ISBN: 978-93-48620-41-5

CURRENT TRENDS IN AGRICULTURAL RESEARCH
VOLUME I

EDITORS:
Dr. V. Swarnalatha
Dr. T. Radhamani
Mr. Kiran Kotyal
Dr. Shakun Mishra

First Edition: February 2025
Bhumi Publishing, India

Current Trends in Agricultural Research Volume I

(ISBN: 978-93-48620-41-5)

Editors

Dr. V. Swarnalatha

Senior Scientist,

Prof. Jayashanakar Telangana

Agricultural University (PJTAU), Hyderabad

Dr. T. Radhamani

Centre for Plant Molecular Biology and

Biotechnology, Tamil Nadu Agricultural

University, Coimbatore, Tamil Nadu

Mr. Kiran Kotyal

Department of Agribusiness Management,

Institute of Agri-Business Management,

University of Agricultural Sciences, Bangalore

Dr. Shakun Mishra

Department of Botany,

S.N. Govt. P.G. College,

Khandwa, M. P.

Bhumi Publishing

February 2025

Title: Current Trends in Agricultural Research Volume I

Editors: Dr. V. Swarnalatha, Dr. T. Radhamani, Mr. Kiran Kotyal, Dr. Shakun Mishra

First Edition: February, 2025

ISBN: 978-93-48620-41-5

Published by:

BHUMI PUBLISHING

Nigave Khalasa, Tal – Karveer, Dist – Kolhapur, Maharashtra, INDIA 416 207

E-mail: bhumipublishing@gmail.com

PREFACE

Agriculture has always been the backbone of human civilization, supporting communities, economies, and global food security. Over the years, advancements in technology, biotechnology, and sustainable farming practices have significantly transformed agricultural research, leading to increased productivity, improved crop resilience, and enhanced environmental sustainability. In the face of climate change, population growth, and resource constraints, the need for innovative agricultural solutions has never been more pressing.

The book Current Trends in Agricultural Research aims to provide a comprehensive overview of contemporary developments in the field, encompassing a broad spectrum of topics including precision agriculture, genetic improvements, soil health management, sustainable farming techniques, and the application of artificial intelligence in agriculture. It brings together contributions from eminent researchers, academicians, and industry experts to explore cutting-edge methodologies and emerging trends that are shaping the future of agriculture.

One of the key aspects of modern agricultural research is the integration of interdisciplinary approaches, combining traditional knowledge with modern technological advancements. The application of biotechnology, remote sensing, nanotechnology, and climate-smart practices is redefining the way we cultivate crops and manage natural resources. This book highlights these transformative innovations and offers insights into their practical applications for achieving global food security and environmental conservation.

As the agricultural sector evolves, researchers, policymakers, and farmers must collaborate to implement strategies that enhance productivity while ensuring ecological balance. This book serves as a valuable resource for students, researchers, and professionals in agricultural sciences, providing a foundation for future studies and applications in sustainable agriculture.

We extend our sincere gratitude to all the contributors who have shared their knowledge and expertise to make this book a reality. Their dedication to advancing agricultural research is commendable and will undoubtedly inspire further innovations in the field. We hope that this book will stimulate discussions, encourage new research endeavors, and contribute to the ongoing efforts to build a resilient and sustainable agricultural system.

- Editors

TABLE OF CONTENT

Sr. No.	Book Chapter and Author(s)	Page No.
1.	**AI-DRIVEN INNOVATIONS IN AGRICULTURAL ENGINEERING: TRANSFORMING FARMING PRACTICES** Amit Singh, Raj Kumar, Kuldeep Kumar and Harish Kumar	1 – 7
2.	**EXPLORING CIRCULAR LIVESTOCK FARMING: CAN IT BALANCE PRODUCTIVITY AND ENVIRONMENTAL SUSTAINABILITY?** Nithin Raj and Chinmayee Sahu	8 – 16
3.	**THE FARMER'S BILL IN INDIA: POLICY SHIFT OR POLITICAL MISSTEP?** Paramita Bhattacharyya, Sudipta Adhikary and Subham Chatterjee	17 – 24
4.	**REVOLUTIONIZING AGRICULTURE: THE ROLE OF ELECTROMAGNETIC WAVES IN SUSTAINABLE CROP PRODUCTION AND PROTECTION** Datta Ashok Nalle	25 – 32
5.	**MILLETS: A RESILIENT SOLUTION FOR A CHANGING CLIMATE** Angshuman Sarmah and Dhyan Jyoti Bora	33 – 44
6.	**TRANSFORMING INDIAN LIVESTOCK FARMING WITH PRECISION TECHNOLOGY** Raj Kumar, Kuldeep Kumar and Rajbir Singh	45 – 53
7.	**RECENT APPROACHES FOR PHYTOREMEDIATION OF WATER POLLUTANTS** Anjalika Roy and Anirban Paul	54 – 70
8.	**SEED PROCESSING AND STEPS TO BE FOLLOWED FOR HIGH SEED RECOVERY** Singarapu Snigda Srilaasya and V. Swarnalatha	71 – 77
9.	**AGRICULTURE RESEARCH AND INNOVATION** K. Parimala Gandhi and R. Subha	78 – 88

10.	**VALUE CHAIN ANALYSIS OF AGRICULTURAL CROPS** Lalit Kumar Verma, Om Prakash Maurya and Dushyant Kumar	89 – 94
11.	**INTRODUCTION TO VALUE ADDITION IN TEA: TRENDS AND MARKET DEMAND** Shyamal Kr Phukon, Supriya Sonowal, Sudeshna Baruah and Sanghomitra Sarma	95 – 98
12.	**ADVANCING CLIMATE-SMART IRRIGATION MANAGEMENT FOR AGRICULTURAL RESILIENCE IN THE CONTEXT OF CLIMATE CHANGE** Rajib Deka, Tinkul Ingti, Debasish Borah and Ankit Mandal	99 – 103
13.	**CURRENT TRENDS IN AGRICULTURAL RESEARCH** K. R. Kartheeswari and R. Balamurugan	104 – 108

AI-DRIVEN INNOVATIONS IN AGRICULTURAL ENGINEERING: TRANSFORMING FARMING PRACTICES

Amit Singh*[1], Raj Kumar[2], Kuldeep Kumar[3] and Harish Kumar[4]

[1]Department of Agriculture Engineering,

[2]Department of Animal Science,

[3]Department of Agronomy,

[4]Department of Plant Pathology,

School of Agricultural Sciences, IIMT University, Meerut

*Corresponding author E-mail: amitsingh@iimtindia.net

Introduction:

Agriculture has long been a cornerstone of human civilization, providing sustenance and shaping economies around the world. Yet, despite its foundational role, the sector has faced challenges for centuries—limited resources, unpredictable climates, pests, diseases, and labor shortages. Traditional farming practices have often struggled to keep pace with the demands of a growing global population, changing weather patterns, and the increasing pressure to produce more food with fewer resources.

In recent years, however, Artificial Intelligence (AI) has emerged as a transformative force in the agricultural sector. AI-driven innovations in agricultural engineering are revolutionizing the way farming is practiced. From precision farming and crop monitoring to automated harvesting and predictive analytics, AI is enabling farmers to make smarter decisions, optimize their operations, and increase yields while reducing waste. This chapter explores the profound impact AI is having on agricultural engineering and how it is reshaping the future of farming practices.

The Rise of Artificial Intelligence in Agriculture

AI is defined as the simulation of human intelligence processes by machines, especially computer systems. These processes include learning (the ability to improve performance based on experience), reasoning (drawing conclusions), and self-correction. In agriculture, AI integrates technologies like machine learning, computer vision, data analytics, and robotics to create smarter farming solutions.

The adoption of AI in agriculture is not a distant dream; it is happening now. AI-driven tools are already being implemented across various agricultural operations worldwide, from small family farms to large industrial agribusinesses. These technologies are enabling farmers to optimize resource use, monitor crop health, predict harvest times, and automate labor-intensive tasks, all with greater precision and efficiency than ever before.

Precision Agriculture: A New Era of Farming

At the core of AI-driven agricultural innovations is the concept of precision agriculture—an approach that uses advanced technologies to monitor and manage field variability in crops. Precision agriculture allows farmers to apply inputs like water, fertilizers, and pesticides more efficiently, ensuring that crops receive exactly what they need to grow, no more and no less.

AI-powered sensors and drones equipped with imaging and environmental sensors collect data on everything from soil moisture levels and nutrient content to crop health and pest presence. Machine learning algorithms analyze this data in real-time, allowing farmers to make data-driven decisions about irrigation schedules, fertilization, and pest control. This leads to more efficient use of resources, reduced costs, and less environmental impact.

One example of AI-driven precision agriculture is the use of autonomous tractors and equipment. These vehicles, guided by AI-powered GPS and sensors, can plow fields, plant seeds, and apply fertilizers with a high degree of precision. This reduces the need for manual labor and ensures that every task is performed with optimal accuracy, increasing productivity while minimizing resource waste.

AI-Powered Crop Monitoring & Prediction

AI is transforming the way we monitor and manage crop health. Traditionally, farmers had to rely on visual inspections or manual sampling to assess crop conditions, a labor-intensive and time-consuming process. Today, AI-powered tools like drones, satellite imagery, and sensors provide farmers with real-time, high-resolution data on the health of their crops.

Computer Vision: AI uses computer vision to monitor plant growth, detect early signs of diseases, and assess the overall health of crops. Platforms like Deep Field and Plantix are commonly used to assist farmers in diagnosing crop issues through images captured via smartphones.

Crop Yield Prediction: AI analyzes historical weather, soil, and crop data to predict yields more accurately. This helps farmers plan their harvests and adjust to climate variability.

Moreover, AI can also predict the likelihood of disease outbreaks based on environmental conditions and historical data. This proactive approach allows farmers to take preventive measures, reducing crop loss and improving overall yield.

Robotics and Automation in Agriculture

Autonomous tractors are one of the most exciting developments in the field of agricultural automation. These tractors are equipped with advanced technologies, including AI, GPS, sensors, and cameras, which allow them to perform tasks without human intervention. Here's a closer look at what makes autonomous tractors so innovative and how they are transforming farming:

Key Features of Autonomous Tractors:

1. GPS and Precision Navigation: Autonomous tractors use GPS and high-precision satellite data to navigate fields with incredible accuracy. This allows them to work at night or in low-visibility conditions and follow predetermined paths with minimal human input.
2. AI and Machine Learning: AI is responsible for interpreting data from the tractor's sensors and making real-time decisions based on that information. For example, the AI system can detect soil conditions or obstacles in the field and adjust the tractor’s operations accordingly (such as speed or steering).
3. Remote Control and Monitoring: Operators can monitor and control autonomous tractors remotely through mobile apps or desktop platforms. This provides flexibility, as farmers can monitor multiple tractors from one location and even make adjustments without being physically present on the field.
4. Autonomous Tasks: Tilling and Plowing: Autonomous tractors can prepare the soil for planting by plowing, tilling, or cultivating the land.
5. Planting: Tractors can plant seeds at optimal depths and intervals based on soil and crop data.
6. Spraying: These tractors can autonomously spray pesticides, herbicides, and fertilizers with high precision, ensuring that only the necessary areas are treated and reducing chemical waste.
7. Harvesting: Some autonomous tractors are integrated with harvesting equipment, able to autonomously collect crops.
8. Sensors and Cameras: Autonomous tractors are equipped with a range of sensors and cameras to detect obstacles like rocks, trees, or uneven terrain. They also monitor the crop condition, helping to make adjustments as needed during operations.
9. Energy Efficiency: Many autonomous tractors are electric or hybrid, making them more environmentally friendly than traditional fuel-powered models. The energy efficiency is further enhanced through precision farming techniques, reducing energy consumption and resource waste.

Benefits of Autonomous Tractors:

1. Labor Savings: Autonomous tractors can operate continuously without the need for rest, reducing labor costs and the reliance on human workers, especially during peak seasons. This is particularly important given the global shortage of skilled labor in agriculture.
2. Increased Efficiency: With GPS and AI, autonomous tractors can work more precisely than human operators. They can perform tasks faster and with greater accuracy, leading to higher productivity and less resource waste.
3. 24/7 Operation: Autonomous tractors can work around the clock, maximizing productivity. They can operate during the night or on weekends when human workers would typically not be available.
4. Reduced Operational Costs: By optimizing tasks like fuel usage, labor, and resource input (fertilizer, water), autonomous tractors can significantly reduce operational costs for farmers.
5. Data Collection and Analysis: Autonomous tractors generate a wealth of data while operating. This data can be used for real-time decision-making or for long-term analysis of farm performance, crop yield predictions, and resource optimization.

Popular Companies and Models:

1. John Deere
2. CNH Industrial’s Case IH
3. Agco’s Fendt Xaver
4. Kubota

Robotic Harvesters: AI-driven robots, like FF Robotics, can harvest fruits and vegetables with precision, cutting down on labor costs and minimizing waste. Robotic harvesters can autonomously pick fruit or vegetables with a level of precision that was once thought impossible. These robots use AI algorithms to navigate fields, recognize ripe produce, and delicately pick crops without damaging them. In addition to reducing labor costs, automation also ensures that harvests are collected at the optimal time, which can significantly enhance quality and shelf-life.

In the realm of weed control, AI-powered robots are capable of distinguishing between crops and weeds. These robots can then target weeds with lasers or precision herbicide application, avoiding damage to valuable crops while reducing the need for harmful chemical pesticides.

Weed & Pest Control

AI-Powered Sprayers: These sprayers use AI to differentiate between crops and weeds, applying pesticides or herbicides only where needed. This targeted approach reduces chemical use and environmental impact.

AI-Enhanced Farm Management Software

Farm Management Platforms: AI-based platforms, such as John Deere's Operations Center, allow farmers to manage everything from planting schedules to harvesting logistics. The system gathers data from machines, sensors, and weather forecasts to optimize operations.

Data-Driven Decision Making and Predictive Analytics

Another significant advantage of AI in agriculture is its ability to harness the power of big data. With AI-driven data analytics, farmers can gather vast amounts of information about their crops, soil, climate conditions, and market trends. This data can then be analyzed to uncover patterns, trends, and insights that inform decision-making.

Predictive analytics, a key AI capability, allows farmers to anticipate future events, such as the likelihood of drought, pest infestations, or price fluctuations in the market. For example, by analyzing historical weather data, soil conditions, and crop growth patterns, AI can predict when a particular crop will be ready for harvest, helping farmers plan more effectively.

This predictive capability can also extend to financial aspects of farming. AI tools can forecast market trends and commodity prices, enabling farmers to make informed decisions about when to sell their produce for maximum profitability.

Sustainability and Environmental Impact

As the global population grows, the demand for food continues to rise, putting increasing pressure on the environment. AI-driven innovations in agriculture are helping farmers meet these demands while reducing the environmental footprint of farming practices.

AI enables more precise and efficient use of resources such as water and fertilizers. By monitoring environmental conditions in real-time and adjusting inputs accordingly, AI technologies help minimize overuse and waste. For example, AI-powered irrigation systems can determine the exact amount of water needed by crops, reducing water waste in areas where water resources are scarce.

Furthermore, AI can help reduce the environmental impact of agriculture by optimizing land use. With the help of AI, farmers can make better decisions about crop rotation, soil health, and land management, promoting long-term sustainability and biodiversity.

Challenges and the Future of AI in Agricultural Engineering

1. **Cost of Technology:** Autonomous tractors are still relatively expensive, and many small-scale farmers may find the investment challenging. However, as the technology matures and becomes more widespread, prices are expected to decrease.
2. **Regulatory and Legal Issues:** The widespread use of autonomous machines in agriculture will require updated regulations on safety, liability, and the use of AI in farming. Governments will need to develop frameworks for their safe integration into the agricultural ecosystem.
3. **Technology Integration:** While autonomous tractors are capable of performing complex tasks, they still need to be integrated with other farm management technologies (e.g., sensors, drones, AI platforms) for optimal performance across all farming activities.
4. **Climate and Terrain Adaptability:** Some regions with unpredictable weather conditions or rugged terrains may pose challenges for autonomous tractors. Manufacturers are working on improving their technology to make these machines more adaptable to different environments.

Conclusion:

AI-driven innovations in agricultural engineering are transforming farming practices in profound ways. From precision farming and crop health monitoring to automation and data-driven decision-making, AI is enabling farmers to increase efficiency, reduce costs, and improve sustainability. While challenges remain, the future of AI in agriculture looks promising, with the potential to address the growing demand for food while minimizing the environmental impact of farming.

As AI continues to evolve, so too will its role in shaping the future of agriculture. The synergy between artificial intelligence and agricultural engineering holds the key to building a more sustainable, productive, and resilient global food system.

References:

1. Anderson, J., & Lee, S. (2022). *Precision Agriculture and the Role of Artificial Intelligence: Innovations for the Modern Farm*. Cambridge University Press.
2. Bhatnagar, R., & Gupta, A. (2021). "The Impact of AI on Crop Monitoring and Pest Control." *Journal of Agricultural Engineering and Technology*, 44(3), 112-126.
3. Chen, X., Zhang, L., & Sun, H. (2020). "Machine Learning and Computer Vision in Agricultural Engineering." *International Journal of Agricultural Robotics*, 15(2), 98-115.
4. Fisher, B. & Zhang, J. (2023). *Automation in Agriculture: Robotics and AI Solutions for Sustainable Farming*. Wiley & Sons.
5. Guo, M., & Shi, L. (2021). "AI-Driven Precision Irrigation: Enhancing Water Use Efficiency in Agriculture." *Agricultural Water Management*, 220, 95-106.
6. Lee, K., & Lim, D. (2022). "Predictive Analytics for Climate-Smart Agriculture." *Journal of Agricultural Systems*, 188, 85-98.
7. Patel, S., & Kumar, P. (2020). "Artificial Intelligence in Agricultural Engineering: Current Trends and Future Prospects." *AI in Agriculture*, 3(1), 12-25.
8. Singh, V., & Sharma, M. (2021). "AI-Powered Autonomous Machinery for Crop Harvesting: Challenges and Opportunities." *Robotics in Agriculture*, 5(4), 222-235.
9. Tiwari, R., & Gupta, S. (2023). "Sustainable Farming Practices with Artificial Intelligence: Innovations in Precision Agriculture." *Sustainability and Innovation in Agriculture*, 10(2), 153-164.
10. Zhang, J., & Hu, F. (2022). "AI for Climate Resilience in Agriculture: A Comprehensive Overview." *Environmental Monitoring and Climate Change*, 36(1), 34-49.

EXPLORING CIRCULAR LIVESTOCK FARMING: CAN IT BALANCE PRODUCTIVITY AND ENVIRONMENTAL SUSTAINABILITY?

Nithin Raj*[1] and Chinmayee Sahu[2]

[1]ICAR- National Dairy Research Institute, Karnal

[2]Subject Matter Specialist (LPM), KVK, ERS,

ICAR- National Dairy Research Institute, Kalyani

*Corresponding author E-mail: nithinplus96@gmail.com

Abstract:

The livestock sector plays a crucial role in agricultural economies, contributing to employment opportunities, rural infrastructure development, and agricultural value chains. The sector is indispensable for rural economies, providing livelihoods and nutrition to millions worldwide, particularly in developing nations. Despite its critical importance to global food security and rural sustenance, the sector also poses significant environmental challenges, including greenhouse gas emissions, land degradation, water pollution and biodiversity depletion. Adopting circular economy principles offers a compelling approach to addressing these issues and reshaping the livestock industry towards sustainability. Circular economy practices focus on reducing waste and enhancing resource efficiency by eliminating waste and pollution, maintaining the circulation of products and materials, and restoring natural systems.

Keywords: Livestock Farming, Circular Economy, Sustainability, Bioeconomy, Waste Management

Concept of the Circular Economy

The circular economy is a regenerative economic model that aims to minimize waste, maximize resource efficiency, and promote sustainable consumption and production patterns. Unlike the traditional linear economy, which follows a "take-make-dispose" approach, the circular economy seeks to close the loop by keeping products and materials in use for as long as possible through reuse, recycling, and regeneration. The key principles of the circular economy represent a paradigm shift towards sustainable resource management and economic development. At its core, the circular economy seeks to minimize waste and pollution by designing products and processes that are inherently more efficient and less resource-intensive (Ramirez *et al.,* 2021). Instead of adopting a linear "take-make-dispose" model, the circular economy emphasizes the importance of extending the lifespan of products through repair, refurbishment, and remanufacturing. This not only reduces the demand for new raw materials but also conserves energy and reduces greenhouse gas emissions associated with manufacturing. In addition to prolonging the life of products, the circular economy focuses on regenerating natural systems. This involves restoring and preserving ecosystems, biodiversity, and natural resources that are essential for sustaining life on Earth. By prioritizing environmental conservation and restoration efforts, the circular economy aims to create a more resilient and sustainable future for both humanity and the planet.

Introduction to Circular Livestock Farming

Livestock farming stands as a cornerstone of agricultural economies globally, offering sustenance and employment to millions, particularly in rural areas (Yadav and Sharma, 2015). It serves not only as a source of income and nutrition but also as a lifeline for small-scale farmers and rural communities, contributing significantly to poverty reduction and economic prosperity (Herrero *et al.*, 2013; Enahoro *et al.*, 2018). However, amidst its vital role, the livestock sector faces mounting pressure to embrace sustainable practices. Over recent years, there has been a growing acknowledgment of the imperative to transition towards more resilient and environmentally-friendly agricultural methods, including those within livestock farming. While the sector is essential for global food production and rural livelihoods, it also poses considerable environmental challenges such as greenhouse gas emissions, land degradation, water contamination, and biodiversity depletion (Xu *et al.*, 2021). In response to these challenges, the adoption of circular economy principles has emerged as a promising pathway for transforming the livestock sector. Circular economy practices aim to minimize waste and maximize resource efficiency by designing out waste and pollution, keeping products and materials in use, regenerating natural systems, and rethinking business models and consumption patterns.

In the context of livestock farming, embracing circular economy principles entails a range of strategies. This may involve optimizing feed efficiency to reduce resource inputs and minimize waste, implementing sustainable manure management practices to recycle nutrients and mitigate pollution, adopting regenerative grazing techniques to enhance soil health and carbon sequestration, and exploring innovative technologies like bioconversion and waste-to-energy systems to extract value from organic waste streams. By embracing circular economy principles, stakeholders in the livestock sector can not only address environmental challenges but also enhance productivity, resilience, and sustainability. Through collaborative efforts and innovative approaches, the livestock industry can pave the way towards a more circular and resilient future, ensuring the well-being of both people and the planet.

Principles of Circular Livestock Farming

The concept of the circular economy offers a promising framework for achieving sustainability by reimagining traditional linear production and consumption models. By applying circular economy principles to the livestock sector, significant environmental, economic, and social benefits can be realized. One of the key reasons for applying circular economy principles to the livestock sector is the need to address environmental challenges such as resource depletion, pollution, and greenhouse gas emissions. Livestock farming is a resource-intensive activity, requiring vast amounts of land, water, and feed. By adopting circular practices such as waste valorization, nutrient recycling, and sustainable feed production, the sector can reduce its environmental footprint and contribute to climate change mitigation efforts. Furthermore, the circular economy offers opportunities for improving resource efficiency and resilience within the livestock value chain. By closing resource loops and minimizing waste generation, livestock producers can reduce input costs, enhance productivity, and improve overall profitability. For example, using manure as a fertilizer can reduce the need for synthetic fertilizers, while converting organic waste into biogas can provide renewable energy sources for farm operations. Additionally, adopting circular economy principles can help enhance the social sustainability of the livestock sector by promoting inclusivity, equity, and community engagement. Circular practices such as agro-ecology, integrated farming systems, and local food networks can create opportunities for smallholder dairy farmers, empower rural communities, and foster greater resilience to external shocks.

Waste Management and Resource Optimization in Livestock Production

Livestock farming generates significant quantities of waste, including manure, effluents, and other by-products, which pose environmental challenges if not managed effectively (Usmani *et al.*, 2022). This section explores strategies and techniques for waste management and resource optimization in livestock production systems.

Closed-loop Nutrient Cycles in Livestock Farming

Closed-loop nutrient cycles are essential components of circular livestock farming, aiming to recycle and reuse nutrients within the farming system. This sustainable practice not only reduces waste and pollution but also promotes resource efficiency and environmental resilience. In traditional farming systems, nutrients are often lost through inefficient management practices, leading to soil degradation, water pollution, and nutrient imbalance (Lal, 2015). However, by implementing closed-loop nutrient cycles, farmers can effectively manage and optimize nutrient use, minimizing environmental impact while maximizing agricultural productivity. One of the key strategies in closed-loop nutrient cycles is the recycling of animal manure. Instead of allowing manure to accumulate and pollute water bodies, farmers can collect and compost it to produce organic fertilizer. This nutrient-rich compost can then be applied to crops or pasturelands, replenishing soil fertility and enhancing plant growth. By closing the loop on nutrient flow, farmers can reduce the need for synthetic fertilizers, saving costs and minimizing nutrient runoff into waterways. Additionally, integrating livestock and crop production systems can further enhance nutrient cycling. For example, rotational grazing allows animals to graze on pasturelands, depositing manure directly onto the soil surface. This natural fertilization process enriches the soil with organic matter and nutrients, supporting healthy plant growth and reducing the need for external inputs.

Furthermore, agro-forestry systems, which combine trees with livestock and/or crop production, can play a vital role in nutrient cycling. Trees capture atmospheric carbon and fix nitrogen in the soil, providing additional nutrients for crops and forage. Their deep root systems also help prevent soil erosion and improve water retention, contributing to overall ecosystem health.

Water Conservation and Reuse in Livestock Farming

Water is a precious resource in livestock farming, essential for animal health, hygiene, and various production processes. However, the intensive nature of livestock operations can lead to significant water usage and environmental impact. The inefficient water use practices and inadequate management can lead to water wastage, environmental degradation, and increased production costs (Rasul, 2016). To minimize water wastage, optimize resource utilization, and enhance overall sustainability, water conservation and reuse strategies are increasingly being adopted in livestock farming.

One key approach to water conservation in livestock farming is the implementation of efficient water management practices. This involves the use of technologies and techniques to reduce water consumption, such as installing water-saving devices and optimizing watering schedules for animal drinking and cleaning. By minimizing water wastage, farmers can significantly reduce their water footprint and environmental impact. Also by capturing and recycling rainwater and wastewater, farmers can reduce their reliance on freshwater sources and minimize the environmental impact of livestock operations. Another important aspect of water conservation in livestock farming is the reuse of wastewater and effluents. Instead of allowing wastewater to be discharged untreated into the environment, farmers can implement wastewater treatment systems to remove contaminants and pathogens, making the water suitable for reuse in various on-farm applications. Treated wastewater can be used for irrigation, cleaning, or even for replenishing water sources on the farm, thus reducing the demand for freshwater resources.

In addition to technological solutions, behavioral changes and best management practices also play a crucial role in promoting water conservation and reuse in livestock farming. Farmers can adopt practices such as proper manure management to prevent nutrient runoff and water pollution, implement rotational grazing to improve soil health and water infiltration, and practice rainwater harvesting to capture and store rainfall for later use. These sustainable farming practices not only help conserve water but also contribute to overall farm resilience and environmental stewardship. Furthermore, regulatory frameworks and incentive programs can incentivize farmers to adopt water conservation and reuse practices by providing financial support, technical assistance, and regulatory compliance incentives. By aligning policy objectives with sustainable farming practices, governments and regulatory bodies can facilitate the transition towards more water-efficient and environmentally sustainable livestock farming systems.

Waste Valorization and Bioeconomy

In the pursuit of sustainable agricultural practices, waste valorization and the promotion of a bioeconomy play integral roles in maximizing resource efficiency and minimizing environmental impact within the livestock farming sector. Waste valorization involves the transformation of waste materials into valuable products or energy sources, thereby contributing to the circularity of agricultural systems and reducing dependency on finite resources. Livestock farming generates various types of waste, including manure, effluents, and organic by-products, which, if not managed properly, can pose environmental challenges such as nutrient runoff, soil degradation, and greenhouse gas emissions. However, through innovative waste valorization techniques, these organic residues can be repurposed to create biogas, biofertilizers, animal feed supplements, and other value-added products.

Biogas production from anaerobic digestion of livestock manure, not only provides renewable energy for on-farm use but also mitigates methane emissions, a potent greenhouse gas (Chaudhary *et al.*, 2022). Similarly, composting of organic waste can yield nutrient rich fertilizers that enhance soil health and fertility, promoting sustainable crop production. The concept of a bioeconomy extends beyond waste valorization to encompass the utilization of biological resources and processes to produce food, feed, materials, and energy sustainably. In the context of livestock farming, the bioeconomy paradigm emphasizes the efficient use of biomass and bio-products derived from animals and plants, fostering a circular and regenerative approach to agricultural production. By embracing waste valorization and the principles of the bioeconomy, livestock farmers can not only reduce their environmental footprint but also unlock new revenue streams and enhance the overall resilience of their operations. Moreover, the transition towards a bio-based circular economy offers opportunities for rural development, job creation, and innovation, driving positive socio-economic outcomes for farming communities.

Energy Optimization in Livestock Farming

Energy optimization in livestock farming is crucial for enhancing sustainability, reducing environmental impact, and improving economic efficiency. Livestock operations require energy for various activities, including feed production, heating, ventilation, lighting, and manure management. By implementing energy-efficient practices and technologies, farmers can minimize energy consumption; lower operating costs, and mitigate greenhouse gas emissions (Maraveas, 2023). One key aspect of energy optimization in livestock farming is the adoption of renewable energy sources. Solar panels, wind turbines, and biomass energy systems can generate clean and renewable energy to power farm operations. By harnessing natural resources such as sunlight and wind, farmers can reduce their reliance on fossil fuels and decrease their carbon footprint.

Another strategy for energy optimization is the implementation of energy-efficient equipment and systems. This includes using energy-efficient lighting fixtures, insulation materials, and ventilation systems to reduce energy wastage and improve thermal comfort for animals. Additionally, advanced technologies such as heat recovery systems and variable speed drives can further enhance energy efficiency in livestock facilities.

Optimizing feed production processes is also essential for reducing energy consumption in livestock farming. Sustainable feed ingredients, such as locally sourced grains and by-products, require less energy for transportation and processing compared to imported or highly processed feeds. Furthermore, implementing precision feeding strategies and utilizing feed additives can improve feed conversion efficiency, thereby reducing energy inputs per unit of animal product produced.

Circular Business Models in Livestock Farming

Circular business models in livestock farming represent innovative approaches to farming practices that prioritize resource efficiency, waste reduction, and circularity. These models aim to transform traditional linear value chains into closed-loop systems that minimize waste and optimize resource utilization. One prominent circular business model in livestock farming is the concept of nutrient cycling, where waste materials such as manure are recycled and reused within the farming system. Instead of being treated as a waste product, manure is transformed into a valuable resource that can be used as organic fertilizer for crops or bedding material for animals. This closed-loop approach helps to conserve nutrients, improve soil health, and minimize pollution, contributing to overall sustainability.

Another circular business model is resource-efficient feed production, which involves utilizing alternative feed sources to reduce reliance on virgin resources such as grain or soy. By incorporating agricultural by-products, food waste, or other locally available feedstock into animal diets, farmers can minimize environmental impact while lowering production costs. This not only conserves natural resources but also reduces the carbon footprint associated with feed production and transportation. Water conservation, reuse, and energy optimization are also integral to circular business models in livestock farming. By adopting water-saving technologies such as rainwater harvesting, water recycling systems, and efficient irrigation methods, farmers can significantly reduce water usage and preserve resources for future generations. Similarly, integrating renewable energy sources like solar panels and biogas digesters enables onsite energy generation, reducing reliance on fossil fuels, lowering greenhouse gas emissions, and enhancing energy security. These practices not only promote sustainability but also provide cost savings and resilience against resource price fluctuations.

Policy and Regulatory Frameworks for Circular Livestock Farming

By providing incentives, setting standards, and establishing guidelines, governments can encourage farmers and stakeholders to embrace sustainable and resource-efficient practices. Policymakers can incentivize farmers to adopt circular practices through financial incentives, subsidies, and grants (Smol *et al.,* 2019). Financial support can also be provided for the implementation of waste management systems, such as composting facilities or anaerobic digesters, to recycle organic waste and produce valuable bioenergy or fertilizers.

Regulatory frameworks can establish standards and guidelines for sustainable livestock farming practices. This includes setting limits on pollution emissions, such as methane and ammonia from manure, and regulating the use of antibiotics and growth hormones in animal husbandry. By enforcing strict environmental regulations and animal welfare standards, governments can ensure that livestock farming operations minimize their environmental footprint and prioritize animal welfare. Additionally, policy interventions can promote circular business models and value chains in the livestock sector. Governments can encourage the development of local food systems and promote the use of circular procurement practices by sourcing products from sustainable and eco-friendly suppliers. By supporting the establishment of cooperative networks and circular supply chains, policymakers can create opportunities for farmers to access new markets and value-added products derived from waste streams.

Furthermore, public awareness and education campaigns can raise awareness about the benefits of circular livestock farming and promote consumer demand for sustainably produced animal products. Governments can collaborate with industry stakeholders, NGOs, and research institutions to develop educational programs and outreach initiatives that inform consumers about the environmental, social, and economic benefits of supporting circular agriculture.

Future Directions and Challenges in Circular Livestock Farming

As the world increasingly recognizes the importance of sustainability in agriculture, the concept of circular livestock farming has emerged as a promising approach to address environmental, economic, and social challenges. Looking ahead, several key directions and challenges shape the future of circular livestock farming. One promising avenue is the adoption of advanced technologies and innovations to enhance resource efficiency and resilience in livestock production systems. This includes the development of precision farming technologies, such as sensor-based monitoring systems and automated feeding equipment, to optimize resource use and minimize waste. Additionally, the integration of renewable energy sources, such as solar and wind power, can further enhance the sustainability of livestock operations. Another major direction is the promotion of circular business models and value chains in the livestock sector. This involves fostering collaboration and partnerships among stakeholders across the entire supply chain, from feed producers and farmers to processors and retailers. By closing the loop and creating circular value chains, opportunities for waste valorization, resource sharing, and product innovation can be maximized.

However, several challenges must be addressed to realize the full potential of circular livestock farming. The lack of awareness and knowledge among farmers about circular practices and technologies is a serious concern. Education and extension programs are essential to equip farmers with the necessary skills and information to adopt sustainable farming practices effectively. Another challenge is the high initial costs associated with transitioning to circular livestock farming systems. While circular practices have long-term benefits, such as cost savings and environmental sustainability, the upfront investment required for infrastructure upgrades and technology adoption can be prohibitive for many farmers, particularly smallholders. Additionally, the complexity of livestock production systems and the diverse needs of different stakeholders pose challenges to implementing holistic circular solutions. Effective collaboration and communication among stakeholders are essential to overcome these challenges and foster a shared understanding of the benefits of circular livestock farming.

Conclusion: Towards Sustainable and Resilient Livestock Systems

By embracing circular practices, stakeholders in the livestock sector can minimize waste generation, maximize resource utilization, and enhance the overall sustainability and resilience of livestock production systems. However, the transition to circular livestock farming is not without challenges, including the need for advanced technologies, circular business models, supportive policies, and stakeholder collaboration.

Moving forward, it is essential for farmers, policymakers, researchers, and other stakeholders to work together to overcome these challenges and realize the full potential of circular livestock farming. Through continued innovation, investment, and cooperation, we can create a more sustainable, efficient, and resilient livestock sector that meets the needs of both present and future generations while safeguarding the environment and promoting economic prosperity.

References:

1. Chaudhary, V. P., Chandra, R., Denis, D. M., D'Silva, T. C., & Isha, A. (2022). Agri-biomass-based bio-energy supply model: An inclusive sustainable and circular

economy approach for a self-resilient rural India. *Biofuels, Bioproducts and Biorefining*, *16*(5), 1284-1296.

2. Enahoro, D., Lannerstad, M., Pfeifer, C. & Dominguez- Salas, P. (2018). Contributions of livestock-derived foods to nutrient supply under changing demand in low-and middle-income countries. *Global Food Security*, *19*, 1-10.
3. Herrero, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S. & Rufino, M. C. (2013). The roles of livestock in developing countries. *Animal*, *7*(s1), 3-18.
4. Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, *7*(5), 5875-5895.
5. Maraveas, C., Karavas, C. S., Loukatos, D., Bartzanas, T., Arvanitis, K. G., & Symeonaki, E. (2023). Agricultural greenhouses: Resource management technologies and perspectives for zero greenhouse gas emissions. *Agriculture*, *13*(7), 1464.
6. Ramirez, J., McCabe, B., Jensen, P. D., Speight, R., Harrison, M., Van Den Berg, L., & O'Hara, I. (2021). Wastes to profit: a circular economy approach to value-addition in livestock industries. Animal Production Science, 61(6), 541-550.
7. Rasul, G. (2016). Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia. *Environmental development*, *18*, 14-25.
8. Smol, M., Kulczycka, J., Czaplicka-Kotas, A., & Włóka, D. (2019). Management and monitoring of municipal waste in Poland in the context of circular economy (CE) implementation. *Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi Polskiej Akademii Nauk*, 165-184.
9. Usmani, Z., Sharma, M., Gaffey, J., Sharma, M., Dewhurst, R.J., Moreau, B., Newbold, J., Clark, W., Thakur, V.K., & Gupta, V.K. (2022). Valorization of Dairy Waste and By-Products Through Microbial Bioprocesses. *Bioresource technology*, *346*pp.
10. Xu, X., Sharma, P., Shu, S., Lin, T.-S., Ciais, P., Tubiello, F.N., Smith, P., Campbell, N., Jain, A.K., 2021. Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. Nat. Food 2, 724–732.
11. Yadav P and Sharma A K. 2015. Agriculture credit in developing economies: A review of relevant literature. *International Journal of Economics and Finance* **7**(12): 219-244.

THE FARMER'S BILL IN INDIA: POLICY SHIFT OR POLITICAL MISSTEP?

Paramita Bhattacharyya, Sudipta Adhikary and Subham Chatterjee*
School of Law, Brainware University, Kolkata
*Corresponding author E-mail: sc.law@brainwareuniversity.ac.in

Abstract:

The Farmers' Bill in India signifies one of the most significant changes in agricultural policy in recent times, igniting extensive discussions in political, economic, and social domains. Presented with the apparent aim of liberalizing agricultural markets, improving farmer incomes, and diminishing bureaucratic inefficiencies, the legislation faced intense opposition, leading to ongoing protests that resulted in its eventual withdrawal. This article analyzes whether the Farmers' Bill was an essential reform for India's agricultural sector or a political error that failed to account for the socio-economic intricacies of rural life.

The policy framework of the Farmers' Bill aimed to eliminate the traditional Agricultural Produce Market Committee (APMC) system, allowing farmers to conduct direct business with private entities outside of state-regulated mandis. Supporters of the Bill contended that this deregulation would remove exploitative intermediaries, draw corporate investments, and incorporate Indian agriculture into a more competitive market system. By promoting contract farming and reducing inter-state trade obstacles, the law was designed to herald agricultural modernization. Nonetheless, this perspective sharply contrasted with the concerns of small and marginal farmers who worried about a corporate takeover, price fluctuations, and the decline of Minimum Support Prices (MSP).

The Bill's passage without thorough parliamentary examination or grassroots engagement heightened skepticism within the farming community, especially in agriculturally significant states like Punjab and Haryana. Critics argued that the government's one-sided method of policymaking neglected the systemic weaknesses of India's agricultural economy, where millions of farmers depend on MSP as protection against changing market prices. The uneven advantages expected for major agribusinesses heightened the sense of policy favoritism against small farmers, prompting widespread protests that quickly evolved into a larger socio-political movement.

Keywords: Farmers Bill, Policy, Right to Livelihood, Agriculture, Liberalization

Introduction:

In the complex realm of Indian agricultural policy, the Farmers' Bill of 2020 marks a pivotal moment—one that sparked fervent discussions regarding the future direction of farming in the country. Presented as a forward-thinking reform designed to reshape India's agricultural scene, the Bill pledged to modernize the sector, enhance market efficiency, and free farmers from the grip of state-run monopolies. The government's message was clear: the Bill aimed to empower farmers by allowing them to sell their products freely beyond the limitations imposed by the Agricultural Produce Market Committee (APMC) mandis, thereby creating opportunities for direct transactions with private companies and encouraging corporate investments. Moreover, it aimed to enhance contract farming, guarantee improved market connections, and reduce the power of intermediaries. The Bill was framed as an essential advancement for the agricultural industry within a more globalized economy.

Nonetheless, the true nature of the Bill was significantly more controversial. Instead of a smooth policy transition, the law quickly ignited strong political and social opposition, especially from farmer unions and agricultural groups who viewed it as a threat to their means of living. Critics contended that the Bill did not include adequate measures to shield farmers from being exploited by large corporations, worried about the decline of Minimum Support Prices (MSP), and voiced apprehensions regarding the possible disbanding of APMC mandis, which were vital market structures for small farmers. What was initially seen as a reform soon transformed into a political dilemma, as farmers in various states, especially Punjab and Haryana, flooded the streets in significant numbers.

The Farmers' Bill, which originally vowed to revitalize agriculture, turned into one of the most crucial political battlegrounds in India's recent past. This article aims to critically evaluate if the Bill represented a genuine policy transformation or a political blunder, highlighting the complex interplay among agricultural policy, governance, and the socio-economic conditions of rural India. This analysis will examine into the intricacies of India's agricultural reforms and the wider consequences for future policy development.

Salient Features of The Bill

The Farmers' Bill, officially referred to as the Farmers’ Empowerment and Protection Agreement on Price Assurance and Farm Services Bill, 2020, brought forth numerous revolutionary changes intended to reshape India’s agricultural system. At its essence, the Bill aimed to relax regulations on agricultural markets, grant farmers greater independence, and encourage involvement from the private sector. The key characteristics outlined below summarize its main goals:

a) ***Liberty to Trade Outside APMC Mandis:*** The Bill abolishes the enduring monopoly of Agricultural Produce Market Committees (APMC), allowing farmers to conduct direct sales with purchasers beyond government-controlled mandis. This provision aimed to offer farmers enhanced market access and better pricing competitiveness by removing the intermediary role of the APMCs.

b) ***Encouragement of Contract Farming:*** The law aids in forming contract farming agreements, enabling farmers to create legally enforceable contracts with private companies or agribusinesses. This measure was created to give farmers guaranteed prices and reduce the risks tied to changing market prices, while also ensuring stable supply for agribusinesses.

c) ***Price Assurance Mechanism:*** A pivotal aspect of the Bill was the creation of price assurance mechanisms via contract farming. The Bill ensures that farmers receive a fair price for their crops via pre-established contracts, offering protection against price fluctuations.

d) ***Trade Regulation:*** The Bill establishes a structure for regulating trade and guarantees that private entities engaged in agriculture must function in a transparent and responsible manner, thus protecting farmers from exploitative practices.

e) ***Conflict Resolution System:*** To resolve issues from contract farming or sale agreements, the Bill established a streamlined conflict resolution system, providing farmers with a legal pathway through an organized framework, minimizing dependence on the courts.

These elements sought to update the agricultural sector by encouraging private investment and enhancing market access, although they faced significant opposition due to concerns about protecting farmer interests.

Examination of The Farmers' Bill as A Change in Policy

The Farmers’ Bill stands as one of the most important agricultural policy changes in India's history since independence. The primary aim was to shift Indian agriculture from a heavily regulated and government-dominated system to a more liberalized, market-oriented framework, harmonizing the sector with globalization and economic modernization forces. This analysis aims to assess the Bill as a change in policy, exploring its possible ramifications, the underlying vision, and the challenges it presents.

The Perspective on Agricultural Liberalization

Central to the Bill was the idea of an agricultural economy liberated from the limitations of obsolete regulatory structures. The Bill aimed to accomplish this by removing the monopoly held by the Agricultural Produce Market Committees (APMCs), which had overseen the sale of agricultural products for many years. The Bill aimed to promote a more competitive, open market environment by enabling farmers to sell their crops directly to private buyers or in markets beyond APMCs. Supporters of the Bill contended that this change would establish a fair environment for farmers by allowing access to broader markets and guaranteeing improved pricing systems through competition. The expected advantages consisted of fairer pricing, increased investment in farming infrastructure, and the decrease of intermediaries who typically took a considerable share of farmers' earnings.

Another important policy change included in the Bill was the encouragement of contract farming. By promoting formal contracts between farmers and private companies, the government aimed to ensure farmers received a more stable income, protected from the uncertainties of price changes. These agreements aimed to provide assured pricing, supply contracts, and even technical assistance from agribusinesses, thus reducing the financial risks linked to agriculture.

Structural Innovation and Market Cohesion

The Bill also sought to connect India's mostly fragmented agricultural sector with both global and domestic supply chains. In this regard, it aimed to update agricultural methods by prompting companies to collaborate with farmers, thereby promoting technological and logistical improvements in farming. As multinational companies continue to enter the Indian market, the Bill was regarded as a move to enhance the competitiveness and productivity of the agricultural sector.

The policy aimed to lower transaction costs and enhance efficiency in agricultural trade by allowing the sale of farm products beyond government-regulated mandis and encouraging direct negotiations between farmers and traders. This was especially significant regarding India’s expanding food processing and retail industries, which need a steady, dependable supply of raw materials. In this context, the Farmers' Bill was framed as a sustainable catalyst for rural economic growth, associated with the wider narrative of economic liberalization.

The Discontents of The Policy Change

Nonetheless, the policy change reflected in the Bill faced considerable resistance, particularly from farmers' unions and agricultural organizations. The main criticism focused on the perceived sidelining of small and marginal farmers, who make up the bulk of India's agricultural labor force. Although the Bill assured increased prices via direct selling and contract farming, detractors argued that it did not sufficiently shield farmers from possible exploitation by major agribusinesses and corporate entities. Farmers worried that a lack of strong regulations would weaken their bargaining power, making them susceptible to price manipulation by large corporations.

Another controversial aspect was the provision regarding Minimum Support Price (MSP) in the Bill. The Bill did not feature legal assurances for MSP, a governmental price minimum designed to safeguard farmers from urgent sales. Many viewed the lack of this safeguard in the legislation as an implicit neglect of the farmer’s safety net, especially in states where MSP is vital for maintaining price stability for key crops such as wheat and rice. In the absence of sufficient MSP assurances, small farmers feared that the private sector would take advantage of them more, particularly during times of market volatility or crop failures.

Moreover, the Bill's advocacy for deregulated markets was viewed as a dismantling of the APMC system, which, despite its flaws, acted as a crucial tool for overseeing farm trade and shielding farmers from the control of local middlemen. Critics claimed that the Bill's emphasis on open markets might lead to farmers losing their negotiating power without robust market regulations.

Political and Social Reaction

The government's choice to advance the Bill via an ordinance and then in Parliament, without thorough discussions with stakeholders, turned out to be a major error regarding public involvement. The absence of communication and the perceived authoritative stance heightened mistrust, especially within the farming community in regions such as Punjab, Haryana, and Uttar Pradesh, where agriculture is intricately woven into the socio-economic structure. The demonstrations that ensued were not solely focused on the specifics of the Bill but also on the perceived neglect of farmers' opinions in crafting policies.

Although the Farmers’ Bill represented a significant policy change intended to modernize and liberalize agricultural practices in India, it also contained numerous risks and contradictions. The idea of a more vibrant, market-oriented agricultural economy, while attractive, did not completely tackle the inherent weaknesses of India’s farming sector. The lack of protections for small farmers and the absence of a robust system to shield them from market volatility rendered the implementation of the Bill uncertain. Consequently, what was meant to be a policy transformation turned into a politically divisive topic, highlighting the necessity for more nuanced, inclusive agricultural reforms that reconcile the needs of modernization with the realities faced by rural communities.

Suggestive Reforms

To successfully modernize Indian agriculture and protect the interests of its mainly small and marginal farmers, a more detailed and inclusive reform strategy is necessary. The ensuing reforms are recommended to harmonize market liberalization with the necessity for farmer safeguarding and sustainability:

a) Instead of eliminating the Agricultural Produce Market Committees (APMCs), reforms ought to prioritize their modernization. Improving the infrastructure of APMCs, increasing transparency in pricing, and providing superior facilities for storage and transport can enhance the efficiency of these markets and benefit farmers. Moreover, enhancing the competitiveness of APMCs by facilitating private entities to work alongside them could bring about the necessary market dynamism while retaining the current system.

b) The establishment of a mandatory Minimum Support Price (MSP) statute, incorporating enforceable legal clauses, would offer farmers the essential protection they need. Although the market ought to determine produce prices, the government must establish MSP as a minimum price, especially for vital crops such as wheat, rice, and pulses, to safeguard farmers from market exploitation and price fluctuations.

c) To guarantee that contract farming arrangements are advantageous for both farmers and companies, the government should create specific and enforceable rules. These ought to encompass clauses for equitable pricing, risk-sharing arrangements, and conflict resolution methods. The agreements should not only fulfill corporate goals but also safeguard farmers from exploitation and mandatory adherence.

d) Strengthening farmers' bargaining power can be achieved by empowering them through collective action in the promotion of Farmer Producer Organizations (FPOs). FPOs can function as intermediaries to secure improved conditions for farmers, consolidate produce for large sales, and invest in infrastructure, facilitating economies of scale.

e) The government should provide budget-friendly loans, insurance options, and technology implementation initiatives for small-scale farmers. Implementing cutting-edge agricultural methods, including precision agriculture, climate-adaptive crops, and digital marketplaces for market connections, would enhance efficiency and financial returns.

If successfully carried out, these reforms could change Indian agriculture into a more sustainable, competitive, and farmer-focused industry.

Conclusion:

The Farmers' Bill aimed to modernize India's agricultural system and showcased a daring vision for reforms driven by market forces. Nonetheless, its implementation, which disregarded essential safeguards for small farmers and lacked adequate legal protections, highlights the challenges of reconciling liberalization with the socio-economic conditions of rural India. Although the concepts underlying the Bill—market deregulation, contract farming, and price guarantee—offer potential for creating a more competitive and efficient agricultural industry, they require a broader strategy that considers the challenges faced by India's farming population. The cancellation of the Bill, while politically important, highlights the necessity for inclusive policymaking, in which stakeholders, especially farmers, are not just recipients of reforms but engaged participants in the process. Future agricultural strategies should focus on enhancing current systems like the APMC, guaranteeing statutory MSP, and supporting farmers through collaborative efforts and strong legal structures. By doing this, India can strike a careful balance between promoting economic development and safeguarding the interests of its most at-risk citizens.

In the end, the future of India's agricultural reforms depends on a detailed, conversation-based strategy that aligns economic goals with social fairness, making sure that modernization does not undermine the rural foundation that supports the country's agrarian economy.

References:

1. Bhagat, R. B. (2020). Farmers' Bill 2020: A new dawn or a political blunder? Economic and Political Weekly, 55(50), 16-18.
2. Chand, R. (2021). Agricultural reforms in India: Moving towards a new market economy. Indian Journal of Agricultural Economics, 76(1), 12-29.
3. Gupta, A., & Sharma, R. (2020). The politics of farm laws and farmer protests: An analysis of the 2020 Farmers' Bill. Journal of South Asian Development, 15(3), 193-212. https://doi.org/10.1177/0973174120956554
4. Joshi, P. K., & Gulati, A. (2019). Agricultural market reforms in India: Opportunities and challenges. Economic and Political Weekly, 54(7), 30-32.
5. Kumar, S. (2021). Farm laws and farmer protests: The legal and economic dynamics. National Law Journal, 52(1), 45-58.
6. Mohanty, S. (2020). The implications of the 2020 farm bills on small farmers in India. Economic & Political Weekly, 55(12), 35-38.
7. Rao, M. G. (2021). Understanding the impact of deregulated farm laws on rural livelihoods in India. International Journal of Rural Development, 34(4), 40-56.
8. Sharma, R. (2020). Economic reforms in India: A closer look at agricultural liberalization. Journal of Policy Analysis, 12(3), 101-115.
9. Singh, R. (2020). Market liberalization and the future of smallholder agriculture in India: A critique of the Farmers' Bill. Journal of Development Studies, 57(5), 674-692.
10. Thakur, A., & Choudhury, S. (2021). The road to agricultural prosperity: A critical analysis of India's Farmers' Bill. Agricultural Policy Review, 45(1), 74-89.

11. Vyas, A. (2020). Policy implications of contract farming in India: Lessons from the new farm laws. South Asian Economic Review, 20(4), 43-61.
12. Shah, G. (2020). A critical review of India's 2020 Farmers' Bill: Path to prosperity or peril? Journal of Indian Law and Society, 29(3), 75-92.
13. Saini, R. P. (2020). Farmers' Bill 2020 and the dismantling of APMC: An economic analysis. Indian Journal of Economics, 68(2), 112-130.
14. Banerjee, A., & Mehta, P. (2021). Corporate agribusiness and its impact on Indian farmers: A policy critique. Journal of Rural Studies, 39(1), 1-13. https://doi.org/10.1016/j.jrurstud.2021.01.006
15. Kapoor, S., & Patel, D. (2020). Rural protests and policy reform: Understanding the farmers' movement against the 2020 Bills. Social Change Review, 48(2), 23-40.

REVOLUTIONIZING AGRICULTURE: THE ROLE OF ELECTROMAGNETIC WAVES IN SUSTAINABLE CROP PRODUCTION AND PROTECTION

Datta Ashok Nalle

Department of Zoology and Fishery Science,
Rajarshi Shahu Mahavidyalaya, (Autonomous) Latur-413512 (MS), India.
Corresponding author E-mail: iprometheous007@gmail.com

Abstract:

The integration of electromagnetic wave (EMW) technologies in agriculture has emerged as a transformative approach to address modern challenges such as food security, environmental sustainability, and resource optimization. This chapter explores the multifaceted applications of EMWs and electromagnetic fields (EMFs) in enhancing crop production, protecting plants, and improving post-harvest management. By leveraging the unique properties of EMWs across the electromagnetic spectrum, these technologies provide eco-friendly, non-invasive, and energy-efficient alternatives to traditional agricultural methods. Key applications include seed germination enhancement, pest control, soil health improvement, and crop quality preservation. Furthermore, the use of EMFs in integral plant protection offers innovative solutions for mitigating abiotic and biotic stresses, ensuring higher yields and better resilience to environmental changes. While the potential of EMW technologies in agriculture is immense, challenges such as standardization, biological variability, and high initial costs need to be addressed. This chapter highlights the mechanisms, benefits, and future directions of EMW applications, underscoring their critical role in advancing sustainable agricultural practices.

Keywords: Electromagnetic Treatment, Plant Protection, Sustainable Agriculture, Pest Control, Pathogen Inhibition, Crop Enhancement.

Introduction:

In the ever-evolving landscape of modern agriculture, the integration of advanced technologies has become essential to meet global food security challenges, address environmental concerns, and optimize resource utilization. Among the innovative approaches gaining attention is the application of electromagnetic waves (EMWs), which offer a sustainable and effective solution to various agricultural challenges. Electromagnetic waves, spanning a broad spectrum of frequencies, have demonstrated remarkable versatility in addressing issues related to crop health, pest control, and post-harvest management. The growing demand for eco-friendly and non-chemical alternatives in agriculture has further amplified the importance of electromagnetic wave technologies. Unlike traditional methods that often rely on chemical interventions with adverse environmental impacts, EMW treatments provide a non-invasive, energy-efficient, and environmentally sustainable option. These treatments harness the unique properties of electromagnetic radiation to achieve multiple objectives, including pest eradication, microbial decontamination, soil parameter measurement, and crop quality enhancement.

Integral plant protection through electromagnetic treatment is a key area of focus within this domain. This approach employs targeted electromagnetic energy to safeguard crops from pests, pathogens, and environmental stresses while preserving the integrity of the agricultural product. Research has shown that electromagnetic waves can selectively eliminate pests without damaging the taste, texture, or nutritional value of crops. Additionally, EMW treatments offer promising solutions for mitigating the effects of frost, improving soil health, and extending the shelf life of agricultural produce.

This chapter delves into the transformative role of electromagnetic waves in agriculture, with a specific emphasis on their application in integral plant protection. By examining the mechanisms, benefits, and potential applications of electromagnetic treatments, it highlights how these technologies contribute to sustainable farming practices and pave the way for a more resilient agricultural future.

Electromagnetic Waves: Electromagnetic waves (EMWs) are fundamental phenomena that play a crucial role in the modern understanding of physics, engineering, and a wide array of practical applications. These waves are composed of oscillating electric and magnetic fields that propagate through space, carrying energy. Unlike mechanical waves, electromagnetic waves do not require a medium for transmission and can travel through a vacuum, making them uniquely versatile. The electromagnetic spectrum encompasses a wide range of frequencies and wavelengths, from low-frequency radio waves to high-frequency gamma rays. This spectrum is categorized into different regions, including radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays, each with distinct properties and applications. The generation and behavior of electromagnetic waves are governed by Maxwell's equations, which describe how electric and magnetic fields interact and influence each other. These waves travel at the speed of light in a vacuum and exhibit properties such as reflection, refraction, diffraction, and interference. Their ability to transmit energy without physical contact has made them an indispensable tool in communication, medicine, industry, and research. In agriculture, electromagnetic waves are being increasingly utilized due to their ability to interact with biological systems, detect environmental changes, and influence physical and chemical properties. This versatility has led to innovations in pest control, soil analysis, crop monitoring, and post-harvest treatments, providing eco-friendly and efficient solutions to traditional farming challenges.

Electromagnetic Waves in Agricultural Applications

Electromagnetic waves have been applied in agriculture for a variety of purposes, including remote sensing, imaging, quality assessment, and dielectric heating, both before and after harvest. This chapter emphasizes their application in heating, a core effect of electromagnetic waves. Among the various methods, radio frequency (RF) power has gained attention as a non-chemical thermal technique. Similar to using heat to kill bacteria in food, RF power can be utilized to disinfest foods and other materials, such as soil. Additionally, radio frequency applications extend to measuring soil properties and salinity, further showcasing their versatility in agriculture.

Pest Control Using Electromagnetic Waves

Traditionally, farmers have relied on chemical sprays, such as methyl bromide, for pest control. Despite being easy to use, these fumigants have significant drawbacks, including contributing to ozone layer depletion [1]. The potential global ban on methyl bromide for post-harvest treatments underscores the need for alternative approaches. Three primary methods ionizing radiation, cold treatments, and conventional heating—have been explored as substitutes [2]. However, these techniques also face limitations. Ionizing radiation cannot be turned off after treatment, and its commercial viability remains constrained. Cold treatments are costly and time-consuming, while conventional heating may compromise product quality by heating both pests and crops uniformly. To address these challenges, modern techniques such as genetic treatments, ultrasonic waves, and electromagnetic wave treatments have been proposed. Electromagnetic heating, first explored by Frings (1952),[3] Thomas (1952),[4], has evolved into a promising method. Initially limited to post-harvest applications, recent research suggests its potential as an in-field technique for pest control and frost prevention [5]

Radio Frequency (RF) for Deactivation of Microbes

Radio frequency (RF) heating achieves microbial decontamination by rapidly transferring heat within the microbial cells, which occurs at a faster rate compared to other methods. This rapid heating results in the thermal destruction of cells even at relatively low heating rates [6]. The mechanism of RF heat transfer involves radiation, where microbial DNA and essential proteins absorb the energy, leading to physical alterations in the cellular structure and functionality. The effectiveness of RF heat treatment in reducing microbial populations depends on various factors, including the microbial species, the structure of the cell wall, RF frequency, and the uniformity of heating. For example, a study on low-temperature, long-duration RF pasteurization of onion powder evaluated the inactivation of *Salmonella enterica*. The RF heating process achieved a temperature of 66 °C within 180 seconds, and after 38 hours, the microbial population was reduced by 3.4 log units. Importantly, the process preserved the quality of the onion powder.

Although *Salmonella* is commonly used to validate thermal pasteurization, several studies suggest *Enterococcus faecium* as a suitable alternative for testing the pasteurization of spices and herbs [7]. The colour of the samples remained unaffected by RF heating, regardless of the level of grinding. Another study assessed RF technology for pasteurizing egg white powder in a continuous process [8]. Heating at 80 °C for 2 hours achieved a microbial reduction of >6.69 log for *Salmonella* and >6.78 log for *E. faecium*. The resistance and thermal response of *E. faecium* make it a viable surrogate for evaluating pathogen reduction. The validated thermal process can be adapted for use in the egg industry, and continuous RF heating allows for the treatment of larger quantities in less time compared to stationary systems. Additionally, the uniformity of heating can be enhanced through the use of hot air, intermittent stirring, or modifications to the electrodes [9, 10].

Radio Frequency (RF) for Deactivation of Enzyme

Enzymes, acting as biocatalysts, are essential for plant metabolism and physiology. However, post-harvest enzymatic activity can lead to food spoilage through colour changes, unpleasant odors, and nutrient loss. In food grains, the most problematic enzymes are those that cause discoloration and the development of off-flavours due to interactions with substrates like lipids, polyphenols, and proteins [11]. Compared to disinfestation and pasteurization, RF heating is less frequently reported for enzyme inactivation. Nevertheless, a combined RF treatment at 80 °C followed by one minute of steam application has demonstrated exceptional results. This method achieved uniform heating and high-quality samples, reducing peroxidase activity by 95% while retaining nearly 80% of vitamin C content. Modern agriculture faces significant challenges, including pest infestations, diseases, and environmental stresses, all of which threaten crop productivity. Traditional methods of plant protection often rely on chemical pesticides and fertilizers, which, while effective, have raised concerns regarding environmental degradation, human health risks, and the emergence of resistant pest species. As a result, there is a growing interest in alternative and sustainable solutions. Electromagnetic (EM) treatment offers a novel, non-invasive approach to plant protection and growth enhancement. This technology utilizes electromagnetic fields (EMFs) of varying frequencies and intensities to stimulate physiological processes in plants, inhibit pathogen proliferation, and deter pests. The purpose of this review is to summarize current research on EM treatment for integral plant protection, highlight its advantages, and identify gaps in knowledge for future investigation.

Electromagnetic Fields and Their Role in Enhancing Seed Germination

The use of electromagnetic fields (EMFs) in agriculture has gained significant attention due to their potential to enhance seed germination and early seedling development. EMFs, as a non-invasive and energy-efficient method, interact with biological systems in ways that can improve the physiological processes critical for plant growth. This approach has emerged as a promising alternative to chemical treatments, offering a sustainable solution to improve crop yields and optimize agricultural practices. The geomagnetic field (GMF) plays a crucial role in protecting living organisms on Earth from cosmic radiation and other environmental influences, shaping their evolution over time. Its impact on the growth and development of plants has been a topic of interest for many researchers. This chapter explores various methods of utilizing different types of magnetic fields (MFs) to examine their biological effects on plants, with the goal of enhancing seed germination, plant growth, and crop yield. The methods discussed include: Utilizing Magnetic Fields below GMF: Investigating the influence of GMF on plant growth and productivity by applying magnetic fields weaker than the natural geomagnetic field.

Reversed Magnetic Fields (RMFs) Below GMF: Exploring the effects of reversed magnetic fields, weaker than GMF, on the evolutionary growth and development of plants.

Static Magnetic Fields (SMFs) Higher than GMF: Studying the impact of static magnetic fields stronger than GMF, including reversed SMFs, to determine how the north (N) and south (S) magnetic poles affect plant biology.

Electromagnetic Fields (EMFs): Using electromagnetic fields to accelerate and enhance seed germination, growth, and yield, as well as to strengthen plants' resilience against environmental stresses.

Magnetized Water (MW): Applying magnetized water to improve seed germination, plant growth, and crop productivity.

High Gradient Magnetic Fields (HGMF): Studying magnetotropism in plants by employing high gradient magnetic fields. This paper advocates for the application of various magnetic field techniques to analyse their biological effects on plants, aiming to enhance agricultural productivity and improve crop management practices. [12]

Applications in Agriculture

Seed Treatment: Pre-sowing EM treatment has demonstrated improvements in seed germination rates, uniformity, and vigor. This approach is particularly beneficial for enhancing the performance of seeds under suboptimal conditions.

Crop Growth Enhancement: Continuous exposure to optimized EMFs during the growing season has been linked to improved biomass production, enhanced photosynthetic efficiency, and increased resistance to abiotic stressors such as drought and salinity.

Disease Management: EM treatment offers a chemical-free solution for controlling plant pathogens. Applications in post-harvest storage have also been explored, with promising results in reducing spoilage and extending shelf life.

Pest Control: Electromagnetic devices have been developed to create pest-free zones in fields and storage facilities. These systems are environmentally friendly and reduce reliance on chemical pesticides.

Advantages of Electromagnetic Treatment

Eco-Friendly: No chemical residues or environmental pollutants.

Cost-Effective: Reduces dependency on expensive agrochemicals.

Non-Invasive: Minimal disruption to plant tissues and surrounding ecosystems.

Scalability: Suitable for both small-scale and industrial agricultural operations.

Limitations and Challenges

Standardization: The lack of standardized protocols for EM treatment frequencies, durations, and intensities limits its widespread adoption.

Biological Variability: Plant species and varieties respond differently to EMFs, necessitating tailored approaches.

Long-Term Effects: Limited research on the long-term impacts of EM exposure on plants, soil, and non-target organisms.

Technical Barriers: High initial costs of EM equipment and the need for specialized expertise can be prohibitive for some farmers.

Future Perspectives

Further research is needed to optimize EM treatment parameters and understand its molecular mechanisms. Collaboration between biophysicists, agronomists, and engineers could lead to the development of more efficient and affordable EM technologies. Additionally, integrating EM treatment with other sustainable agricultural practices, such as organic farming and precision agriculture, could amplify its benefits.

Conclusion:

Electromagnetic wave and electromagnetic field technologies hold significant promise for revolutionizing agricultural practices in a sustainable and environmentally conscious manner. These technologies offer a wide range of applications, including seed treatment, crop growth enhancement, pest control, and post-harvest quality preservation, making them a viable alternative to chemical-intensive methods. By improving seed germination rates, strengthening plant resilience against stresses, and extending the shelf life of agricultural produce, EMWs contribute to higher productivity and reduced ecological footprints. However, realizing the full potential of EMW technologies requires overcoming certain challenges, including the lack of standardized protocols, variability in plant responses, and the need for cost-effective and scalable solutions. Future research should focus on optimizing treatment parameters, understanding molecular mechanisms, and integrating EMW applications with other sustainable farming techniques. Collaborative efforts among researchers, agronomists, and technology developers will be essential to address these challenges and unlock the transformative potential of electromagnetic technologies in agriculture. EMW-based agricultural solutions pave the way for a resilient and sustainable agricultural future, offering innovative tools to meet the growing demands of global food production while preserving environmental integrity.

References:

1. Tang, J.; Wang, S.; Hansen, J.; Johnson J.; Mitcham E.; Drake S.; Hallman G.; (2003). “Postharvest Control of Insect Pests in Nuts and Fruits Based on Radio Frequency Energy”; ISHS Acta Horticultura, 2003, ISSU 599, pp. 175-182.
2. Wang, S.; Tang J.; (2001). "Radio Frequency and Microwave Alternative Treatments for Insect Control in Nuts: A Review"; Agricultural Engineering Journal, vol. 10 (3&4), pp.105-120, 2001.
3. Frings, H. (1952). “Factors determining the effects of radio-frequency electromagnetic fields and materials they infest”, Journal of economic entomology, Vol. 45(3), pp. 396-408, 1952.
4. Thomas, A.M. (1952). “Pest control by high-frequency electric fields critical resume”, Technical report W/T23. Leatherhead, Surrey, England: British electric and allied industries association, 1952.
5. Marra F, Zhang L, Lyng JG (2009) Radio frequency treatment of foods: review of recent advances. J Food Eng 91:497–508.
6. Chen L, Wei X, Irmak S, Chaves BD, Subbiah J (2019) Inactivation of *Salmonella enterica* and *Enterococcus faecium* NRRL B-2354 in cumin seeds by radiofrequency heating. Food Control 103:59–69.
7. Ozturk S, Kong F, Singh RK (2020) Evaluation of *Enterococcus faecium* NRRL B-2354 as a potential surrogate of *Salmonella* in packaged paprika, white pepper and cumin powder during radio frequency heating. Food Control.

8. Wei X, Lau SK, Reddy BS, Subbiah J (2020) A microbial challenge study for validating continuous radio-frequency assisted thermal processing pasteurization of egg white powder. Food Microbiol 85:103306.
9. Chen L, Huang Z, Wang K, Li W, Wang S (2016) Simulation and validation of radio frequency heating with conveyor movement. J Electromagn Waves Appl 30:473–491.
10. Jiao Y, Shi H, Tang J, Li F, Wang S (2015) Improvement of radio frequency (RF) heating uniformity on low moisture foods with polyetherimide (PEI) blocks. Food Res Int 74:106–114.
11. Doblado-Maldonado AF, Pike OA, Sweley JC, Rose DJ (2012) Key issues and challenges in whole wheat flour milling and storage. J Cereal Sci 56:119–126.
12. Shabrangy A. Using Magnetic Fields to Enhance the Seed Germination, Growth, and Yield of Plants. Methods Mol Biol. 2024;2788:375-395.

MILLETS: A RESILIENT SOLUTION FOR A CHANGING CLIMATE

Angshuman Sarmah*[1] and Dhyan Jyoti Bora[2]

[1]Krishi Vigyan Kendra, Darrang, Assam

[2]Krishi Vigyan Kendra, Nalbari, Assam

*Corresponding author E-mail: sarmahangshuman97@gmail.com

Abstract:

Millets, often celebrated as "climate-smart" and "nutri-cereals," have emerged as vital crops in the global discourse on sustainable agriculture, particularly in the face of escalating climate challenges. This chapter examines the transformative potential of millets within the Indian context, a nation with a deep-rooted history of millet cultivation, now poised to reclaim its significance in contemporary food systems. Renowned for their resilience to abiotic stresses, millets thrive under adverse conditions, including drought, erratic rainfall, and nutrient-poor soils, rendering them indispensable for ensuring agricultural sustainability in a changing climate. The chapter explores the multifaceted contributions of millets, from enhancing food and nutritional security to supporting smallholder farmers in semi-arid and marginal regions. Their remarkable nutrient profile, including high fiber content, essential amino acids, and minerals, positions them as pivotal in addressing India's dual burden of malnutrition and lifestyle diseases. Millets' low water and input requirements, coupled with their ability to act as carbon sinks, underscore their role in climate mitigation and adaptation strategies.

Policy interventions, such as United Nations, at the behest of the Government of India, declared 2023 the International Year Millets, India's declaration of 2018 as the "National Year of Millets" and the inclusion of millets in the National Food Security Mission, are analyzed for their impact on promoting millet cultivation and consumption. The chapter also critically addresses barriers such as market inefficiencies, limited consumer awareness, and the need for robust research and innovation to enhance millet productivity and value chain integration.

By synthesizing traditional knowledge with modern advancements, this chapter highlights the strategic importance of millets in building climate-resilient food systems. It calls for a paradigm shift to re-establish millets as cornerstone crops in India's agricultural and dietary landscape, presenting a sustainable pathway for addressing the intertwined crises of climate change and food insecurity.

Keywords: Millet, India, Climate-Smart, Cereal

Introduction:

Climate change poses a formidable challenge to global food security, intensifying the frequency and severity of extreme weather events such as droughts, heatwaves, and erratic rainfall patterns. These conditions threaten the productivity of staple crops like wheat, rice, and maize, which are highly sensitive to water stress and temperature fluctuations (IPCC, 2021). In this context, millets—a group of small-seeded cereal crops that include pearl millet, finger millet, foxtail millet, and others—have emerged as a promising alternative for building resilience in agricultural systems. Their inherent drought tolerance, low water requirement, and ability to thrive in marginal soils position them as a critical solution for mitigating the adverse impacts of climate change (Gupta *et al.,* 2017).

Millets have a long history of cultivation in arid and semi-arid regions, particularly in Asia and Africa, where their resilience has supported food security for centuries (FAO, 2023). Unlike major cereals, millets exhibit a unique combination of traits that enable them to withstand extreme climatic conditions. For example, pearl millet (*Pennisetum glaucum*) can produce viable yields even under prolonged drought conditions, thanks to its deep root system and high water-use efficiency (Sehgal *et al.,* 2018). Additionally, millets are naturally resistant to many pests and diseases, further reducing their vulnerability to climate-induced stresses.

The nutritional benefits of millets also contribute to their growing appeal. These grains are rich in essential nutrients such as iron, calcium, and dietary fiber, making them a valuable addition to diets in regions prone to malnutrition. Their low glycemic index and gluten-free properties further expand their relevance in global food systems (Saleh *et al.,* 2013). By promoting millet cultivation, countries can address not only the environmental challenges posed by climate change but also critical issues of health and nutrition.

India, with its predominantly agrarian economy, faces a dual challenge of feeding a growing population while adapting to the increasing impacts of climate change. Droughts, exacerbated by erratic monsoons and rising temperatures, have become more frequent, severely affecting agricultural productivity and rural livelihoods. In this context, millets—referred to as “nutri-cereals” in India—offer a sustainable and climate-resilient alternative. Known for their ability to thrive in arid and semi-arid regions with minimal water and inputs, millets are a lifeline for smallholder farmers in drought-prone areas (Reddy *et al.,* 2021).

Millets, including varieties such as pearl millet (*Bajra*), finger millet (*Ragi*), sorghum (*Jowar*), and foxtail millet (*Kangni*), have historically been integral to India’s traditional agricultural systems. These crops are well-suited to the rainfed regions that constitute over 50% of the country’s cultivated area. Their resilience to drought, low input requirements, and ability to grow on marginal soils make them a critical resource for farmers facing water scarcity and unpredictable climatic conditions (ICRISAT, 2022). Furthermore, millets have a short cropping cycle, enabling farmers to secure multiple harvests in a year even under constrained conditions (Kumar *et al.,* 2020).

The revival of millet cultivation aligns with India's broader goals of ensuring food security and empowering farmers, particularly in regions prone to agrarian distress. As drought-resistant crops, millets reduce the dependence on erratic rainfall, thereby minimizing crop failures and income losses for farmers. Moreover, the nutritional richness of millets provides an opportunity to address widespread malnutrition in India. Rich in iron, calcium, magnesium, and dietary fiber, millets are often described as "superfoods," capable of contributing to both human and ecological health (Pradhan *et al.,* 2018).

Despite their advantages, millet cultivation in India has declined significantly over the past few decades due to policy biases favoring rice and wheat under the Green Revolution. These policies, coupled with shifting dietary preferences, have marginalized millets from mainstream agriculture. Recognizing this trend, the Indian government has taken several initiatives to promote millets, including the declaration of 2018 as the "National Year of Millets" and subsequent inclusion of millets under the Public Distribution System (PDS) (MoAFW, 2018). Additionally, India played a pivotal role in advocating for the United Nations to declare 2023 as the "International Year of Millets," signaling a renewed commitment to these resilient grains on a global scale (FAO, 2023).

This chapter explores the potential of millets as a sustainable crop for combating drought and climate extremes. It delves into the physiological and genetic traits that make millets uniquely suited to dryland farming, highlighting recent advances in breeding and agronomic practices aimed at enhancing their climate resilience. Additionally, the chapter examines the socio-economic implications of millet cultivation, emphasizing its role in empowering smallholder farmers and promoting agro-ecological balance.

Despite their advantages, the adoption of millets in mainstream agriculture faces significant barriers, including limited awareness, lack of market support, and cultural preferences for more familiar grains like rice and wheat (Pingali *et al.,* 2019). To fully harness the potential of millets, coordinated efforts are needed across research, policy, and market domains. This chapter aims to provide a comprehensive overview of the current state of millet cultivation and its prospects for addressing the twin challenges of food security and climate resilience.

By reintroducing millets into the global agricultural narrative, we can unlock their potential as a shield against the growing threats of drought and climate extremes, ensuring a more sustainable and food-secure future for vulnerable populations worldwide.

How Millets Survive Drought Conditions: A Physiological Perspective

Millets are often referred to as "drought-tolerant crops" due to their unique physiological and morphological traits that allow them to thrive under water-limited conditions. These adaptations include efficient water use, robust root systems, and specific biochemical mechanisms that enhance their ability to withstand drought stress. Below, the internal physiological mechanisms through which millets survive drought conditions are explained.

1. Deep and Extensive Root Systems

Millets possess deep, fibrous root systems that allow them to access moisture from deeper soil layers, making them highly effective in extracting water during periods of drought (Sehgal *et al.,* 2018). The root-to-shoot ratio in millets is higher compared to other cereals, ensuring efficient allocation of resources to water absorption. For instance, pearl millet (Pennisetum glaucum) can develop roots extending up to 2 meters, enabling it to sustain growth even in arid conditions (Yadav *et al.,* 2020).

2. High Water-Use Efficiency (WUE)

Millets exhibit superior water-use efficiency (WUE) compared to other staple crops. They achieve this through a combination of physiological traits:

Stomatal Regulation: Millets can regulate stomatal aperture effectively, reducing water loss through transpiration.

Reduced Leaf Area: Smaller leaves in millets minimize surface area for water evaporation, conserving moisture during drought stress (Kholová *et al.,* 2013).

Crassulacean Acid Metabolism (CAM)-like Traits in Some Varieties: Certain millet species can switch to water-saving metabolic pathways under severe stress, further enhancing WUE.

3. Efficient Photosynthesis Mechanisms

Millets, particularly pearl millet and sorghum (Sorghum bicolor), utilize the C4 photosynthetic pathway, which is inherently more efficient under high temperatures and low water availability. The C4 pathway minimizes photorespiration, conserves water, and maintains high photosynthetic rates even during periods of drought (Rao *et al.,* 2017).

4. Osmotic Adjustment and Cellular Tolerance

Millets are capable of osmotic adjustment, which is crucial for maintaining cellular turgor under drought conditions. This involves the accumulation of osmolytes such as proline, glycine betaine, and soluble sugars, which stabilize cellular structures and maintain enzymatic functions during water stress (Sairam & Srivastava, 2001).

Proline Accumulation: Proline acts as an osmoprotectant and antioxidant, reducing oxidative stress caused by drought (Prasad *et al.,* 2018).

Cell Membrane Stability: Millets exhibit superior membrane stability under drought stress, which helps maintain cellular integrity.

5. Antioxidant Defense Mechanisms

Drought conditions often lead to oxidative stress due to the accumulation of reactive oxygen species (ROS). Millets have robust antioxidant defense systems, including enzymatic antioxidants such as superoxide dismutase (SOD), catalase (CAT), and peroxidases. These enzymes scavenge ROS and prevent damage to cellular structures like lipids, proteins, and DNA (Reddy *et al.,* 2021).

6. Reduced Growth Rate During Stress

Millets have the ability to slow their growth rate during periods of water scarcity, conserving resources and redirecting energy toward survival. This phenological plasticity allows them to recover quickly when favorable conditions return, ensuring yield stability under erratic rainfall patterns (Kumar *et al.,* 2020).

The remarkable drought tolerance of millets is a result of their specialized physiological traits, including deep root systems, efficient photosynthesis, osmotic adjustment, and antioxidant defenses. These features make millets an invaluable crop for combating the impacts of climate change in drought-prone regions. By understanding and leveraging these physiological mechanisms, millet cultivation can be further optimized to enhance food security in arid and semi-arid areas.

Potential of Millets in Combating Climate Challenges in India

India faces significant climate challenges, including rising temperatures, erratic rainfall, frequent droughts, and soil degradation, which have serious implications for agriculture. With nearly 55% of India’s arable land being rainfed, ensuring food security under changing climatic conditions necessitates a shift toward more resilient cropping systems (ICRISAT, 2022). Millets, often termed "climate-smart crops," present an exceptional opportunity to address these challenges due to their drought tolerance, low input requirements, and adaptability to marginal lands.

1. Drought Resistance and Water Efficiency

Millets, including pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), and sorghum (*Sorghum bicolor*), are naturally drought-tolerant crops. Their deep root systems allow them to access water from deeper soil layers, making them highly efficient in water use compared to staple cereals like rice and wheat. For example, pearl millet requires 30-40% less water than rice while offering comparable calorific value (Kumar *et al.,* 2020). This makes millets a vital crop for regions prone to water scarcity, such as Rajasthan, Gujarat, and parts of central India.

2. Short Growing Season and Stress Adaptation

Millets have a shorter growing season, with some varieties maturing in as little as 60-90 days. This characteristic allows farmers to cultivate multiple crops annually or adapt to shortened growing windows caused by delayed or erratic monsoons (Sehgal *et al.,* 2018). Additionally, millets are resilient to high temperatures and can withstand extreme climatic fluctuations, making them suitable for cultivation under future climate scenarios.

3. Contribution to Soil Health and Low Input Requirements

Millets are particularly suitable for cultivation on degraded and nutrient-poor soils. Unlike resource-intensive crops such as rice and wheat, millets require minimal chemical fertilizers and pesticides. Their cultivation helps maintain soil health by improving organic matter content and reducing soil erosion, especially on sloping terrains in hilly regions (Pradhan *et al.,* 2018). Intercropping millets with legumes further enhance nitrogen fixation in the soil, promoting sustainable farming systems.

4. Reducing Greenhouse Gas Emissions

Millet cultivation produces lower greenhouse gas emissions compared to high-input crops like paddy rice, which is associated with significant methane emissions from flooded fields. By promoting millets, India can reduce the carbon footprint of its agriculture sector while ensuring sustainable food production (ICAR, 2022).

5. Ensuring Food and Nutritional Security

Millets are rich in essential nutrients such as iron, calcium, magnesium, and dietary fiber, addressing the dual challenge of food and nutritional insecurity in India. In regions affected by climate-induced crop failures, millets serve as a reliable source of sustenance for vulnerable populations (Singh *et al.,* 2021). Furthermore, their gluten-free and low glycemic index properties make them suitable for managing lifestyle diseases, which are increasingly prevalent in both rural and urban India.

6. Policy and Market Potential

The Indian government has recognized the potential of millets in combating climate challenges. Initiatives such as the inclusion of millets in the Public Distribution System (PDS), minimum support price (MSP) for millet crops, and the promotion of the "International Year of

Millets 2023" have created a conducive environment for scaling up millet production (MoAFW, 2023). Additionally, expanding millet-based value chains and agro-industries can provide economic incentives for farmers while boosting rural livelihoods.

The potential of millets in combating climate challenges lies in their unique agronomic and nutritional traits, which make them indispensable for climate-resilient agriculture. By integrating millets into India's mainstream agricultural systems, policymakers, researchers, and farmers can collectively address the twin challenges of climate adaptation and food security. Scaling up millet cultivation requires a multi-pronged approach, including targeted research, market support, and community engagement to ensure these traditional grains reclaim their place in India's agricultural landscape.

Millet as a Drought-Tolerant Crop: Enhancing India's Food Security and Sustainability

India's agriculture is highly sensitive to climate variability, with over 55% of its cultivable area being rainfed and dependent on the monsoon (ICRISAT, 2022). The increasing frequency of erratic rainfall, prolonged droughts, and heatwaves has adversely affected the productivity of water-intensive crops like rice and wheat, threatening food security. In this context, millet cultivation has emerged as a sustainable solution to ensure food security and resilience amidst climate challenges.

Millets, including pearl millet (Bajra), finger millet (Ragi), and sorghum (Jowar), are highly drought-tolerant crops that can thrive on marginal soils with minimal water and inputs. Their ability to adapt to arid and semi-arid regions has made them indispensable for achieving food security in India, particularly in drought-prone areas.

1. Millets and Food Security amid Low Rainfall

In recent years, several parts of India have experienced below-average rainfall. For instance:

Rainfall Deficit: According to the India Meteorological Department (IMD, 2023), the monsoon season of 2022-2023 witnessed a rainfall deficit of 8% in key agricultural states like Rajasthan, Maharashtra, and Karnataka.

Impact on Water-Intensive Crops: Rice and wheat yields in these regions declined significantly, while millet production remained stable, highlighting their resilience (MoAFW, 2023).

Evidence of millet's role in ensuring food security during drought years includes:

Pearl Millet in Rajasthan: Rajasthan, one of India's most drought-prone states, recorded a 7% increase in pearl millet production during the 2022 drought year, providing a crucial buffer for local food security (ICAR, 2023).

Finger Millet in Karnataka: Farmers in Karnataka shifted to finger millet during the 2020 drought, resulting in a 12% increase in millet cultivation area and ensuring sufficient food supplies at the local level (Kumar *et al.*, 2021).

2. Nutritional Security through Millets

In addition to their resilience to climate variability, millets contribute to nutritional security, addressing malnutrition in vulnerable populations.

- High Nutritional Value: Millets are rich in essential micronutrients like iron, calcium, magnesium, and dietary fiber, which are critical for addressing India’s widespread anemia and malnutrition issues (Pradhan *et al.*, 2018).
- Public Distribution System (PDS): Recent inclusion of millets in the PDS has made these nutrient-dense grains more accessible to low-income households, especially in drought-prone areas (MoAFW, 2023).

3. Millet Production Trends and Policy Support

Millet production in India has been steadily increasing due to supportive policies and farmer awareness of their climate resilience:

- Production Growth: According to the Ministry of Agriculture, millet production in India increased from 17.26 million tons in 2020-2021 to 18.3 million tons in 2022-2023, despite erratic rainfall during this period (MoAFW, 2023).
- Policy Measures: Initiatives like the declaration of 2023 as the International Year of Millets and the introduction of millet-based value chains have incentivized farmers to adopt millets (FAO, 2023).
- Global Leadership: India is the largest producer of millets globally, accounting for over 40% of global millet production, positioning the country as a leader in climate-resilient agriculture (ICRISAT, 2022).

4. Sustainability and Climate Adaptation

Millets contribute to agricultural sustainability by:

Reducing Water Use: Millet cultivation requires 30-40% less water than rice, significantly reducing pressure on depleting groundwater resources (Kholová *et al.*, 2013).

Lowering Carbon Emissions: Compared to rice, millet farming produces lower greenhouse gas emissions, aligning with India's climate goals under the Paris Agreement (Rao *et al.*, 2017).

Promoting Agro-Ecological Systems: Millet-based intercropping systems improve soil health through nitrogen fixation and organic matter enrichment, fostering long-term sustainability (Reddy *et al.*, 2021).

Millets have proven to be a vital tool for ensuring food and nutritional security in India amidst climate variability and drought conditions. Their ability to sustain yields under low rainfall, coupled with their nutritional richness and environmental benefits, makes them an indispensable part of India's agricultural strategy. Strengthening millet production and integrating them into mainstream agricultural policies is crucial for addressing the dual challenges of food security and climate resilience.

Millet Production in Assam: Climate Suitability and Recent Trends

Millets have historically been an integral part of traditional agriculture in Assam, though their prominence declined in the past few decades. However, with increasing awareness about their climate resilience and nutritional benefits, efforts to revitalize millet cultivation in the state are gaining momentum. Assam’s climate and agro-ecological conditions make it highly suitable for millet cultivation, and recent trends highlight a positive trajectory for millet production.

1. Climate Suitability of Assam for Millet Cultivation

Assam's subtropical climate, characterized by moderate rainfall and warm temperatures, aligns well with the growth requirements of millets. Key climatic factors include:

Temperature: Millets such as finger millet (Eleusine coracana) and foxtail millet (Setaria italica) thrive in temperatures ranging from 20°C to 35°C, which are common in Assam during the growing season (Kumar *et al.,* 2020).

Rainfall: Assam receives an average annual rainfall of 1,500–2,500 mm. Millets, being drought-tolerant, are capable of surviving even in regions with lower rainfall distribution, but the state's well-distributed monsoon rains provide an added advantage for millet growth.

Soil Conditions: The light, well-drained soils in the hilly and plateau regions of Assam are ideal for millet cultivation. Finger millet and other small millets adapt well to marginal lands where other cereals might fail (ICRISAT, 2022).

2. Recent Production Trends in Assam

Although millet production in Assam has been relatively low compared to other states, recent years have witnessed resurgence due to policy interventions and growing demand.

Current Area and Production: As of 2022, Assam has around 6,000 hectares under millet cultivation, primarily in 15 districts, including Nagaon, Dhubri, and Bongaigaon (ARIAS, 2023). These districts contribute to 97% of the total millet production in the state.

Expansion Efforts: The Assam Millet Mission, launched in 2021, aims to increase millet cultivation to 50,000 hectares by 2026. This expansion is expected to boost production significantly and promote millets as a staple in the local diet (ARIAS, 2023).

Yield Improvement: The average yield of millets in Assam stands at 1.5–2 tons per hectare. Recent adoption of improved seed varieties and better farming practices has contributed to increased productivity (Caritas India, 2022).

3. Role of Policy and Farmer Initiatives

The Assam Millet Mission, in collaboration with organizations such as ICRISAT and Caritas India, has been pivotal in promoting millet cultivation. Key interventions include:

- Training and Capacity Building: Training programs for farmers on millet cultivation techniques have improved adoption rates in rural areas.
- Market Linkages: Efforts to integrate millets into supply chains, such as the Public Distribution System (PDS), have incentivized farmers to grow these crops (ICAR, 2023).
- Nutritional Awareness: Campaigns highlighting the nutritional benefits of millets have increased consumer demand, encouraging production.

4. Challenges and Opportunities

- Challenges: Limited awareness about millet processing and marketing, coupled with a focus on rice and wheat cultivation, has restricted millet production in Assam.
- Opportunities: The state's favorable climate, combined with national and state-level policies, presents a unique opportunity to position Assam as a leader in millet production.

Millets are regaining importance in Assam's agricultural landscape due to their climate adaptability, nutritional value, and sustainability. With favorable agro-climatic conditions and increasing support from initiatives like the Assam Millet Mission, the state is poised to become a significant contributor to India’s millet production in the near future.

Conclusion:

Millets have emerged as a cornerstone of climate-resilient agriculture, offering a sustainable pathway to address the dual challenges of food security and environmental sustainability in the face of climate change. Their inherent adaptability to harsh growing conditions, including drought, heat, and poor soil fertility, positions them as vital crops for ensuring agricultural resilience. As global temperatures rise and rainfall patterns become increasingly erratic, millets provide a robust alternative to water-intensive staples like rice and wheat, especially in arid and semi-arid regions.

Beyond their agronomic advantages, millets contribute significantly to nutritional security, offering a rich source of essential nutrients and aiding in the fight against malnutrition. Their cultivation aligns with eco-friendly practices, as they require minimal water, fertilizers, and pesticides, thereby reducing the carbon footprint of agriculture. Integrating millets into farming systems not only enhances soil health and biodiversity but also provides economic stability to smallholder farmers, particularly in vulnerable regions.

However, unlocking the full potential of millets requires a multidimensional approach. Policy support is critical to incentivize millet production, streamline market access, and promote their inclusion in public food programs. Research and innovation in millet breeding, processing, and value addition are essential to enhance productivity and consumer appeal. Awareness campaigns to educate farmers and consumers about the benefits of millets can further boost their adoption.

In the context of a rapidly changing climate, millets symbolize resilience, sustainability, and inclusivity. By embracing these ancient grains as a modern solution, agriculture can be transformed into a more climate-adaptive system, ensuring a secure and sustainable food future for generations to come.

References:

1. FAO. (2023). *Millets for Food Security and Nutrition.* Food and Agriculture Organization.
2. FAO. (2023). *International Year of Millets: Celebrating India's Leadership.* Food and Agriculture Organization.
3. Gupta, S. M., Arora, S., & Pundir, R. P. (2017). Drought-resilient crops: Millets. *Journal of Crop Improvement*, 31(3), 123–136.
4. ICAR. (2022). *Millet-Based Farming Systems: A Path to Sustainability.* Indian Council of Agricultural Research.
5. ICAR. (2023). *Millets in Indian Agriculture: Resilience and Adaptation to Climate Change.* Indian Council of Agricultural Research.
6. ICRISAT. (2022). *Millets for Climate-Resilient Agriculture in India.* International Crops Research Institute for the Semi-Arid Tropics.
7. IMD. (2023). *Annual Monsoon Report: Trends and Impacts of Rainfall Variability in India.* India Meteorological Department.
8. IPCC. (2021). *Climate Change 2021: The Physical Science Basis.* Intergovernmental Panel on Climate Change.
9. Kholová, J., Hash, C. T., Kumar, P. L., Yadav, R. S., & Vadez, V. (2013). Terminal drought-tolerant pearl millet (*Pennisetum glaucum*): Physiological and molecular mechanisms. *Plant Physiology and Biochemistry*, 68, 22–30.
10. Kumar, A., Yadav, R., & Singh, M. (2020). Potential of millets in combating climate challenges in India. *Indian Journal of Agricultural Sciences*, 90(8), 1245–1253.

11. Kumar, A., Yadav, R., & Singh, M. (2021). Role of millets in ensuring food security during drought years in Karnataka. *Indian Journal of Agricultural Sciences*, 91(6), 876–883.
12. MoAFW. (2018). *National Year of Millets: Policy Measures and Impacts.* Ministry of Agriculture and Farmers Welfare, Government of India.
13. MoAFW. (2023). *International Year of Millets 2023: Policy Measures and Impacts.* Ministry of Agriculture and Farmers Welfare, Government of India.
14. Pingali, P. L., Mittra, B., & Rahman, A. (2019). *Transforming Food Systems for a Rising India.* Palgrave Macmillan.
15. Pradhan, A., Nag, S. K., & Patil, S. (2018). Millets: Nutritional composition and impact on human health. *Indian Journal of Nutrition and Dietetics*, 55(3), 233–240.
16. Prasad, P. V. V., Staggenborg, S. A., & Ristic, Z. (2018). Impacts of drought and/or heat stress on physiological, developmental, growth, and yield processes of crops. *Field Crops Research*, 221, 36–51.
17. Rao, K. P., Basavaraj, G., & Sehgal, D. (2017). Genetic improvement of drought tolerance in millets: A review. *Crop Science*, 57(6), 2748–2758
18. Reddy, B. V. S., Rao, K. P., & Sharma, K. K. (2021). Millets: A sustainable option for combating climate change in India. *Current Science*, 121(7), 865–873.
19. Sairam, R. K., & Srivastava, G. C. (2001). Water stress tolerance of wheat (*Triticum aestivum*) and its relation to antioxidant enzyme activity. *Indian Journal of Agricultural Research*, 75, 303–305.
20. Saleh, A. S. M., Zhang, Q., Chen, J., & Shen, Q. (2013). Millet grains: Nutritional quality, processing, and potential health benefits. *Comprehensive Reviews in Food Science and Food Safety*, 12(3), 281–295.
21. Sehgal, D., Mondal, S., & Varshney, R. K. (2018). Enhancing drought tolerance in pearl millet through genetic improvement. *Plant Breeding Reviews*, 42, 1–27.
22. Singh, B., Singh, J. P., & Kaur, R. (2021). Role of millets in climate-resilient agriculture: Challenges and opportunities. *Current Science*, 120(5), 879–884.
23. Yadav, O. P., Rai, K. N., & Gupta, S. K. (2020). Genetic improvement of pearl millet for arid and semi-arid ecologies of India. *Crop Improvement*, 46, 15–22.

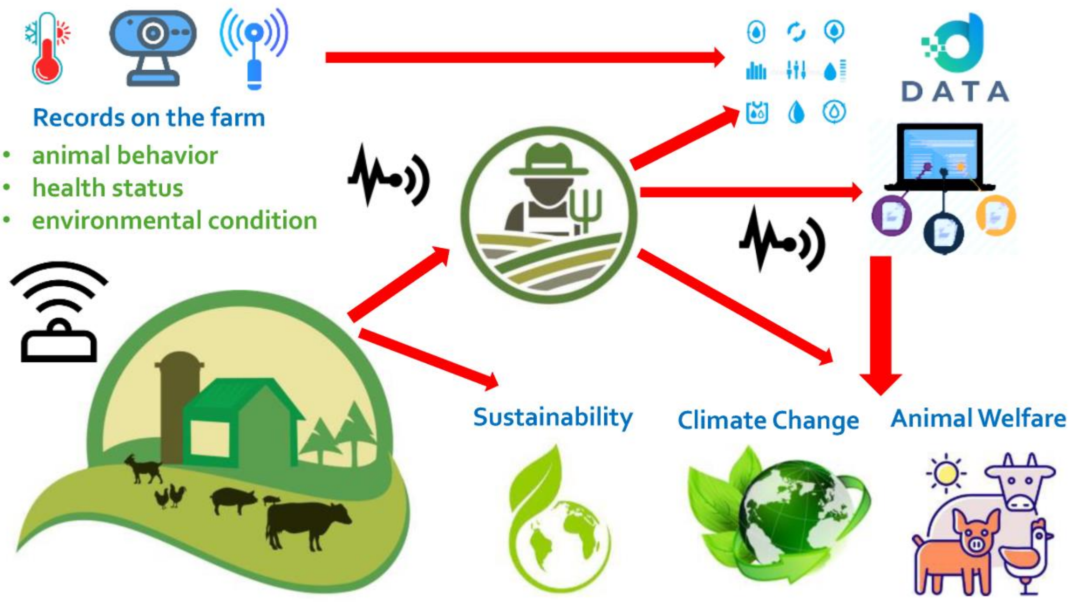
TRANSFORMING INDIAN LIVESTOCK FARMING WITH PRECISION TECHNOLOGY

Raj Kumar*[1], Kuldeep Kumar[2] and Rajbir Singh[1]
[1]Department of Animal Science,
[2]Department of Agronomy,
School of Agricultural Sciences, IIMT University, Meerut
*Corresponding author E-mail: raj.kumar@iimtindia.net

Introduction:

Precision livestock farming (PLF) in India refers to the use of technology and data-driven approaches to monitor and manage livestock more effectively and sustainably. The goal is to optimize livestock productivity, improve animal welfare, and reduce environmental impacts. In India, where livestock farming is integral to the rural economy, PLF can play a significant role in transforming traditional farming practices. Digitalization, the Internet of Things (IoT), Big Data—Buzzwords which are increasingly associated with dairy farming. Not only agricultural and veterinary publications are embracing this topic, the general media also cover it: while a headline like “The Connected Cow: Optimizing Dairy Cow Health And Productivity With Technology” [1] appears to make huge promises, another reads “Big Brother in the Cowshed” [2] and may be understood as displaying a certain caution towards technical monitoring of animals and possibly a deterioration of the human–animal relationship.

The worldwide demand for meat, milk and animal products might increase by more than 65% over the next 40 years. In order to secure food supplies for more than nine billion people worldwide, the number of pigs and chickens and the scale of farms where they are raised must increase. A parallel development is the declining number of farmers. This means that each farmer has to care for a growing number of animals, while there is an increase in demand from society that the right of animals to individual attention is respected. Because of this, precision livestock technologies are of great importance to deal with these challenges. At the same time, the livestock production sector has to solve serious problems such as: animal health in relation to human health, improved animal welfare, to minimize negative impact on the environment, while retaining comparative price. Precision Livestock Farming (PLF) systems offer a farmer modern real-time monitoring sensing technologies and centric-animal management concept, aiming to allow the farmers to make living from their livestock business while facing the serious problems mentioned above.



Key Aspects of Precision Livestock Farming in India

1. Use of Technology

- **Sensors and Wearables:** Technologies such as GPS collars, activity trackers, and health-monitoring sensors help farmers track animals' movements, monitor their health, and detect early signs of diseases or stress.
- **Sensors:** A "sensor" is commonly defined as "a device that is used to record that something is present or that there are changes in something" [3].

  In dairy cattle husbandry, "sensor" still seems to be associated primarily with automated heat detection based on activity data. This application is widely being used and is well researched; its practicability had already been documented more than a decade ago [4]. Kempf [5] reported a regular estrus detection rate of 95% using activity monitoring for estrus detection and generally higher effectivity compared to visual heat detection. This study is just one of many examples for estrus detection based on activity. The use of these sensors seems to be economically advantageous [6] and may in the future be integrated with physiological data to target cows more individually for even higher reproductive performance [7].
- **Data Analytics:** Data collected from these devices can be analyzed to monitor factors such as feed intake, milk production, weight gain, and overall health, helping farmers make informed decisions.
- **Drones and Cameras:** These tools can be used to monitor large herds and ensure that animals are grazing appropriately or to track their location in vast farming areas.

2. Health Monitoring

- Continuous monitoring of livestock health through sensors can help detect diseases early, reducing the need for antibiotics and promoting animal welfare.
- **Automatic Disease Detection:** Innovations like thermal cameras and smart collars can help identify abnormalities in body temperature, movement patterns, and behavior, which could indicate illness.
- **Behavior Analysis:** Behavioral changes such as reduced movement or grazing can indicate health issues. PLF uses data analytics to detect these changes, allowing farmers to take prompt action

3. **Improved Productivity and Efficiency**

- **Feeding Management:** PLF can assist in optimizing feed consumption by ensuring that each animal receives the appropriate amount of nutrition. This is essential for maximizing productivity (e.g., milk or meat production) while minimizing waste.
- **Milk and Meat Production:** For dairy and meat animals, PLF helps track production levels, such as milk yield, growth rate, or feed conversion efficiency. By analyzing these data, farmers can optimize breeding, feeding, and overall management practices to maximize production.
- **Breeding Programs:** PLF helps in optimizing breeding programs by analyzing genetic traits, reproduction cycles, and performance data. This can lead to better quality livestock and higher productivity.

4. Resource Management and Sustainability

- **Water and Feed Usage:** PLF can optimize the use of resources like water and feed by ensuring they are used efficiently. For example, sensors can monitor the water intake of animals and adjust watering systems to avoid wastage.
- **Waste Management:** Proper waste management is critical for sustainability. PLF systems can track waste production and offer data to manage manure and waste more effectively, converting it into useful products like compost or biogas.
- **Environmental Impact:** PLF technologies can reduce environmental footprints by optimizing the use of resources (water, feed, land) and reducing emissions from livestock farming.

Technology Adoption in Rural India

- **Mobile and Cloud Platforms:** With the increasing penetration of mobile phones and internet connectivity in rural India, cloud-based applications and mobile platforms can provide farmers with access to real-time information and insights, even in remote areas.
- **Affordable Solutions:** Given that many Indian farmers operate on small scales, there is a need for affordable and scalable PLF solutions. Companies are now developing cost-effective technologies tailored for the Indian context, such as low-cost health monitoring devices and mobile apps for farmers.
- **Training and Support:** To facilitate the adoption of PLF, training programs and local extension services are essential. Farmers need guidance on how to interpret data and use these technologies effectively.

5. Challenges and Opportunities in India

- **Infrastructure and Connectivity:** One of the key challenges in India is the lack of reliable internet connectivity in rural areas, which limits the use of advanced technologies.
- **High Initial Investment:** The cost of implementing PLF technologies can be a barrier for small-scale farmers.
- **Training and Awareness:** Farmers need training and education to understand and effectively use PLF tools, which requires collaboration with local agricultural extension services and tech companies.

6. Role of Government and Private Sector

- **Government Initiatives:** The Indian government has initiated programs to promote agricultural innovation and sustainable farming practices, which can also benefit livestock farming. Programs like Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) for water management or National Animal Disease Control Program (NADCP) can be integrated with PLF technologies for better disease management.

- **Private Sector Innovation:** Private companies are developing and marketing PLF solutions tailored for India’s diverse agricultural environment. For example, startups are offering affordable health monitoring tools and mobile apps that can be used to monitor and manage livestock health and productivity.

7. Future Potential of Precision Livestock Farming in India

The rise of mobile phone use among rural farmers also presents an opportunity for greater adoption of PLF through accessible apps and platforms

- **Growth of Dairy and Meat Sector:** India's livestock sector grows to dairy and meet products the demands of a growing population, PLF could become a key component of enhancing food security and boosting productivity while ensuring animal welfare.
- **Improved Livestock Traceability:** The traceability of livestock products can be improved, ensuring food safety and quality. This will help increase the trust of consumers and open doors to international markets for Indian products.
- **Integration with Agri-Tech:** As the agricultural ecosystem in India becomes more digitized, integrating PLF with broader agri-tech systems can lead to a holistic approach to farm management, improving overall efficiency and sustainability.

Scope of PLF

The scope of precision farming in India is vast and has the potential to revolutionize the agricultural sector. Precision farming refers to the use of modern technologies such as GPS, sensors, drones, IoT, data analytics, and artificial intelligence to optimize agricultural practices. In India, where agriculture is a major part of the economy, precision farming can lead to improved productivity, resource management, and sustainability.

1. Increased Crop Productivity

- **Data-Driven Decisions:** Precision farming enables farmers to make more informed decisions based on real-time data, such as soil moisture levels, weather forecasts, and crop health. This leads to better yields and more efficient use of resources.
- **Precision Irrigation:** By using sensors and weather data, farmers can apply water more efficiently, ensuring that crops get the right amount of water, reducing water wastage, and increasing crop productivity. In water-scarce regions like Rajasthan and Gujarat, precision irrigation can be especially impactful.

2. Resource Efficiency

- **Optimized Input Use:** Precision farming helps in the accurate application of fertilizers, pesticides, and herbicides. By applying these inputs only when and where they are needed, farmers can reduce costs and environmental impact.
- **Soil Health Monitoring:** Sensors can analyze soil conditions, helping farmers maintain soil health and prevent over-fertilization, which can degrade the land over time.

3. Sustainability and Environmental Impact

- **Reduced Chemical Use:** By using precision application methods, the need for excessive chemical fertilizers and pesticides is minimized, leading to lower environmental pollution.
- **Carbon Footprint Reduction:** Precision farming can contribute to sustainable farming practices by reducing overuse of water and chemicals, which can significantly reduce the carbon footprint of farming.

4. Cost Savings

- **Efficient Resource Allocation:** By using resources like water, fertilizers, and labor more efficiently, precision farming can help reduce overall costs for farmers.
- **Automation and Labor Reduction:** Technologies like automated tractors, drones for crop monitoring, and harvesters can reduce the need for manual labor, leading to cost savings, especially in labor-scarce areas.

5. Better Pest and Disease Management

- **Early Detection:** Remote sensing tools, drones, and AI can help detect pest infestations or disease outbreaks early, allowing farmers to take preventive actions before the problem spreads. This can help reduce crop losses and the need for widespread pesticide use.

- **Precision Spraying:** By using drones or automated sprayers, pesticides and herbicides can be applied precisely to affected areas, minimizing their use and reducing potential harm to the environment and non-target organisms.

6. Improved Decision Making Through Data

- **Weather Forecasting and Analysis:** Precision farming can integrate weather forecasts with data analytics to help farmers plan their activities, such as planting, irrigation, and harvesting, based on optimal conditions.
- **Yield Prediction:** By combining historical data, satellite imagery, and sensor inputs, precision farming can help predict crop yields more accurately, allowing farmers to plan better and optimize supply chains.

7. Market Linkages and Profitability

- **Supply Chain Optimization:** Precision farming can lead to better planning and forecasting, which helps optimize supply chains. This is especially important for reducing post-harvest losses, a major challenge in India.
- **Premium Produce:** With better quality produce and higher yields, farmers can potentially command higher prices in the market, improving their income and profitability.

8. Challenges and Barriers in India

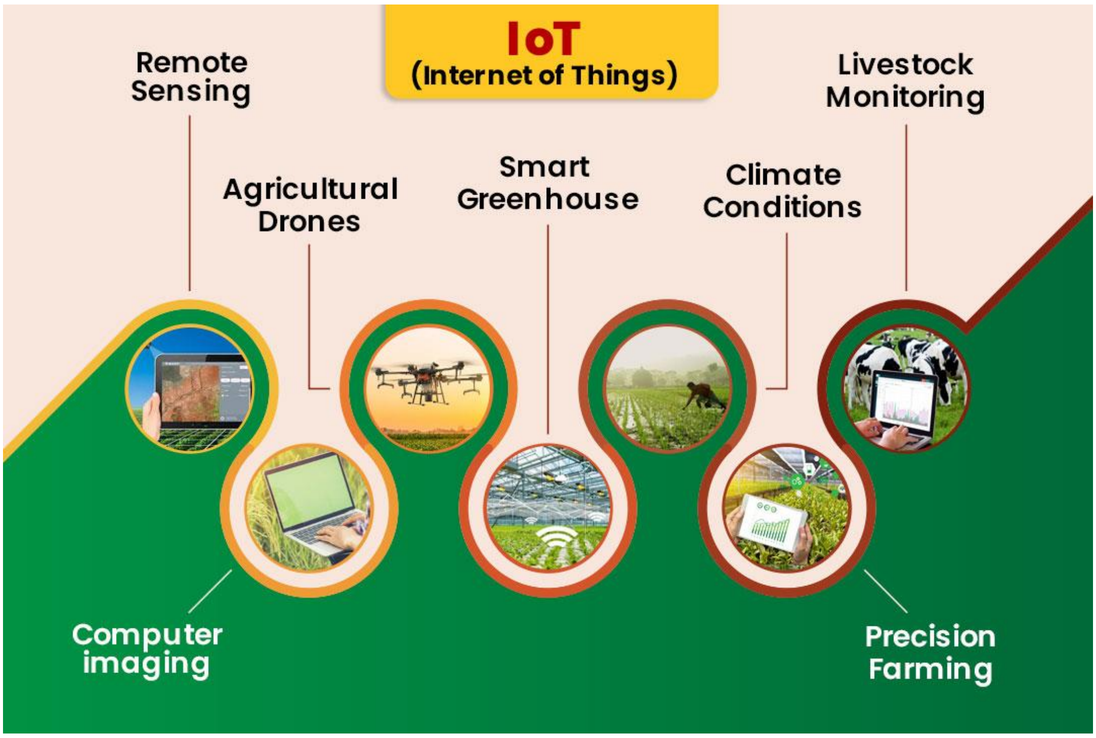
- **High Initial Investment:** The cost of adopting precision farming technology can be high, which may discourage small-scale farmers from using these tools.
- **Lack of Infrastructure**: Many rural areas in India still suffer from poor internet connectivity and lack of electricity, which limits the effectiveness of technologies that depend on constant data collection and transmission.
- **Education and Awareness:** A lack of awareness and technical knowledge among farmers about how to use these technologies is a major barrier. Training and support from government agencies and private companies are critical to overcoming this challenge.
- **Fragmented Landholdings:** Many Indian farmers have small, fragmented plots of land, which can make the implementation of large-scale precision farming technologies less feasible. However, solutions tailored to smallholder farmers, such as mobile apps or community-based models, are emerging.

9. Government Support

- The Indian government has recognized the potential of precision farming and is actively promoting it through various schemes and initiatives. Programs like National Mission on Sustainable Agriculture and Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) aim to promote efficient irrigation and sustainable agricultural practices.
- The government is also partnering with private sector companies to introduce affordable technologies, especially for small and medium-sized farmers.

10. Emerging Technologies

- **Drones and UAVs:** These are used for crop monitoring, pest management, and precision spraying.
- **Artificial Intelligence (AI) and Machine Learning (ML):** These technologies help analyze vast amounts of data to offer predictions and recommendations for crop management, optimizing everything from planting times to harvest predictions.
- **Internet of Things (IoT):** IoT devices can monitor field conditions like temperature, humidity, soil moisture, and nutrient levels, allowing for continuous monitoring and data-driven farming decisions.
- **Block chain:** Block chain can help create transparent supply chains, ensuring that farmers can track the provenance of their produce and establish direct links with consumers.



References:

1. Savage S. The Connected Cow: Optimizing Dairy Cow Health and Productivity with Technology. Forbes. Jun 9, 2022. Available online: https://www.forbes.com/sites/stevensavage/2022/06/09/the-connected-cow-optimizing-dairy-cow-health-and-productivity-with-technology/?sh=2d36a0b2656e.
2. Deutschlandfunk Big Brother im Kuhstall—Digitalisierung in der Landwirtschaft mit Nebenwirkungen. Available online: https://www.deutschlandfunk.de/big-brother-im-kuhstall-digitalisierung-in-der.697.de.html?dram:article_id=433167.
3. Cambridge Dictionary Definition: “Sensor”. Available online: https://dictionary.cambridge.org/us/dictionary/english/sensor
4. Galon, N. The use of pedometry for estrus detection in dairy cows in Israel. J. Reprod. Dev. 2010, 56, S48–S52. 22. Kempf, A. Visuelle und computergestützte
5. Brunsterkennung. Ph.D. Dissertation, Stiftung Tierärztliche Hochschule, Hannover, Germany, 2016.
6. Adenuga, A.H.; Jack, C.; Olagunju, K.O.; Ashfield, A. Economic Viability of Adoption of Automated Oestrus Detection Technologies on Dairy Farms: A Review. Animals 2020, 10, 1241.
7. Cerri, R.L.A.; Burnett, T.A.; Madureira, A.M.L.; Silper, B.F.; Denis-Robichaud, J.; LeBlanc, S.; Cooke, R.F.; Vasconcelos, J.L.M. Symposium review: Linking activity-sensor data and physiology to improve dairy cow fertility. J. Dairy Sci. 2021, 104, 1220–1231.

RECENT APPROACHES FOR PHYTOREMEDIATION OF WATER POLLUTANTS

Anjalika Roy*[1] and Anirban Paul[2]

[1]Department of Botany (UGC DRS(SAP-II) DST-FIST), Visva-Bharati, Santiniketan 731235

[2]Suri Vidyasagar College, Suri, Birbhum, West Bengal 731101

*Corresponding author E-mail: anjalika.roy@visva-bharati.ac.in

Abstract:

The food shortage and malnutrition has become a serious global problem of world in current century because of overpopulation, lack of agricultural lands, mechanized farming, havoc of plant diseases in developing and underdeveloped countries. The estimated annual loss of crops worldwide as a result of disease is 25,000 million dollars. Pesticides are widely used in sustainable agriculture by preventing the attack of pathogens thus reducing yield losses. Pesticides are major concern of environmental hazards because residues of its enter in food chain through soil and water. The farmers applied pesticides for control of disease without have a thought on harmful effects on plants, animal and human beings and the residues of applied fungicides can increase manifold the environmental pollution. Unjustified use increases higher relative risk in sprayers due to lack of protective measures among farmers as they are directly exposed. The large efforts are required to mitigate agricultural pesticides associated harm for water by controlling pesticide movement after their application. Some biological remediation processes are very interesting to reduce the toxicity of pesticides which awaking us due to indirect harmful effect on organism also.

Keywords: Environment, Pesticides, Pests, Phytoremediation, Water

Introduction:

Deccan Herald (Newspaper of Indian state of Karnataka) published ‘Danger looms as pesticides reign supreme on India’s farms’ by Chiranjeevi Kulkarni on 19 November 2023 describing that EU sounded an alarm for import of turmeric from India due to presence of residues of banned pesticide Chloropyrifos having scientific evidences of threat to health of children (https://www.deccanherald.com). Air, water and soil have widely detected traces of pesticides in the environment. The DDT and HCH have been used in India in both domestic and agricultural sector despite their ban. A majority of population earned through agriculture in whole world. Pesticidesis a inseparable part of agriculture because without it damage to fruits 78%, Vegetables 54% and cereals 32% can reach. The pesticides have ability to improve crop yields and restrict dietary threats to human health such as mycotoxins, there remains a longstanding concern over the impact of the sheer quantity of pesticide usage on the environment. An average of 2 million tons of pesticides was used each year globally to confront weeds, insects and pests (De *et al.,* 2014). However, according to the FAO, 2021 report, 4.12 Mt of pesticides were used globally for agricultural activities in 2018, which fell to 2.7 Mt in 2020 (FAO, 2022). The global pesticide consumption in 2019 was approximately 4.19 million metric tons, where China was by far the largest pesticide-consuming country (1.76 million metric tons), followed by the United States (408 thousand tons), Brazil (377 thousand tons), and Argentina (204 thousand tons) (Fernández, 2021). The application of pesticides give rise to a range of benefits, including increased the quality and quantity of food and reduced insect-borne disease but raised the issues on the potential detrimental effects to the environment, including water resources. India is one of the major contributors of POP distribution (Yadav *et al.,* 2015). The associated are mainly due to the the persistent and ubiquitous characteristics of pesticides that have several environmental impacts ultimately loss of biodiversity. The dissolution of pesticides depends on the nature of the compound, pesticide application techniques and climatic factors. The pesticides that are not readily degrading will either get accumulated in soils or mobilized from one site to another in the form of degraded products, with unknown toxicity to human health (Sharma *et al.,* 2019). Chemical pesticides in the hydrogeological system are a global concern as they pose a severe threat to humans and other organisms. In agriculture, around 4.12 million tons of pesticides were used globally in 2018, which is 50% more than in the 1990s (Rajan *et al.,* 2023). Plenty of research work has been reported regarding pesticidal effect on non-target flora and fauna. Pesticide is a common term that characterizes several classes of insecticides, herbicides, fungicides, rodenticides, wood preservatives, garden chemicals and household disinfectants that are used to either to kill or protect from pests (Eldridge B.F. 2008). These pesticides differ in their physical, chemical and identical properties from one class to other. Presently, there are three most popular method of pesticides classification suggested by Drum (Drum C. 1980).

Classification of Pesticides

1. Mode of Entry:

The way of pesticides come in contact with or enter the target further classified as

i. **Systemic pesticides** which absorbed by plants or animals and transfer to untreated tissues. Systemic herbicide moves through the plant and can reach to untreated areas of leaves, stems or roots. They are capable in killing of weeds with partial spray coverage. They can effectively penetrate in the plant tissues and move through plant vascular system to kill specific pests.

ii. **Non-systemic (Contact) pesticides** acts on target pests when they come in contact. The pesticide enters the body of pests via their epidermis upon contact and causes death by poisoning.

2. Function of Pesticides

The most common type classification based on target pest-based activity thus named cide (actually word cide means kill in latin) according their action against the organism.

Table 1: Name of pesticide based on killing of target pests /organisms

Sl No.	Type of pests	Target pests/organisms
1.	Avicides	Birds
2.	Acricides	Mites that feed on plants as well as animals
3.	Bactericides	Bacteria
4.	Fungicides	Fungus like blight, mildew, mold, rust
5.	Herbicides	Weeds and other plant
6.	Insecticides	Insects other arthopods
7.	Larvacides	Minimize growth of larvae
8.	Mollusicides	Mollusks or snail
9.	Nematicides	Nematodes
10.	Piscicides	Fishes
11.	Rodenticides	Rodents or mice
12.	Termicides	Termites

3. Chemical Composition of Pesticides

The most common and useful method of classifying pesticide is based on their chemical composition and nature of active ingredients. It is such kind of classification that gives the clue about the efficacy, physical and chemical properties of the respective pesticides. The information on chemical and physical characteristics of pesticides is very useful in determining the mode of application, precautions that need to be taken during application and the application rates. Based on chemical composition, pesticides are classified into four main groups namely; organochlorines, organophosphorus, carbamates and pyrethrin and pyrethroids (Buchel K.H. 1983).

Depending on the health risk associated with pesticides and toxic behavior of pesticides. The World Health Organization (WHO) classified them into four categories (Eddleston M. 2002).

Sl No.	WHO class	Toxicity level	Pesticide label
1.	Class I a	Extremely hazardous	Red labelled
2.	Class I b	Highly hazardous	Yellow labelled
3.	Class II	Moderately hazardous	Blue labelled
4.	Class III	Slightly hazardous	Green labelled

Beneficial Effect of Pesticides

The production of pesticides started in India in 1952 with the establishment of a plant for the production of BHC near Calcutta, and India is now the second largest manufacturer of pesticides in Asia after China and ranks twelfth globally (Mathur, 1999). The crop-based application of pesticides incorporates all types of carbohydrate rich grains and protein rich cereals, pulses and oil seeds, vitamins and flavanoids rich and fruits and vegetables. The increasing consumption of crops such as fruits and vegetables which are present day assumed as neutraceuticals by consumers thus lead to increased demand for safe cultivation methods to accelerate the use of agrochemicals. The Indian Agrochemicals Market size is forecast to increase by USD 12.90 billion, at a CAGR of 10.17**%** between 2023 and 2028 by in-depth analysis of drivers, trends, and challenges of current market scenario as well as historical data examination from 2018-2022 (https://www.technavio.com/report/agrochemicals-market-industry-analysis).The primary benefits are the direct consequences of the pesticides' application like gain in yield and quality of crops, which ultimately generate more revenue. Use of synthetic insecticides is to kill leaf feeding caterpillars on the crop brings the primary benefit of higher yields resulted better quality of vegetables like cauliflower and cabbage etc. The secondary benefits are indirect gain of primary benefits in long run which may be the powerful justification of pesticide use. The higher yield of agricultural crops might generate additional revenue that could be uplift financial status of producers. Thus, they can afford better education and health benefits for themselves and their family. Another beneficial aspect is growth of country's GDP. There are various secondary benefits identified, ranging from healthy and wealthy people to conserve biodiversity. Tremendous benefits have been derived from the use of pesticides in forestry, public health and the domestic sphere and, of course, in agriculture, a sector upon which the Indian economy is largely dependent (Aktar *et al.,* 2009). The mere 50 million tons of food production in 1948–49, had increased to 198 million tons by the end of 1996–97 from an estimated 169 million hectares of agricultural land by effective control on vector-borne diseases and weeds by use of pesticide. In medium land, rice even under puddle conditions during the critical period warranted an effective and economic weed control practice to prevent reduction in rice yield due to weeds that ranged from 28 to 48%, based on comparisons that included control (weedy) plots (Behera and Singh,1999). Thus, benefits of Pesticides can be categorized into:

i. improved production
ii. Protection from yield loss
iii. Vector control
iv. Quality control

How Pesticides Reach in Water?

Pesticides are often applied directly to soil as drenches and granules and increasingly in the form of seed coatings. Residues of Pesticide after their application in agricultural land or from manufacturing unit reach in water is a serious issue as they exert harmful effects on living beings. Pesticides can enter into water systems by several pathways like agriculture runoff, spillage, drifts, industrial effluents, washing of spray equipment, aerial sprays and transport from soils treated with pesticide (Srivastava *et al.,* 2022). The easiest way of reaching pesticide to soil by percolation to table soil and ground water as well as drainage and runoff to water source like pond, lake or river etc. Unscientific and careless handling of pesticides by farmers or labors pose threat to environment. The movement of pesticides from large regions from the watersheds or from agriculture land to water systems by runoffs, erosion or leaching during improper handling, storage and discharge. The spills of pesticides or direct movement of pesticides in groundwater is a point source kind of pollution (Srivastava *et al.,* 2022). Spraying is a way of applying pesticides in agricultural fields which ultimately pollute soil and water. After being applying on land, pesticides which are not taken up by crops or land would be retain in soil or degrade to some other form. Soluble pesticides would be passed away by water molecules particularly during rainfall and percolate downward in the layers of soil and then reach to groundwater or else, the insoluble one will be bound to the particles of soil and get collected in the top most layer of the soil. These accumulated particles have a high tendency to contaminate surface water, streams, lakes and rivers by erosion or runoff (Syafrudin *et al.,* 2021). The occurrence of pesticides in the water body is derived by the runoff from the agricultural field and industrial wastewater. Despite the soil matrix that serves as a storage compartment of pesticide due to the high affinity of agrochemicals with soil, surface water resources like streams, estuaries and lakes, as well as the groundwater are susceptible to pesticide contamination because of the close interconnection of soil with water bodies. The low concentration of pesticides built up in water can get magnified through the food chain and enter aquatic organisms that are hazardous for human consumption. Organophosphorus pesticides are still highly toxic to humans but their ability to decompose rapidly in the environment reduces their occurrence in groundwater. Carbamate pesticides are also being introduced to replace chlorinated hydrocarbons. The active ingredients of carbamate pesticides are not likely to be adsorbed to soil particles, therefore these compounds may have made their way into surface waters (Trautmann *et al.,* 2020). Soluble pesticides will be carried away by water molecules especially during precipitation events by percolating downward into the soil layers and eventually reaching the groundwater. Otherwise, those insoluble chemicals tightly bound to soil particles accumulate in the topsoil layer, which has a high possibility subjected to runoff and erosion to surface waters, contaminating lakes, stream and river with pesticides.

Current Status of Pesticides in Water

The occurrence of pesticides in specific environmental compartments, such as in soils and streambed sediment, groundwater and surface water is a widespread issue (McKnight *et al.,* 2015) The distribution of wide range of pesticides used by farmers, gardeners and labrours (past and present) in water streams and groundwater depends on the hydrological and drainage system. The results of a comprehensive set of studies done by the U.S. Geological Survey (USGS) on major river basins across the country in the early to mid- 90s yielded startling results. More than 90 percent of water and fish samples from all streams contained one, or more often, several pesticides (Kole *et al.,* 2001). The herbicides 2,4-D, diuron, and prometon, and the insecticides chlorpyrifos and diazinon, all commonly used by urban homeowners and school districts, were among the 21 pesticides detected most often in surface and ground water across the nation (U.S. Geological Survey, 1998). Based on the U.S. Geological Survey (USGS) carried out in mid 199s, 90% of major rivers' water and fish samples close to agricultural and urban land contained pesticides (Kole *et al.,* 2001). High concentrations of pesticides above their threshold limits were detected at 13–30% of all surface and ground waters in Europe between 2013 and 2019. Pesticides with high persistence and a low tendency to adsorb to soils and sediments are detected easily (Suk *et al.,* 2002). A higher concentration of pesticides is generally observed in shallower groundwater than deeper (Close *et al.,* 2020). The improper management of pesticides resulted their interaction with freshwater used for irrigation and be a part of hydrological systems via surface loss and leaching from soil. River Yamuna, one of the major rivers of India with a total stretch of 345,843 km^2, passes through Haryana state along its eastern border enriched with high-density population growth and fast industrialization, Yamuna River has concentration of

Hexachlorocyclohexane and DDT at different sites of the river ranged between 12.76–593.49 ng/L and 66.17–722.94 ng/L, respectively (Kaushik *et al.,* 2008). In the water of Gomti River, pesticide residues ranged between 2.16 to 567.49 ng/L and in the bed sediments it ranged from 0.92 to 813.59 ng/L. The results revealed that bed-sediments of the Gomti River are contaminated with lindane, endrin, heptachlor epoxides and DDT and may contribute to sediment toxicity in the freshwater ecosystem of the river (Malik *et al.*, 2009).

Strategies Regarding Pesticide Control

The nature of pesticides are organic persistent compounds therefore they can degrade by photochemical, microbial, and chemical reactions. The pesticides degrade via mineralization process and break down into carbon dioxide in microbial decomposition whereas through photolysis and break down by UV light in photo-chemical degradation. Pesticides degradation in chemical decomposition done by redox reactions. Residues of some persistent pesticides may remain longer in target crops and find their way into humans through the food chain (Bhushan *et al.,* 2013). The residues of these pesticides should not exceed extreme limits as this may cause a threat to human health. Hence, maximum residue limits (MRLs), acceptable daily intake (ADI) and theoretical maximum daily intake (TMDI) have been proposed and developed to monitor residues of these pesticides in the food chain (Bhushan *et al.,* 2013). In Indian drinking water, the residual limit for lindane is roughly 20 times higher than in the Czech Republic; heptachlor is more than 30 times than in the EU; and 200 times more aldrin and endosulfan is permitted than in the Czech Republic (IPEN, 2006). These figures indicate the alarming variation of MRLs for pesticides in India. It appears that the levels are being wrongly formulated, while their implementation status is much worse (Yadav *et al.,* 2015). Some mathematical models are designed which are simplified representation used to estimate the changes in water quality at different locations to an acceptable level due to presence of pollutants. These can be applied at different scales to support planners and policymakers in designing cost-effective measures for addressing water pollution in agriculture (Abraha *et al.*, 2021). An acceptable pesticide pollution control is biodegradation process which is beneficial for a long-term in environment. Some preventive measures can mitigate the pesticide pollution. Pesticide loss can be reduced by proper storage of pesticides, preventing accidents, assuring proper mixing, handling and disposal and by well-maintained construction (Srivastava *et al.,* 2022). Bhopal gas leak tragedy is one of the disastrous examples of careless handling and storage. Reducing runoff of pesticides after spraying can lessen the water contamination. Grass waterways, filter strips, buffer zones etc, may reduce the run-off velocity and then help in increasing the infiltration of water, adsorption on soil or on vegetation. This can lessen the quantity of pesticide loss from a land (Srivastava *et al.*, 2022).

Amelioration of Water from Pesticides

As most of the pesticides are organic persistent compounds, they go through degradation by photochemical, microbial, and chemical reactions. In microbial decomposition, the pesticides degrade via mineralization process and break down into carbon dioxide and some other chemical form. In photo-chemical degradation, pesticides degrade through photolysis and break down by UV light. In chemical decomposition, the pesticides degrade by redox reactions like advanced oxidation processes (AOPs) where hydroxyl radicals degrade pesticides to nontoxic waste water (Zhu *et al.,* 2016). Titania is the most commonly used photocatalyst that can generate electron-hole pair when irradiated by ultraviolet light to initiate reactions, leading to the formation of hydroxyl groups. AOPs have been successfully employed for decomposition of pesticides (Marican & Duran-Lara, 2018). Nearly complete mineralization of pesticides in water can be achieved using H_2O_2, ozone, and metallic oxide (Derbalah *et al.,* 2019). Microorganisms i.e. fungi and bacteria are effective in the degradation of pesticides in water. Jariyal *et al.* (2018) used three different microorganisms (*Brevibacterium frigoritolerans, Bacillus aerophilus* and *Pseudomonas fulva*) to remove organophosphate residues in water achieving biodegradation efficiencies over 97.5 percent (Jariyal *et al.*, 2018). Complete degradation of Carbaryl was reported using *Rhodopseudomonas sphaeroides* (Wu *et al.,* 2019). Recently, living plants have been used for the degradation of pesticides in water which is known as phytoremediation with 50% efficiency (Escoto, 2019).

A study was conducted to test the potential of calabash, sweet potato, pumpkin, simsim, and finger millet to phytoaccumulate dichlorodiphenyltrichloroethane (DDT) and its metabolites from NHC Morogoro- and PPO Tengeru-contaminated sites (Tindwa, 2024). Overall, calabash and sweet potato exhibited the highest (4.63 mg kg^{-1}) and second highest (3.45 mg kg^{-1}) DDT concentrations from the high residual DDT potted soil experiment.

1. Phytoremediation

Phytoremediation is a low-cost, environmentally friendly technology that utilises specific plants or plant-associated bacteria strains to remove pollutants from water resources, notably organic, inorganic chemicals, and heavy metals (Shalini *et al.,* 2016; Singh and Singh, 2017). Phytoremediation of organic pollutants involves four mechanisms: direct uptake and accumulation of contaminants and subsequent metabolism in plant tissues, transpiration of volatile organic hydrocarbons through the leaves, release of exudates that stimulate microbial activity and biochemical transformations around the root system, and enhancement of mineral content at the root-soil interface, which is attributed to mycorrhizal fungi and microbial concortia (Melania *et al.*, 2014).

Several types of phytoremediation techniques are developed, such as Phytovolatilization, Phytodegradation, Rhizodegradation, Phytostabilization, Phytofiltration, Phycoremediation, Phytoextraction; which are briefly discussed here.

2. Phytovolatilization:

This type of phytoremediation involves the use of plants to absorb pollutants from polluted media, convert them to volatile form, and then release them into the atmosphere. Phytovolatilization occurs when plants absorb water, organic and inorganic substances, allowing some contamination to flow through plant components to the leaves and, at low concentrations, volatilise into the atmosphere (Mueller et al,1999). Phytovolatilization radionuclides, such as Tritium(3H) from soil and the considerable uptake of selenium compounds consisting dimethyldiselenide and dimethylselenide by *Brassica* species are some examples of phytovolatilization. One disadvantage of mercury phytovolatilization is that it recycles through rain and leaves a residue in the ecosystem (Bañuelos *et al.*, 2000; Dushenkov, 2003).

3. Phyodegradation or phytotransformation:

It refers to two types of plant responses that are independent of rhizosphere microorganisms (Vishnoi and Srivastava, 2007). include phytoreduction, which is the reductive transformation of oxidised organic compounds by reducing plant enzymes, and phytooxidation, which is the oxidative transformation events catalysed by plant oxidising enzymes (Nzengung and Jeffers, 2001).

The primary phytodegradation pathways for organic pollution in plants include absorption, translocation, and metabolism (Dzantor *et al.,* 2002). The majority of polycyclic aromatic hydrocarbons (PAHs) taken in by plants are difficult to degrade (Reichenauer and Germida, 2008). Hexachloroethane (HCA), dichlorodiphenyltrichloroethane (DDT) (Nzengung and Jeffers, 2001), and carbon tetrachloride (Wang *et al.,* 2004) are among the most common organic compounds successfully decomposed by plant species. Inorganic substances such as sulphur oxides and ambient nitrogen oxides can be absorbed by plants for breakdown. Genetically engineered plant species have also been employed in phytodegradation (Doty *et al.,* 2000).

4. Rhizodegradation:

It is also known as phytostimulation, is the breakdown of organic compounds (fuels and solvents) into plant nutrients in the rhizosphere via microbial activity (fungi, yeast, bacteria, and other microorganisms) and is much slower than phytodegradation (Hutchinson *et al.,* 2003;

Ghosh and Singh, 2005; Ridzuan *et al.,* 2010). This approach is frequently used in soil treatment. In Germany, rhizoremediation has a more than 100-year history. Plant exudates, such as carboxylic, amino acids, and carbohydrates, have the ability to promote overall rhizosphere microbial activity and accelerate the rhizodegradation process (Dzantor, 2007). *Hibiscus cannabinus* for used lubricating oil (Abioye *et al.,* 2012), *Sorghum bicolour* L. for crude oil (Banks *et al.,* 2003), Broadleaf plantain plant (*Plantago major* L.) for Imidacloprid (insecticide) in water and soil (Romeh, 2009), and willow (*Salix babylonica*) for perchlorate in soil and water (Mwegoha *et al.,* 2007).

5. Phytostabilization:

This technology is used to reduce the bioavailability of contaminants in the environment and stabilise pollutants, rather than eliminating them (usually metallic elements) by plants (hydraulic control). (Padmavathiamma and Li. 2007). Enhancing proper soil modification by plants resulted in lower bioavailability of metallic elements, whereas plant cover reduced leaching and improved environmental protection.

6. Phytofiltration:

Phytofiltration or rhyzofiltration, is a green technology for eliminating contaminants caused by plant roots in aquatic media such as ground water, most wastewaters, and extracted groundwater. Terrestrial, aquatic, and wetland plants are excellent for phytofiltration, and manmade wetlands are the most effective way to remove metallic elements from wastewater (Cheng *et al.,* 2002). *Limnocharis flava* (L.), *Brassica juncea* (L.) Czern, *Pteris cretica* Mayii (Moonlight fern), and *Pteris vittata*, among others, are highly potent phytofiltration agents.

7. Phycoremediation:

It is the use of macro and micro algae to biotransform or remove pollutants from wastewater, as well as CO_2 from waste air (Mulbry *et al.,* 2008; Rawat *et al.,* 2011). Algae are appropriate plants for the decontamination of metallic elements, xenobiotics, and nutrients in various wastewaters, as well as the consumption of carbon dioxide from exhausts (Olguin, 2003). Micro algae are a plant capable of treating several types of wastewaters, including industrial, residential, and solid wastes, both aerobically and anaerobically (Safonova *et al.,* 2004).

The oldest scientific research on this technology dates back half a century (Oswald and Gotaas, 1957). In a pilot investigation on chrome sludge, phycoremediation with Desmococcus olivaceus was found to effectively reduce nitrate, phosphate, ammonia, TDS, TSS, and chrome levels. Freshwater blue green algae were successfully employed to clean dairy manure effluent (Mulbry *et al.,* 2008). Sewage water treated with various algae including Chlorella vulgaris could eliminate practically all contaminants, and following the treatment procedure.

8. Phytoextraction:

Phytoextraction or phytoaccumulation (Khan *et al.,* 2000) is a viable green approach for extracting metallic elements from aquatic environments (Wang *et al.,* 2008). This type of remediation is utilised to accumulate zinc in duckwood (*Lemna gibba*) (Khellaf and Zerdaoui, 2009), cadmium in water spinach (*Ipomoea aquatic*) (Wang *et al.,* 2008), and chromium in small pondweed (*Potamogeton pusillus*) in the presence of Cu2+ (Monferrán *et al.,* 2012). A recent study found that *Ceratophyllum demersum* and *Myriophyllum spicatum* accumulate Pb and are eventually used as phytoremediators and bioindicators of Pb. (El Khatib *et al.,* 2014) Water hyacinth (*Eichhornia crassipes*) is utilised to remove heavy metals from coastal water (Agunbiade *et al.,* 2009), crude oil from artificial wastewater supplemented with urea fertiliser (Ndimele and Ndimele 2013), and palm oil mill effluent treatment (Christwardana and Soetrisnanto, 2013). In addition, heavy metals from industrial effluent have been recovered by vetiver (*Chrysopogan zizanioides*) (Roongtanakiat, 2009).

Aquatic plants have a high potential for usage as on-site biosinks and biofilters for aquatic contaminants because of their abundance and limited mobility (Gupta *et al.,* 2012). They have been effectively employed to sequester specific heavy metals and nutrients via their root systems and absorption via their plant bodies (Olette *et al.,* 2008). A high removal rate of pesticides takes place when pesticide mobility is proportionate to surface adsorption on a region of the plant. Chemical and physical features of pesticide compounds, as well as the interaction of environmental conditions, all play an important influence in aquatic plant eradication efficiency (Dosnon-Olette *et al.,* 2010).

Aquatic plants such as Eichhornia crassipes, Lemna minor, and Elodea canadensis have been utilised in water treatment due to their photosynthetic activity, plant growth rate, quick harvesting, and high pollutant absorption. Pesticide absorption, volatilisation, and translocation rates vary, resulting in varying elimination rates in *Eichhornia crassipes, Lemna minor,* and *Elodea canadensis* (Chander *et al.,* 2018).

Conclusion:

Application of the treatment processes for a very large amount of agriculture wastewater needs more research to optimize the process for an effective, feasible, and environmentally friendly treatment. Several experiments have been undertaken to remove heavy metals from diverse water sources. There has been limited research on pesticide removal from water sources utilising aquatic plants, as well as details on the four phytoremediation methods. More research is needed to remove pesticides from water bodies using aquatic plants. The widespread use of pesticides by 2050 will harm human health and the ecosystem (Chander *et al.,* 2018).

References:

1. Abioye, O., Agamuthu, P. and Aziz, A. (2012). Phytotreatment of soil contaminated with used lubricating oil using Hibiscus cannabinus. Biodegradation, 23(2), 277-286.
2. Abraha, M., Chen, J., Hamilton, S. K., Sciusco, P., Lei, C., Shirkey, G., Yuan, J. and Robertson, G. P. (2021). Albedo-induced global warming impact of Conservation Reserve Program grasslands converted to annual and perennial bioenergy crops. Environ. Res. Lett. 16, 084059.
3. Agunbiade, F. O., Olu-Owolabi, B. I. and Adebowale, K. O. (2009). Phytoremediation potential of *Eichornia crassipes* in metal-contaminated coastal water. Bioresource Technology, 100(19), 4521-4526.
4. Aktar, W., Sengupta, D. and Chowdhury, A. (2009). Impact of pesticides use in agriculture: Their benefits and hazards. Interdiscip. Toxicol., 2, 1–12.
5. Banks, M., Kulakow, P., Schwab, A., Chen, Z. and Rathbone, K. (2003). Degradation of crude oil in the rhizosphere of Sorghum bicolor. International Journal of Phytoremediation, 5(3), 225-234.
6. Bañuelos, G., Zambrzuski, S. and Mackey, B. (2000). Phytoextraction of selenium from soils irrigated with selenium-laden effluent. Plant and Soil, 224(2), 251-258.
7. Behera, B. and Singh, S. G. (1999). Studies on Weed Management in Monsoon Season Crop of Tomato. Indian J Weed Sci. 31(1–2), 67.
8. Bhushan, C., Bhardwaj, A. and Misra, S. S. (2013). State of Pesticide Regulations in India, Centre for Science and Environment; New Delhi.
9. Buchel, K. H. (Ed.). (1983). Chemistry of pesticides (pp. xii+-518).
10. Chander, P. D., Fai, C. M. and Kin, C. M. (2018). Removal of Pesticides Using Aquatic Plants in Water Resources: A Review. IOP Conf. Series: Earth and Environmental Science, 164.
11. Cheng, S., Grosse, W., Karrenbrock, F. and Thoennessen, M. (2002). Efficiency of constructed wetlands in decontamination of water polluted by heavy metals. Ecological Engineering, 18(3), 317-325.
12. Chiranjeevi Kulkarni. Retrieved November 19, 2023, from https://www.deccanherald.com
13. Christwardana, M. and Soetrisnanto, D. (2013). Phytoremediations of Palm Oil Mill Effluent (POME) by Using Aquatic Plants and Microalgae for Biomass Production. Journal of Environmental Science & Technology, 6(2).

14. Close, M. E., Humphries, B. and Northcott, G. (2020). Outcomes of the first combined national survey of pesticides and emerging organic contaminants (EOCs) in groundwater in New Zealand. Sci. Total Environ., 754, 142005.
15. De, A., Bose, R., Kumar, A., and Mozumdar, S. (2014). Targeted Delivery of Pesticides Using Biodegradable Polymeric Nanoparticles. New Delhi: Springer.
16. Derbalah, A., Sunday, M., Chidya, R., Jadoon, W. and Sakugawa, H. (2019). Kinetics of photocatalytic removal of imidacloprid from water by advanced oxidation processes with respect to nanotechnology. J. Water Health, 17, 254–265.
17. Dosnon-Olette, R., Couderchet, M., El Arfaoui, A., Sayen, S. and Eullaffroy, P. (2010). Influence of initial pesticide concentrations and plant population density on dimethomorph toxicity and removal by two duckweed species. Science of The Total Environment, 408(10), 2254-2259.
18. Doty, S. L., Shang, T.Q., Wilson, A. M., Tangen, J., Westergreen, A. D., Newman, L. A., Strand, S. E. and Gordon, M. P. (2000). Enhanced metabolism of halogenated hydrocarbons in transgenic plants containing mammalian cytochrome P450 2E1. Proceedings of the National Academy of Sciences, 97(12), 6287-6291.
19. Drum, C. (1980). "Soil chemistry of pesticides." *USA: PPG Industries, Inn*.
20. Dushenkov, S. (2003). Trends in phytoremediation of radionuclides. Plant and Soil, 249(1), 167-175.
21. Dzantor, E. K. (2007). Phytoremediation: the state of rhizosphere ‘e gi eeri g’for acce erated rhizodegradation of xenobiotic contaminants. Journal of Chemical Technology and Biotechnology, 82(3), 228-232.
22. Dzantor, E. K., Woolston, J. and Momen, B. (2002). PCB dissipation and microbial community analysis in rhizosphere soil under substrate amendment conditions. International Journal of Phytoremediation, 4(4), 283-295.
23. Eddleston, M., Karalliedde, L., Buckley, N., Fernando, R., Hutchinson, G., Isbister, G. *et al.* (2002). Pesticide poisoning in the developing world—a minimum pesticides list. The Lancet, 360(9340), 1163-1167.
24. Eldridge, B. F. (2008). Pesticide application and safety training for applicators of public health pesticides. California Department of Public Health, Vector-Borne Disease Section, 1616.
25. El-Khatib, A., Hegazy, A., Abo-El-Kassem, A. M. (2014). Bioaccumulation Potential and Physiological Responses of Aquatic Macrophytes to Pb Pollution. International Journal of Phytoremediation, 16(1), 29-45.

26. Escoto, D.F., Gayer, M. C., Bianchini, M. C., da Cruz Pereira, G., Roehrs, R. and Denardin, E. (2019). Use of *Pistia stratiotes* for phytoremediation of water resources contaminated by clomazone. Chemosphere, 227, 299–304.
27. FAO. 2022. Pesticides use, pesticides trade and pesticides indicators—Global, regional and country trends, 1990–2020. FAOSTAT Analytical Briefs, no. 46. Rome. doi.10.4060/cc0918en
28. Fernández, L. (2021). Global pesticide use by country. Statista. Retrieved from https://www.statista.com/statistics/1263069/global-pesticide-use-by-country/
29. Ghosh, M. and Singh, S. (2005). A review on phytoremediation of heavy metals and utilization of it's by products. Asian J Energy Environ, 6(4), 18.
30. Gupta, P., Roy, S. and Mahindrakar, A. B. (2012). Treatment of Water Using Water Hyacinth, Water Lettuce and Vetiver Grass - A Review. Resources and Environment, 2(5), 202-215.
31. Hutchinson, S., Schwab, A. and Banks, M. (2003). Biodegradation of petroleum hydrocarbons in the rhizosphere. Phytoremediation: transformation and control of contaminants.
32. India Agrochemicals Market by Application, Product and Type - Forecast and Analyst 2024-2028, Retrieved February, 2024 from https://www.technavio.com/report/agrochemicals-market-industry-analysis
33. Jariyal, M., Jindal, V., Mandal, K., Gupta, V. K. and Singh, B. (2018). Bioremediation of organophosphorus pesticide phorate in soil by microbial consortia. Ecotoxicol. Environ. Saf., 159, 310–316.
34. Kaushik, C. P., Sharma, H. R., Jain, S., Dawra, J . and Kaushik, A. (2008). Pesticide residues in river Yamuna and its canals in Haryana and Delhi, India, Environmental Monitoring and Assessment , 144(1-3), 329-40. doi: 10.1007/s10661-007-9996-4.
35. Khan, A., Kuek, C., Chaudhry, T., Khoo, C. and Hayes, W. (2000). Role of plants, mycorrhizae and phytochelators in heavy metal contaminated land remediation. Chemosphere, 41(1), 197- 207.
36. Khellaf, N. and Zerdaoui, M. (2009). Phytoaccumulation of zinc by the aquatic plant, *Lemna gibba* L. Bioresource technology, 100 (23), 6137-6140.
37. Kole, R. K., Banerjee, H. and Bhattacharyya, A. (2001). Monitoring of market fish samples for Endosulfan and Hexachlorocyclohexane residues in and around Calcutta. Bull. Envirron. Contam. Toxicol., 67, 554–559.

38. Malik, A., Ojha, P. and Singh, K. P. (2009). Levels and distribution of persistent organochlorine pesticide residues in water and sediments of Gomti River (India)—A tributary of the Ganges River. Environ. Monit. Assess., 148, 421–435.
39. Marican, A. and Durán-Lara, E. (2018). A review on pesticide removal through different processes. Environ. Sci. Pollut. Res. Int., 25, 2051–2064.
40. Mathur, S. C. (1999). Future of Indian pesticides industry in next millennium. Pesticide Information, 24 (4), 9–23.
41. McKnight, U.S., Rasmussen, J. J., Kronvang, B., Binning, P. J. and Bjerg, P. L. (2015). Sources, occurrence and predicted aquatic impact of legacy and contemporary pesticides in streams. Environ. Pollut., 200, 64–76.
42. Melania, B., Valer, M. and Simona, E. (2014). Study on the mechanisms of phytoremediation. Journal of Environmental Research and Protection, 11(3), 67-73.
43. Monferrán, M. V., Pignata, M. L., Wunderlin, D. A. (2012). Enhanced phytoextraction of chromium by the aquatic macrophyte Potamogeton pusillus in presence of copper. Environmental Pollution, 161, 15-22.
44. Mueller, B., Rock, S., Gowswami, D. and Ensley, D. (1999). Phytoremediation decision tree. Prepared by– Interstate Technology and Regulatory Cooperation Work Group, 1-36.
45. Mulbry, W., Kondrad, S., Pizarro, C. and Kebede-Westhead, E. (2008). Treatment of dairy manure effluent using freshwater algae: algal productivity and recovery of manure nutrients using pilot-scale algal turf scrubbers. Bioresource technology, 99 (17), 8137-8142.
46. Mwegoha, W., Mbuya, O. S., Jain A., Ugochukwu, N. H. and Abazinge, M. D. (2007). Use of chicken manure extract for biostimulation and enhancement of perchlorate rhizodegradation in soil and water media. Bioremediation journal, 11(2), 61-70.
47. Ndimele, P. and Ndimele, C. (2013). Comparative effects of biostimulation and phytoremediation on crude oil degradation and absorption by water hyacinth (Eichhornia crassipes [Mart.] Solms). International Journal of Environmental Studies, 70(2), 241-258.
48. Nzengung, V. A. and Jeffers, P. (2001). Sequestration, phytoreduction, and phytooxidation of halogenated organic chemicals by aquatic and terrestrial plants. International Journal of Phytoremediation, 3 (1), 13-40.
49. Olette, R., Couderchet, M., Biagianti, S. and Eullaffroy, P. (2008). Toxicity and removal of pesticides by selected aquatic plants. Chemosphere, 70 (8), 1414-1421.
50. Olguin, E. J. (2003). Phycoremediation: key issues for cost-effective nutrient removal processes. Biotechnology Advances, 22 (1), 81-91.

51. Oswald, W. J., Gotaas, H. B. (1957). Photosynthesis in sewage treatment. Trans. Am. Soc. Civ. Eng, 122, 73-105.
52. Padmavathiamma, P. K. and Li, L. Y. (2007). Phytoremediation technology: hyperaccumulation metals in plants. Water, Air, and Soil Pollution, 184 (1-4), 105-126.
53. Rajan, S., Parween, M. and · Raju, N. J. (2023). Pesticides in the hydrogeo-environment: a review of contaminant prevalence, source and mobilisation in India, Environ Geochem Health, 45, 5481–5513.
54. Rawat, I., Ranjith, K. R., Mutanda, T. and Bux, F. (2011). Dual role of microalgae: phycoremediation of domestic wastewater and biomass production for sustainable biofuels production. Applied Energy, 88 (10), 3411-3424.
55. Reichenauer, T. G. and Germida, J. J. (2008). Phytoremediation of organic contaminants in soil and groundwater. ChemSusChem, 1(8-9), 708-717.
56. Ridzuan, M. B. B., Yeoh, D. E. C. and Hung, Y. T. (2010). Heavy Metal Removal by Crops from Land Application of Sludge. Environmental Bioengineering, Springer, 211-232.
57. Romeh, A. (2009). Phytoremediation of Water and Soil Contaminated with Imidacloprid Pesticide by Plantago Major, L. International Journal of Phytoremediation, 12(2), 188-199.
58. Roongtanakiat, N. (2009). Vetiver phytoremediation for heavy metal decontamination. PRVN Technical Bulletins (2009/1).
59. Safonova, E., Kvitko, K., Iankevitch, M., Surgko, L., Afti, I. and Reisser, W. (2004). Biotreatment of Industrial Wastewater by Selected Algal-Bacterial Consortia. Engineering in life sciences, 4 (4): 347-353.
60. Shalini, T., Radhika, D. and Ankita, P. (2016). Removal Of Pesticide Carbofuran Using Wetland Plants. International Journal of Advance Biological Research, 6(4), 482-485.
61. Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G. P. S., Handa, N., Kohli, S. K., Yadav, P., Bali, A. S. and Parihar, R. D. (2019). Worldwide pesticide usage and its impacts on ecosystem. SN Appl. Sci., 10, 1446.
62. Singh, T. and Singh, D. (2017). Phytoremediation of organochlorine pesticides: Concept, method, and recent developments. International Journal of Phytoremediation, 19(9), 834-843.
63. Srivastava, M., Malin, B., Srivastava, A., Yadav, A. and Banger, A. (2022). Role of Pesticides in Water Pollution, Journal of Agricultural Science and Food Research, 13 (03), 1-8. doi: 10.35248/2593-9173.22.13.495

64. Suk, W. A., Olden, K. and Yang, R. S. H. (2002). Chemical mixtures research: Significance and future perspectives. Environ. Health Perspect., 110, 891–892.
65. Syafrudin, M., Kristanti, R. A., Yuniarto, A., Hadibarata, T., Rhee, J., Al- Onazi, W. A., *et al.* (2021). Pesticides in drinking water: A review. Int J Environ Res Public Health, 18(2), 468.
66. Tindwa, H. J. and Singh, B. R. (2024). Potential of Calabash (*Lagenaria siceraria*) and Sweet Potato (*Solanum tuberosum*) for the Remediation of Dichlorodiphenyltrichloroethane-Contaminated Soils in Tanzania, Soil Systems, 8(1): 1-14. doi: 10.3390/soilsystems8010001
67. Trautmann, N. M., Porter, K. S. and Wagenet, R. H. (23 October, 2020). Pesticides: Health Effects in Drinking Water. Retrieved from https:// ecommons .cornell.edu/bitstream/handle/1813/3335/P esticides+-+Health+Effects.pdf?sequence=2
68. Vishnoi, S. R. and Srivastava, P. (2007). Phytoremediation– Green for Environmental Clean. Proceedings of Taal 2007: The 12th World Lake Conference/
69. Wang, K. S., Huang, L. C., Lee, H. S., Chen, P. Y. and Chang, S. H. (2008). Phytoextraction of cadmium by Ipomoea aquatica (water spinach) in hydroponic solution: Effects of cadmium speciation. Chemosphere, 72(4), 666-672.
70. Wang, X., Dossett, M. P., Gordon, M. P. and Strand, S. E. (2004). Fate of carbon tetrachloride during phytoremediation with poplar under controlled field conditions. Environmental science & technology, 38 (21), 5744-5749.
71. Wu, P., Xie, L., Mo, W., Wang, B., Ge, H., Sun, X., Tian, Y., Zhao, R., Zhu, F., Zhang, Y., *et al.* (2019). The biodegradation of carbaryl in soil with *Rhodopseudomonas capsulata* in wastewater treatment effluent. J. Environ. Manag., 249, 109226.
72. Yadav, I. C., Devi, N. L., Syed, J. H., Cheng, Z., Li, J., Zhang, G. and Jones, K. C. (2015). Current status of persistent organic pesticides residues in air, water, and soil, and their possible effect on neighboring countries: A comprehensive review of India, Science of The Total Environment, 511, 123-137. doi: 10.1016/j.scitotenv.2014.12.041.
73. Zhu, C., Fang, G., Dionysiou, D. D., Liu, C., Gao, J., Qin, W. and Zhou, D. (2016). Efficient transformation of DDTs with persulfate activation by zero-valent iron nanoparticles: A mechanistic study. J. Hazard Mater., 316, 232–241.

SEED PROCESSING AND STEPS TO BE FOLLOWED FOR HIGH SEED RECOVERY

Singarapu Snigda Srilaasya*[1] and V. Swarnalatha[2]
[1]Department of Seed Science and Technology, PJTSAU, Hyderabad - 500030
[2]Genetics and Plant Breeding, Seed Research and Technology Centre, PJTAU, 500030
*Corresponding author E-mail: singarapusnigda13@gmail.com

Abstract:

A key element of seed technology that aims to improve the vigour, viability, and quality of seeds for agricultural application is seed processing. Pre-cleaning, drying, threshing and shelling, cleaning and grading, seed treatment, and storage are some of the methodical processes. Every stage is intended to optimize seed recovery while upholding strict requirements for homogeneity, germination, and purity. To increase productivity and reduce waste, advanced technologies like AI-driven grading systems, optical sorting, and near-infrared spectroscopy are being used now-a-days. In agricultural systems, good seed quality, improved crop establishment, and sustainability are guaranteed when these procedures are carried out correctly. Insights into attaining high seed recovery rates while abiding by industry standards are provided in this chapter, which describes the concepts, procedures, and advancements in seed processing. In order to meet the increasing demand for high-quality seeds in the global agriculture industry, it is essential to integrate contemporary technologies and adhere to best practices.

Keywords: Seed, Seed Processing, Seed Recovery.

Introduction:

Commercial or grain crop production is not the same as quality seed production in a number of ways. Special processes, precautions and activities are needed to deploy to produce seed of best quality. Seed processing affects both the quality and marketability of seeds and can be used to separate healthy seeds from damaged and diseased seeds Dayal *et al.* (2021). Soundness, proper filling, uniformity in size, and other physical attributes of seeds such as shape, bulk density, surface texture, colour, and the presence or absence of appendages are critical determinants of seed quality. These characteristics significantly influence the seed's physiological vigour, ease of handling during mechanical planting, and the success of crop establishment. A key factor in raising agricultural productivity and output is high-quality seed Yalamalle *et al.* (2023). Seed processing is a systematic and scientifically-driven procedure aimed at upgrading the quality of harvested seed lots and preparing them for safe storage and efficient use Chala and Bekana (2017). The seed processing process is designed to improve the genetic purity, physical purity, and physiological quality of seeds Doshi *et al.* (2013) by utilizing specific physical and morphological attributes of seeds as well as the constituents of the harvested seed mass Sinha *et al.* (2001). The process incorporates precise techniques and advanced machinery to optimize seed recovery and enhance seed viability and germinability.

Importance of Seed Processing in Detail:

1. **Genetic Purity Enhancement:** Ensuring the seed lot meets genetic standards Singh and Agrawal (2001).
2. **Physical Purity Improvement:** Eliminating inert materials, damaged seeds, and contaminants Desai (2005).
3. **Viability and Vigor Maximization:** Retaining seeds with high germination potential ISTA (2023).
4. **Uniformity for Sowing:** Grading seeds for consistent size and shape, aiding mechanical planting Hudson (2023).
5. **Storage Preparation:** Treating seeds to prevent storage deterioration FAO (1995).

The primary objectives of seed processing are:

1. **Improving Seed Quality:** Removing inert materials, immature seeds, and other impurities to ensure high germination and vigour.
2. **Maximizing Seed Recovery:** Ensuring minimal loss of viable seeds during processing to maximize yield.
3. **Enhancing Uniformity:** Grading seeds for uniform size and weight, which improves sowing efficiency and plant stand establishment.
4. **Prolonging Seed Longevity:** Treating and storing seeds under optimal conditions to maintain viability over time.

Seed processing is essential for obtaining high-quality seeds with maximum recovery. The general steps involved in seed processing include:

1. **Harvesting**: Collect mature seeds or fruits at the appropriate time to ensure optimal seed quality.
2. **Temporary Storage**: Store harvested fruits or seeds in conditions that protect them from moisture, pests, and diseases until further processing. This may involve air-drying or precuring to reduce moisture content.
3. **Pre-cleaning**: Remove large debris, such as leaves, stems, and soil, from the harvested material to facilitate subsequent processing steps.

4. **Extraction**: Separate seeds from their surrounding fruit or plant material. This can be done through various methods
5. **Drying**: Reduce seed moisture content to safe levels (typically around 5-7%) to prevent mold growth and maintain viability during storage. This can be achieved through air drying or using desiccants like silica gel.
6. **Cleaning**: Remove remaining debris, inert materials, and non-viable seeds using screens, air blowers, or gravity separators to enhance seed purity.
7. **Sorting and Grading**: Classify seeds based on size, weight, and quality to ensure uniformity and improve sowing efficiency.
8. **Treatment**: Apply chemical or biological agents to protect seeds from pests and diseases during storage and germination.
9. **Storage**: Store processed seeds in controlled environments with appropriate temperature and humidity to maintain viability until planting. Proper packaging and containers are essential to protect seeds from environmental factors.

Implementing these steps meticulously can lead to high seed recovery rates and ensure the production of vigorous, healthy plants.

High seed recovery is essential for both commercial and research purposes, as it directly impacts the efficiency and profitability of seed production. By implementing effective processing techniques, it is possible to optimize the use of raw seed material, reduce wastage, and ensure the availability of high-quality seeds for sowing.

Factors Influencing Seed Recovery:

1. **Seed Morphology:** Differences in size, shape, and density affect processing efficiency Desai (2005).
2. **Harvesting Conditions:** Timely harvesting minimizes immature and damaged seeds FAO (1995).
3. **Moisture Content:** Maintaining safe levels (8-12%) prevents damage ISTA (2023).
4. **Processing Equipment:** Advanced tools ensure precise grading and cleaning Hudson (2023).
5. **Techniques Used:** Techniques like air-screening and gravity separation improve results Singh and Agrawal (2001).

The three stages of seed processing for high seed recovery:

Seed processing is categorized into conditioning, grading, and treatment stages. Each step utilizes standard practices to ensure optimal recovery and seed quality.

1. Conditioning:

In order to maximize the effectiveness of related machinery and handle raw seed lots securely in subsequent seed processing activities, conditioning is necessary. To make the lot free-flowing and free of mechanical abuses in subsequent processing activities, it may involve moisture conditioning, appendage removal, substantial dockage removal, or a combination of these. Generally speaking, a moisture level of about 10% is deemed safe for mechanical processing. Particularly in pulses, an excessively high or low moisture content might cause mechanical harm. Therefore, it is advised to dry or humidify seed lots in order to maintain a safe moisture content prior to additional processing steps Dadlani *et al.* (2023).

Conditioning involves preparing the harvested seed lot for further steps:

Pre-cleaning: Removing debris and large impurities using air-screen cleaners Desai (2005).

Drying: Reducing moisture content to safe levels using natural or mechanical methods Rao *et al.* (2006).

Threshing/Shelling: Separating seeds from their coverings with minimal mechanical damage Singh and Agrawal (2001).

2. Cleaning and Grading:

Depending on the type of crops, cleaning methods are of two types Mc Cormack (2004):

- Wet cleaning: This technique can be used to clean plants that contain seeds in their moist flesh. After being removed from the flesh of a mature fruit, the seeds should be gathered in a container and forcefully rubbed with gritty sand to get rid of the surrounding flesh. After that, the seeds are placed in a sieve and repeatedly cleaned under running water to get rid of the mucilage and meat fragments. Seeds should be dried for ten days following such cleaning before being stored. Fruit trees, tomatoes, cucumbers, coffee, etc.
- Dry cleaning: The ripened seeds in a dry capsule or pod are cleaned using the dry cleaning procedure. Either the entire plant with the pod is removed, shade-dried, and threshed to obtain the seeds, or the dry pods can be harvested separately. Before being stored, seeds are winnowed or softly crushed after threshing. For instance, the majority of grains, oilseeds, millets, and paddy.

This step removes contaminants and sorts seeds based on physical attributes:

Air-Screen Cleaning: Utilizing screens and air currents to separate seeds by size and weight Hudson (2023).

Gravity Separation: Specific gravity separators isolate denser, more viable seeds Desai (2005).

Length Grading: Using indented cylinders to separate seeds by length (ISTA, 2023).

Electrostatic Separation: Removing seeds or materials based on surface properties Matsuda and Ohara (2023).

3. Treatment and Enhancement:

Treatments ensure long-term viability and improved performance:

Chemical Treatments: Application of fungicides and insecticides protects against pests and diseases ISTA (2023).

Nutritional Coating: Micronutrient or bio-inoculant coatings boost seed vigor Desai (2005).

Pelleting: Creating uniform pellets enhances sowing efficiency Singh and Agrawal (2001).

4. Storage and Packaging

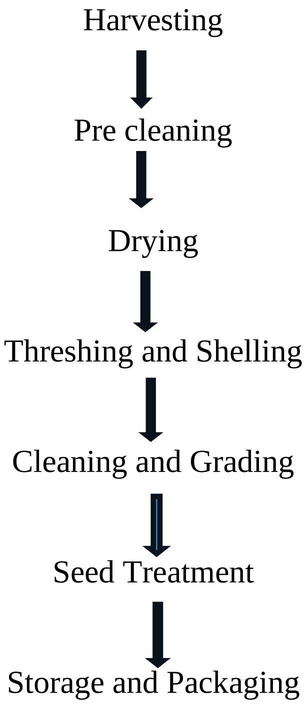
Proper storage methods preserve seed quality:

Hermetic Packaging: Moisture-proof containers prevent seed deterioration (FAO, 1995).

Controlled Environment: Maintaining low temperature (10-15°C) and humidity (≤50%) extends viability (ISTA, 2023).

By adhering to these standard principles and advanced methodologies in seed technology, seed processing ensures high-quality seed lots that are well-suited for planting, long-term storage, and superior crop establishment.

Seed processing steps for high seed recovery in flow chat form



Advanced Technologies in Seed Processing:

1. Near-Infrared Spectroscopy (NIRS)

- NIRS evaluates seed quality traits like moisture and germination potential non-destructively Matsuda and Ohara (2023).

2. Optical Sorting

- Sorting systems use color and texture to eliminate discolored or damaged seeds Hudson (2023).

3. Seed Priming

- Hydrating seeds before drying enhances germination and uniform growth Desai (2005).

4. Robotic Systems

- AI-driven robotic tools improve efficiency in cleaning and grading Singh and Agrawal (2001).

Principles for Higher Seed Recovery

1. **Harvest Timing:** According to the FAO (1995), seeds should be picked when they reach physiological maturity.
2. **Moisture Management:** Damage can be prevented by maintaining proper moisture levels (ISTA, 2023).
3. **Equipment Calibration:** Seed loss is reduced by using the right equipment settings Hudson (2023).
4. **Quality Standards:** Consistent outcomes are guaranteed when ISTA requirements are followed (ISTA, 2023).
5. **Preventing Damage:** According to Singh and Agrawal (2001), proper machinery operation lowers mechanical injuries.

Conclusion:

Delivering high-quality seeds that satisfy agricultural and market demands depends heavily on seed processing. Seed recovery rates can be greatly increased by implementing cutting-edge methods, following best practices, and resolving obstacles, all of which will support long-term agricultural productivity.

References:

1. Atwal S S and Sinha S. N. (2002). Production of genetically pure basmati seed through maintenance breeding. *Journal of All India Rice Exporters Association*. 12(4): 22-4.
2. Chala, M and Bekana, G., (2017). Review on seed process and storage condition in relation to seed moisture and ecological factor. *Journal of Natural Sciences Research*. 7(9): 84-90.

3. Dadlani, M and Yadava D.K. (2022). Seed Science and Technology. Biology, Production, Quality. Springer Publications.
4. Dayal, G., Sharma, A.K., Mishra, C.N., Kamble, U.R., Kumar, R. and Gaurav, S.S., (2021). Mechanical seed processing improves the seed quality and reduces Karnal bunt in seed lots of wheat cultivars. *Journal of Cereal Research*. 13(1):51-56.
5. Desai, B. B. (2005). *Seeds Handbook: Processing and Storage*. Routledge.
6. Doshi J. S, Patel B, Patel JB and Patel JA. (2013). Quantification of quality improvement in wheat seed processing. *Journal of Agricultural Engineering*. 50(4):83-86.
7. FAO. 1995. *Tropical Forest Seed*. Food and Agriculture Organization.
8. Hudson, J. (2023). *Seed Processing: A Practical Approach*. Hudson Booksellers.
9. ISTA. 2023. *International Rules for Seed Testing*. International Seed Testing Association.
10. Matsuda O and Ohara Y. (2023). Last-percent improvement in eligibility rates of crop seeds based on quality evaluation using near-infrared imaging spectrometry. *Plos one*. 18(9): e0291105.
11. McCormack and J.H., (2004). Principles and practices of seed harvesting, processing, and storage: an organic seed production manual for seed growers, Creative Commons. Stanford, California. 94305: 28.
12. Rao N. K, Hanson J, Dulloo ME, Ghosh K, Nowell D and Larinde M, (2006). Manual of seed handling in genebanks. Handbooks for genebanks No.8. Biodiversity International, Rome, Italy.
13. Sinha J.P, Vishwakarma M.K, Satwal S.S and Sinha S.N. (2002). Quality Improvement in rice (*Oryza sativa*) seed through mechanical seed processing. *Indian Journal of Agricultural Sciences*. 72 (11): 643-7.
14. Singh, S. P and Agrawal, R. L. (2001). *Seed Technology*. Kalyani Publishers.
15. Yalamalle V.R, Singh C and Chakrabarty S.K. (2023). Quality Improvement in Paddy Seeds during Seed Processing. *Journal of Agri Research*.10(4):266-269.

AGRICULTURE RESEARCH AND INNOVATION

K. Parimala Gandhi*[1] and R. Subha[2]
[1]Department of Science & Humanities, Nehru Institute of Technology, Coimbatore
[2]Department of Chemistry, Cauvery College for Women, Trichy, Tamil Nadu, India
*Corresponding author E-mail: nitparimala@nehrucolleges.com

Abstract:

Agriculture research and innovation are critical to ensuring sustainable food production and addressing global challenges like food security and climate change. This abstract examines the value of innovation and research in agriculture and emphasizes current practices and technological developments that are transforming the sector. Researchers and innovators are always trying to increase agricultural production, efficiency, and environmental sustainability from biotechnology and precision agriculture to sustainable farming practices and crop breeding. The necessity of cooperation between scientists, policymakers, and farmers is also covered in this abstract in order to guarantee that innovative research and practices are successfully applied and incorporated into agricultural systems across the globe. In the end, innovation and research in agriculture play a major role in the sector's development and transformation, opening the door to a more resilient and sustainable food system for coming generations. Scientific and educational establishments in industrialized nations have always prioritized research on novel agricultural technologies. Simultaneously, the agricultural supply industries have established their own independent role in research and development and have come to dominate specific categories of agricultural inputs, such as pesticides and machinery.

Keywords: Agriculture, Research, Innovation, Circular Economy

Introduction:

The roots of agricultural innovation can be found in the early days of the industry. Natural selection has led to the evolution of traditional crop types as a result of environmental adaptability. The invention of basic hand tools and the subsequent addition of animal-drawn implements resulted in modifications to cultivation techniques. Farmer creativity is also greatly responsible for advancements in farm machinery, especially when combined with mechanical and blacksmithing abilities. Compared to wealthy countries, developing countries have more traditional manufacturing processes, which present substantial hurdles to their pursuit of economic progress [1]. It is understandable that these nations would look for new technologies to apply to many facets of society in an effort to improve and increase their current capacities for generating goods and services. Technologies related to information and communications are seen to be instruments that improve competitiveness and productivity in businesses and manufacturing facilities. The more ICTs are used and used, the greater these advantages become. In a similar vein, quality and safety regulations are driving pressure on agricultural businesses to implement information and communication technologies. Customers are embracing models similar to those seen in industrialized nations, which forces companies to contend in local and regional markets where traded goods are subject to set criteria. The focus of innovation in developed nations has moved from the farm to formalized agricultural research and development conducted by public and commercial organizations. A notable feature of the nineteenth and twentieth centuries was the establishment of specialized institutions where scientists and technicians could work on issues related to agricultural output [2].

Over the past 200 years, the requirements of society and policy have shaped agricultural research, with significant shifts occurring over time. The focus of study as well as the range of consequences that would need to be measured in order to account for these effects has changed in recent years due to the growing awareness of the role that agriculture plays in producing public goods. Productivity can be broadly defined as the capacity of production components to generate output. A ratio of input to output can be used to quantify this. Nonetheless, a large corpus of research has addressed productivity measurements in agriculture, covering both theoretical and practical challenges in putting this idea into practice. Total Factor Productivity (TFP), which is a ratio of the sum of all inputs and all outputs, is a more thorough indicator of productivity. Time series analysis is frequently used in this idea to account for productivity gains based on TFP variations. Though its importance varies depending on the period and the location, TFP plays a significant part in explaining how agricultural productivity has grown throughout time. Productivity indices have been explored and expanded to take into consideration various factors, such as the increasing diversity of inputs and outputs associated with environmental and resource-related issues. A number of resource-saving, dynamic, or multi-output standards are now making an effort to address these problems. This has resulted in the proposal of extensions like environmentally modified TFP or even green TFP, among other things [3]. This dynamic and complicated environment needs a variety of talents, tactical preparation, and paradigm shifts to manage. The central source model of innovation from the 1970s and 1980s has gradually changed to become the present agricultural innovation systems approach in response to these changes.

Patterns in Agriculture's Knowledge and Innovation Systems:

AKIS are undergoing change in a number of nations. It is moving toward new arrangements that enable stronger interactions within the system. The system was formerly dominated by a public system where knowledge created by agricultural universities and research agencies was transmitted via applied research institutes and experimental farms, to extension service, and ultimately to farmers. While research is still a key driver of agricultural innovation, it is happening more and more in an interactive, reactive innovation system that helps agriculture become more demand-responsive. Today's agricultural innovation is more sophisticated and has a wider scope. Previously, agricultural production practices were the main focus of agricultural research and development (R&D). However, current focus is more on innovation throughout the food supply chain, nontechnological innovations like institutional or marketing innovations, and environmental, animal welfare, food, and health issues. New parties have joined the conversation as a result, including consumer and environmental advocacy groups and ministries of health and the environment. It has also aided in university mergers as well as more comprehensive trans disciplinary research methodologies among academic faculties [4]. Agricultural research has become more interwoven with other sciences and is dependent on innovation in other fields, including biotechnology, nanotechnology, and information and communication technology (ICT). Simultaneously, there appears to be a regional decline in research and experimentation across Europe, most likely as a result of standardization in industrial methods.

1. Adoption of technology and digitalization:

Precision farming, drones, sensors, and other digital technology are becoming more and more common in agriculture. Farmers are benefiting from these technologies by increasing yields, decreasing input costs, and improving efficiency.

2. Sustainable farming methods:

Sustainable agricultural methods including organic farming, agroecology, and conservation agriculture are becoming more and more important. These methods seek to enhance soil health, lessen their negative effects on the ecosystem, and increase biodiversity.

3. Collaboration and the exchange of knowledge:

A growing number of stakeholders, including farmers, researchers, policymakers, and industry, are collaborating to address shared challenges and exchange best practices, resulting in increasingly linked and collaborative agricultural knowledge and innovation systems.

4. Climate-smart agriculture:

Climate-smart agriculture strategies, which assist farmers in adapting to changing climate conditions and lowering greenhouse gas emissions, are becoming more and more important as the effects of climate change on agriculture become more apparent.

5. Building capacity and providing training:

The significance of increasing farmers' and other stakeholders' competence in agricultural knowledge and innovation systems is acknowledged. To assist farmers in implementing new techniques and technology, extension services and training programs are being created.

6. Partnerships between the public and private sectors:

The role of partnerships among the public, commercial, and non-governmental sectors in promoting agricultural innovation is growing. These collaborations aid in utilizing networks, resources, and knowledge to tackle difficult agricultural problems.

The Evolution of the Innovation Systems Framework's Application in Agriculture

The initial stages of agricultural modernization (1960s-1970s) goal was to use modern inputs like insecticides, fertilizers, and improved crop types to increase agricultural production. The majority of innovation systems followed a linear path, with research institutions creating innovations that were subsequently distributed to farmers via extension services. Making the Switch to Sustainable Agriculture (1980s-1990s) a move toward sustainable agriculture was prompted by worries about resource depletion, environmental deterioration, and the social effects of modernity. Farmers, non-governmental organizations, and local communities were among the stakeholders included in the innovation systems framework. To accommodate the varied needs and settings of farmers, participatory approaches, knowledge sharing, and adaptive management were emphasized. The rise of participatory research and agroecology (2000s-2010s) sprang to prominence as a comprehensive strategy for agricultural growth that placed a strong emphasis on incorporating ecological concepts into farming practices [5]. Farmers are now directly involved in the process of research and innovation thanks to the increasing use of participatory research approaches. The paradigm for innovation systems in agriculture has developed to acknowledge the significance of indigenous techniques, social networks, and local knowledge. Precision farming and digital agriculture (2010s-Present) are the results of the revolution in agriculture brought about by advances in data analytics, remote sensing, and information technology. Digital platforms, data-driven decision-making, and partnerships between agribusinesses, tech firms, and farmers are now all part of the innovation systems framework. Open innovation is becoming more and more important, with the sharing of technologies, data, and algorithms to speed up agricultural innovation and tackle difficult issues like food security and climate change. Integration of Social and Economic Dimensions (Present-Future) systems framework for agriculture could see a stronger integration of social and economic aspects, such as market access, equity, and rural development concerns. Innovations will prioritize improving the livelihoods and general well-being of farmers and rural communities in addition to raising production and sustainability [6]. Building a more resilient and equitable agricultural innovation system will require multi-stakeholder collaborations, inclusive policies, and human capital investment.

A Few Challenges about Productivity and Research

1. Eco-innovation and entrepreneurship

Another aspect of research and innovation that is undergoing significant change is the role of the various individuals involved. A more traditional and simplified view of research and technology adoption placed a strong emphasis on the market and policy. While the public sector provided research and promoted targeted technology uptake through subsidies, the market was perceived as the primary driver of technology adoption and a promoter of private research [8]. Over time, many have questioned this naive notion of technological transfer, most notably by looking at the amount of people, organizations, and systems that act as a link between research and the agricultural industry and by taking feedback loops into account. This has grown in significance in agriculture, particularly in connection to the bioeconomy, according to the extensive literature on Agricultural Knowledge and Innovation Systems. Relevant categories extend beyond farmers and individual extension units [9]. In this discipline, networks are a category that is growing more and more significant. Networks also facilitate a dynamic understanding of the innovation process, wherein various actors might participate at different phases and innovators must constantly assess and adjust their position in relation to their surroundings. This perspective on the innovation process also suggests that innovation monitoring and assessment techniques, as well as facilitators, may be very important.

2 New techniques to gauge the effects of research

Examining instruments for evaluating the effects of new technologies and, indirectly, research, is another way to comprehend the consequences of current trends in the examination of the relationships between research and production. Life-cycle assessment (LCA) currently has a prominent role in this approach. LCA is a method of assessment that concentrates on the effects that every product unit or, more accurately, each functional unit creates over the course of its lifecycle, from "cradle to grave." The method's foundation is an inventory of inputs and outputs, particularly as it relates to important resources like greenhouse gases and nitrogen [10]. In addition to the inventory phase, life cycle assessment is being extended to encompass the assessment of variations between technological options. This includes the application of multi-criteria analysis and the connection with economic performance, such as lifecycle costing, throughout a product's life cycle. LCA is being used more often to bolster marketing messages and has been utilized for more than 20 years as an environmental assessment method. Product selection in "green procurement" and product inclusion in various national and regional eco-labelling schemes are increasingly based on it. LCA addresses the need to better account for the broader implications of technical research, thereby taking a potentially wide variety of effects on complex systems into consideration, from the perspective of the relationship between research and productivity [11].

3. Ecosystem services and sustainability: from performance to positioning

The broader context in which the aforementioned difficulties have emerged is typified by the pervasive application of the notion of sustainability as the goal of agriculture and food systems, and, in turn, of technical change that is directed toward sustainability. Without getting into the definitional issue, it is abundantly evident from the literature that social constructions of sustainability play a significant role in its definition. On the one hand, the literature emphasizes and supports the requirement that sustainability be defined through the democratic process [12]. However, it is asserted that sustainability is a road of constant social learning and that this kind of change needs to be "profound, transversal, and counter-hegemonic." It is imperative to underscore that the challenges faced extend beyond the provision of sufficient definitions. These issues also pertain to the empirical conceptualization and pragmatic measurement of sustainability, encompassing its correlation with globalization and development literature. The methods used to evaluate the environmental sustainability of agriculture arguably the aspect of sustainability that has received more attention than economic and social sustainability provide a fair illustration of the practical challenges associated with measuring sustainability [13]. Indicators have been used extensively in the literature to solve this issue.

Implications and Challenges:

Implications of Agriculture for Development Research While appreciating the importance of technological, organizational, and institutional management and service delivery inventions, an agricultural stresses the use of inventions to provide economic, social, and environmental gains. Technology development and research in agriculture make up a small portion of the innovation system. The organization, administration, and functioning of the research system as well as the practices of researchers are significantly impacted by the change from seeing research as the main player in the innovation system to just one of its crucial components. Thus, a variety of new actions and procedures that were previously outside the purview of research systems and researchers are now expected of them [14]. This covers the ways in which research is conducted to generate products and services. Establishing and fostering partnerships requires specific interactions within the agricultural R&D system as well as learning through networking with other actors who innovate dynamically to adapt to changing conditions. Therefore, fostering relationships with other players in the innovation ecology should be part of building research capacity. Researchers will need to be proficient in dispute resolution, facilitation, and negotiation. More than ever, funding and incentives will be required to institutionalize and promote partnerships and partner interactions [15]. Therefore, enhanced governance of the research system that promotes collaborations is needed for the innovations systems perspective. The structure of research management should enable participation from pertinent players in strategy formulation, funding and priority setting, assessment, and co-learning. A multidisciplinary and multi-organizational approach to research and development is necessary to promote advances in agriculture. Research institutes' structural layouts must to take into account the multidisciplinary character of their work [16]. A culture that strives to satisfy the demands of all parties involved users, teams, workers, legislators, development professionals, and so forth will promote innovation. Strong processes and structures that foster innovation are combined with leadership and culture by those who are thought to succeed at it. High-level management will have to establish a common vision, where innovation is recognized and has a purpose, as well as an organizational culture that encourages and rewards user attention, teamwork, creativity, and high performance standards.

Reducing the Relationship between Innovation and Agricultural Research

A number of different and complimentary approaches to organizing innovation have been proposed in response to the criticism of research devoid of novelty over the past 30 years. These employ research to differing degrees and in various methods. These are not given as opposing strategies, as we have already made clear, but rather as examples of the kinds of viewpoints that are beginning to encroach on the shared policy narrative. It's also crucial to remember that there is a lot of overlap and that these choices are not exclusive of one another. The following outlines the variety of approaches to organizing agricultural innovation that have been covered in the relevant literature [17].

1. Technology Development through Participation:

Since they are better knowledgeable about their production and social surroundings, farmers ought to be at the center of the innovation process. While Biggs identifies several forms of participatory research with varying levels of farmer involvement and distinct roles for research, the role of research is largely incidental. Numerous variations of client-oriented breeding and Farmer Field Schools fall under this category.

2. Encouragement of Regional Innovation:

The concept that untapped agricultural inventions can be promoted more widely and that rural people are the main sources of agricultural innovation was first introduced by Anil Gupta's Honeybee network in India. Another version of this viewpoint is held by the global network known by the abbreviation Prolinnova, which views research's function as occasionally serving as both a validation tool for farmer technologies and a source of assistance for local innovation.

3. Governance of Innovation:

Governance of Innovation Planning for agricultural science and technology fails to include the voice of underprivileged groups. Both the scientific community and the corporate sector have vested interests that tilt the power dynamics in their favor. The creation of citizen juries and panels, as well as increasing engagement in scenario planning and foresight exercises that tackle the power dynamics in innovation, technology, and research, are some remedies.

4. Various Innovation Sources:

The information required for innovation comes from a variety of sources, including the corporate sector and farmers, in addition to research. Relationships between various knowledge sources rely heavily on historical and sociopolitical settings. Research will be more productive and innovation will continue if these connections are strengthened.

5. Developing Hopeful Innovation Processes:

New kinds of innovation processes and products are emerging mostly because of markets and the opportunity they provide for the impoverished. There exist innovation processes that remain unseen to research and corporate groups because of differing professional perspectives on success and quality. These are referred to as under-the-radar innovation, bottom-of-the-pyramid innovation, and bottom-up bottom-line business models. All of this shows that coordinating innovation processes and capacities is not the place of policy. Instead, it involves looking for new, socially significant abilities and processes and assisting in their growth.

6. Building Innovation Capabilities:

The degree of innovation capacity development rather than technology development or promotion in and of itself is the rate-limiting phase in technical progress. From a systems' perspective, this capability is understood to represent the actions of loose networks of actors involved in innovation as well as the institutional and regulatory environments that influence these actors' actions and development. The main goal of interventions is to investigate how learning and experimentation might foster the development of these networked capacities.

7. Multiple Roles for Research:

Research plays a wide range of responsibilities in the process of innovation. It can occasionally inspire innovation by bringing forth novel techniques, strategies, or regulations. It can occasionally be a quick-thinking, helpful source of knowledge. In other cases, it serves as a framework for organizing instruction around large-scale issues like the environment or health. Consequently, every function necessitates distinct arrangements of the broader innovation process, within which research is integrated [18].

8. Sector-to-Sector Collaborations:

The agricultural research and related activities have not received enough support from the business sector. It occasionally possesses independent research experience. Incentives, systems, and procedures are also in place to provide customers with the technologies they want. Creating social capital between businesses and other components of the agricultural innovation system, as well as offering incentives to partners, can help the private sector participate in innovation more.

Conclusion:

In particular, this paper has examined the implications of a few key bioeconomy-related issues for research, innovation, and productivity studies. These issues include: a) the concepts of bioeconomy, circular economy, resource efficiency, and bio-refinery; b) the relationship between eco-innovation and entrepreneurship; c) the evolving use of life cycle assessment (LCA) in research evaluation; and d) the evolving notions of sustainability and ecosystem services. Though contemporary research tendencies are more focused on producing "potential" than they were in the past, we suggest that the "traditional" idea of productivity, meant as an output/input ratio, maintains (and may increase) its importance overall. Additionally, we discover that although research is probably playing a bigger role in changing productivity, it is getting harder to directly correlate productivity gains with particular research initiatives. Because of the aforementioned, knowledge of the links and processes that connect research to productivity is becoming more important than the actual productivity measurements, despite the fact that they are now much harder to track down. Better methods for doing ex-ante and ex-post studies that are more integrated with decision-making processes and able to handle interactions between aggregate and disaggregate levels are needed by policymakers and practitioners. This aligns with the increasing focus on integrating sustainability considerations into individual and corporate behavior, as well as addressing global environmental and social issues in the context of globalized markets. This draws attention to several new issues facing economics study, particularly those pertaining to food, agriculture, and the bioeconomy.

References:

1. Spiertz, H. (2014). Agricultural Sciences in Transition from 1800 to 2020: Exploring Knowledge and Creating Impact. European Journal of Agronomy 59 (September): 96-106. doi: 10.1016/j.eja.2014.06.001.
2. Spielman, D., & von Grebmer, K. (2006). Public–Private Partnerships in International Agricultural Research: An Analysis of Constraints. The Journal of Technology Transfer, 31(2), 291-300. 10.1007/s10961-005-6112-1

3. MacMillan, T., and Benton, T. (2014). Agriculture: engage farmers in research. Nature 509, 25–27. doi: 10.1038/509025a
4. Alston, J. M., Andersen, M. A., James, J. S. and Pardey, P. G. (2011). The Economic Returns to U.S. Public Agricultural Research. American Journal of Agricultural Economics 93 (5): 1257-1277. doi:10.1093/ajae/aar044.
5. Tewari, V.K.; Pareek, C.M.; Lal, G.; Dhruw, L.K.; Singh, N. (2020). Image processing based real-time variable-rate chemical spraying system for disease control in paddy crop. Artif. Intell. Agric. 4, 21–30. 10.1016/j.aiia.2020.01.002
6. Bibi, F.; Rahman, (2023). A. An Overview of Climate Change Impacts on Agriculture and their mitigation strategies. Agriculture. 13, 1508. 10.3390/agriculture13081508
7. Farooque, A.A.; Hussain, N.; Schumann, A.W.; Abbas, F.; Afzaal, H.; McKenzie-Gopsill, A.; Esau, T.; Zaman, Q.; Wang, X. Field evaluation of a deep learning-based smart variable-rate sprayer for targeted application of agrochemicals. Smart Agric. Technol. 2023, 3, 100073. 10.1016/j.atech.2022.100073
8. Hejna, M.; Kapusci nska, D.; Aksmann, A. Pharmaceuticals in the aquatic environment: A review on eco-toxicology and the remediation potential of algae. Int. J. Environ. Res. Public Health 2022, 19, 7717. 10.3390/ijerph19137717
9. Bhakta, I.; Phadikar, S.; Majumder, K. (2019). State-of-the-art technologies in precision agriculture: A systematic review. J. Sci. Food Agric. 99, 4878–4888. 10.1002/jsfa.9693
10. Wang, S.L., Heisey, P.W., Huffman, W.E. and Fuglie, K.O. (2013). Public R&D, Private R&D, and U.S. Agricultural Productivity Growth: Dynamic and Long-Run Relationships. American Journal of Agricultural Economics 95 (5): 1287-1293. doi: 10.1093/ ajae/aat032.
11. Klerkx, L. Hall, A. and Leeuwis, C. (2009). “Strengthening Agricultural Innovation Capacity: Are Innovation Brokers the Answer?”, International Journal of Agricultural Resources, Governance and Ecology, Vol. 8, Nos. 5/6, pp. 409-438. 10.1504/IJARGE.2009.032643.
12. Pfau, S., Hagens, J., Dankbaar, B. and Smits A. (2014). Visions of Sustainability in Bioeconomy Research. Sustainability 6 (3): 1222-1249. doi: 10.3390/su6031222.
13. Srivastava, S.K. Assessment of groundwater quality for the suitability of irrigation and its impacts on crop yields in the Guna district, India. Agric. Water Manag. 2019, 216, 224–241. 10.1016/j.agwat.2019.02.005
14. Negrete, J.C. (2020). Proposed Spray System for Family Agriculture with A Remote-Controlled UAV (Small Drone or Helicopter) and An Economical Sprinkler. J. Agron. Res. 3, 1–8. :10.14302/issn.2639-3166.jar-20-3283

15. He X. K., Bonds J, Herbst A, Langenakens J.(2017). Recent development of unmanned aerial vehicle for plant protection in East Asia. Int J Agric & Biol Eng,; 10(3): 18–30. 10.3965/j.ijabe.20171003.3248
16. Olsson, L., Hourcade, J.-C. and Kohler, J. (2014). Sustainable Development in a Globalized World. The Journal of Environment & Development 23 (1): 3-14. doi: 10.1177/1070496514521418.
17. Spielman, D., & von Grebmer, K. (2006). Public–Private Partnerships in International Agricultural Research: An Analysis of Constraints. The Journal of Technology Transfer, 31(2), 291-300. 10.1007/s10961-005-6112-1
18. Koushesh Saba, M., Arzani, K., & Barzegar, M. (2012). Postharvest polyamine application alleviates chilling injury and affects apricot storage ability. Journal of Agricultural and Food Chemistry, 60(36), 8947-8953. https://doi.org/10.1021/jf302088e
19. Sanjeev kumar, B. P Bhatt, A Dey, Shivani Shivani, Ujjwal kumar, MD Idris, J S mishra, Santosh kumar. (2018). Integrated farming system in India: Current status, scope and future prospects in changing agricultural scenario. Indian Journal of Agricultural Sciences, 88(11), 1661-1675. 10.56093/ijas.v88i11.84880

VALUE CHAIN ANALYSIS OF AGRICULTURAL CROPS

Lalit Kumar Verma*[1], Om Prakash Maurya[1] and Dushyant Kumar[2]
[1]Department of Agricultural Economics & Statistics,
R.S.M. (P.G.) College, Dhampur, Bijnor (U.P.)
[2]Department of Agricultural Economics, U.P. (P.G.) College, Varanasi, (U.P.)
*Corresponding author E-mail: verma.lalitkumar49@gmail.com

Introduction:

Agriculture is one of the important pillars of economic growth of the nation. To enhance the competitiveness of the sector, there is a need to bring about diversification in the agriculture sector by focusing on non-traditional crop cultivation, value addition and commercialization of farms. The value chain analysis concept is a business management concept described and popularized by Michael Porter in 1985. Most products change hands several times before reaching the end consumer. Input suppliers, manufacturers, processors, wholesalers and retailers are the major stakeholders in the value chain. Value chain refers to the range of activities that bring a product from the producer to the end consumer. Value chain analysis is an important tool for creating the best possible value for produce. Value chain analysis plays an important role in identifying the distribution of benefits of the participants in the chain.

Value chains involve actors or stakeholders and their activities with the aim of exploiting the total value of a product by linking producers to processors and markets. In general, very simple value chains exist for most agricultural commodities, in which buyers and producers exchange only price information. But the best value chains exist when their stakeholders collaborate to create high quality products and generate greater income for all stakeholders in the chain.

The most important function in the value chain is to connect producers to processors and companies. This linkage will ultimately develop a contract manufacturing system in which farmers/growers will also be supported through input supply and extension services, advice and transportation of the produce.

Agriculture Value Chains:

Agricultural value chain in fruits, vegetables and oilseeds provides an opportunity to diversify agriculture with the objective of improving income levels of stakeholders, employment opportunities and increasing foreign earnings by improving export of produce.

The conceptual framework of agricultural value chains includes a sequence of value-added activities from production through processing and marketing to consumption. Each segment of the chain has one or more backward and forward linkages. A value chain in agriculture identifies the set of actors and activities that bring a basic agricultural product from production in the field to final consumption, where value is added to the product at each stage.

The terms value chain and supply chain are often used interchangeably (Food and Agriculture Organization 2005). According to Dunn (2014) an agricultural value chain can be a vertical linking or a network between different independent business organizations and may include processing, packaging, storage, transportation and distribution. In South Asian countries such as India, agricultural value chains are often fragmented; lack of investment; and fail to include vulnerable groups and lack critical linkages to farms and markets.

Globalization of agricultural value chains is a major challenge to serve local and national markets. A study by the United Nations Conference on Trade and Development (UNCTAD 2006) found that major companies, with few exceptions, are reluctant to cooperate with local farmers because of structural shortcomings, such as a lack of quality products and poor credibility. Availability and quality of domestic suppliers is a major determinant of participation in companies/private firm based value chains.

Agriculture Value Chains in India:

In the last few decades, especially after the economic reforms of the 1990s, the agricultural system in India has undergone rapid changes. The emergence of integrated agriculture and food supply and value chains is one of the most visible market events in India. All segments of the value chain are seeing an increasing concentration on processing, marketing and exports. With greater coordination between farmers, processors, retailers, exporters and other stakeholders in the agricultural value chain, the traditional way of food production is being replaced by practices similar to manufacturing processes (Kumar *et al.* 2011).

In India, farming system with value chain framework is not envisaged as the main strategy to bring more efficiency, productivity and earnings. There is not enough emphasis on growth and development of efficient agriculture value chains in India. Through the development of modern agricultural value chains at the national and regional levels, farmers in India can benefit from enhanced knowledge, data and information and communication technologies. Also, the modern and especially the urban consumers in India will get better quality and safer food products as per their taste and preferences. With better value addition, the cost, risk and loss of retailers and exporters will also reduce.

Agricultural value chains in fruits and vegetables provide an option for diversification of agriculture in view of higher income, employment, foreign exchange earnings and a new approach to meet the challenges of food security. The income elasticity of demand for these products is high. Whenever and wherever the income of the population increases, the demand for these products also increases, mainly in the middle income groups of the developing countries. Income growth and stress on quality have impacted the demand side while new technologies and trade agreements have the potential to impact the supply side.

Agricultural value chain comprises input suppliers, producers, market intermediaries, processors and consumers. One end of the agricultural value chain consists of farmers/producers who are primarily involved in the production of commodities and the other end of the chain consists of consumers who are involved in the consumption of the commodities produced.

Generally, the agricultural value chain consists of the following steps:

1. **Input Suppliers/ Input logistics:**

   This stage involves movement of the inputs from input suppliers to the farmers/producers. Value chain analysis of agricultural crops begins with the input suppliers, who provide essential resources to the farmers. Seed companies, fertilizer manufacturers, pesticide suppliers, machinery and equipment manufacturers, and other input providers play a vital role in ensuring the availability and quality of inputs. Their efficiency and responsiveness to the needs of the farmers make a significant impact on the crop production process. Collaboration between input suppliers and farmers is critical to align inputs with specific crop requirements and promote sustainable practices.

2. **Production:**

   Production stage encompasses all activities related to crop production, starting from land preparation to harvesting. Farmers make decisions on crop selection, planting techniques, irrigation, pest control, and crop maintenance. Efficient resource management, including water and energy usage, plays a crucial role in sustainable agriculture. Technological advancements such as precision agriculture, remote sensing, and data analytics enable farmers to optimize crop yields, minimize resource waste, and mitigate risks. The Production stage's success depends on factors such as access to information, training, credit facilities, and support from agricultural extension services.

3. **Post-harvest Handling and Processing:**

   Once the crops have been harvested, post-harvest handling and processing activities come into play. This stage includes cleaning, sorting, grading and packaging of agricultural crops to ensure quality and shelf life. Depending on the crop and market demands, additional processing steps such as milling, drying, canning or freezing may be necessary. Proper handling and processing techniques minimize post-harvest losses, maintain nutritional value and enhance marketability. Technological innovations such as automated sorting and grading systems improve efficiency and reduce human error. Sustainable practices like waste management, energy-efficient processing and packaging materials also contribute to overall value chain sustainability.

4. **Storage and Transportation:**

   Efficient storage facilities are crucial for maintaining crop quality and minimizing post-harvest losses. This stage involves activities such as warehousing, cold storage, and logistics management. Proper storage conditions, including temperature, humidity, and ventilation, ensure optimal preservation of agricultural crops. Transportation plays a vital role in connecting farms or processing facilities with distribution centers or markets. Well-managed logistics systems minimize spoilage, reduce transportation costs, and ensure timely delivery. Technologies such as real-time monitoring, traceability systems, and refrigerated transport facilitate efficient storage and transportation, enhancing overall value chain efficiency. Strengthening storage infrastructure, improving logistics management, and promoting sustainable transportation practices contribute to the reliability and competitiveness of the agricultural crop value chain.

5. **Distribution and Marketing:**

   The distribution and marketing stage involves getting agricultural crops from storage or processing facilities to the end consumers. This stage includes activities such as wholesaling, retailing, and marketing through various channels. Effective distribution networks ensure that crops reach the intended markets efficiently. Collaborations between farmers, cooperatives, traders, and retailers contribute to market access and price stability. Understanding consumer preferences, market trends, and demand patterns is crucial for successful marketing. Strategies such as branding, product differentiation, and consumer education enhance market competitiveness. Additionally, e-commerce platforms and direct-to-consumer models provide new opportunities for farmers to reach a wider customer base. Strengthening distribution networks, promoting market linkages, and supporting marketing innovations empower farmers to access diverse markets and capture greater value from their crops.

6. **Consumption:**

   The final stage of value chain analysis is the consumption of agricultural crops by final consumers. Consumers use crops for direct consumption, food processing, or industrial purposes. Quality, safety and nutritional value are major considerations for consumers. Meeting consumer demands for organic, locally sourced, or sustainably produced crops is becoming increasingly important. Consumer preferences and changing dietary patterns impact the value chain, increasing the need for diversification, innovation and value-added products.

Mapping a Value Chain:

Value chain mapping involves visual representation of the various steps and activities involved in the production and distribution of a product or service. Here's a step-by-step guide on how to map a value chain (Fig-1):

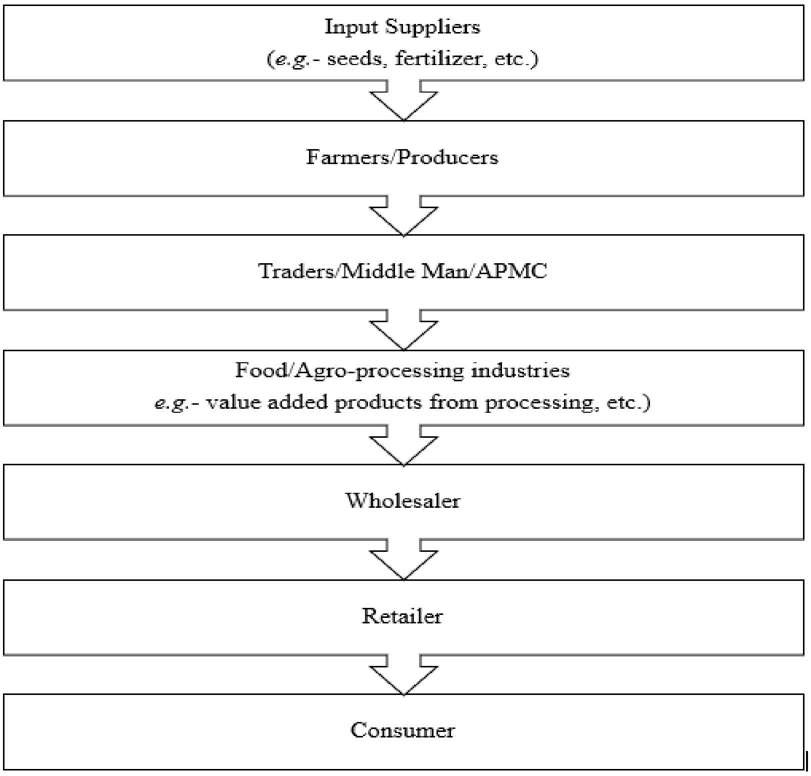


Fig-1: Value chain mapping for Agricultural Crops

A Model of Agriculture Value Chain:

Agriculture value chain refers to the sequence of activities and processes involved in bringing agricultural products from the farm to the consumer. It encompasses all stages, from the production of raw materials on the farm to the processing, distribution, and retailing of the final products.

Value chain development involves linking farmers/producers with processing industries or firms up and down the value chain. Inclusive value chains play a major role in the development of the entire value chain by including small scale farmers so as to enhance production efficiency and quality. Finance is also an important part of the agricultural value chain as meeting the financial needs of the stakeholders of the chain is very essential in carrying out its activities. Information communication technologies (ICTs) will also help in strengthening the value chain by providing timely and accurate data related to commodity prices, farming methods, and improving knowledge on value addition.

Conclusion:

Value chain analysis of agricultural crops provides a comprehensive understanding of the complex processes and stakeholders involved in bringing food from farm to farm. By analyzing each step of the value chain, opportunities can be identified to add value, reduce costs, improve quality and increase sustainability. Quality improvement of the produce, inclusion of the small famers into the chain, increasing the profits of the stakeholders and development of value added products can be achieved through value chain analysis; hence value chain analysis is an essential tool for overall development of agricultural sector.

References:

1. Alam, M. (2020). Value chain analysis of high value crop: Farm to market, *International Supply Chain Technology Journal*. 6(5).
2. Cucagnaa, M.E and Goldsmith, P.D. (2017). Value adding in the agri-food value chain. *International Food and Agribusiness Management Review*.
3. Dunn, Elizabeth (2014). Smallholders and inclusive growth in agricultural value chains, Field Report 18, USAID
4. Gandhi, Vasant P. (2015). Transformation of agribusiness and food value chains in India: Investment, models and challenges. http://www.ifama.org/files/conf/2015%20Conference/1362_paper_Ghandi.pdf.
5. Kumar, Anjani, Harbir Singh, Sant Kumar and Surabhi Mittal (2011). Value chains of Agricultural commodities and their role in food security and poverty alleviation: A synthesis, *Agricultural Economics Research Review*, Vol. 24, pp 169-181.
6. Kumar, S. (2018). Training programme on Value chain for agricultural commodities. National Institute of Agricultural Marketing.
7. Kumar, Saurabh and Sharma, Aparna (2016). Agricultural Value Chains in India: Prospects and Challenges.
8. Pal, Deepak & Sharma, Laveena. (2018). Agricultural value chain: Concepts, definitions and analysis tool. International Journal of Commerce and Business Managet. 11. 184-190.
9. Rota, Antonio (2010). Value chains, linking producers to the markets, IFAD. https://www.ifad.org/documents/10180/65cc8da1-d0f9-41d8-acb51175850b768f.
10. Sowmya, G. *et.al.* (2023). Value Chain Analysis of Agricultural Crops, New Era Agriculture Magazine; 2 (1), 166-169.

INTRODUCTION TO VALUE ADDITION IN TEA: TRENDS AND MARKET DEMAND

Shyamal Kr Phukon[1], Supriya Sonowal*[2], Sudeshna Baruah[3] and Sanghomitra Sarma[4]

[1]Advisory Department, Tocklai Tea Research Institute, Jorhat, Assam

[2]Department of Tea Husbandry and Technology

Assam Agricultural University, Jorhat, Assam

[3]Department of Horticulture, AAU, Jorhat, Assam

[4]Krishi Vigyan Kendra, Dibrugarh, AAU, Assam

*Corresponding author E-mail: supriya.sonowal@aau.ac.in

Introduction:

Tea is one of the world's most popular beverages, with a long history and cultural significance in many countries. Tea has traditionally been provided in four basic forms: black, green, oolong, and white. However, as customer preferences change and processing technology progress, value addition in tea has emerged as an important trend. Tea cola, tea toffee, tea ice cream, a wide range of herbal teas (Tulsi tea, ginger tea, turmeric tea, cinnamon tea etc), tea wine, tea based confectionary products and cosmeceuticals have occupied significant places in Indian market (Baruah *et al.*, 2007 and Baruah *et al.*, 2008). In recent years, research on value-added tea has gained momentum due to increasing consumer demand for functional and premium tea products. Value-added tea refers to tea that has undergone enhancements in flavours, health benefits, processing techniques, or packaging to increase its market appeal and consumer preference.

A. Types of Value-Added Tea

1. Specialty and Artisan Teas

Consumers are increasingly looking for premium and artisanal teas with distinct tastes, origins, and processing methods. Hand-rolled, matured, and single-origin teas have grown in popularity due to their superior flavour and uniqueness. Micro-lot and limited-edition teas appeal to enthusiasts who are willing to pay a premium for high-quality items.

2. Flavoured and Blended Tea

Flavoured and blended teas have grown in popularity, appealing to a diverse range of consumers. Flavoured and blended teas use natural ingredients like herbs, fruits, and spices to improve taste and aroma.

Popular examples include:

- Earl Grey (black tea with bergamot oil)
- Masala tea (blended with spices like cinnamon, cardamom, and ginger)
- Herbal-infused teas (*e.g.,* Tulsi, peppermint, lemon grass)
- Fruit-flavoured teas (*e.g.,* berry, mango, citrus)
- Floral teas (*e.g.*, chamomile, hibiscus, rose, lavender, jasmine-infused tea)

3. Functional and Wellness Teas

Health-conscious consumers are driving the demand for functional teas that offer additional health benefits beyond basic hydration. Turmeric incorporated black tea is found to exert enhanced antihypertensive and neuroprotective effect with respect to black tea alone (Bhandari *et al.,* 2019). Lemon Grass Tea is found to exhibit synergistic hypolipidemic effect in comparison to black tea alone (De B *et al.,* 2019). These teas incorporate ingredients with known health-promoting properties, such as:

- **Detox and digestive teas:** Containing ginger, fennel, peppermint and dandelion.
- **Immunity-boosting teas:** Infused with turmeric, echinacea, and vitamin C.
- **Weight management teas:** Blended with green tea, Garcinia cambogia, and matcha.
- **Relaxation teas:** Featuring chamomile, valerian root, and ashwagandha.

4. Organic and Sustainable Tea

Organic tea, devoid of pesticides and chemicals, has grown in popularity as people become more concerned about their health and the environment. Sustainable farming practices promote ethical sourcing and environmentally favourable output.

5. Ready-to-Drink (RTD) Tea

RTD tea beverages offer convenience and are available in bottled, canned, or tetra pack forms. These may include:

- Iced tea with fruit infusions
- Kombucha (fermented tea rich in probiotics)
- Sparkling tea with added carbonation

6. Tea Extracts and Supplements

Tea extracts, concentrates, and powders are becoming used in food, beverages, and dietary supplements. Tea extracts, powders, and capsules deliver rich antioxidants and polyphenols. Green tea extract, for example, is commonly found in dietary supplements and beauty products. Catechin candy, green tea ice cream, catechin tea bar, matcha powder and vitamin fortified unsweetened high antioxidant enhanced flavoured catechin beverages are popular nutraceutical confections (Kuroda *et al.,* 2004).

B. Innovations in Processing Techniques

Advancements in processing have improved the quality and functionality of tea. Some notable developments include:

- **Cold brewing** to enhance flavour and reduce bitterness
- **Fermentation techniques** for probiotic-rich tea (e.g., kombucha)
- **Encapsulation technology** to improve the bioavailability of tea extracts in supplements

C. Market Trends and Consumer Preferences

Premium, organic, and ethically sourced teas are becoming increasingly popular among consumers, as is the demand for personalised tea experiences, such as DIY tea blends and subscription services.

D. Sustainable and Organic Tea Products

Consumers are increasingly seeking sustainable and organic tea products, encouraging manufacturers to implement environmentally responsible techniques. Organic certification, fair-trade sourcing, biodegradable tea bags, and environmental packaging are all important elements in purchasing decisions.

E. Personalized and Smart Tea Solutions

Technology is revolutionising the tea industry by providing personalised and smart tea solutions. Companies are using artificial intelligence (AI) and data analytics to produce personalised tea blends based on customer preferences and health requirements. Smart tea brewing gadgets that control temperature and steeping time are also becoming popular.

F. Challenges and Future Directions

Despite the growth of value-added tea, challenges remain:

- **Quality Control**: Maintaining consistency in flavour and health benefits across different batches.
- **Regulatory Compliance**: Meeting food safety and labelling regulations in different markets.
- **Sustainability Issues**: Addressing the environmental impact of large-scale tea production.

Future research may focus on improving extraction methods for bioactive compounds, enhancing sustainable packaging solutions, and exploring new plant-based ingredients for innovative tea formulations.

Conclusion:

The tea business is undergoing a rapid development, with a focus on value addition. Market growth is being driven by innovations in speciality teas, health-focused blends, functional beverages, and sustainable methods. As consumer preferences vary, the future of tea lies in variety, personalisation, and the incorporation of cutting-edge technologies. By embracing these trends, tea companies can improve the whole tea-drinking experience while also expanding their market share.

References:

1. Baruah S, Bordoloi AK, Hazarika M (2007) Tea Toffee - A Value-Added Products of Tea. Two and a Bud 54: 48-49.20.
2. Baruah S, Bordoloi AK, Hazarika M (2008) Diversified Products: Bakery items of tea - tea biscuits and tea cakes. Two and a Bud 55(1&2): 48-49.
3. Bhandari K, Satyanarayana VS, De B, Katakam P, Saha G (2019) Variancein Antioxidant Potentials and Neuroprotective Effect of Black Tea Dueto Seasonal Effect. Indo Glob J Pharm Sci 9(1): (In Press).
4. De B, Satyanarayana VS, Bhandari K, Katakam P, Saha G (2019) Synergistic Hypolipidemic Effect of Lemon Grass Tea. Indo Glob JPharm Sci 9(1): (In Press). *(PDF) Tea Diversification Products and Value Addition*. Available from: https://www.researchgate.net/publication/377316265_Tea_Diversification_Products_and_Value_Addition [accessed Jan 30 2025].
5. Kuroda Y, Hara Y (2004) Health effects of tea and its catechin. Kluwer Academic/ Plenum Publishers, New York, USA

ADVANCING CLIMATE-SMART IRRIGATION MANAGEMENT FOR AGRICULTURAL RESILIENCE IN THE CONTEXT OF CLIMATE CHANGE

Rajib Deka*[1], Tinkul Ingti[1], Debasish Borah[1] and Ankit Mandal[2]

[1]Department of Agronomy,

[2]Department of Agricultural Economics and Farm Management,

Assam Agricultural University, Jorhat, Assam, India

*Corresponding author E-mail: rajib.deka.amj24@aau.ac.in

Abstract:

India's agriculture sector, which employs over 55% of the workforce and contributes 18% to GDP, is facing severe water scarcity due to inefficient irrigation, groundwater depletion, and climate variability. Conventional irrigation methods, such as flood irrigation, result in up to 60% water losses through evaporation and seepage, exacerbating water stress in key agricultural states. India, the world's largest groundwater extractor, withdraws over 250 billion cubic meters annually, leading to alarming depletion rates of 0.5–1 meter per year in Punjab, Haryana, and Rajasthan. Additionally, increasing monsoon variability and rising temperatures intensify evapotranspiration, further straining water resources. Climate-smart irrigation management (CSIM) integrates precision irrigation, artificial intelligence (AI)-based decision support, and renewable energy technologies to enhance water-use efficiency (WUE) and climate resilience. Drip irrigation, supported by Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), reduces water use by 60% and increases crop yields by 30-40%, particularly in horticultural crops. Precision sprinkler irrigation improves WUE by 30-50%, while alternate wetting and drying (AWD) in rice farming cuts methane emissions by 30-50% and irrigation demand by 30%. AI and IoT-based irrigation systems optimize water allocation, reducing water use by 25%, while solar-powered irrigation, promoted under PM-KUSUM, lowers irrigation costs by 40-60% and mitigates carbon emissions. Despite proven benefits, CSIM adoption is limited by high initial costs, low digital literacy, and weak policy frameworks. Expanding financial incentives, strengthening groundwater governance, and developing low-cost AI-driven irrigation solutions are crucial for large-scale implementation. Future research should focus on nanotechnology-based soil amendments and adaptive irrigation strategies for diverse agro-ecological zones. CSIM is essential for ensuring sustainable water management, enhancing agricultural productivity, and achieving India's climate action commitments under the Paris Agreement.

Keywords: Climate-Smart Irrigation, Precision Irrigation, Groundwater Depletion, AI In Irrigation, Water-Use Efficiency, AWD, Iot Irrigation, Sustainable Water Management, Climate-Resilient Agriculture, Solar Irrigation

Introduction:

India, home to over 1.4 billion people, is one of the world's largest agricultural economies, with over 55% of its workforce engaged in farming (FAO, 2022). Agriculture contributes nearly 18% to the country's GDP, and the sector remains heavily dependent on irrigation, accounting for over 80% of total freshwater withdrawals (Ministry of Jal Shakti, 2021). However, climate change, coupled with inefficient irrigation practices, has intensified water scarcity, groundwater depletion, and erratic monsoons, threatening food security and rural livelihoods. Traditional irrigation systems, such as flood and canal irrigation, dominate Indian agriculture but suffer from low water-use efficiency (WUE), excessive evaporation, and high dependency on depleting groundwater reserves. Climate-smart irrigation management (CSIM) presents a transformative approach that integrates precision irrigation, artificial intelligence (AI)-based decision-support systems, and renewable energy solutions to optimize water utilization, enhance agricultural sustainability, and mitigate climate change impacts.

This chapter delves into the challenges posed by conventional irrigation systems in India, explores scientific advancements in CSIM, and evaluates the economic and environmental benefits of precision irrigation technologies. It also examines policy constraints, infrastructural barriers, and future research priorities to ensure the sustainable adoption of climate-smart irrigation across diverse agro-ecological regions in India.

The Imperative for Climate-Smart Irrigation in India

1. Groundwater Depletion and Over-Extraction

India is the largest user of groundwater in the world, extracting over 250 billion cubic meters annually, accounting for 25% of global groundwater withdrawal (Central Ground Water Board, 2021). States such as Punjab, Haryana, and Rajasthan have witnessed groundwater levels declining at an alarming rate of 0.5–1 meter per year due to over-reliance on tube well irrigation, exacerbated by the free electricity policies promoting unrestricted water use.

2. Inefficient Water Utilization in Irrigation

Traditional irrigation systems such as flood irrigation in paddy fields result in up to 60% water losses due to evaporation, seepage, and percolation (Sharma *et al.*, 2022). The widespread use of high delta crops like sugarcane and rice, particularly in water-stressed states such as Maharashtra and Punjab, further aggravates the water crisis.

3. Climate Variability and Erratic Monsoons

With over 50% of Indian agriculture still rainfed, increasing monsoon variability and prolonged droughts have led to crop failures, farmer distress, and reduced water availability for irrigation (IPCC, 2021). The rising frequency of heatwaves has also increased evapotranspiration rates, intensifying soil moisture deficits and amplifying the need for efficient water management strategies.

Advanced Climate-Smart Irrigation Technologies in India

1. Drip Irrigation and Subsurface Drip Irrigation (SDI)

Drip irrigation has emerged as a highly effective water-saving technique in India, particularly in states like Maharashtra, Karnataka, and Tamil Nadu where water scarcity is acute. The **Jal Shakti Abhiyan** and **Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)** promote micro-irrigation adoption, with studies showing water savings of up to 60% and a 30-40% increase in crop yields in horticultural crops such as grapes, bananas, and tomatoes (National Institute of Agricultural Economics and Policy Research, 2020).

2. Precision Sprinkler Irrigation Systems

Sprinkler irrigation is gaining traction, especially in semi-arid regions like Rajasthan and Gujarat, where groundwater recharge is limited. Precision sprinkler systems with automated flow control have demonstrated 30–50% water savings, reducing water wastage in wheat, maize, and mustard cultivation (Singh *et al.,* 2021).

3. Artificial Intelligence (AI) and IoT-Based Smart Irrigation

The adoption of AI-driven Internet of Things (IoT) irrigation systems in India is transforming farm management through real-time soil moisture sensing, weather prediction models, and automated irrigation scheduling. Startups like Fasal, Khetigaadi, and DeHaat have developed mobile-based irrigation advisory platforms that help farmers optimize water use. AI-based irrigation systems have resulted in up to 25% reduction in water usage while maintaining crop productivity in pilot projects across Andhra Pradesh and Telangana (NITI Aayog, 2022).

4. Alternate Wetting and Drying (AWD) for Rice Cultivation

Given that paddy rice accounts for nearly 50% of India's irrigation water use, AWD has emerged as a sustainable alternative to conventional continuous flooding. Research conducted by ICAR (Indian Council of Agricultural Research) indicates that AWD can reduce methane (CH_4) emissions by 30-50% and save up to 30% of irrigation water, without compromising rice yields (Richards & Sander, 2021). AWD is now being promoted in West Bengal, Odisha, and Tamil Nadu as a climate-smart rice irrigation practice.

5. Solar-Powered Irrigation Systems (SPIS)

India has witnessed a sharp increase in solar-powered irrigation, driven by initiatives such as the PM-KUSUM scheme, which provides subsidies for solar-powered pumps. SPIS has enabled farmers to reduce diesel dependency, bringing down irrigation costs by 40-60% while contributing to low-carbon agriculture (Burney *et al.,* 2017).

Economic and Environmental Benefits of CSIM in India

1. Enhancing Water-Use Efficiency and Crop Productivity

CSIM technologies have demonstrated 50–60% reductions in water consumption, while increasing crop productivity by 25-40%, particularly in horticulture, pulses, and oilseeds (Sharma *et al.,* 2022).

2. Financial Savings and Farmer Profitability

Precision irrigation systems reduce irrigation costs by 30-50%, while also lowering fertilizer application through fertigation systems, improving overall farmer income.

3. Contribution to Climate Change Mitigation

By optimizing water management and reducing GHG emissions, CSIM contributes to India’s Nationally Determined Contributions (NDCs) under the Paris Agreement and promotes low-carbon agricultural development.

Challenges and Future Policy Directions

1. Barriers to Large-Scale CSIM Adoption

- High initial investment costs for precision irrigation technologies.
- Limited access to real-time data and digital literacy among smallholder farmers.

2. Strengthening Policy Frameworks

- Expanding subsidies and financial incentives under PMKSY and PM-KUSUM for CSIM adoption.
- Strengthening water governance frameworks to regulate groundwater withdrawal and efficient irrigation practices.

3. Future Research Priorities

- Developing low-cost, AI-driven irrigation solutions tailored for resource-constrained farmers.
- Advancing nanotechnology-based soil amendments for improved water retention.

Conclusion:

Climate-smart irrigation management (CSIM) is imperative for ensuring sustainable and climate-resilient agriculture in India. By integrating precision irrigation, AI-based decision support, and renewable energy-driven irrigation systems, CSIM enhances water efficiency, increases farm profitability, and contributes to India's climate action goals. Future policies must prioritize scalability, affordability, and inclusivity, ensuring widespread adoption of sustainable irrigation technologies to safeguard India’s food and water security.

References:

1. Food and Agriculture Organization (FAO). (2022). *The state of food and agriculture: Overcoming water challenges in agriculture.* FAO. Retrieved from https://www.fao.org/3/cc0630en/cc0630en.pdf
2. Intergovernmental Panel on Climate Change (IPCC). (2021). *Climate change 2021: The physical science basis.* Contribution of Working Group I to the Sixth Assessment Report. Cambridge University Press. Retrieved from https://www.ipcc.ch/report/ar6/wg1/
3. Central Ground Water Board (CGWB). (2021). *Annual groundwater report: Status of groundwater development and management in India.* Ministry of Jal Shakti, Government of India. Retrieved from http://cgwb.gov.in/
4. Richards, M., & Sander, B. O. (2021). Alternate wetting and drying in irrigated rice: Constraints and opportunities for scaling up. *Agricultural Systems, 191,* 103142. https://doi.org/10.1016/j.agsy.2021.103142
5. Sharma, R., Kumar, S., & Verma, P. (2022). Groundwater depletion and its impact on agriculture in North India: A case study of Punjab and Haryana. *Environmental Research Letters, 17*(2), 245-260. https://doi.org/10.1088/1748-9326/ac32d7
6. Singh, R., Mishra, D., & Patel, K. (2021). Precision irrigation technologies and their adoption in India: A review. *Agricultural Water Management, 256,* 107059. https://doi.org/10.1016/j.agwat.2021.107059
7. National Institute of Agricultural Economics and Policy Research (NIAP). (2020). *Micro-irrigation and agricultural productivity: Policy perspectives for India.* Indian Council of Agricultural Research (ICAR). Retrieved from https://icar.org.in/
8. Burney, J., Woltering, L., Burke, M., Naylor, R., & Pasternak, D. (2017). Solar-powered drip irrigation enhances food security in the Sudano-Sahel. *Proceedings of the National Academy of Sciences, 107*(5), 1848-1853. https://doi.org/10.1073/pnas.0909678107
9. Ministry of Jal Shakti, Government of India. (2021). *India water resources and management strategies.* Retrieved from https://jalshakti-dowr.gov.in/
10. Indian Council of Agricultural Research (ICAR). (2022). *Irrigation management in rice-based cropping systems of India.* New Delhi: ICAR Publications. Retrieved from https://icar.org.in/
11. NITI Aayog. (2022). *Artificial intelligence in agriculture: Trends and opportunities in India.* Government of India. Retrieved from https://www.niti.gov.in/
12. Ministry of New and Renewable Energy, Government of India. (2022). *PM-KUSUM Scheme: Solar energy for irrigation – A policy review.* Retrieved from https://mnre.gov.in/

CURRENT TRENDS IN AGRICULTURAL RESEARCH

K. R. Kartheeswari[1] and R. Balamurugan[2]
[1]Department of EEE,
Mohamed Sathak AJ College of Engineering, Chennai
[2]Department of Advanced Computing & Analytics, School of Computing Sciences,
Vels Institute of Science Technology and Advanced Studies, Chennai
Corresponding author E-mail: eee.kartheeswari@msajce-edu.in, bmurugan.scs@vistas.ac.in

Introduction:

Agriculture has been the backbone of human civilization, providing food, fiber, and raw materials for industries. With the rapid growth of the global population and climate change challenges, agricultural research is increasingly focusing on technological innovations, sustainability, and efficiency. This chapter explores key emerging trends in agricultural research that are shaping the future of food production and resource management.

Precision Agriculture and Smart Farming

Precision agriculture integrates advanced technologies like the Internet of Things (IoT), artificial intelligence (AI), and remote sensing to optimize farm productivity. Drones, soil sensors, and GPS-guided machinery allow real-time monitoring of crop health, soil moisture, and nutrient levels, reducing waste and increasing efficiency (Zhang *et al.*, 2020). Automated irrigation and fertilization systems enhance water conservation and ensure balanced nutrient supply.

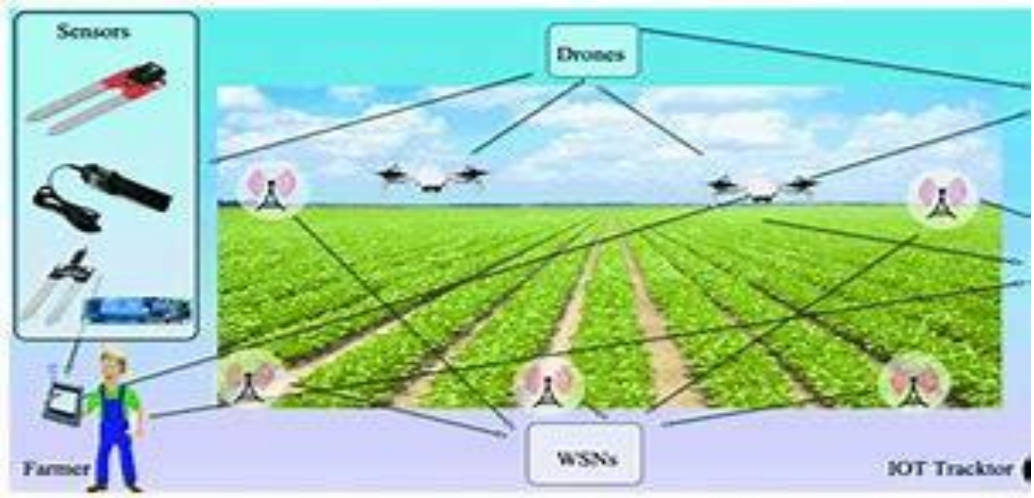


Figure 1: Precision Agriculture and Smart Farming
(Course: https://www.mdpi.com/2073-4395/12/1/127)

3. Sustainable and Climate-Resilient Agriculture

Climate change poses a significant threat to global agriculture, necessitating the development of climate-resilient practices. Conservation agriculture techniques, such as minimal tillage and crop rotation, improve soil health and carbon sequestration (Lal, 2019). Additionally, research on climate-resilient crops, including drought- and heat-tolerant varieties, is critical for ensuring food security in changing environmental conditions.

Figure 2: Sustainable and Climate-Resilient Agriculture

(Source: https://www.smsfoundation.org/climate-resilient-agricultural-practices/)

4. Biotechnology and Genetic Engineering

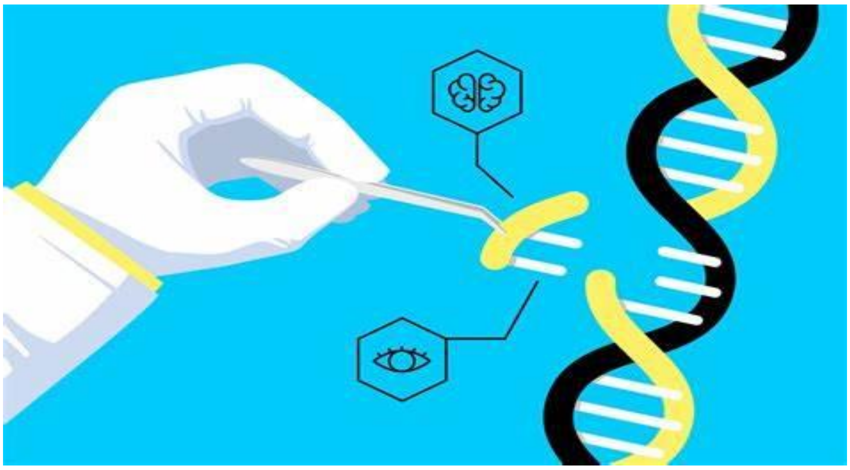


Figure 3: Biotechnology and Genetic Engineering

(Source: https://theisozone.com/genetic-engineering-pros-and-cons/)

Advancements in genetic engineering, particularly through CRISPR and gene-editing technologies, have enabled the development of high-yield, pest-resistant, and climate-adaptive crop varieties (Jaganathan *et al.*, 2018). Genetically modified organisms (GMOs) have played a crucial role in increasing productivity while reducing dependency on chemical pesticides and fertilizers. However, regulatory and ethical concerns continue to shape the adoption of biotech solutions in different regions.

5. Urban Agriculture and Vertical Farming

Urbanization has led to a growing interest in alternative farming methods such as vertical farming, hydroponics, and aeroponics. These techniques allow food production in controlled environments with minimal land use, reducing the impact of transportation and enhancing food security in urban areas (Despommier, 2010). Advances in LED lighting and nutrient delivery systems have further improved efficiency and productivity.

Figure 4: Vertical Farms in Cities are the Future of Urban Farming

6. Alternative Protein Sources and Sustainable Livestock Management

The rising demand for protein has driven research into alternative sources, such as plant-based proteins, insect farming, and lab-grown meat. Sustainable livestock management practices, including precision feeding and methane emission reduction strategies, are also gaining attention (Steinfeld *et al.*, 2006). These innovations aim to minimize environmental impact while meeting nutritional needs.

Figure 5: Transition to Alternative Proteins Continues (Food Engineering)

7. Role of Big Data and Blockchain in Agriculture

Big data analytics and blockchain technology are transforming agricultural supply chains. Predictive analytics assist farmers in making data-driven decisions on crop selection and pest management. Blockchain enhances traceability and transparency in food supply chains, reducing fraud and improving food safety (Tripoli & Schmidhuber, 2018).

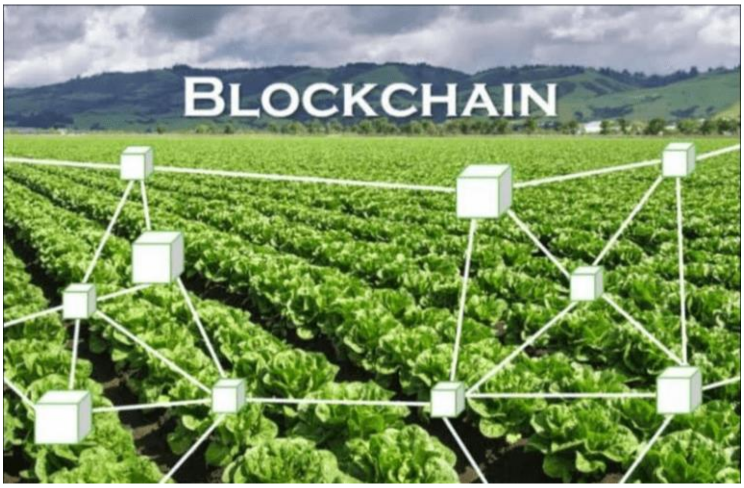


Figure 6: Blockchain Technology in Agriculture

(Source: https://agric4profits.com/blockchain-technology-in-agriculture/)

8. Future Prospects and Challenges

While technological advancements in agriculture offer promising solutions, challenges such as high implementation costs, limited technical knowledge, and regulatory barriers hinder widespread adoption. Policies supporting research, education, and infrastructure development are crucial for enabling sustainable agricultural progress.

Figure 7: Future agriculture techniques

(Source: https://gmo-research.com/news-events/articles/future-agriculture-smart-farming)

Conclusion:

Agricultural research is evolving rapidly to address food security, environmental sustainability, and economic viability. Precision farming, biotechnology, urban agriculture, alternative proteins, and digital innovations are reshaping the agricultural landscape. Continued research and investment in these areas will be key to ensuring a resilient and productive agricultural sector in the future.

References:

1. Despommier, D. (2010). *The Vertical Farm: Feeding the World in the 21st Century*. Thomas Dunne Books.
2. Jaganathan, D., Ramasamy, K., Sellamuthu, G., Jayabalan, S., & Venkataraman, G. (2018). CRISPR for crop improvement: An update review. *Frontiers in Plant Science, 9*, 985.
3. Lal, R. (2019). Soil health and carbon management. *Food and Energy Security, 8*(2), e00164.
4. Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & de Haan, C. (2006). *Livestock's Long Shadow: Environmental Issues and Options*. FAO.
5. Tripoli, M., & Schmidhuber, J. (2018). *Emerging opportunities for the application of blockchain in the agri-food industry*. FAO and ICTSD.

Current Trends in Agricultural Research Volume I

ISBN: 978-93-48620-41-5

About Editors

Dr. V. Swarna Latha is working as Senior Scientist in Professor Jayashanakar Telangana Agricultural University (PJTAU). She obtained her Bachelor's Degree in Agriculture from Acharya N.G.Ranga Agricultural University (ANGRAU), M.Sc (Genetics and Plant Breeding) from University of Agricultural Sciences, Dharwad and Ph.D (GPBR) from Professor Jayashanakar Telangana State Agricultural University (PJTSAU). She has qualified NET (ASRB-ICAR) in Genetics and Plant Breeding. She has an extensive research experience of more than 18 years with research interest in Genetics and Plant Breeding, Biotechnology and Seed Technology. She has published over 45 research papers in reputed NAAS rated Journals and several book chapters. She participated and presented research papers in several seminars, symposiums and conferences. She is a proud member of various professional societies.

Dr. T.Radhamani is currently a Teaching Assistant at Centre for Plant Molecular Biology and Biotechnology, Tamil Nadu Agricultural University, Coimbatore, India. She is a graduate in Agriculture and received Masters and Ph. D. in Plant Breeding & Genetics from the Tamil Nadu Agricultural University in the year 2012 and 2016 respectively. She had been provided liberal monetary support for doing Postgraduate and Doctoral programmes such as Tamil Nadu State Council for Science and Technology Fellowship and Student's SRF Fellowship from TNAU respectively. She is involved in teaching biotechnology practical courses for undergraduate. She has published about 13 research papers in various National & International Journals with the considerable impact factors. She also has published 13 book chapters and 13 popular articles in the Agricultural issues of periodic intervals. She was awarded with gold medal for best editor from Agricultural Scientific Tamil Society, New Delhi during 2020.

Kiran Kotyal, completed his B.Sc. (Hons.) in Home Science from the University of Agricultural Sciences, Dharwad and an MBA in Agribusiness Management from the Institute of Agri-Business Management, University of Agricultural Sciences, Bangalore. He is currently pursuing a Ph.D. in Agribusiness Management at the Institute of Agri-Business Management, University of Agricultural Sciences, Bangalore. Mr. Kiran has four years of research experience, specializing in Agribusiness Management, Agricultural Economics, Supply Chain Management, Commodity Market Analysis, Supply Chain Management and Trade Economics. He has contributed to numerous publications, including research paper, research articles, popular articles, conference papers, book and book chapters. He has received several awards for his presentations and research contribution at various conferences.

Dr. Shakun Mishra is the Head of the Department of Botany at Govt. S. N.P.G. College, Khandwa (M.P.), India. She has 40 years of UG and 30 years of PG teaching experience and has been actively engaged in research for two decades. She earned her Ph.D. in 2011 from D.A.V.V. Indore, focusing on the ethnobotany of Korku, Gond, and Nihal tribes of East Nimar. Dr. Mishra has published 70 research papers, eight book chapters, and served as an associate editor for eight books. She has presented over 60 papers at national and international conferences and has been a guest lecturer and chairperson at national seminars. A Fellow/Life Member of 10 research societies, she serves on the editorial board of two journals. She has received prestigious awards like F.I.C.C.E., F.S.L.Sc., and F.E.S. and completed a U.G.C.-funded research project. She is also an ex-chairperson of BOS in Botany and related subjects.

Bhumi Publishing

ISBN 978-93-48620-41-5