultural activities. These technologies have diverse applications, including growth monitoring, soil moisture and fertility assessment, disease and pest identification, yield prediction and precision agriculture. By supporting sustainable agricultural practices, they contribute to improved productivity and economic growth.

Introduction

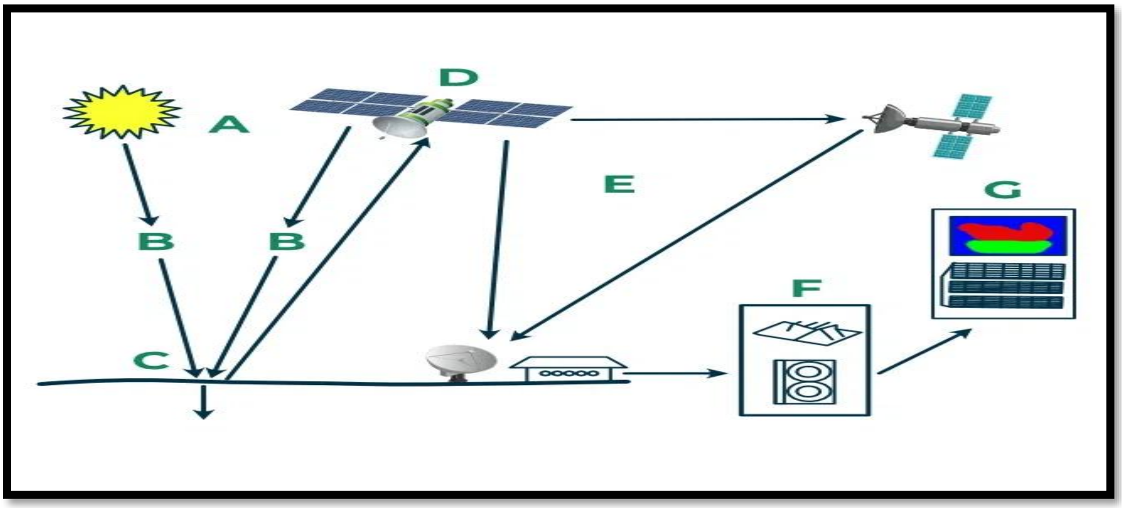
Agriculture has always been a crucial sector for human survival, and with the advance of modern technologies, it has undergone significant transformations. One such advancement is remote sensing, which involves the use of satellites, drones, and sensors to collect data on crops, soil, and environmental conditions. This system uses the information and communication technologies, usually generate a large volume of spectral data due to high different resolutions needed for application in Precision agriculture (Huang *et al*., 2018). Monitoring agriculture through remote sensing is a broad topic and based on specific applications, methods, sensors, RS platform or specific location. Remote sensing data can greatly contribute to the monitoring of earth's surface features by providing timely, synoptic, cost efficient and repetitive information about the earth's surface (Justice *et al*., 2002). It also has several applications in the field of agro meteorological purpose. Remote sensing has revolutionized farming by enabling precision agriculture, improving yield predictions, and ensuring sustainable resource management.

What is Remote Sensing?

Remote sensing refers to the art and science of gathering information about the objects or area of the real world at a distance without coming into direct physical contact with the object under study. It is primarily carried out using satellites, aerial drones, and ground-based sensors, which capture data in various spectral bands. The principle behind remote sensing is the use of electromagnetic spectrum {(visible range (0.4-0.7um), near infrared (0.7-1000um) and microwaves (1mm-0.8m)} for assessing the earth's features. The typical responses of the targets to these wavelength regions are different, so that they are used for distinguishing the vegetation, bare soil, water and other similar features.

The key components of remote sensing include:

1) **Energy Source or Illumination (A):** The first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
2) **Radiation and the Atmosphere (B):** As the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.
3) **Interaction with the Target (C):** Once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.
4) **Recording of Energy by the Sensor (D):** after the energy has been scattered by, or emitted from the target, we require a sensor to collect and record the electromagnetic radiation.
5) **Transmission, Reception, and Processing (E):** The energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image.
6) **Interpretation and Analysis (F):** The processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.



7) **Application (G):** The final element of the remote sensing process is achieved when we apply the information, we have been able to extract from the imagery about the target in order to better understand it.

Applications of Remote Sensing in Agriculture: Remote sensing in agriculture is used for crop monitoring, soil health assessment, and precision farming. Satellite and drone imagery provide real-time data for better decision-making.

1. **Crop Monitoring and Health Assessment:** Remote sensing technology has become a vital tool in the monitoring and assessment of crop health, offering a range of applications that enhance our understanding and management of agricultural ecosystems. This technology provides critical data for observing spatial and temporal patterns, which is essential for effective crop monitoring and management. It can play an important role in agriculture by providing timely spectral information which can be used for assessing the bio-physical indicators of plant health such as nutrient deficiencies, diseases, and pest infestations (Sishodia *et al*., 2020).

2. **Soil Moisture and Irrigation Management:** Remote sensing has become an essential tool in soil moisture monitoring and irrigation management, offering significant advantages in precision agriculture and water resource management. Its data can help distinguish the variability within the field and apply variable rate irrigation with commonly used irrigation systems. Remote sensing images, collected multiple times during a growing season, are used to determine various indicators of crop water demand such as ET, soil moisture and crop water stress. These indicators are used to estimate crop water requirement and schedule irrigation precisely (McDowell, 2007).
3. **Yield Prediction and Forecasting:** Satellite data combined with weather models helps in predicting crop yields well in advance. This technology, combined with advanced machine learning techniques, enhances the accuracy and efficiency of yield predictions across various crops and regions. Crop yield is a function of various parameters like soil, weather, cultivation practice, fertilizer used, irrigation, date of sowing, genotype, pest and diseases, etc. Spectral data of a crop is a manifestation of the overall effect of all these factors on its growth (Ray, 2016).
4. **Pest and Disease Control:** Remote sensing has become an essential tool for monitoring and quantifying crop stress due to biotic and abiotic factors. This approach in assessing and monitoring insect defoliation has been used to relate differences in spectral responses to chlorosis, yellowing of leaves and foliage reduction over a given time period assuming that these differences can be correlated, classified and interpreted. Early detection of pests and diseases through multispectral imagery can save crops from devastation. For instance, remote sensing can identify locust swarms or fungal infections before they become widespread, allowing for timely intervention.

Challenges of Remote Sensing in Agriculture: Despite its benefits, remote sensing faces several challenges:

- ❖ **High Initial Costs**: High initial costs pose a significant challenge in adopting remote sensing technology in agriculture. The expense of acquiring advanced sensors, drones, and satellite data can be prohibitive for small and medium-sized farmers. Additionally, the cost of setting up necessary infrastructure, such as data processing systems and software, further increases the financial burden.
- ❖ **Data Complexity**: It may require a significant amount of technical knowledge and expertise to process them for real-world applications. The large amount of data collected from satellites, drones, and sensors requires advanced processing techniques for meaningful analysis. Additionally, integrating multi-source data with different resolutions and formats can be difficult. The need for high computational power and specialized software also limits its accessibility for farmers.
- ❖ **Environmental issues:** Remote sensing in agriculture faces several challenges, particularly in addressing environmental issues. Cloud cover and atmospheric interference can hinder the accuracy of satellite imagery, making it difficult to monitor crops effectively. High-resolution imagery requires significant computational resources and expertise for processing and analysis. Additionally, integrating remote sensing data with ground-based observations remains a challenge, as discrepancies can arise due to differences in scale and measurement techniques.

- **Spatial and Temporal Resolution Issues**: Remote sensing in agriculture faces challenges related to spatial and temporal resolution. High spatial resolution data can be expensive and may not cover large areas efficiently, while low-resolution imagery lacks the detail needed for precise monitoring. Temporal resolution issues arise when satellite revisit times are too long, causing delays in detecting rapid crop changes or stress conditions.

Future of Remote Sensing in Agriculture

Remote sensing is highly useful in assessing various abiotic and biotic stresses in different crop and also very useful in detecting and management of various crop issues even at small farm holdings. With advancements in Artificial Intelligence (AI), Machine Learning (ML), and Internet of Things (IoT), remote sensing is becoming more accessible and efficient. The governments can use remote sensing data in order to make important decisions about the policies they will adopt or how to tackle national issues regarding agriculture. Clearly, these and other new approaches will reinforce the importance of remote sensing in future analysis of agricultural sciences.

Conclusion

Remote sensing has transformed agriculture by enabling data-driven decision-making, improving productivity, and promoting sustainability. As technology advances, its applications will continue to expand, making farming more efficient, resilient, and environmentally friendly. Governments, researchers, and farmers must collaborate to leverage remote sensing for global food security and agricultural development.

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ROLE OF ARTIFICIAL INTELLIGENCE IN FISHERIES AND AQUACULTURE

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Abstract

This article highlights the significant role of artificial intelligence (AI) in advancing aquaculture by enhancing efficiency, sustainability, and fish health management. The origins of artificial intelligence trace back to the 1940s, has evolved into a transformative tool for the aquaculture industry. The growing global population is boosting a higher demand for food, with fish being a favoured source of protein. AI-driven technologies, such as the Internet of Things (IoT), machine learning, imaging systems, and advanced algorithms, offer innovative solutions to reduce human intervention while improving productivity and ensuring effective fish health monitoring. These technologies optimize feeding strategies, regulate water resources, track fish stocks, enhance biodiversity conservation, predict weather patterns, and support breeding and marketing efforts. The adoption of AI in aquaculture presents numerous benefits, including improved management, automation, resource optimization, and environmental sustainability. It increases productivity, minimizes waste, and enables precise control of aquatic environments. However, AI also poses challenges, such as high implementation costs, potential job displacement, and limited data availability, particularly affecting small-scale farmers and remote aquaculture operations. Despite these challenges, AI remains a crucial driver in fostering a sustainable and profitable aquaculture sector. By leveraging AI technologies, the industry can ensure ecological balance, strengthen global food security, and contribute to the long-term sustainability of fisheries.

Key words: Artificial intelligence (AI), Machine learning (ML), Aquaculture, Fisheries, Sustainability

Introduction

Artificial intelligence (AI) refers to the capability of machines or software to exhibit intelligence, originally designed to replicate basic human cognitive functions. The journey towards artificial intelligence began in the 1940s. From the past decades AI has deeply embedded in our everyday lives. Modern computers enable us to process enormous volumes of data, both structured (organized in databases and spreadsheets) and unstructured (like text, audio, video, and images). AI-driven data processing enhances our capacity to predict future trends, identify historical patterns, provide recommendations, and make better use of the vast amount of available information. AI is widely used to enhance productivity across industries. Artificial Intelligence (AI) can help overcome these limitations by automating tasks, such as controlling machines and tools without human intervention. Currently, artificial intelligence is widely utilized across numerous fields such as Automobiles, Transportation & logistics, Business, Media & Entertainment, Education, Finance, Manufacturing, Gaming, cyber security, Healthcare, Marketing and agriculture. As AI technology continues to advance, its application is expanding into notable economy generating fields like aquaculture and fisheries.

Since, fish being an important source of protein, aquatic ecosystems are gaining recognition for their diverse contributions to enhancing food security and nutrition, reducing poverty, and promoting socioeconomic development. Therefore, it is a necessary to bring a balance between fish production fisheries resource management. To tackle the increasing imbalance between global demand and supply, advanced aquaculture technologies emerge as the only feasible solution.

Applications of Artificial intelligence in Fisheries and Aquaculture

Fishers and farmers utilize artificial intelligence as a tool to monitor the fish in natural habitats as well as in farming. In aquaculture farms, AI enables meaningful data exploration, offering continuous analysis and objective insights into how fish growth responds to farm inputs under different conditions. AI has been utilized to improve various aspects of aquaculture, including feed management, disease detection, water quality monitoring, and market trend analysis. AI can enhance fish growth, improve fish welfare, and reduce the environmental impact of fish farming. Capture fisheries adopt AI-powered data collection systems to improve seafood traceability, promote sustainable fishing, minimize overfishing, and enhance accountability in fishing operations. Nations with extensive coastlines, use Artificial Intelligence and Machine Learning - equipped cameras to track fishing vessels and estimate catch species.

- **Catch – monitoring**

The capture fisheries increasingly using in-trawl camera systems for catch monitoring, though current methods rely heavily on manual video processing and storage. To improve efficiency, automated data processing is essential. Advanced 3D camera technologies, such as stereo imaging and time-of-flight techniques, could soon enable precise fish size and position detection, even in murky waters. Electronic monitoring systems integrate onboard cameras, gear sensors, video storage, and GPS units to record fishing activities, including catch volume, bycatch, and discards. Traditionally, video data is stored on hard drives for later analysis, but newer systems now utilize Wi-Fi, satellite, or cellular networks to transmit data in near real-time. Some systems even use automated video analysis to identify key vessel activities, reducing dependence on gear sensors. These advancements enhance fisheries management by ensuring regulatory compliance, improving transparency, and promoting sustainability through better monitoring of fish stocks and bycatch reduction.

- **Biodiversity Conservation**

AI can be employed in biodiversity conservation by classifying species and landscapes observed through camera traps and satellite images. Furthermore, it plays a crucial role in tracking factors that contribute to biodiversity decline, including the monitoring of fishing trawlers and detection of illegal timber logging activities. AI also support fishery conservation initiatives by utilizing drones and transmitters to track endangered species, identify various species, and predict extinction risks, which is essential for understanding and preservation of coral reefs. Additionally, AI and robotics are employed to evaluate population recovery in fisheries and facilitate improved resource management strategies.

- **Stock assessment**

The application of artificial intelligence in fish stock assessment offers numerous advantages. Automatic fish detection systems through image processing and pattern recognition, enhances the efficiency of monitoring fish populations in diverse ecosystems from aquaculture to open oceans. With the combination of historical data and environmental factors such as water temperature and algal availability, machine learning and AI have improved our ability to predict fish stock abundance, distribution, and migration patterns. This predictive power helps in identify migration routes and spawning sites, informing fishing quotas and to promote efficient management of fishery resources.

- **Weather forecasting**

The advanced AI and ML enables Ocean Information and Advisory Services to deliver timely updates on various marine conditions. These include Potential Fishing Zone (PFZ) advisories, Ocean State Forecasts (OSF), High Wave Alerts, and Tsunami early warnings. By delivering real-time weather and oceanic insights, these services help the coastal fishermen to make decisions, ensuring safer and more efficient fishing operations. The integration of AI enhances data analysis, enabling precise forecasting and risk assessment. This proactive approach not only optimizes fishing activities but also improves preparedness for natural hazards, ultimately support the sustainability and safety of marine-based livelihoods.

- **Water quality monitoring**

Fish behaviour is greatly affected by water quality due to their strong reliance on the aquatic environment. As a result, monitoring water quality is a vital issue, particularly in various aquaculture practices, where artificial intelligence is increasingly being employed to improve the process. By analysing data from sensors various parameters *viz.* temperature, dissolved oxygen, pH, and ammonia levels are measure so as to ensure corrective action plan by the fish farmers. AI-powered water quality monitoring systems provide the benefit of continuous, real-time tracking of multiple parameters, offering more accurate and timely information than traditional manual monitoring methods. This capability allows farmers to quickly respond to any changes in water quality, thereby reducing the risk of fish mortality and other harmful effects.

- **Disease tracking**

Integrating AI with aquatic systems to predict and manage fish health is a major step toward sustainable aquaculture. This advanced AI-powered Predictive and Health Management (PHM) system continuously monitors aquaculture environment and fish health, employ highly advanced data analytics and precise pattern recognition to rapidly detect disease outbreaks. This approach allows farmers to quickly address many health problems in their crops via the provision of several early detection as well as warning systems, thus decreases the effect of disease outbreaks. AI-powered Predictive Health Management (PHM) systems assist farmers in analysing disease patterns and root causes, enhancing disease prevention and epidemic management. The system continuously monitors water quality parameters and adjusts treatments, ensuring optimal conditions for fish and enabling precise decision-making.

- **Feed management**

In aquaculture feed cost account for nearly 40–50% of total cost, and the excess feeding leads to water pollution, low dissolved oxygen and release harmful substances that hinder fish growth. Measuring fish feed intake is a challenge however AI and ML can optimize feeding by analysing real-time data from sensors, cameras, and historical records. Adaptive algorithms adjust feeding schedules, ensuring efficiency and reducing waste. ML also balances diets based on species' nutritional needs and local ingredient availability, enhancing growth and health. AI improves feeding control, accelerates growth, cuts costs, and minimizes environmental impact, promoting a sustainable aquaculture industry with better water quality and resource efficiency.

- **Fish breeding**

Sensor technology effectively monitors environmental conditions and results an improved breeding management. Sensors collect crucial data on water temperature, pH, and dissolved oxygen, essential for maintaining a stable aquatic environment and fish health. The integration of sensors with communication technologies allows for real-time monitoring, enabling quick management decisions. Additionally, sensors track fish behaviour, such as swimming speed and social interactions, helping farmers respond to environmental changes and optimize growth conditions. Continuous data flow provides immediate updates on the breeding environment and fish status, facilitating rapid responses to challenges, reducing disease prevalence, and enhancing overall productivity.

AI utilizes genomic data to develop prediction models for fish performance, enhancing breeding programs for traits like disease resistance and growth rate. By analysing genetic variations, AI predicts fish performance under different conditions, optimizing breeding selection. This improves efficiency, reduces costs, and boosts sustainability, significantly benefits aquaculture, fisheries management, and genetic quality in fish populations.

- **Marketing**

AI in fisheries marketing is beneficial as it provides information on the price forecasting and marketing supply chain through authorised Apps and IoTs which is advantage for farmers and fishers.

Advantages

AI enhances aquaculture by optimizing management, automating monitoring, and improving resource efficiency. It boosts productivity, reduces waste, and supports sustainability through real-time data analysis, disease detection, and precise environmental adjustments.

Disadvantages

Despite its benefits, AI has drawbacks, including high costs, job displacement, and data scarcity. Small-scale farmers struggle with expenses, while limited, inconsistent data affects AI accuracy, especially in remote aquaculture operations.

Conclusion

Artificial intelligence plays a vital role in improving efficiency, sustainability, and profitability in aquaculture by enabling precise monitoring, optimized feeding, disease control, and real-time data analysis, driving informed decisions and reducing environmental impact. Highlighting the use of AI in the aquaculture sector can lead to the adoption of sustainable, efficient, and productive practices. The combination of advanced technologies will play a crucial role in addressing challenges and realizing the complete potential of fisheries. Successful initiatives like AI need to be expanded to strengthen the essential contribution of aquatic foods to global food security, nutrition, and livelihoods. This strategy not only ensures ecological sustainability but also enhances operational efficiency to address the increasing global demand for fish while promoting strong and sustainable aquaculture systems.

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FLOCPONICS: INTEGRATING AQUACULTURE AND BIOFLOC TECHNOLOGY

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Abstract

The core concept is to use the bioflocs (microscopic clusters of bacteria, algae, and organic matter) produced in a fish tank as a natural fertilizer for plants grown in a hydroponic system. FLOCponics is an alternative type of aquaponics that integrates biofloc technology (BFT) with soilless plant production. This novel technique would help solve the technical, economical and environmental challenges of traditional aquaculture by promising improved source utilization, waste management and less environmental impacts. By merging the fish culture with hydroponics and microbial floc, this technique makes it easier to create closed- loop, self efficient system. Its use promotes the recycling of nutrients as the waste outputs are diminished due to the synergistic interaction between the fish and plants. Important key components of the flocponics system include fish culture tanks, hydroponics beds and water filtration units. Even though this unit initial cost is very high and system complexity might hinder the system establishment, careful monitoring and management can increase the systems profitability.

Keywords: FLOCponics, BFT, Hydroponics, Aquaponics, Integration, Profit

Introduction

The global demand for safe and healthy food has increased significantly in the last few years due to world population growth, projected to reach 9.7 billion people in 2050. Providing them with healthy food is a major global challenge, especially in the current scenario of natural resource scarcity. Many countries were still face problems with hunger while others are trying to address their high rates of population obesity and malnutrition. Hence, investment and research into sustainable food production technologies that produce nutritious food and consume fewer natural resources are needed. Modern aquaculture systems, for example, can contribute to the production of fish for a healthy human diet in a more sustainable way.

Principle

FLOCponics is defined as the integration of biofloc-based aqua-culture with hydroponics. Thus, FLOCponics is an alternative type of aquaponics system where RAS is replaced by a system based on BFT. A system that integrates aquaculture practices with biofloc technology, essentially combining the rearing of fish in a biofloc system with the hydroponic cultivation of plants, where the nutrient-rich water from the fish tanks is reused to nourish the plants, creating a more sustainable and efficient food production method; it is considered a type of aquaponics that utilizes biofloc technology as its foundation for water quality management. FLOCponics shares the principles of integrated agri-aquaculture systems, it is expected that FLOCponics will be more sustainable and efficient than biofloc-based monoculture. However, it is still unknown how efficient the utilisation of water and nutrients is in FLOCponics and whether the outputs from

FLOCponics are sufficient, given the demanded resource inputs to integrate BFT and hydroponics successfully.

Aquaponics with BFT

Aquaponics is an integrated polytrophic system that combines elements of aquaculture with circulating aquaculture, such as BFT and recirculating aquaculture systems (RAS). Water rich in nitrogen sources, such as ammonia and nitrite, that nurture aquatic organisms are used as nutrients for plants to grow, and the water from which the nitrogen source has been removed through the plants goes back into the tank and helps the stable growth of aquatic animals. The interconnection between aquaculture and hydroponics can effectively solve the problems of each system, which can be used as a promising sustainable food production technique in the agricultural and fishery industry. Aquaponics is being proposed as a sustainable aquaculture concept because high yields of aquatic life and plants can be expected by diversifying food production, saving water consumption, and substantially utilizing aquaculture feed in a small space. The integrated system with BFT and aquaponics is an environmentally–friendly method of food production due to its focus on nutrient recycling and water conservation. Pinho et al named this integrated aquaculture system 'FLOCponics' and introduced it as a new type of aquaponics system that replaced RAS with the BFT system. This integrated system has the potential to enhance economic diversity by producing value–added plant products and mitigate the accumulation of nitrate and phosphorus in the management of the BFT system. The integrated system of BFT and aquaponics maintains low nitrate levels through continuous absorption by plants, as well as keeping phosphate levels either unchanged or within the recommended range for plant growth (Hwang et al., 2023).

Conclusion

Traditional aquaculture, characterized by high–density aquaculture, leads to coastal environmental pollution, resulting in deteriorating farm health and reduced production. BFT is attracting attention as an aquaculture technology that can solve the problems of traditional aquaculture. BFT is a closed water purification process that effectively manages water quality, controls pathogen infection, and promotes high production yield through a zero water exchange system. BFT not only reduces operating costs, but also improves the overall health and growth of aquatic organisms (Avnimelech, 2009). BFT faces challenges such as vulnerability to water quality fluctuations, changing seasons, and the need for aeration to maintain oxygen levels. In order to overcome the disadvantages of BFT, development through a combination with other aquaculture technologies, such as aquaponics and vertical aquaculture, is needed. Aquaponics is a technology that combines two technologies, a closed circulation aquaculture system and hydroponics, into a closed loop system. Vertical aquaculture utilizes the vertical space of a high–rise building to efficiently produce aquatic organisms while controlling the environment. Aquaponics and vertical aquaculture are advantageous for urban environments due to their space efficiency and potential to mitigate environmental problems. The development of these innovative aquaculture technologies is predicted to play an important role in a world that needs more food in the future. The development of sustainable and safe aquaculture systems will play a crucial role in supporting the food supply of rapidly growing populations.

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PHENOLOGY OF *Shorea robusta* INCLUDING EFFECTIVE QUALITY MANAGEMENT PRACTICES

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Abstract

Shorea robusta, commonly known as the sal tree, holds a position of immense significance within the Indian subcontinent, especially among the tribal communities of Odisha. This remarkable species serves not only as a cornerstone of ecological stability but also as a vital resource for cultural and therapeutic applications. Every part of the sal tree contributes to human welfare, offering medicinal benefits, supporting livelihoods, and providing a habitat for wildlife. Its natural symbiosis with insect's aids in pest management, ensuring the health of the ecosystem it inhabits. For generations, tribal communities have upheld the conservation of this species through sustainable practices, worship, and active restoration efforts. By combining traditional knowledge with modern conservation techniques, the sal tree's ecological and cultural value can be further preserved and expanded, benefiting both nature and humankind.

Introduction

Shorea robusta, widely known as the Sal tree, is a native species of the Indian subcontinent and extends into parts of Southeast Asia. Its natural habitat stretches from the Western Ghats in southern India to the northern Himalayan foothills, flourishing in diverse regions. In Nepal, it thrives in the Terai lowlands and the Siwalik hills, while southern Bhutan also hosts this species. Sal forests are prominent in the northeastern and southeastern areas of Bangladesh and extend into Myanmar and Thailand. Esteemed for its durability, the Sal tree is a vital timber resource, playing a significant role in construction, furniture-making, and as a sustainable source of fuelwood.

Fig. 1 *Shorea robusta* Forest

Taxonomy

Shorea robusta is classified within the Kingdom Plantae. It belongs to the Phylum Angiosperms and the Class Eudicots. The tree is further categorized under the Order Malvales, within the Family Dipterocarpaceae. Its Genus is Shorea, and the specific species is *Shorea robusta*.

Climate

Shorea robusta, native to the Indian subcontinent, thrives in tropical and subtropical regions. It flourishes in warm, humid conditions, with an optimal temperature range of 20°C to 35°C (68°F to 95°F). Although the tree is highly resistant to heat, it is sensitive to frost and low temperatures. It requires an annual rainfall of 1000 to 2000 mm (39 to 79 inches) to achieve healthy growth. This species is well-suited to monsoon climates and can endure periods of heavy rainfall and waterlogged soils during the rainy season. While it exhibits some tolerance to drought, prolonged dry periods can negatively impact its growth and overall survival.

Soil Requirement

Shorea robusta, widely recognized as the Sal tree, thrives in well-drained soils and demonstrates remarkable adaptability to various soil types, including sandy, loamy, and clayey textures. It is often found in regions with nutrient-rich alluvial soils, which provide optimal fertility for its growth. While the tree can survive in both acidic and alkaline soils, it achieves its best development in soils with a slightly acidic to neutral pH. The presence of organic matter further enhances the tree's growth and overall health.

Phenology

Fully matured *Shorea robusta* trees can grow up to an impressive height of 30–35 meters. Their large, glossy, elliptical leaves have a tough, leathery texture, adding to their distinct appearance. The tree usually blooms from February to April, depending on regional climate variations, producing clusters of small, greenish-yellow, aromatic flowers. Its fruits, which are hard, woody capsules containing winged seeds, ripen and are dispersed between April and June. These seeds mature from May to June, but their viability under normal conditions typically lasts only 6 to 10 days. The heartwood of the sal tree is renowned for its strength and durability, making it highly sought after for construction, furniture crafting, and boat-building. As a deciduous species, the sal tree sheds its leaves during the dry season, usually from November to February, adapting to the seasonal climate.

Nursery Techniques:

Mature seeds should be harvested from healthy and robust trees. To soften their hard seed coats, immerse the seeds in water for 24 hours. Prepare a nursery bed with good drainage, combining soil, sand, and organic matter to create an ideal growing medium. Plant the treated seeds either in rows or distribute them evenly across the nursery bed. Ensure regular watering to maintain consistent moisture levels, avoiding waterlogging. Provide partial shade to shield the seedlings from direct sunlight. Weed the nursery bed frequently to eliminate competition for nutrients and space. Apply organic or inorganic fertilizers to support the vigorous development of the seedlings. Once the seedlings grow to a height of 15–20 cm, carefully transplant them into polybags or containers. Gradually expose the seedlings to outdoor conditions, allowing them to acclimate before being transplanted into their permanent field locations.

Propagation:

Natural regeneration of *Shorea robusta* occurs as mature seeds are dispersed through natural agents such as wind, water, or animals. When these seeds settle in favourable environments, they germinate and grow into seedlings. However, these young plants face significant challenges from competing vegetation and environmental stresses. Only the strongest and most adaptable seedlings manage to thrive and continue their growth into mature trees, ensuring the survival of the species in its natural habitat.

Seed Propagation: During the fruiting season, mature seeds are carefully collected from parent trees. To enhance germination, the seeds are soaked in water for 24 hours, which helps to soften their hard outer coats. Once treated, the seeds are sown in nursery beds or containers prepared with an appropriate growing medium. To ensure successful germination, the seeds are provided with optimal moisture levels and maintained under suitable temperature conditions.

Vegetative Propagation: Disease-free and healthy stem cuttings are collected from parent trees and treated with rooting hormones to stimulate root development. These cuttings are planted in an appropriate rooting medium, ensuring optimal conditions for growth. To promote root formation, a small section of the stem is intentionally wounded and surrounded by the rooting medium. Once the roots have successfully formed, the rooted section is separated and transplanted as an independent plant. Additionally, vegetative propagation techniques may involve grafting, where a selected scion from a desired variety is attached to the rootstock of *Shorea robusta*, facilitating the growth of a hybrid or improved plant.

Tissue Culture: A small segment of plant tissue is carefully chosen as an explant to initiate tissue culture. To ensure contamination-free conditions, the explant undergoes sterilization. It is then placed in a nutrient-rich culture medium infused with growth regulators to stimulate cell division and encourage callus formation. Once the callus develops, it is transferred to a specialized medium designed to promote shoot multiplication. The newly formed shoots are subsequently moved to a rooting medium, which facilitates the development of robust root systems.

Silvicultural Techniques: Natural regeneration supports ecological processes such as seed dispersal and germination, allowing the species to thrive without external intervention. Artificial regeneration, on the other hand, involves manually planting seeds or seedlings in targeted areas to establish a forest stand. Effective site preparation includes clearing the site of unwanted vegetation and debris while enhancing soil conditions to create a favourable environment for seedlings to grow. Planting techniques may include direct seeding, where seeds are sown directly into the prepared ground, facilitating efficient forest regeneration.

Spacing: In forestry, spacing refers to the distance maintained between individual trees during planting to ensure optimal growth. For *Shorea robusta*, it is generally recommended to leave a gap of 3 to 4 meters between trees. This spacing facilitates sufficient access to sunlight, water, and nutrients for each tree, fostering healthy and balanced development within the forest stand.

Natural Regeneration Methods

Seed Dispersal: The seeds of *Shorea robusta* are dispersed through natural agents like wind, water, and animals. Wind dispersal takes place when seeds are released from the parent tree and carried to new locations by air currents. Animals, including birds and mammals, also play a key role in seed dispersal. They consume the fruits, and the seeds are later excreted at different sites, contributing to the spread and establishment of the species in diverse habitats.

Fig. 2 Brown Sal Seeds

Seed Germination: The seeds of *Shorea robusta* are protected by a tough outer coat, which must be broken or scarified to facilitate germination. This process can occur naturally when seeds are exposed to environmental conditions such as variations in temperature, moisture, or the activity of microorganisms. Additionally, fire can act as a natural agent of scarification, as the heat weakens or cracks the seed coat, encouraging the seeds to germinate and grow.

Soil Seed Bank: The seeds of *Shorea robusta* can remain dormant in the soil for several years, forming a natural seed bank that acts as a reservoir of viable seeds. These seeds germinate when conditions become favourable, such as after events like fire or logging. This seed bank ensures the species' ability to regenerate naturally, even when active seed dispersal is limited, thereby playing a crucial role in the survival of the species.

Canopy Gaps: Naturally occurring canopy gaps, caused by disturbances such as falling trees or diseases, provide ideal conditions for the regeneration of *Shorea robusta*. These gaps allow more sunlight to reach the forest floor, stimulating seed germination and the growth of seedlings. Furthermore, the absence of competition from mature trees in these openings gives young *Shorea robusta* plants the space and resources needed to establish and grow successfully.

Nurse Trees: Larger, well-established trees, known as nurse trees, play a crucial role in supporting the growth of young *Shorea robusta* seedlings. These trees create a favourable microenvironment by providing shade and protection, making it easier for seedlings to establish and thrive. The shade from nurse trees minimizes competition from surrounding plant species and shields young seedlings from excessive sunlight, which could otherwise hinder their growth.

Root Suckering: *Shorea robusta* demonstrates a remarkable ability to regenerate through root suckering, where new shoots emerge from the roots of mature trees. This regeneration method is particularly beneficial in highly disturbed areas or locations with limited seed availability. Root suckering enables the rapid colonization of degraded habitats and significantly contributes to the recovery and sustainability of *Shorea robusta* populations.

Artificial Regeneration Methods

Direct Seeding: This method involves sowing seeds directly into the field without any prior treatment. It is most suitable for locations with adequate soil moisture and an abundant supply of seeds. Success depends on selecting an appropriate site and protecting the area from grazing animals to ensure proper seed germination and seedling establishment.

Nursery Raising: In this technique, seeds are collected and germinated in a controlled nursery environment. The seedlings are then transplanted to the field when they are strong enough to survive. This method provides better control over the quality and survival rates of seedlings but requires proper nursery management and protection from pests and diseases.

Vegetative Propagation: This approach uses vegetative parts of the plant, such as cuttings or tissue cultures, to generate new plants. It ensures uniform genetic traits and promotes faster growth. However, it demands specialized techniques and facilities for successful propagation.

Artificial Regeneration through Plantation: This method involves planting seedlings or saplings in pre-determined areas to establish a forest stand. Compared to natural regeneration, it allows for higher tree density and faster growth. Proper site preparation, regular weed control, and consistent maintenance are critical for the success of this approach.

Agroforestry Systems: *Shorea robusta* is integrated with agricultural crops or livestock in agroforestry systems, providing dual benefits. This approach enhances soil fertility and boosts farmers' income while supporting sustainable land use. However, careful planning and management are necessary to ensure compatibility between the tree species and other components of the system.

Assisted Natural Regeneration: This method focuses on supporting the natural regrowth of *Shorea robusta* by creating conditions favourable for germination and seedling development. Activities such as selective thinning, removal of competing vegetation, and protection from disturbances are implemented. A solid understanding of the species' ecological requirements and continuous monitoring are crucial for success.

Afforestation: Afforestation involves transforming barren or degraded lands into thriving forests. This process requires comprehensive site preparation, including soil improvement and erosion control measures. It delivers long-term environmental benefits such as enhanced carbon sequestration, biodiversity conservation, and restoration of ecosystems.

Community Participation: Actively engaging local communities in forest regeneration encourages a sense of responsibility and ownership. By involving them, the process benefits from their insights and dedication. Capacity-building initiatives and awareness programs are essential to teach sustainable practices, ensuring the long-term health and vitality of the forest.

***Shorea Robusta*: Principles Governing the Felling of Trees in Forests**

The goal of sustainable forest management is to preserve the ecological balance and biodiversity within forest ecosystems. Practices such as selective logging ensure that the overall structure and composition of the forest are maintained, while also safeguarding habitats for numerous species. The Minimum Diameter Limit principle establishes a threshold diameter for trees that can be harvested, protecting smaller, younger trees from being felled. Additionally, following tree harvesting, regeneration and reforestation activities are crucial to replenishing the forest cover and maintaining its health and vitality.

***Shorea Robusta*: Mortality, Pests, Diseases and Their Control**

Mortality: *Shorea robusta*, commonly referred to as the Sal tree, is vulnerable to several factors that may contribute to its mortality. These include extreme conditions such as drought, flooding, and fire, as well as poor management practices, all of which can negatively impact the tree's survival.

Pests: The Sal tree is susceptible to attacks by various pests, including defoliators like caterpillars and leaf miners, bark beetles, and termites. These pests have the potential to inflict significant damage, affecting both the health and growth of the tree.

Fig. 3 Red weaver ants harvested from Sal trees

Diseases: *Shorea robusta* is also prone to fungal infections, such as root rot, stem canker, and leaf spot diseases. These infections can weaken the tree, leaving it more vulnerable to pest infestations and environmental stresses, further threatening its health and survival.

Control Measures: To reduce mortality in *Shorea robusta*, it is essential to adopt effective management practices such as regular monitoring, timely irrigation, fire prevention strategies, and careful harvesting techniques. Pest management can be achieved through the application of insecticides, biological control methods, and cultural practices like pruning and maintaining cleanliness around the trees.

Fungal diseases can be controlled by using fungicides, ensuring proper sanitation, and removing infected plant parts to prevent the spread of the infection.

Tree Improvement

Enhancing the genetic traits of *Shorea robusta*, such as its growth rate, wood quality, and resilience against pests and diseases, can be achieved through tree improvement programs. These programs often involve selective breeding and hybridization techniques to produce superior plant varieties.

Preserving and promoting genetic diversity in *Shorea robusta* is essential for ensuring its adaptability and long-term survival. This can be achieved by collecting and conserving seeds from various populations, which helps in maintaining a broader genetic pool.

Advanced clonal propagation methods, including tissue culture and vegetative propagation, are valuable for producing genetically identical and improved individuals of *Shorea robusta.* These techniques enable the large-scale production of high-quality planting materials, supporting reforestation and afforestation efforts.

Management

Implementing proper silvicultural techniques is essential for managing *Shorea robusta* forests sustainably. These practices include site preparation, planting, thinning, and harvesting, all aimed at preserving a productive and healthy forest ecosystem.

To ensure the continual renewal of *Shorea robusta* forests, effective regeneration methods must be utilized. This can involve natural regeneration or artificial approaches such as direct seeding or transplanting nursery-grown seedlings.

Preventing overexploitation of *Shorea robusta* requires adopting sustainable harvesting strategies. These include selective logging, timing harvests appropriately, and adhering to legal guidelines and policies to maintain forest balance and promote long-term conservation.

Fig. 4 Resins of *S. robusta* sold in

Engaging local communities in the stewardship of *Shorea robusta* forests plays a vital role in fostering sustainable management practices and conserving this invaluable resource. This can be achieved through participatory methods that actively involve community members, capacity-building initiatives to empower them with knowledge and skills, and equitable sharing of benefits derived from forest resources.

***Shorea Robusta*: Rotation Age, Tending Operations and Yield**

Rotation Age: The term "rotation age" refers to the duration required for a tree species to reach full maturity and become suitable for harvesting. In the case of *Shorea robusta*, this period is typically around 50 to 60 years, representing the time it takes for the trees to grow to a harvestable size.

Tending Techniques: Maintaining the health and promoting the growth of *Shorea robusta* trees requires various tending practices. Weeding removes invasive vegetation that competes with Sal trees for resources, ensuring better growth. Thinning is performed by selectively removing some trees, reducing overcrowding and allowing the remaining trees to grow more vigorously. Pruning helps to shape the trees and eliminate any diseased or damaged branches, improving their structural integrity. Additionally, pest management strategies are essential to protect the trees from harmful insects and diseases, ensuring their overall productivity and health.

Yield: The yield represents the quantity of usable timber or other forest products obtained from an area of *Shorea robusta* forest. Factors such as site quality, forest management strategies, and the rotation age of the trees influence the yield significantly. On average, these forests can produce about 10 to 15 cubic meters of timber per hectare. Employing advanced silvicultural techniques and adopting sustainable management practices can further boost the productivity and efficiency of the yield.

Fig.5 Collecting Leaves of *S. robusta*

Significance of *Shorea robusta*: *Shorea robusta* is highly regarded for its versatile timber, widely used in construction, furniture crafting, and the production of plywood and veneers. The tree also serves as an excellent source of fuelwood, utilized for cooking and heating. Its resin, commonly known as Sal resin, is a key ingredient in manufacturing varnishes, adhesives, and incense. Additionally, various parts of the tree, such as its bark, leaves, and resin, are valued for their medicinal properties and are traditionally used to treat ailments like diarrhoea, dysentery, and skin disorders. The flowers of *Shorea robusta* are known to attract bees, contributing to honey production, which holds significant economic value.

Calculating Economic Yield of *Shorea robusta*: Determining the economic yield of *Shorea robusta* (Sal) involves several key factors, including the tree's volume, form factor, and the market value of its timber. Below is a simplified method to estimate yield:

Measure Diameter at Breast Height (DBH): The DBH is measured at approximately 1.3 meters above the ground to obtain the tree's diameter, a critical parameter for volume estimation.

Estimate Tree Volume: Utilize volume tables or form factor equations specific to *Shorea robusta*. These resources, often tailored to regional conditions, take into account the tree's height and DBH to estimate the timber volume.

Determine Timber Value: Calculate the economic value by multiplying the estimated tree volume by the prevailing market price of Sal timber.

Fig. 6 Timber Production of *S. robusta*

Economic Potential and Employment Impact of Sal Seeds and Timber: The annual production of Sal seeds is estimated at approximately 80,168 tonnes, creating around 146,025 man-days of employment during the seed collection season each year. With a prevailing market rate of Rs.10 per kilogram, Sal seed collection provides significant income opportunities.

For timber yield calculations, consider a Sal tree with a Diameter at Breast Height (DBH) of 50 cm and a height of 20 meters. Using volume tables, such a tree has an estimated volume of 2 cubic meters. Given the current market price of Sal timber at Rs.2,600 per cubic meter, the economic yield of a single tree would be Rs.2 × 2,600 = Rs.5,200. When scaled to a plantation density of 100 trees per hectare, and assuming an average volume of 1 cubic meter per tree, the total timber volume per hectare amounts to 100 cubic meters, resulting in a total yield of Rs.260,000 per hectare.

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SILVICULTURE AND CLIMATE CHANGE: STRATEGIES FOR ADAPTIVE FOREST MANAGEMENT

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Abstract

Climate change is significantly altering forest ecosystems worldwide, influencing species distribution, physiological functioning, and ecological dynamics. Rising temperatures, irregular precipitation patterns, prolonged droughts, and increased frequency of disturbances such as pest outbreaks and wildfires pose severe threats to forest health. These environmental stressors impact tree species through acclimatization, phenotypic plasticity, migration, and, in extreme cases, increased mortality. Various modeling tools, including Bioclimatic Niche Models (BNMs), Eco-physiological Process-Based Models (PBMs), and Forest Dynamics Models, are employed to assess forest responses to climate change and inform sustainable forest management strategies.

Adaptive silviculture strategies, including resistance, resilience, and transition approaches, provide a framework for enhancing forest adaptation to climate change. Additionally, species diversification within plantations is a crucial risk management strategy to enhance resilience and ensure successful carbon sequestration efforts. However, forest regeneration faces challenges such as seed and seedling shortages, workforce limitations, and prolonged environmental assessments. Integrating Indigenous Forest management practices can offer valuable insights into sustainable forestry, leveraging traditional ecological knowledge to enhance biodiversity conservation and climate resilience.

Addressing these challenges requires a collaborative approach that combines scientific advancements, sustainable forest management, and traditional knowledge. By implementing adaptive silviculture strategies, promoting species diversity, and incorporating climate-resilient reforestation practices, forest ecosystems can be better equipped to withstand climate-induced disturbances while maintaining their ecological and economic significance.

Keywords: Silviculture, climate change, Forest management

Introduction

Climate change significantly influences the global distribution of plant species, leading to extreme climatic events such as prolonged droughts, increased storm frequency and irregular precipitation patterns (Bolte *et al.,* 2010; Rigling *et al.*, 2013; Scheffers *et al.*, 2016). Also, global warming exacerbates the prevalence of insect infestations, fungal diseases and forest fires which causes further stress to forest ecosystem (Bosela *et al.,* 2018). These adverse conditions trigger various response in tree species, including acclimatization, phenotypic plasticity, local adaptation, migration, and in some cases increases mortality (Bussotti *et al*., 2015). Given these challenges, sustainable forest management has become increasingly critical. Therefore, sustainable forest management ultimately aims to attain a balance between the increasing demand for forest products and other services in society, leading to the long-term preservation of forest health and biodiversity.

Climate change interacts with other factors such as nitrogen deposition, atmospheric CO2 concentration increase, 03 pollution, land use, and forest management. These factors have antagonistic or partially offsetting effects on the physiological functioning of trees and the ecological dynamics of forests (Lindner *et al.,* 2014). For example, increasing atmospheric CO2 concentration can increase water use efficiency on one hand and photosynthesis on the other hand rising temperatures can also increase the length of the growing season (i.e., the period between leaf budburst and leaf fall and consequently increase tree growth and forest productivity. However, the combination of rising temperatures and decreasing summer precipitation in some regions has been associated with increasing frequency and duration of droughts. This results in a decreasing tree growth and forest productivity increasing risks of tree mortality and increasing risk of disturbances.

Different modelling tools:

1. **Correlative bioclimatic niche models (BNMs).**
   This popular modeling tools is used to predict the future risk of mortality and species distribution ranges. A major strength of BNMs is that the data needed to calibrate them (e.g., speciesspecific presence/absence) are available in large numbers and with increasing resolution in open-access databases. However, most BNMs are not mechanistic and are usually not able to take into account the physiological response of trees to new environments.
2. **Eco-physiological process-based models (PBMs)**
   They offer the advantage to simulate vegetation functioning in response to explicit climate and soil variability, through their impacts on plant physiology. Regarding the prediction of future tree species distribution range, PBMs are generally less pessimistic than BNMs (Cheaib *et al.,* 2012). Eco-physiological PBMs were initially developed to simulate carbon and water fluxes in forest ecosystems, but can also be used to investigate the environmental drivers and physiological processes triggering tree mortality under climate change.
3. **Forest dynamics models**
   It also has a long tradition of being used to support forest management. Recently, both eco-physiological PBMs or forest dynamics models incorporating eco-physiological processes have been applied to evaluate how management and climate change may interact to influence forest dynamics (Oddou-Muratorio *et al.,* 2020).

   Thus, Assessing the future physiological functioning and ecological dynamics, a forest stands requires not only accounting for the multiple effects of climate change and their variation across tree species distribution ranges, but also for the adaptive response of tree populations and the possible effects of forest. The adaptive potential of tree populations in face of a changing environment is usually assumed to be non-negligible, besides tracking their ecological niche spatially through migration, tree populations can adapt in the short-run through individual physiological tolerance, and/or in the long run through evolutionary response to environment-induced natural selection.

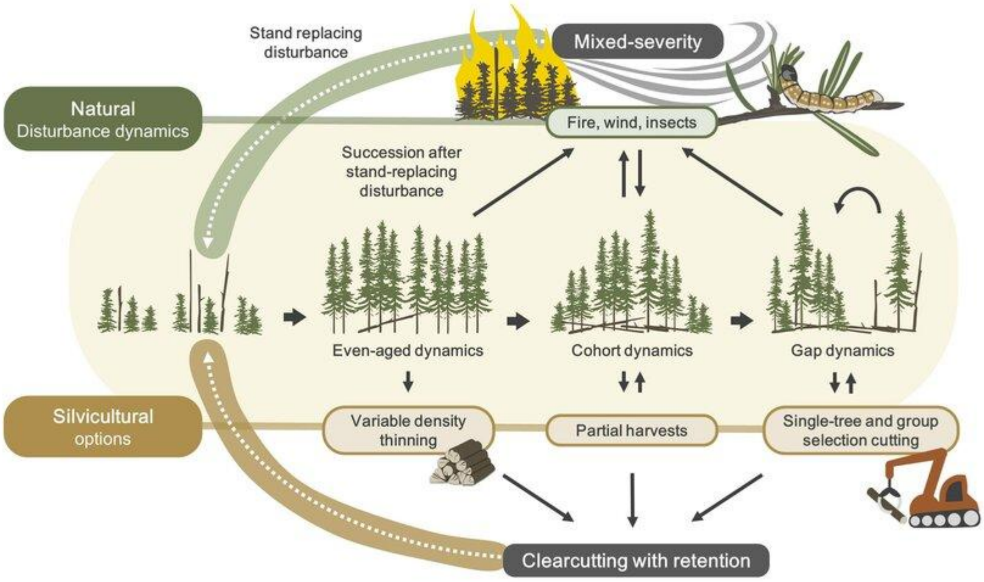

Fig 1: This model represents silvicultural options for maintaining landscape-level forest structures and age distributions similar to those that would exist under a natural disturbance regime.

Adaptive Silviculture strategies:

The adaptive silviculture strategies for climate change (ASCC) exemplifies a collaborative approach to develop and test climate adaptation strategies across diverse forest ecosystem. The ASCC employs three primary management strategies:

1. **Resistance**
2. **Resilience**
3. **Transition**

Each strategy is tailored to specific site conditions and management objectives, providing a practical framework for integrating climate change considerations into silvicultural planning (Nagel *et al.,* 2017).

Species diversity and risk management:

Diversifying tree species within plantation is a critical risk management strategy under changing climatic conditions. A study by environmental economist at Exeter University advocates for an "investment portfolio approach" to tree planting, emphasizing the selection of diverse species and planting locations to spread risk. This strategy enhances resilience against climate and economic uncertainties, thereby maximizing the efficiency and success of carbon sequestration efforts.

Challenges in Forest Regeneration

Climate change has altered forests' ability to regenerate after disturbances such as wildfires. Factors hindering reforestation efforts include:

- **Seed and Seedling Shortages:** Insufficient availability of seeds and seedlings hampers large-scale replanting initiatives.
- **Workforce Limitations:** A lack of trained personnel delays site preparation and planting activities.
- **Environmental Assessments:** Lengthy processes for environmental and cultural assessments can postpone reforestation efforts.

These challenges underscore the need for innovative solutions, such as targeted planting and the selection of climate-resilient species, to ensure successful forest regeneration.

Indigenous Forest Management Practices

Integrating Indigenous forest management practices offers valuable insights into sustainable forest stewardship. Indigenous communities possess traditional ecological knowledge that can inform adaptive management strategies, contributing to climate change mitigation and the preservation of biodiversity (Findlay 2021).

Conclusion

Adaptive silviculture is essential for addressing the multifaceted challenges that climate change poses to forest ecosystems. By implementing strategies that promote species diversity, integrate traditional knowledge, and enhance forest resilience, we can ensure the sustainability of forest resources and their critical role in global carbon sequestration.

Discussion

Climate change is currently one of the major challenges for the protection and management of forest ecosystems (Cotillas *et al*., 2009; Borys *et al*., 2016). It is therefore necessary to develop appropriate forestry strategies to mitigate the impact of global climate change on forest ecosystems (Chapin *et al.,* 2001; Alvarez *et al*., 2016). In relation to ecological stability, it is then desirable to grow forests spatially, age and species differentiated (Brang *et al*., 2014). Promotion of mixed forests and species diversity is therefore often identified as a forest adaptation

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THE IMPACT OF DECORATIVE LIGHTING ON PLANT HEALTH: NAVIGATING THE BALANCE BETWEEN AESTHETICS AND ECOLOGY

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Abstract

Decorative lighting in cafes and restaurants, such as fairy lights and colorful LEDs, enhances ambiance but can negatively impact plant health. Plants rely on natural light cycles to regulate their biological processes, and artificial lighting, especially at night, disrupts these rhythms. Exposure to artificial light, particularly blue and ultraviolet (UV) light, can impair photosynthesis, stunt growth, and cause hormonal imbalances, resulting in stress symptoms like leaf chlorosis and reduced flowering. Prolonged exposure may also harm local ecosystems by affecting plant vitality, disrupting pollinators, and altering food webs. To mitigate these effects, cafes and restaurants can adopt lighting strategies that prioritize plant well-being, such as using warm-colored LEDs and light shielding techniques. By understanding the interplay between artificial lighting and plant biology, spaces can be designed to balance aesthetic appeal with ecological sensitivity, supporting both the ambiance and the vitality of plant life.

Keywords : Sustainable lighting, Decorative lighting, Artificial light, Plant health, Plant stress

Introduction

In the quest to create cozy and inviting atmospheres, cafes and restaurants often turn to decorative lighting to set the mood. Twinkling fairy lights and colorful LED strips have become ubiquitous, adorning not just the walls and ceilings but also the greenery that adds life to these spaces. However, while these lights may charm patrons, they may also be casting a shadow on the health and well-being of the plants they illuminate. Decorative lights have become an integral part of the ambiance in modern dining establishments. From trendy cafes to upscale restaurants, owners are increasingly relying on lighting fixtures to enhance the aesthetic appeal of their spaces. Unfortunately, the unintended consequences of these lights on the plants that share the environment are often overlooked. Disrupting the Natural Rhythms. Plants, like humans, have evolved to rely on natural cycles of light and darkness to regulate their biological processes. Exposure to artificial light at night can disrupt these circadian rhythms, leading to confusion and stress in plants. This disruption can affect critical functions such as growth, flowering, and nutrient absorption, ultimately compromising the health of the plants. Photosynthesis, the process by which

plants convert light energy into chemical energy, is essential for their growth and survival. However, artificial lights used for decorative purposes may not provide the full spectrum of light that plants require for optimal photosynthesis. As a result, plants exposed to these lights may experience reduced photosynthetic efficiency, leading to stunted growth and diminished vitality. In addition to disrupting photosynthesis, decorative lights can also interfere with other aspects of plant growth and development. Prolonged exposure to artificial light may cause plants to allocate resources inefficiently, resulting in leggy growth, abnormal leaf development, and reduced fruit or flower production. Over time, these effects can weaken the plants and make them more susceptible to pests and diseases.

Effects on Plant Growth and Development: The allure of cozy cafés and vibrant restaurants often hinges on the carefully curated ambiance, where decorative lighting plays a pivotal role. Yet, amidst the charm and warmth these lights provide, a lesser-known consequence emerges: the potential harm inflicted on nearby plants. Recent scientific inquiries have delved into the intricate relationship between artificial lighting and plant biology, uncovering a nuanced narrative of how decorative lights, particularly those emitting high levels of blue and ultraviolet (UV) light, can detrimentally impact plant growth and development.

Plants, inherently attuned to natural light cues, rely on the cyclical patterns of daylight and darkness to regulate their biological processes. However, the introduction of artificial lighting, especially during nighttime hours, disrupts this delicate equilibrium. The excessive presence of blue and UV light, prevalent in many decorative lighting fixtures, interferes with plants perception of photoperiod and circadian rhythms, leading to a cascade of physiological disturbances.

One significant consequence of this disruption is the inhibition of growth-promoting processes such as photosynthesis and hormone regulation. While plants may exhibit an initial response to increased light intensity, prolonged exposure to artificial light at night can impede their ability to photosynthesize efficiently, ultimately hindering overall growth and vigor. Furthermore, altered light conditions can disrupt the synthesis and distribution of essential hormones like auxin and gibberellins, crucial for proper development and flowering. Consequently, affected plants may display symptoms of stress, including stunted growth, leaf chlorosis, and reduced reproductive output.

Moreover, the adverse effects of decorative lighting extend beyond mere illumination; they permeate the very fabric of ecosystems within these urban spaces. As plants struggle to thrive under artificial light regimes, their diminished vitality can disrupt local biodiversity and ecological balance. Pollinators, reliant on flowering plants for sustenance, may suffer from reduced floral resources, impacting their population dynamics and ecosystem services. Furthermore, altered plant physiology can reverberate through food webs, affecting herbivores and higher trophic levels, with potential ramifications for ecosystem stability.

As we revel in the enchanting ambiance created by decorative lighting in cafés and restaurants, it becomes imperative to recognize and mitigate its unintended consequences on the living organisms cohabiting these spaces. By adopting lighting strategies that prioritize the well-being of both patrons and plants, such as using warm-colored LEDs and implementing light shielding techniques, we can foster environments that harmoniously balance aesthetic appeal with ecological sensitivity. Ultimately, by nurturing a deeper understanding of the intricate interplay between artificial lighting and plant life, we can cultivate spaces that not only delight the senses but also nurture the vitality of the natural world.

Decorative lights have potential drawbacks to consider:

1. Disruption of Circadian Rhythms: Like humans and animals, plants have circadian rhythms that regulate their growth, flowering, and other physiological processes. Excessive exposure to artificial light, especially during the night, can disrupt these rhythms, leading to altered growth patterns and reduced overall health.

2. Light Pollution: In urban environments where artificial lighting is abundant, excessive light can cause light pollution. This not only affects human health and wildlife but can also impact plants. Light pollution can interfere with the ability of plants to sense changes in day length, which is critical for triggering seasonal events such as flowering and dormancy.

3. Energy Wastage: While LED lights are energy-efficient compared to traditional lighting sources, excessive use of decorative lighting can still contribute to unnecessary energy consumption. This not only increases electricity costs but also has indirect environmental impacts associated with energy production.

4. Inhibition of Flowering: Some plants require specific light conditions, including the duration and intensity of light, to initiate flowering. Excessive or inappropriate light exposure, particularly during the night, can inhibit flowering in certain plant species or disrupt the timing of flowering events.

5. Altered Nutrient Uptake: Prolonged exposure to artificial light may affect the balance of nutrients within plants, leading to nutrient deficiencies or imbalances. This can impair overall growth and vitality.

6. Increased Susceptibility to Pests and Diseases: Artificial lighting can attract certain pests or disrupt natural predator-prey relationships, leading to increased pest populations. Additionally, plants stressed by inappropriate light conditions may become more susceptible to diseases.

While these negative effects are possible, they are generally more pronounced in situations of prolonged or excessive exposure to artificial light. Properly managing the use of decorative lights and ensuring that plants receive adequate periods of darkness can help mitigate these potential drawbacks.

Mitigating the Damage:

While the allure of decorative lighting is undeniable, there are steps that café and restaurant owners can take to minimize its impact on plants:

1. Choose Plant-Friendly Lighting: Opt for LED lights with a balanced spectrum that closely mimics natural sunlight. Avoid lights that emit excessive amounts of blue or red wavelengths, as these can disrupt plant growth.

2. Limit Exposure: Turn off decorative lights during the night or reduce their intensity to give plants a chance to rest and recuperate. Consider using timers or dimmer switches to control lighting levels automatically.

3. Monitor Plant Health: Regularly inspect plants for signs of stress, such as wilting, yellowing leaves, or stunted growth. Take proactive measures to address any issues, such as adjusting lighting conditions or providing supplemental nutrients.

Conclusion

In conclusion, the enchanting ambiance created by decorative lights in cafés and restaurants can cast a shadow on the well-being of nearby plants. While these lights contribute to the cozy and inviting atmosphere cherished by patrons, their unintended consequences on plant growth and development warrant careful consideration. The disruption of natural light cues, particularly by blue and ultraviolet (UV) light, can lead to stunted growth, reduced flowering, and overall diminished health in plants. Moreover, the repercussions extend beyond individual organisms, impacting local biodiversity and ecosystem dynamics. As we strive to cultivate urban spaces that seamlessly blend aesthetics with ecological sensitivity, it becomes imperative to adopt lighting strategies that prioritize the vitality of both patrons and plants. By embracing technologies and practices that mitigate the adverse effects of artificial lighting, we can create environments where the allure of ambiance coexists harmoniously with the resilience of the natural world. In doing so, we not only enhance the experiential quality of these spaces but also cultivate a deeper appreciation for the interconnectedness of all living organisms within our urban ecosystems.

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THE SCENT OF MANAGEMENT: INSECT PHEROMONES IN PEST REGULATION

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Abstract
Insect pheromones are naturally occurring chemicals utilized for communication among the same species of different insect pests, and they are employed to manage pest populations that disrupt the agricultural ecosystem. Insect pheromones are highly advantageous in pest management since they do not harm the environment compared to other pest control methods. This article provides details on various kinds of pheromones, including sex pheromones, trail pheromones, and more. The use of pheromones for managing pest populations to protect the host plants. Different techniques are employed for the application of pheromones (including pheromone dispensers, hollow fibres, traps baited with pheromones, and microencapsulation).

Keywords : IPM, Pheromone, Push-pull strategy, Semiochemicals

Introduction

Agriculture and the environment are closely interconnected with together means the productivity of agriculture depends on the environment for the abiotic factors such as land utilization, precipitation, sunlight hours, and various types of biotic factors including insect pests and diseases. Among all of these, the primary issue in the agriculture sector for attaining production (Islam, 2012). The pest population reduced the crop production and farmers got the yield losses. For the solution to this issue, the farmers rely on synthetic insecticides which are easily available in the market and affordable and easy to use. Subsequently, the application of synthetic insecticides also reduces the beneficial insect population and non-targeted arthropods which are advantageous for us. After that the residues of insecticides contaminate water bodies, they affect the food and water available for human consumption. Consequently, the other approaches for controlling pest populations including cultural, biological, botanical, and others can be utilized for safety.

The insects interact with each other through the scents – pheromones, for communication. Using the pheromones, they find the location and pair up. The pheromones are naturally occurring substances that are found in small amounts throughout the entire insect population in gaseous form. Every insect possesses its distinct fragrance. The identification of pheromones has a history spanning centuries, seemingly beginning with accounts of numerous bees stinging in response to substances released by the sting of one bee. In 1959, researchers from Germany isolated and recognized the first pheromone, which belonged to the silkworm. Since then, progressively more advanced equipment has been able to identify hundreds, if not thousands, of insect pheromones (Islam, 2012).

Pheromones

Pheromones are natural substances or combinations of molecules, which cause individuals of the same species to behave in a specific manner. The pheromones that aid in communication between

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different species of insects are known as Allelochemicals, while those that facilitate communication within the insect species are called Semiochemicals. The term pheromones is derived from two Greek words, “pherein” meaning ‘to carry’ and “hormone” meaning ‘to excite’. In 1959, German chemists Karlson and Luscher introduced the term pheromones.

Pheromones are semiochemicals that regulate insect behaviour. As the body emits these chemicals, they function as messengers in a setting known as ecto-hormones (Ganai *et al*., 2017).

Classification of Semiochemicals

1. *Pheromones (Intraspecific):* These substances function outside and individual’s body, similar to hormones, and influence their behaviour (Figure 1).
2. *Allelochemical (Interspecific):* Allelochemicals refer to chemicals influence the growth and behaviour of the other individual. These substances, present in microorganisms, plants, and insects, play a vital role in interactions between different species (Figure 2).

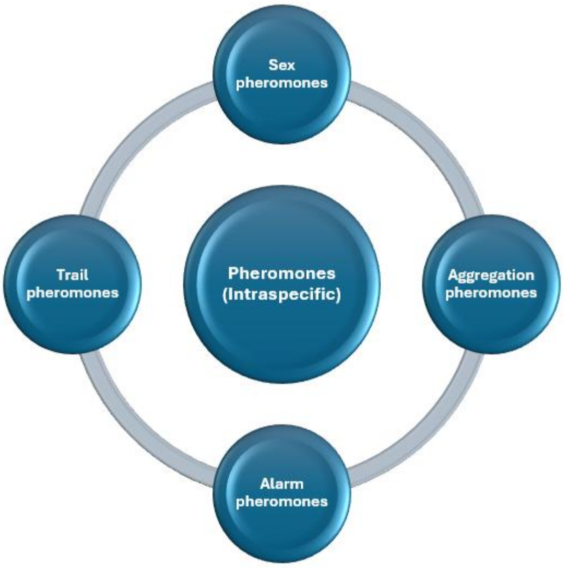

Figure 1: Types of pheromones

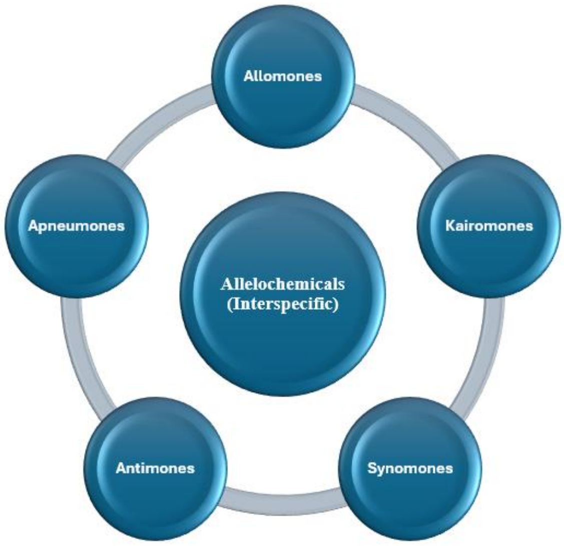

Figure 2: Types of allelochemicals

Classification of Pheromones

Pheromones are classified based on their effects:

1. Primer Effect Pheromones : They do not instantly change the insect's behaviour but rather initiate a sequence of physiological alternations. They are not present in Lepidopteron insects and operate via gustatory (taste) sensilla.

2. Releaser Effect Pheromones : Substances that induce alternations in insect behaviour are referred to as releaser pheromones. These have a direct impact on the insect’s central nervous system (CNS) and modify their behaviour through olfactory (smell) receptors.

Sex Pheromone

When one sex emits them, the opposite sex is generally attracted and sexually stimulated (Table 1). Insects utilize sex pheromones to identify if a female is ready for mating. The amount of sex pheromones produced and emitted by each insect into the air is typically in the range of nanograms (10^{-9} g) or lower. Composed of fatty acids, terpenes, amino acids, simple aromatic derivatives, hydrocarbons, and numerous other chemical families, most known pheromones are safe for living

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organisms. The farmers for observation and detection of insect population in orchards by utilizing traps that contain sex pheromones.

Table 1: List of various sex pheromones with their sources

Sex pheromone	**Source**
Bombykol	Silk moth, *Bombyx mori*
Gyplure	Gypsy moth, *Lymantria dispar*
Gossyplure	Pink bollworm, *Pectinophora gossypiella*
Looplure	Cabbage looper, *Trichoplusia ni*
Queen substance	Queen honeybee, *Apis spp.*

Aggregation Pheromones

Aggregation pheromones are used in mate selection to overcome host resistance through mass attack and predator defense. Since male-produced sex attractants typically encourage both sexes to arrive at a calling site and raise the density of conspecifics around the pheromone source, they have been dubbed aggregation pheromones.

- Members of the Coleoptera, Diptera, Hemiptera, Dictyoptera, and Orthoptera have been discovered to exhibit aggregation pheromones.
- One of the most environmentally selective pest control strategies is the use of aggregation pheromones. They work well at very low concentrations and are non-toxic.

Alarm Pheromones

Alarm pheromones are volatile substances released by certain species in response to predator attacks. These substances can cause aggression (in termites, ants, and bees) or flight (in aphids) in other members of the same species. *Vespula squamosa*, for instance, warns others of danger by using alarm pheromones. Alarm pheromones are also employed by *Polistes exclamans* to warn of approaching predators.

Trail Pheromones

Trial pheromones are released and used by insects having social behaviour. These pheromones are used to make volatile hydrocarbons to mart their routes by Ants. When the ants return to the colony with food, they release the trail pheromones behind them. The path works as a guide and draws in other ants. The pheromone will be continuously released as distance of food source availability. When rapid evaporation, then pheromones need to be continuously released. The ants communicate with together and send information to each other by trial pheromones which is presented in Figure 3.

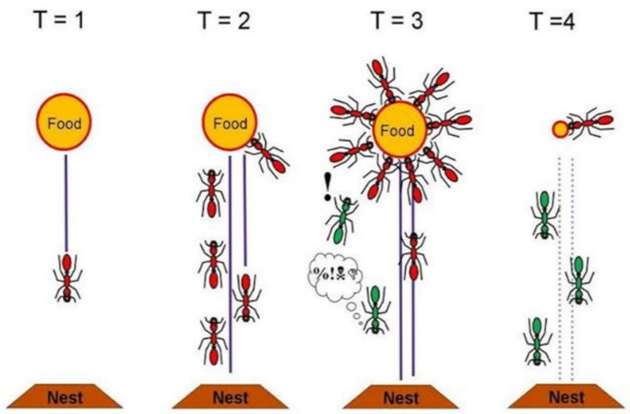

Figure 3: Communication of ants through Trail pheromones

The figure represents how they search for food and release pheromones for their colony members (Bade *et al.*, 2020).

Methods of Pheromones Application

Pheromones have been applied using a variety of techniques in the following fields (Ganai *et al.*, 2017):

1. Micro-Encapsulation Method : Small plastic capsules containing the pheromone are distributed using standard spray equipment to ensure consistent dispersion.

2. Hollow Fibre Method : The pheromone is stored in hollow plastic threads that are broken up into tiny fragments and dispersed by an aeroplane. The fibers can also be connected to the top of the stems after being fashioned into hoops, or coils.

3. Pheromone Baited Traps : These are specially designed structures that come in a variety of sizes and shapes and can be hung from trees or other high objects. Nowadays, a wide variety of traps are commercially available, with the Pherocon R, Sector XC-26, and Sector 1 traps being the most widely used.

4. Pheromone Dispensers : These are the newest gadgets capable of releasing the pheromone at precisely timed intervals. The Pherocon-controlled release dispenser is a widely used dispenser that has been patented. It is composed of plastic laminates, with the outer layer serving as a barrier that controls the rate of pheromone release and the middle layer serving as a reservoir where the pheromone (or any lure) is implanted.

Pheromone Traps

Attracting the insect is one thing, but catching it can be quite difficult. For instance, the male Tuta absoluta moth may become confused near a pheromone lure, and the traps may stay almost empty when employing a little trap, even though the Tuta absoluta pheromone is so strong that the moths would swarm around you when you open a package of lures. Simply using a larger trap is the answer in this case (Mahajan and Kawale, 2023). Wing traps, sting bug traps, and mass trapping kits are among the different kinds of pheromone traps that are used to catch insects (Figure 4).

a) Wing Trap

b) Sting Bug Traps

c) Mass trapping kits

Figure 4: Types of pheromone traps

Uses of Pheromones in IPM

There are several different approaches based on the objectives and extent of the task, including the following.

1. Monitoring of Insect Pests

In general, there are three reasons why insect populations are monitored:

a) To find out whether invading pests are present.

b) To calculate the pest population's relative density at a given location.
c) To signal a pest species' initial appearance or peak flying activity in a specific location.

2. Mass Trapping

After the monitoring phase, a mechanical control method called trapping with pheromone lures involves eliminating a significant number of pests from a certain area. Using a deadly substance in conjunction with traps (also known as the "lure and kill" approach) has the advantage of avoiding direct contact with the crop. Additionally, this method works well for controlling pests in stored products (Table 2).

3. Mating Disruption

The primary use of species-specific sex pheromones in large doses to prevent mating is to manage moth populations in orchards. To attract male moths for reproduction, females typically transmit sex pheromones over a considerable distance (several kilometers). Mating disruption is the process of influencing males' behaviour when they are looking for a female to mate with by releasing large amounts of artificial female pheromones into the atmosphere. When the moth population is too high, targeted pesticides applied locally and on time may interfere with mating.

4. Push-Pull Strategy

The push-pull strategy, also known as stimuli-deterrent diversion, is more recent than the other IPM approaches discussed. It involves changing the behaviour of insect pests and/or their natural adversaries by combining appealing and repulsive stimuli. Using a push tactic, the insects are repelled or discouraged from approaching the crops. They are concentrated in other locations where they are confined or controlled while also being drawn in by lures (pull method). A thorough understanding of chemical ecology, pest biology, and interactions with hosts, conspecifics, and natural enemies is necessary for this tactic.

Table 2: Types of lures against various insect pests

Lure used	Insect-pests
Heli-lure	*Helicoverpa armigera*
Spodo-lure	*Spodoptera litura*
FAW-lure	*Spodoptera frugiperda*
Pectino-lure	*Pectinophora gossypiella*
Ervit-lure	*Earias vitella*

Advantages

Several advantages of the scent of insects are the following:

- The pheromones do not pollute the environment and are acceptable for the environment.
- The pheromones are cost-effective because they only need a few amounts to draw in and reduce the pest population.
- Pheromones are species-specific and not risk for non-target organisms.
- Pheromones provide an easy way to track the pest population growth from a high distance.
- When the use of pheromones then saves labor charges because they are not needed.

Disadvantages

- Most sex pheromones only attract adults, and the damage is caused by the larval damage.
- The pheromones only attract one sex, and the other sex may still affect the crop.
- A small number of insect species are known to use for pheromones

- Pheromones are not used for short-term control techniques.
- Pheromones are expensive to synthesize.

Conclusion

Pheromones are crucial for both monitoring and managing insect problems. A solid understanding of the insect's presence, mobility, and propensity to enter a trap is necessary when using an odour-baited trapping device. Pheromone use may result in a significant decrease in chemical treatments, which would have positive effects on both the economy and quality. Future integrated pest management programs will rely more heavily on pheromones and all semiochemicals than they do now. One of the economical and environmentally beneficial IPM techniques is the use of pheromones.

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TRANSFORMING AGRICULTURAL DISEASE MANAGEMENT WITH DATA-DRIVEN DECISION SUPPORT SYSTEMS

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Introduction

Agriculture is the backbone of global food security and economic development, yet it faces persistent threats from crop diseases. These diseases, if undetected or improperly managed, can lead to significant losses, impacting both farmers and consumers. Traditional disease detection methods rely on manual observation, which is often subjective, time-consuming, and inefficient. The advent of data-driven decision support systems (DSS) has revolutionized the approach to disease detection in agriculture, enabling timely and precise interventions. By leveraging artificial intelligence (AI), machine learning (ML), remote sensing, and big data analytics, these systems enhance disease monitoring, identification, and mitigation strategies, contributing to sustainable agricultural practices.

The Role of Data-Driven Decision Support in Agriculture

A data-driven decision support system (DSS) utilizes multiple sources of data, including real-time field data, historical disease patterns, environmental conditions, and remote sensing imagery, to generate actionable insights for farmers. These systems employ machine learning algorithms and deep learning models to detect, predict, and diagnose plant diseases with high accuracy, reducing dependence on manual scouting and guesswork.

Key Components of Data-Driven DSS in Agriculture

1. **Data Collection:** Utilizes IoT sensors, satellite imagery, drones, and on-ground cameras to collect data on soil health, temperature, humidity, and leaf conditions.
2. **Data Processing:** Employs AI and ML techniques to analyze collected data and detect anomalies associated with plant diseases.
3. **Prediction and Diagnosis:** Uses trained models to classify plant health and predict potential disease outbreaks.
4. **Decision Support:** Provides farmers with actionable recommendations on disease treatment, pesticide application, and preventive measures.
5. **Visualization and Reporting:** Presents results through mobile apps, dashboards, and automated alerts to ensure timely decision-making.

Advancements in Disease Detection Technologies

1. Deep Learning and Image-Based Disease Detection

Deep learning, particularly convolutional neural networks (CNNs), has proven highly effective in image-based disease detection. By training CNN models on large datasets of diseased and healthy plant images, these systems can classify and diagnose plant diseases with remarkable accuracy. A study on plant disease classification using a deep CNN trained on 54,306 images achieved an accuracy of 99.35% under controlled conditions. However, when tested on real-world images from different sources, the accuracy dropped to 31.4%, highlighting the need for more diverse training datasets.

2. Hyperspectral and Multispectral Imaging

Hyperspectral imaging captures a broad spectrum of light, providing detailed chemical information about plant health. This technology enables early disease detection before visible symptoms appear. In Australia, hyperspectral imaging has been used to detect grapevine diseases and assess nutrient deficiencies in wheat crops.

Multispectral imaging, commonly used with drones, captures specific wavelengths of light to assess crop health. The AMaizeD framework, which utilizes multispectral drones for maize disease detection, has demonstrated high accuracy in identifying diseases such as powdery mildew and leaf blight.

3. Machine Learning Algorithms for Disease Prediction

Beyond deep learning, machine learning techniques such as Support Vector Machines (SVM), Random Forest, and Gradient Boosting have been employed for disease classification. A recent study developed a hybrid model combining SVM and Histogram of Oriented Gradients (HOG) features, achieving superior performance in detecting tomato late blight compared to traditional models.

4. Hybrid Deep Learning Models

Hybrid deep learning models integrating CNNs with attention mechanisms and optimized activation functions have improved disease detection accuracy. A recent study on paddy leaf disease detection using a hybrid CNN framework with channel attention mechanisms and Swish ReLU activation achieved 99.74% accuracy, outperforming existing models.

Challenges and Limitations

Despite the promising advancements, several challenges hinder the widespread adoption of data-driven DSS in agriculture:

1. **Data Quality and Diversity:**
   - Many ML models struggle with generalization due to limited or biased training datasets. Ensuring diverse and high-quality datasets is essential for improving model robustness.
2. **Integration with Traditional Farming Practices:**
   - Many farmers lack the technical expertise to integrate AI-driven DSS into their workflows. Training programs and user-friendly interfaces can facilitate smoother adoption.
3. **Cost and Accessibility:**
   - Advanced technologies such as hyperspectral imaging and drone-based monitoring can be expensive. Cost-effective solutions tailored to small-scale farmers are needed.
4. **Real-Time Processing and Decision-Making:**
   - Disease outbreaks require immediate intervention. Enhancing cloud-based data processing and edge computing can reduce latency in real-time disease detection.
5. **Scalability and Adaptability:**
   - Models trained on one crop or region may not perform well in different conditions. Developing adaptive and scalable solutions can ensure broader applicability.

Future Prospects and Innovations

The future of data-driven disease detection in agriculture is promising, with several emerging trends set to enhance efficiency and effectiveness:

1. **Federated Learning for Distributed Disease Detection:**
   - Federated learning allows multiple farms to train disease detection models collaboratively without sharing raw data, preserving data privacy while improving model generalization.
2. **Edge AI for On-Site Disease Detection:**
   - Implementing AI models on edge devices, such as smart cameras and mobile applications, can enable real-time disease detection directly in the field without requiring cloud processing.
3. **Block chain for Data Transparency and Traceability:**
   - Block chain technology can enhance transparency in disease detection by securely storing disease reports and intervention measures, aiding in tracking outbreaks and regulatory compliance.
4. **Robotic Automation for Disease Management:**
   - Autonomous robots equipped with AI-driven vision systems can perform precision spraying, mechanical removal of diseased plants, and real-time health monitoring.
5. **Synthetic Data for Model Training:**
   - Generating synthetic images of diseased plants using generative adversarial networks (GANs) can help train models on diverse and augmented datasets, improving accuracy.

Conclusion

The integration of data-driven decision support systems is transforming disease detection in agriculture, enabling early diagnosis, precise interventions, and improved farm productivity. AI-powered models, remote sensing technologies, and advanced imaging techniques have demonstrated their potential in reducing crop losses and promoting sustainable farming. However, challenges related to data quality, cost, and adoption must be addressed through collaborative efforts between researchers, policymakers, and agricultural stakeholders. Future innovations, including federated learning, edge AI, and robotic automation, are poised to further enhance disease detection, making agriculture more resilient and food security more attainable.

By embracing these cutting-edge technologies, the agricultural industry can move towards a data-driven future where farmers make informed decisions that maximize yield, minimize losses, and contribute to global food sustainability.

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BREEDING TECHNIQUES TO IMPROVE PROTEIN QUALITY AND CONCENTRATION IN LENTIL

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Abstract

Pulses is an agronomically important crop as along with high nutritional, protein content it also maintains fertility of soil by fixing atmospheric nitrogen. Lentil is one of pulse crop and became centre of agricultural interest due to good Leu/Ile and Leu/Lys ratios (1.24–1.98 and 1.08–2.03, respectively), high nutritional value (Urbano *et al*., 2007), high digestibility (~83%) (Barbana & Boye, 2013). Although, lentil is low in methionine and cystine, but a great source of amino acids and protein. However, pulse breeding is a time taking process if performed by conventional breeding methods for example mass selection, bulk method and backcrossing, etc. but evolution of breeding programs has made the process easier by introducing technologies like molecular markers, genome Selection, QTL analysis. There is also advancement in protein screening which is performed with help of molecular marker and protein content can be screened using IR reflectance or dye binding in conjunction with automated N determination. To enhance the selection procedure and to address global food security genomic selection, speed breeding and many new technologies are used in current scenario.

Keywords: Conventional breeding, molecular marker, QTL analysis, protein screening, genome selection, speed breeding.

Introduction

Globally, food beans are becoming more and more important for both sustainable agriculture and food security. Due to their capacity to fix nitrogen, edible legumes can substitute synthetic fertilizers and consequently lower greenhouse gas emissions, which has significant positive effects on the environment and the economy. One of the world's oldest crops, the cultivated lentil (*Lens culinaris* Medik.) is a healthy staple legume that cooks quickly and is cultivated in over 70 nations. It is consumed whole, dehulled, or split. Yellow, red, or green cotyledons are seen. Throughout the Indian subcontinent and eastern Mediterranean, red cotyledon lentils are a staple protein and nutrient-dense diet. They are primarily eaten as split cotyledons, or dehulled lentils. Protein, dietary fibre, complex carbs, and important micronutrients including zinc, iron, and vitamin B complex are all found in abundance in lentil seeds (Kumar *et al*., 2016). Because of particular phenolic chemicals, its seeds have higher antioxidant activity than those of other grain and legume species. By preserving the balance of amino acids necessary for physiological processes and guarding against non-communicable illnesses and protein-energy malnutrition, the amino acid content of lentil protein can have a positive impact on human health. For the nutritional enhancement of lentil crops worldwide, it is therefore essential to improve the quality of lentil protein through genetic biofortification, i.e., conventional plant breeding and molecular technologies. The effective breeding approaches for protein biofortification in lentils and other pulses are examined, showcasing successful breeding tactics. In order to select sequences that increase protein concentration and quality, future approaches to breeding lentils will include genome editing, phenotypic evaluation, genome-wide association studies, genetic engineering, and rapid germplasm selection.

Types and Role of Proteins

The essential and non-essential amino acids found in lentil proteins are notable for their low concentrations of the sulphur-containing amino acids cysteine and methionine. Storage proteins, which are membrane protein structures found in cotyledonary cells, are where lentil proteins are kept. These seed proteins provide 80% of the total protein needed for germination, following plant growth, and disease resistance. They also supply carbon (C), nitrogen (N), and sulphur (S). Additionally, storage proteins have a protective function against bruchids. These proteins can be divided into four categories: water-soluble albumins, ethanol-soluble prolamins, salt-soluble globulins and acid soluble glutelins.

Globulins: 44-70% of lentil proteins
Albumins: 26-61% of lentil proteins
Prolamins and Glutelins: Scarcely available

The proteins found in lentil seeds, with the exception of storage proteins, serve a purpose in metabolism. The plant's enzymatic activity, as well as its structural and physiological activities, are all regulated by these metabolic proteins.

Table 1. Amino Acid Value (values in g per 100 g dry seed weight)

Total Protein Content	24.63
Alanine	1.029
Arginine	1.903
Aspartic acid	2.725
Cystine	0.322
Glutamic acid	3.819
Glycine	1.002
Histidine	0.693
Isoleucine	1.065
Leucine	1.786
Lysine	1.720
Methionine	0.210
Phenylalanine	1.215
Proline	1.029
Serine	1.136
Threonine	0.882
Tryptophan	0.221
Tyrosine	0.658
Valine	1.223

(Source: https://www.nutritionvalue. org/Lentils%2C_raw_nutritional_ value.html)

Breeding approaches for improving quality and quantity of proteins

In self-pollinated crops, the following breeding methods are commonly used to develop pure-line cultivars:

- Plant Introduction
- Selection
    1. Pure line selection
    2. Mass selection
- Hybridization and selection
    1. Bulk method
    2. Pedigree methods
    3. Single Seed Descent
    4. Doubled Haploid
- Back cross method
- Mutation breeding

The backcross breeding method is utilized in some instances, such as when a breeding program involves converting pure-lines to contain a specific gene or 2-3 genes (of qualitative inheritance). Due to the species' resistance to tissue culture, haploid induction, and rescue, doubled haploid approach is scarcely utilized in legume crops.

Pedigree, bulk, single seed descent, and doubled-haploids are the four main line development methods. Backcross, mutation and multiline breeding methods are useful supplements to line development.

- **Plant Introduction**

The process of introducing a genotype or many genotypes into a new habitat where they have never been grown is known as plant introduction. It includes bringing in new crop species, wild relatives of crops, or crop variations.

- **Selection**

It is one of the oldest breeding technique in which plant is selected with desirable traits to improve yield and quality attributes. Although, there is negative correlation between protein content and grain yield in legumes but it appears to be small enough to enable selection of plants high in protein without impacting yield. Only lines that produce at least as much protein as the original populations should be selected for increased protein content under these circumstances. The quantity of proteins generated per hectare must be taken into account as a selection criterion. The alternative is to select for increased yield while trying to maintain constant protein levels. The correlations between the two qualities in the experimental material determine which of the two conditions is used. Because each species has enough variation to allow for the selection of plants with higher yields and a constant or even higher protein content, breeding work can progress even in species where a negative correlation between yield and crude protein content has been discovered. Because the physiological conflict between the production of proteins and carbohydrates has most likely not reached its maximum, it is still possible to select for both yield and protein content simultaneously in these species, unlike cereals. (Asif *et al.*, 2013).

I. **Pure line selection**

The Danish botanist W. L. Johannsen's work with the bean cultivar Princess in 1903 gave rise to a concept of pure lines. Progenies created by self-pollination of a single homozygous parent are known as pure lines. Pure line selection cannot produce novel genotypes since the genetic makeup of progenies is identical to that of their parents. Pure lines are employed extensively in situations where product homogeneity is highly valued in the market because of their even genetic structure.

II. Mass selection

Mass selection is practiced for both cross pollinated and self- pollinated crops (Allard, 1961). Major objective of mass selection is to enhance productivity of base population by increasing the frequency of desirable traits. Those landraces which has been transferred from generation to generations since ages are improved using mass selection. This type of selection is more useful if the selected traits are highly heritable (Brown and Caligari, 2011).

Some forthcoming research may include

Restricted index selection: In soybeans, restricted index selection has been effectively used to increase yield while maintaining a constant protein concentration and to increase protein concentration (Holdbrook *et al*., 1989) while maintaining oil content increase in protein content (Openshaw and Hadley, 1984).

Recurrent selection: Recurrent selection has been used to improve the protein content of soybeans (Xu and Wilcox, 1992; Carter *et al*., 1982) and to raise seed yield and protein content (Brim and Burton, 1978). In order to simultaneously boost seed production and seed protein percentage, recurrent mass selection for two cycles based on a targeted grain index (Sullivan and bliss, 1983) could raise seed protein content from 21.9 to 24.6%. In segregating generations, selection based on the protein content of a single plant led to an increase in protein content with only minor variation in yield (Meng *et al*., 1990).

Hybridization and Selection

One efficient way for increasing the protein content of pulses is hybridization-based breeding. (Salaria *et al*., 2022).

Bulk Method:

The bulk technique removes undesirable genotypes from the population, hence promoting natural selection. Nilsson-Ehle created the bulk breeding technique at the beginning of the 20th century (Newman, 1912). Early-generation families are planted and harvested as bulk populations in bulk method of line development. First, based on their pedigree, F1 plants' harvesting is done in bulk. Then, to create F3, F2 seeded and harvested in bulk. Once more, the F3 family is planted as a plot, and selection is started. The fixed lines are then planted as rows in the subsequent season, when selection is frequently enforced among rows, after the procedure is repeated until the required degree of homozygosity and uniformity is achieved. The yield and other characteristics are then assessed using the seed that was collected from the chosen rows.

Mass selection within bulk populations was thought to be a key component of Nilsson-Ehle's bulk breeding approach (Reynolds *et al*., 2022). Through the use of biotic and abiotic stressors, the goal was to "assist nature in eliminating the delicate and in conserving the hardy" (Newman, 1912) by facilitating the elimination of individuals with poor adaptations within bulk populations during generations of inbreeding.

The types of features that are chosen for or against will depend on the growing environment, thus it is important to use settings that are appropriate for reaching the program's objectives.

Pedigree method

Vilmorin created the pedigree method of line development in the 1840s, which permits selection between individual plants and entire families at each inbreeding generation (Gayon *et al*., 1998). As the plants get closer to homozygosity, the process tends to place greater weight on visual selection among individual plants in the field over the course of several years. Selection among single plants in early generations requires a significant investment of resources when using the pedigree breeding approach. This calls for assessing the selection criteria, carrying out the selection process, preserving the seed purity of each pedigree, and maintaining thorough documentation of every lineage (Reynolds *et al*., 2022).

Single Seed Descent Method

The single seed descent method (SSD) was developed in response to speed up the breeding program, by rapidly inbreeding a population before beginning individual plant selection and evaluation while reducing loss of genotypes during the segregating generations. The method enables the breeder to advance the maximum number of F2 plants through the F5 generation, without performing selection, allowing the maximum expression of additive variance. The purpose of the early stages of the procedure is on attaining homozygosity as rapidly as feasible; which is accomplished by moving one randomly selected seed per plant through the early segregating stages. (Goulden, 1941; Saxena *et al*., 2019). The SSD method's key benefit is that lines can be produced quickly in an off-season nursery or greenhouse. (Reynolds *et al*., 2022)

Doubled Haploid Method

Double haploid (DH) technology is developed for improvement of the genetic gain in breeding programs. Haploids created via in vitro culture of gametophytic cells, particularly male gametophytes, are crucial for crop improvement programs (Pratap *et al*., 2018). With the help of DH breeding, the breeders are free to develop completely homozygous genotypes from heterozygous parents in a single generation and allows fixing of the recombinant gametes directly as fertile homozygous lines (Forster *et al*., 2007; Pratap *et al*., 2018). However, in some legumes this approach is not feasible, and so its implementation is not applicable, in addition to reducing recombination possibilities it is being costly for the required equipment (Liu *et al*., 2016).

Backcross Method

Backcross breeding is of great importance in terms of to transfer genes for a particular character from donor parent to any elite genetic background. It is believed to be most effective technique to transfer major genes, particularly if they can be recognized before or during flowering.

Backcrosses are typically done between the recurrent parent and the B1 (the generation that comes after the backcross) in a conventional backcross breeding scheme. In order to transfer genes for nutritional quality in pulses, however, backcrosses are made between the B2 generation and the recurrent parent, to enable selection for nutritional quality in the B1/B2 seed. Practically, backcrossing is performed up to six - seven generation.

Mutation breeding

Narrow genetic variability may have been resulted due to result of long-term usage of conventional breeding techniques. Since pulse germplasm has little variation, mutation breeding is highly beneficial. Introducing novel genetic variability is necessary for a crop species to continue improving (Laskar *et al*., 2019). Mutagens are utilized to create variability. In the past, mutagenic effects in pulses have been studied using both chemical and physical mutagens; consequently, varietal development has also emerged. Legume protein has been enhanced by mutation breeding as opposed to selection and hybridization-based techniques. Importantly, compared to the approximately 97 variations developed globally, mutation breeding has given approximately 34 varieties of several pulse crops for commercial production (Gopalakrishna and Reddy, 2009).

For example, NIA-MASOOR-5, a mutant lentil variety created by gamma irradiation of M-85 as a parent, which became popular in Pakistan and had a higher protein concentration, high yield, and disease resistance (Ali and Shaikh, 2007). These historic commercial successes of mutant breeding in pulse crops, such as lentils, show how effective this technique is at enhancing quality attributes (Salaria *et al.*,2022).

Table 2. Varieties of Lentil developed by direct induced mutation

Variety Name	Year	Used Mutagen	Characters improved
S-256 (Ranjan)	1981	X-rays irradiation	High yield and spreading type.
Rajendra Masoor 1	1996	Gamma rays, 100Gy	Tolerance to low temperatures, early maturity and good for late sowing.

(Source: Laskar *et al.*, 2019)

While hybridization takes around 11–12 years to create a new variety, mutation breeding only takes 8–9 years (Brock, 1977). In addition to changing linkage groups, mutations can change alleles at known and unknown loci, causing both quantitative and qualitative variation relatively faster (Konzak *et al.*, 1977). Plant breeders have therefore presented mutant breeding as one of the "peaceful uses of atomic energy."

New emerging technologies

The goal of conventional breeding techniques is to enhance highly heritable features that are controlled by a small number of genes. Protein and other nutritional quality traits are examples of quantitative traits that do not significantly react to selection by traditional breeding approaches because they have low heritability and high environmental impacts (Salaria *et al.*, 2022).

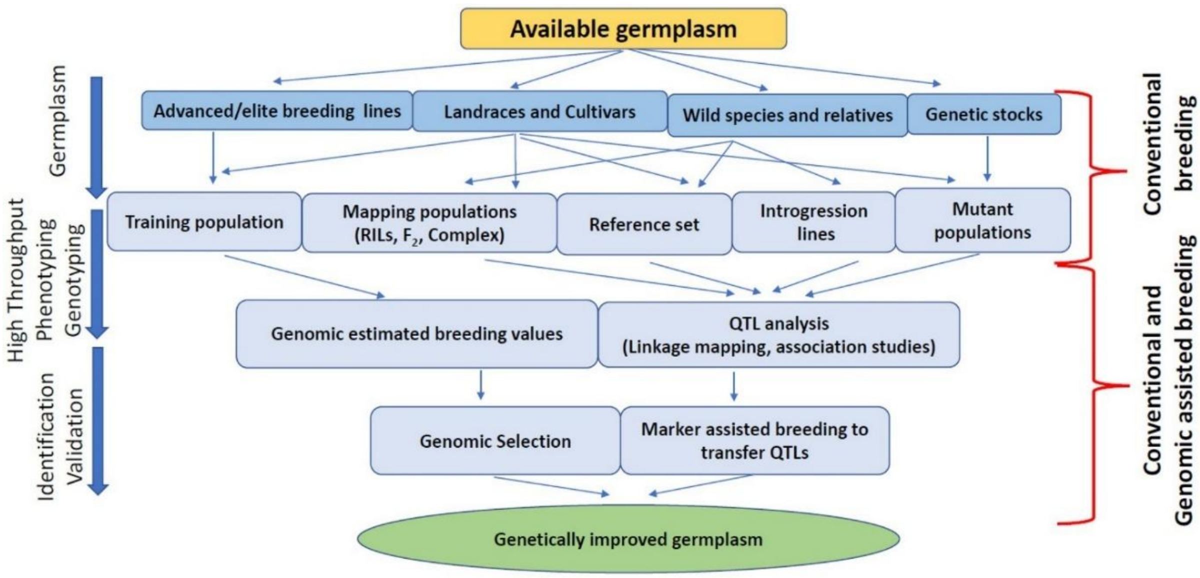

Figure 1. *Schematic representation of improvement in germplasm for protein quality and other quality traits*

The extensive potential for enhancing quantitative traits which are extremely complex, regulated by several genes, and impacted by the environment is demonstrated by genomic-assisted breeding (Kumar *et al*., 2016a). Genetic marker creation, linkage map construction, QTL and alien introgression identification, candidate gene finding, diversity analysis, genome sequencing, and pangenome construction are all currently included in the genomic toolbox for breeding. Multiple studies have been conducted on the application of molecular markers to optimize genomic developments in lentils for different attributes (Kumar *et al*., 2015). The utilization of a number of legume crops, such as chickpea, soybean, and dry pea (Pisum sativum L.), in genomic aided breeding to find potential genetic areas controlling seed protein concentration has been extensively studied. Using a linkage map comprising 207 markers (AFLP, RAPD, and STS markers), the QTL mapping method in dry pea identified three genes controlling protein concentration (Tar'an *et al*., 2004). Several other research found genes related to protein content in dry peas using genomic-assisted breeding (Tayeh *et al*., 2015). Using transcriptome profiling and PCR-based markers, a gene governing seed size, weight, and amino acid content in total protein concentration was identified in the model legumes *Medicago trunculata* and soybean (Ge *et al*., 2016).

Additional insights to increase the protein content of legumes have been made possible by genetic engineering technology. To create transgenic lines in peas (Schroeder *et al*., 1993) and chickpeas (Fontana *et al*., 1993), protocols have been developed. Transgenic soybean lines with more S-containing amino acids have been created by a number of research teams (Guo *et al*., 2020). Recent developments such as paired nickases, high-fidelity Cas9 variations, and base and prime editing have increased the effectiveness of genome editing. Additionally, it can assist reactivate genes that have been silenced and enhance or upregulate gene expression (Phatate, 2024). Although the genome-editing technique CRISPR/Cas 9 has become a ground-breaking method for enhancing staple food crops, it is not commonly used in pulses other than soybean. (Salaria *et al*., 2022).

Further targets for improving the protein content of legume seeds include eliminating anti-nutritional elements and activities that produce an unwanted flavour, eliminating possible allergens, enhancing digestibility, and enhancing processing-related functional behaviour (Wang *et al*., 2003).

Challenges and Approaches for Problem-Solving

In many legume species, there is a negative association between protein concentration and grain yield, as well as between protein content and amino acids which include sulphur. Protein concentration and yield in crop plants, especially pulses, have a negative correlation; that is, as protein content rises, variety yield falls (Qureshi *et al*., 2013). Nevertheless, there have been some documented instances with positive correlations (or no correlation at all), suggesting the potential for concurrent improvement by genetic mutagenesis or recombination and selection.

1. Negative correlation between yield and protein content
2. Negative correlation between protein and sulphur containing amino acids
3. Lack of proper field screening technique

Further are some mitigation strategies while facing challenges

Negative correlation between yield and protein can be altered by breeding

Selecting protein and yield at the same time will greatly enhance the issue. Both trait variation within crop species and between crop types coexist (Boulter, 1982). The range of genetic variation may be expanded by the existence of mutant genes that give grains a higher protein content, such as opaque-2 in maize. Therefore, in the presence of such heterogeneity, the detrimental effects of the yield-protein connection would be countered by inter-family selection for high yield and intra-family selection for high protein content from selected productive families.

Negative correlation between protein quality and quantity can be manipulated

As with cereals, it is feasible to change the negative correlations between protein content and methionine and cysteine content in legumes. In addition, a large number of mutants with enhanced protein levels and better amino acid profiles have also been discovered in legumes, much like rice. By properly genetically altering these mutants, it might be able to greatly improve both the quantity and quality of proteins.

Better screening techniques are now available

Many techniques have been developed for a chemical analysis of the amino acid and protein profiles. Even though some of them are quite reliable and fast, the final selection process takes a long time because each one must be double-screened once in the lab and once in the field.

These techniques include rapid chemical analysis of grains' protein and amino acid profiles in the lab and improved field techniques, like the use of genetic markers associated with high protein content. The availability of molecular markers that are strongly linked to these traits, however, would be the best choice. IR reflectance or dye binding along with automated Nitrogen content determination can be used to screen for protein content. Infrared reflectance is one of the rapid screening methods for sulphur amino acids. When checking for sulphur amino acids, both methionine and cysteine need to be taken into account because the latter one might spare the first one. Total sulphur analysis is often sufficient if aqueous alcohol-soluble sulphur components are eliminated beforehand (Evans & Boulter, 1974). To ensure, for example, that the elevated sulphur content is not due to an increase in trypsin inhibitor level, a secondary protein screen must be conducted following this (Asif *et al*., 2013).

Future prospects

In the upcoming years, we want to make genomics-assisted breeding a reality thanks to the current advancements in lentil genomics (Kumar & Gupta, 2020). Accuracy, quick identification, repairing, and choosing superior alleles in breeding populations led genomics-assisted breeding as emerging and promising method to boost genetic gain in lentils (Kumar *et al*., 2015). In order to create cultivars of lentils that are both highly productive and climate resilient, genomics must be incorporated into the breeding process (Kumar *et al*., 2021). High genetic gain will be seen when genomic-assisted breeding is combined with rapid generation techniques including single-seed descent, speed breeding, and double haploid production. Speed breeding is one of the advance breeding technologies that can reduce time period of breeding cycle and increase selection efficiency, regardless of season, environment changes (Srivastava & Gupta, 2024). Thus, will reduce the selection cycle and boost selection intensity (Cobb *et al*., 2019). The pace of conventional breeding in lentils can be accelerated by the integration of genomic resources and tools like genetic engineering or genome editing, which could ultimately result in innovations in lentil protein improvement initiatives to guarantee nutritional security and enhance human health. (Salaria *et al*., 2022).

Conclusion

Pulses are one of the protein rich crop known for its nutritional benefits. Lentil is a leguminous crop which come under pulses known for its remarkable nutrient content, high protein content (24.63%)

(Table 1). Earlier to improve protein quantity and quality conventional breeding techniques were used but to meet up population demands it is important to reduce selection time period and as a result, new technological approaches like genome selection, speed breeding, etc. paved the pathway for faster selection and release of new varieties adaptable to changing climate and to meet up nutrition demands of rising population.

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A CHEMILUMINESCENCE TECHNIQUE TO DETERMINE THE REACTIVE OXYGEN SPECIES IN SEEDS

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Abstract

Quality Seed being a basic input in agriculture plays a pivotal role in national food production, human nutrition and food security. Seed vigour decides the crop stand establishment by in capacitating the initial biotic and abiotic stresses. Hence it is crucial to ensure the seed vigour status of the seeds being sold to the farmers. Though many methods are available for ensuring the seed vigour in different crops, there is a requirement for 'the method' which could be used across the crops and could estimate the crop establishment precisely under different situations. In this regard, many researchers are working to develop different methods. It has been reported that production of ROS during seed germination in fact represents an active, beneficial biological reaction that is associated with high germination capacity and vigorous seedling development (Liu*et al., 2007*). Also, H_2O_2 promotes seed germination and enhances vigour by the oxidative decomposition of the germination inhibitor(s) present in the pericarp. So there is a possibility that we can use ROS for seed vigour estimation. However, to exploit this concept for seed vigour testing, there is a requirement to develop a cost effective, easy and highly reproducible method to estimate the ROS. ROS can be measured by several means. One of the rapid technique for estimating vigour i.e., "chemiluminescence". Wherein MCLA(2-Methyl-6-(4-methoxyphenyl)-3,7-dihydroimidazo(1,2-a)pyrazin3-one), is used to detect ROS and can be correlated with seed germination and vigour.

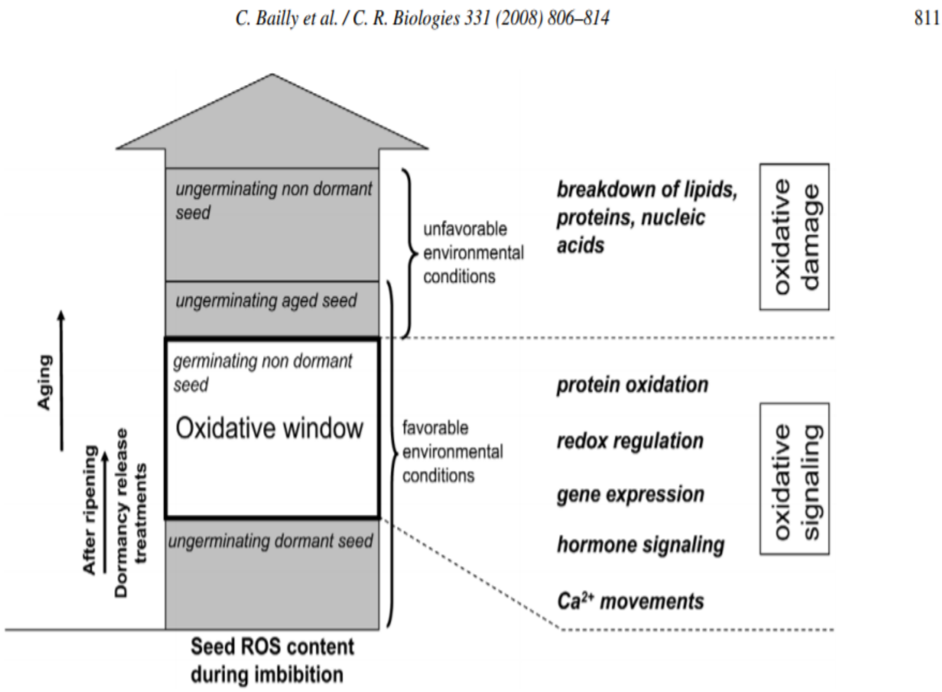
Introduction :

Seed is the most vital and basic input in agriculture. Quality seed is one which is of improved variety with highest germination, physical purity, genetic purity, seed health and seed vigour. Vigour is the property that gives the seed the potential for rapid and uniform emergence and development of normal seedlings under a wide range of field conditions. Among all quality parameters determination of seed vigour a is very important. There are various methods to measure seed vigour. They are physical test, physiological test, stress test and biochemical test. Reactive oxygen species can be used to measure the vigour, which is a biochemical test. Reactive oxygen species (ROS) are derivatives of oxygen that are more reactive than molecular oxygen. Examples peroxides (H_2O_2), superoxide (O_2^-) , hydroxyl radical (OH^-), and singlet oxygen. one of the rapid technique for estimating vigour i.e., "chemiluminescence" (CL). Wherein MCLA (2-Methyl-6-(4-methoxyphenyl)-3,7-dihydroimidazo(1,2-a)pyrazin3-one), a sensitive and physiologically compatible probe of $O_2^{\cdot-}$ is treated with different degrees of aged seeds from seed lot. On imbibition, mixture produces chemiluminescence that can be observed using single photon counting (SPC). So ROS can be detected by this technique and can be correlated with seed germination and vigour.

Reactive oxygen species

They play important roles at all stages of seed life, from germination (embryogenesis) to cell death [programmed cell death (PCD)]. Evidence from proteomics and transcriptomic studies has disproved the concept that ROS are detrimental to the seed. The dual function of ROS in facilitating cell growth and development at low concentrations while triggering cell death at higher concentrations is of key importance in seed physiology (Moller *et al*., 2007).Their amount is tightly regulated by the balance between production and scavenging, appear now as being beneficial and act as a positive signal for seed dormancy release.

Two physiological processes occurring in seeds appear as being tightly linked to the deleterious role of ROS, seed desiccation and seed aging. ROS are also suspected to be involved in loss of seed viability. Such a critical level of ROS not to overcome, which would otherwise prevent germination, and a ROS threshold level, below which germination (radicle protrusion) cannot occur is called **Oxidative window** within which we can exploit it for measuring seed vigour.



How to measure ROS ?

Though several methods available for ROS estimation there is a requirement for 'the method' which could be used across the crops and could estimate the crop establishment precisely under different situations. One such method is **Chemiluminescence** which means giving off light via chemical reaction. The vigour of seeds can be examined by measuring the differential characters of the spontaneous CL intensity of the seed during early imbibition. The degree of ageing of seeds is related to the intensity of spontaneous CL during early imbibition. The germination rate of seeds shows an obvious positive correlation with the intensity of spontaneous CL. So measurement of intensity of light can be used to study seed vigour.

Chemiluminescence (CL) :

The measurements were made with a low noise and highly sensitive single photon counting (SPC) device. The system consists of a temperature-controlled light-tight sample chamber, a single photon counting photo – multiplier tube (PMT) and a computer-controlled photon counter module. The spectral sensitivity of the PMT's photocathode was 185–850nm and the typical quantum efficiency was 20%.

Before the measurement of CL, seeds of equal number were weighed, put in a quartz cuvette and kept in sample ponds of the dark box for darkening 20–30 min, in order to avoid photo-induced delayed luminescence; then the measurement begins. After the average photon counts rate from the dry samples had stabilized, the appropriate amount of distilled water or analytical reagents were injected equably into the cuvette through a light-tight auto-injector controlled by a computer. The intensity of CL was normalized to cps/g dry weight (counts per second /g dw). All operations were performed in three parallel measurements at 20°C, 65% of the relative humidity in complete darkness. The results of measurements presented as the average CL intensity of the samples. CL has been widely used as a method for assessing the capacity of biological systems to producing reactive oxygen species(ROS).MCLA(2-methyl-6-(4-methoxyphenyl)-3,7-dihydroimidazo(1,2-a) pyrazin-3-one) can selectively react to both superoxide anion (O_2^-) and $^1O_2$ generated in biological systems. The measurements were performed in deionized double-distilled water. Therefore ROS can be measured by measuring intensity of luminescence.

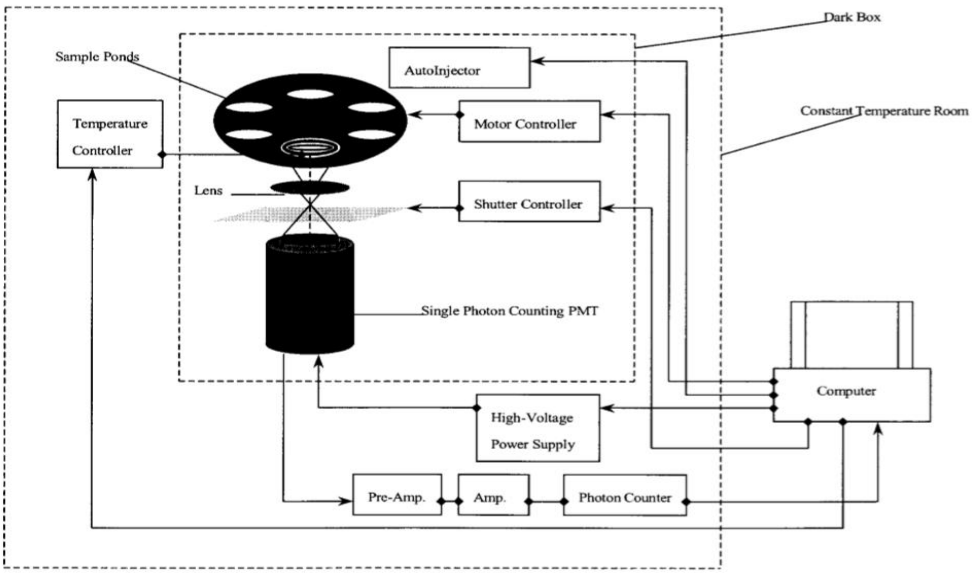


Fig 1: A schematic representation of the single photon counting system for measurements of Chemiluminescence

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IMPACT OF NANO PARTICLES ON SEED GERMINATION AND SEEDLING GROWTH

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Abstract

Nanoparticles (NPs), particles with dimensions between 1-100 nm, are revolutionizing modern science and agriculture through their unique physicochemical properties. These particles, characterized by their interfacial layer of ions and organic molecules, exhibit superior features including enhanced mechanical strength, thermal stability, and catalytic activity. In agriculture, NPs are employed as nano-fertilizers, nano-herbicides, and nano-pesticides, offering targeted delivery and improved efficiency. While NPs demonstrate significant benefits in seed germination through antimicrobial activity, pore creation for nutrient uptake, and enzyme stimulation, they also present potential risks. Research indicates varied effects across different crops: TiO2 and SiO2 nanoparticles enhance soybean germination and spinach growth, while ZnO NPs can exhibit phytotoxicity in some species. The technology's dual nature—beneficial at optimal concentrations but potentially harmful at excessive levels—necessitates comprehensive safety evaluations and toxicological risk assessments before widespread commercialization. This emerging field continues to balance promising agricultural applications with environmental and health considerations.

Keywords: Nanoparticles (NPs), Seed germination, Nano-fertilizers, Nano-herbicides, Antimicrobial activity

Introduction

Nanoparticles are fundamental to modern science and technology. Nanoparticles (NPs) are broadly defined as particles having at least one dimension between 1 and 100 nm in diameter. Because of their unique properties and novel features, NPs have been widely used in many aspects of daily life and energy production, including in catalysts, semiconductors, cosmetics, drug carriers and environmental energy. Among the latest line of technological innovations, nanotechnology occupies a prominent position in transforming agriculture and food production. Nanoparticles are widely using in agriculture as Nano-herbicide, Nano-pesticides and Nano-fertilizers etc. The potential health and environmental effects of NPs need to be thoroughly evaluated before they are widely commercialized because they affect the seed germination, seedling growth during crop production. Nanoparticles have some positive advantages like antimicrobial activity, creation pores for nutrient uptake and stimulation of enzymes for enhanced seed germination. In addition to advantages of NPs they are also phytotoxic to growing seedlings. Hence there is still scope for further understanding of the environmental fate and mechanism of NPs and development of a series safety evaluation and toxicological risk assessment standards.

Nanoparticles:

The word “Nano” is a Greek word, which means dwarf.1 nm = 10^{-9}m i.e. one billionth of a meter. Generally its size ranges between 1 to 100 nm with a surrounding interfacial layer. The interfacial layer is an integral part of nano scale matter, fundamentally affecting all of its properties. The interfacial layer typically consists of ions, inorganic and organic molecules. Organic molecules coating inorganic nanoparticles are known as stabilizers, capping and surface ligands, or passivation agents. In nanotechnology, a particle is defined as a small object that behaves as a whole unit with respect to its transport and properties.

Nanoparticles are more widely preferred than the bulk/macro particles because of several novel features of the NPs such as,

- Higher Mechanical strength
- More Thermal stability
- Increased Catalytic activity
- Improved Electrical conductivity
- Magnetic properties
- Optical properties
- Very light weight and Ultra Hard.

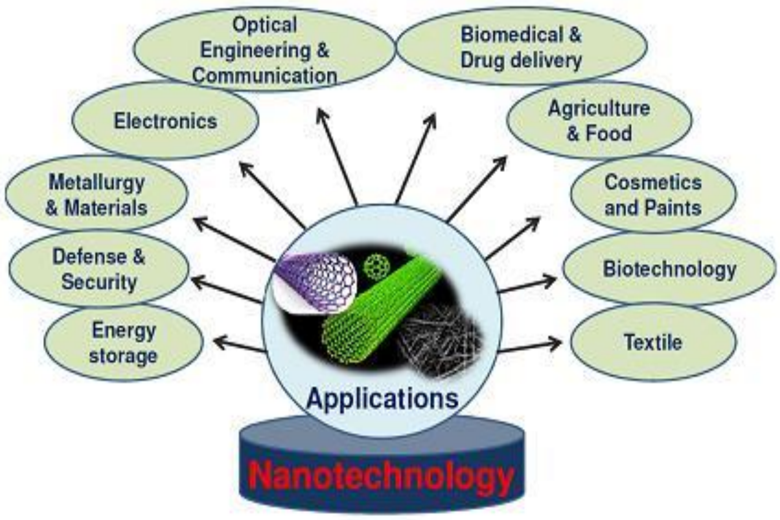

Fig 1: Applications of Nano particles several areas

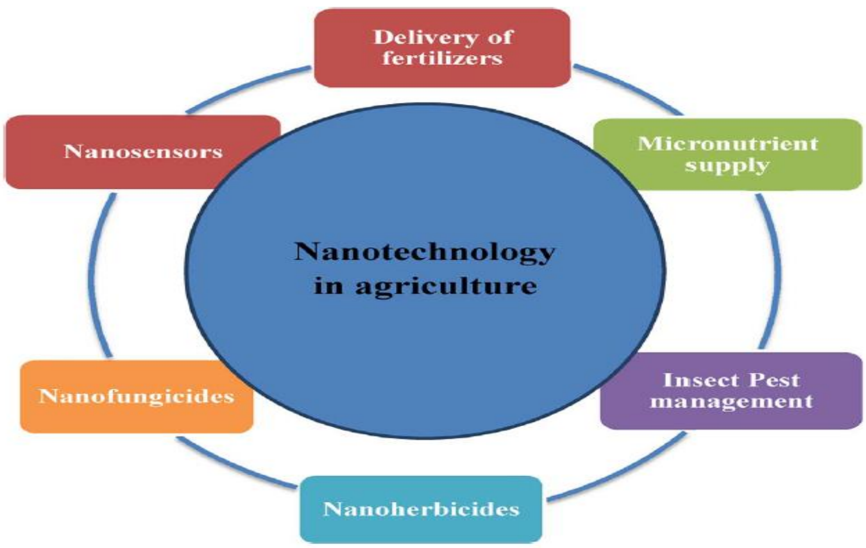

Fig 2: Applications of the Nano particles in Agriculture involves

1. Advanced Nano-fertilizer Systems for Optimized Nutrition

Modern agricultural practices have demonstrated significant yield improvements through the integration of nanoparticle-based fertilizers, particularly in foliar applications and seed treatments. The innovative smart delivery mechanisms and precise site-specific applications minimize fertilizer losses while maximizing nutrient uptake. Notable examples include engineered nano-zinc and nano-boron formulations.

2. Precision Nano-herbicide Technology

Revolutionary weed management strategies employ targeted herbicide molecules encapsulated within nanostructures. These specialized formulations interact with specific root receptors of target weeds, facilitating systematic translocation throughout the plant. By disrupting glycolysis of root system food reserves, these nano-herbicides achieve superior weed control efficacy.

3. Advanced Nano-pesticide Formulations

The incorporation of nano-encapsulation technology in pesticide development has led to breakthrough formulations of insecticides, fungicides, and nematicides. These advanced systems ensure effective pest management while significantly reducing soil residue accumulation.

4. Nanotechnology Solutions in Water Management

Advanced nanomaterials offer innovative solutions for wastewater remediation, effectively removing toxic metal ions and various organic and inorganic contaminants. Nano-clay technology, in particular, demonstrates exceptional capability in filtering and binding diverse toxic substances, including persistent pesticide residues.

5. Innovative Nano-carrier Systems

State-of-the-art nano-scale carrier technology enables precise delivery of agricultural inputs, including fertilizers, pesticides, and growth regulators. A prime example is the development of sophisticated liposome-based nano-biosensors for pesticide detection.

6. Nanotechnology Applications in Crop Enhancement

Cutting-edge applications include precision gene delivery at the cellular level and controlled mutation induction using engineered nanoparticles. Advanced delivery systems transport DNA or RNA to specific plant cells, facilitating genetic transformation and enhancing pathogen defense responses. Mesoporous silica nanoparticles exemplify this technology through their efficient DNA transport capabilities in plant cell transformation. **Seed Germination :** It is defined as "the emergence and development of the seedling to a stage where the aspect of its essential structures indicates whether or not it is able to develop further into a satisfactory plant under favorable conditions in the soil". It is the major seed quality parameter.

Effect of NPs on seed germination and seedling growth.

- It was reported that a mixture of nanoscale SiO_2 (nano-SiO_2) and TiO_2 (nano-TiO_2) could increase nitrate reductase in soybean (*Glycine max*), it results in the increase in germination. (Lu *et al*., 2002).
- An increased germination rate and germination index for *S. oleracea* was noted after exposure to TiO_2NPs at0.25–4 percent (w/v) but not with larger TiO_2 particles at the same concentrations. During the growth of the plants the dry weight and chlorophyll formation were both increased by exposure to the TiO_2NPs (Zheng *et al*., 2005). In case of pepper seed germination the Nano –Cu is more effective in enhancing the germination rather than the $CuSO_4$. (Affipour and Haghighi ,2011).

- ZnO NPs caused a significant decrease in the seedling biomass, root tip shrinkage and collapse of the root epidermis, resulted in the phytotoxic effect of ZnO NPs on *Loliumperenne* seedlings (Lin and Xing, 2008).
- In case of Tobacco and*Onion* has found that genotoxic effects occur with exposure to different concentrations of TiO2 NPs.(100nm). Higher concentrations of TiO2 NPs damages the root causing the reduction in root growth (Ghosh *et al*. 2010).
- In case of Ground nut seeds, Micro-nutrient, Zn can be delivered into seeds through ZnO nanoparticles. A higher amount of Zn was present in the seed when treated with nanoscale ZnO. This improves the germination, root growth, shoot growth dry weight and pod yield of the treated seeds. (Prasad *et al*., 2012)
- In case of the Bitter gourd the application of the Si NPs improved seed germination and antioxidant enzymes, under salt stress conditions (Wang *et al.*, 2011).

Advantages of NPs with respect to seed germination and seedling growth.

1. Enhanced water uptake of Seeds through pores created by NPs.
   Example - Carbon nanotubes (CNTs) were found to penetrate tomato seeds *(Solanum lycopersicum)* and affect their germination and growth rates.
2. Acts as a nutrient for developing seedlings.
   Example- Zinc NPs and Iron NPs.
3. For controlling the seed borne fungal pathogens during seed Germination.
   AgNP reduced viability of *G. fujikuroi*from the seed surface and subsequently prevented the seeds from developing disease symptoms including low germination and stunted growth of seedlings caused by the pathogen. (Young *et al 2015*).
4. Seed treatment with NPs enhance the germination percentage.
   The seeds are treated with different NPs with different concentrations are effective on seed quality, Zn NPs or Fe NPs can be used to enhance the seed quality in pigeonpea along with polymer coating.(Bala Raju and Prashant Kumar Rai, 2017)
5. Cause alterations in the action of enzymes during seed germination.
   Example- In castor AgNPs promotes increase in the activity of POD and SOD enzymes.

Disadvantages of NPs

1. Excessive concentrations of NPs reduce the germination percentage.
2. Reduce the shoot and root growth.
3. Excessive concentrations alters the protien structures and nucleic acids.
4. Alterations in the cell structures.
5. Phytotoxic to germinating seedlings.
6. NPs found to be toxic to the soil microflora.

Conclusion

There is need to further understanding of the environmental fate and mechanism of NPs.

- Characterization of NPs *w.r.t* their beneficial or toxic effect on crop plants and seeds.
- Studies on standardizing the concentration of Nano particles without being phytotoxic to plants.
- Verification of available findings under large scale field conditions.
- Development of a series safety evaluation and toxicological risk assessment standards.

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