SYSTEMS IN AGRI-HORTI
INTERVENTIONS IN THE MODERN ERA

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INTERVENTIONS IN THE MODERN ERA

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Preface

In the ever-evolving landscape of agriculture and horticulture, where traditional practices meet cutting-edge technology, a profound transformation is underway. This transformation is not just a response to the demands of a growing global population, but also a testament to the resilience and adaptability of the human spirit. The book you hold in your hands, **"Systems in Agri-Horti Interventions in the Modern Era"**, explores this dynamic realm where science, nature, and innovation converge to redefine the way we grow and sustain our food.

The role of agriculture and horticulture has never been more critical, as our world faces challenges such as climate change, resource scarcity, and an ever-expanding need for sustenance. In the face of these challenges, we have seen the emergence of novel approaches and systems that are revolutionizing how we produce, manage, and distribute agricultural and horticultural products. This book delves deep into these emerging systems, shedding light on their principles, practices, and impacts on the modern world.

Through a comprehensive exploration of Agri-Horti interventions, this book aims to equip readers with a holistic understanding of the intricate web of factors that shape our food systems today. From precision agriculture and sustainable farming practices to innovative horticultural techniques and advanced crop management, this book is a journey through the multifaceted world of modern Agri-horticulture. We delve into the use of cutting-edge technology, such as drones, alongside timeless wisdom passed down through generations of farmers and gardeners. This integration of old and new, tradition and innovation creates a tapestry of knowledge that is both inspiring and essential in our pursuit of sustainable food systems.

This book is a collaborative effort, bringing together the expertise of researchers, practitioners, and visionaries from all over the globe. Each chapter is a contribution to the broader conversation on how to harness the potential of Agri-Horticulture for a more resilient, productive, and sustainable future. Whether you are a student, a researcher, a farmer, a horticulturist, or simply someone with a deep curiosity about the world of agriculture and horticulture, this book is designed to be a valuable resource and an invitation to explore the opportunities and challenges that lie ahead.

The journey through the pages of this book will undoubtedly reveal the intricate relationships between plants, people, and technology in the pursuit of a better tomorrow. We hope that this book will serve as a source of knowledge, inspiration, and a call to action for all those who are dedicated to shaping the future of Agri-Horticultural systems in the modern era.

We extend our deepest gratitude to the contributors who have shared their expertise and insights, as well as to the readers who embark on this journey with us. The future of agriculture and horticulture is an evolving narrative, and we are all stakeholders in its transformation. Together, we can cultivate a sustainable and prosperous future for our world.

Acknowledgement

We would like to express our heartfelt gratitude to the writers who have played a pivotal role in the creation and realization of this book entitled ***"Systems in Agri-Horti Interventions in the Modern Era"***. Their unwavering support, expertise, and dedication have been instrumental in shaping the work.

First and foremost, we extend our sincere appreciation to our families for their unwavering support and understanding. Their belief in us has been the driving force behind this book.

We would also like to express my deep gratitude to our mentors and advisors for their substantial contributions and expertise in the subject matter. Their unwavering commitment to the advancement of agricultural and horticultural practices has left an indelible mark on this book.

We also thank Empyreal Publishing House, our publisher, and the editing staff for their hard work and skill, which have helped to turn the manuscript into a polished book.

Finally, we would want to express our gratitude to my friends and co-workers for their encouragement and support in helping me finish this project. Your steadfast faith in me has served as a continual source of motivation.

Lastly, we would like to express our gratitude to all of our readers for joining us on this thought-provoking journey. Your open-mindedness and curiosity motivate writers like us to keep pushing the boundaries of knowledge.

In conclusion, we express our gratitude to everyone who has helped with this book, whether directly or indirectly. We really appreciate your participation and support, which have been crucial to the creation of the book ***"Systems in Agri-Horti Interventions in the Modern Era"***.

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About the Editors

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Ms. Laiphrakpam Pinky Chanu has completed her graduation (B.Sc. Agriculture) from HNB University, Garhwal, Srinagar, and postgraduate (M.Sc. Agri.) from Manipur University, Canchipur, Manipur. She has participated in two National seminars and published two research papers. One review paper has also been submitted. She has been working as a guest faculty member at Lilong Haoreibi College, Lilong, Manipur. Her research interests include the study of the management of bacterial wilt in solanaceous crops and the use of bacteriophages as a biocontrol agent for bacterial diseases.

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CHAPTER 1

ARTIFICIAL INTELLIGENCE AND ROBOTICS IN AGRICULTURE

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ABSTRACT
The agricultural sector has been transformed by artificial intelligence (AI) and robotics, which have the capability to completely reshape the industry as a whole. A fundamental need exists to increase agricultural production and sustainability as the global population continues to grow and food demand rises. The numerous uses of artificial intelligence (AI) in agriculture are examined in this abstract, with a particular emphasis on the crucial roles that these technologies play in farm management systems, crop monitoring, and disease detection. Digital technologies like big data, artificial intelligence (AI), robotics, the Internet of Things (IoT), and virtual and augmented reality have already begun to improve the efficiency of farming practises. This data-driven strategy enables farmers to efficiently produce and sustain crops on arable land, allowing them to make the most of the resources at their disposal. Aspart of an effort to shed light on their potential effects in the field of agriculture, a variety ofAI and robotics technologies, with an emphasis on expert systems, robots created for agriculture, and sensors technology for data collection and transmission.

Keyword: AI, robotics, precision agriculture, smart farming, sustainability

INTRODUCTION
Humans are affected by agricultural activities in so far as their dietary needs for energy-dense foods are concerned. The majority of agricultural operations are still carried out in a conventional manner, leading to non-profitable and non-economic farming. Traditional farming without AI and robotics suffers from more time-consumption and effort to manually monitor crops' health and identify diseases, involves more human resources for handling the various agriculture processes, lacks accurate information on weather, soil conditions, and the use of fertilisers, requires labour for pesticide spraying that has an adverse effect on farmers' health as well as lowers crop productivity, and uses subpar storage techniques for harvested food (Wakchaure *et al*., 2023). Any crop's growth cycle comprises three basic phases: cultivation, monitoring, and harvesting. Each phase includes a variety of tasks. Planning and decision-making are crucial in agriculture. The farmer's planning for the crop growth cycle is impacted by the abrupt climate shift (Shahjalal *et al*., 2021).

Robotics, specialised systems, machine learning, language processing, computer vision, and brain networks are only a few of the subfields and methodologies that make up artificial intelligence (Naik *et al*., 2023). Artificial intelligence (AI) in agriculture is being used to solve issues in the seven primary agriculture domains (Figure 1): crop management, water management, soil management, ferti-irrigation, crop prediction, crop classification, disease management, and pest management (Oliveira *et al*., 2023). Over the past years, agriculture has steadily embraced artificial intelligence (AI), with adoption rates rising in recent years.

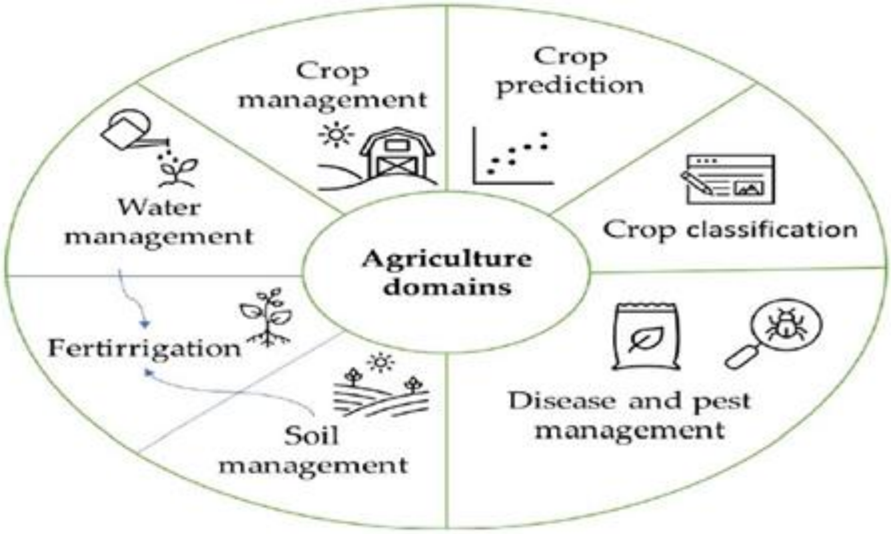

Figure 1: AI and robotics in agriculture domains Source: Adapted from Oliveira *et al.* 2023

In the early 2000s, the idea of precision agriculture, which uses technology for site-specific crop management, first gained popularity. By utilising data collecting techniques like GPS, yield monitoring, and remote sensing, this established the groundwork for the use of AI technology in agriculture. Agricultural surveillance and data collection with autonomous drones has become an important tool. Additionally, many of the younger generations are disengaging from agricultural activities owing to a lack of information, experience, and issues associated with agriculture, which will surely exacerbate the issue of future food supply and demand. To address all of these problems, the agricultural development revolution occurred between 1.0 and 4.0 (now). The most cutting-edge AI-based technology, wherein the machine itself takes judgements for resolving in-the-moment challenges, is replacing the conventional agricultural method. The next stage of agricultural growth is known as "agriculture 5.0," and it builds on the preceding "digital revolution" in agriculture with the goal of making agriculture more intelligent, efficient, and ecologically conscious (Balaska *et al.*, 2023).

Advancements are still being made in fields like robotics, computer vision, machine learning, and data analytics since the application of AI to agriculture is still a work-in-progress. By allowing more effective and sustainable agricultural methods, AI is predicted to play a bigger part in revolutionising agriculture. Aerial and satellite data analysis using machine learning algorithms allowed farmers to more precisely predict production potential, monitor crop health, and find diseases in their crops. Robots and automated systems using AI have been developed to carry out a variety of agricultural activities. To manage tasks like planting, weeding, and harvesting, these systems made use of computer vision, machine learning, and robotic automation. Autonomous drones also became valuable tools for monitoring crops and collecting data. The introduction of AI in agriculture is an ongoing process, and advancements continue to be made in areas such as robotics, computer vision, machine learning, and data analytics. AI is expected to play an increasingly prominent role in transforming agriculture by enabling more efficient and sustainable farming practices.

Artificial Intelligence and Robotics in Agriculture

The science of raising livestock and growing crops is known as agriculture, meaning it is the cultivation of land. The cultivated agricultural plant is their primary production unit, and the physical environment is their main resource base. The difficulty in agriculture is effectively managing the physical environment to meet the biological requirements of the crop plant. The

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main elements that affect agricultural output are soil fertility, water accessibility, climate, and pests and diseases (Elavarasan *et al.*, 2018). Through the optimization of processes and resources, AI is revolutionizing the agriculture industry in all aspect of agriculture domains (Table 1).The use of AI and robotics has improved efficiency in a variety of fields, including crop management by rationalizing resource usage, water management to maximize irrigation and water use on farms, soil management for success cropping systems management and chemical application in the right amounts, fertigation can help fertilizer effectiveness, crop prediction or crop yield prediction is a crucial topic for efficient and sustainable resource utilization, crop classification refers to which crops are grown and can combine image processing and deep learning and finally, management of diseases and pests, which affect crop yield and quality, can increase productivity and significantly contribute to food security.

Table 1: AI and Robotics application domain in agriculture

AI and robotics application domain	Description	References
Crop management	Covers seed sowing, maintenance, harvesting, storage and distribution	Wolfert *et al*. 2017
Water management	Optimizing water usage through irrigation techniques and processes.	Talaviya *et al*. 2020
Soil management	Assuring plant nutritional sufficiency	Delnevo *et al*. 2022
Fertigation	Technology that aims at the application of fertilizers via irrigation water	Lin *et al*. 2020
Crop prediction	Variety of weeds, animals, and microorganisms that threaten agricultural crops requires technology for their	Bali *et al*. 2022
Crop classifications	Crop classification aims to offer a global understanding of crop distribution and information for another application domain.	Albarrak *et al.* 2022
Disease and pest management	Affect crop yields and quality and reduces resource use efficiency. The wide variety of weeds, animals, and microorganisms that threaten agricultural crops requires technology for their protection	Lucas *et al.* 2011

Role of AI and robotics in Agriculture

By enhancing conventional farming's efficiency and removing its obstacles and limitations, artificial intelligence-based solutions enhance agriculture. Artificial intelligence (AI) refers to the process by which people create synthetic machines that are akin to the human brain but are capable of processing bigger amounts of data than the brain. AI naturally belongs in the discipline of computer science, but it should go beyond its bounds to benefit agriculture (Jha *et al*., 2019). AI has been used to produce a variety of technological tools and instruments that have been tested on agricultural fields and optimized. They have been successful in creating a number of agricultural field-steps, including soil testing, weeding, pesticide control, treating diseased crops, inadequate irrigation to meet crop needs, post-harvest activities like storage management and storage parameter optimization, etc. Farmers have enhanced both the quantity and quality of their output (Talaviya *et al*., 2020).

Contrarily, AI can be used in agriculture to reduce environmental concerns brought on by unfavourable agricultural practices, such as the high use of pesticides, unregulated irrigation that results in water loss, and water contamination with fertilizers. AI implementation might be beneficial in both of these areas. In the past, numerous scientists have proposed and constructed different AI systems for numerous plantations (Bannerjee *et al*., 2018). Utilizing AI-based

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technologies' primary goal is to decrease the amount of labour required to provide the desired output. Additionally, problems that humans are unable to answer are readily addressed by AI-based gadgets because of their capacity to collect and analyse vast volumes of data from official websites up to real-time field data. They can then offer solutions to issues that, if produced by people, would require a lot of effort and sophisticated knowledge. Farmers with the necessary abilities will also need to be trained in these AI technologies because AI requires training with the biological skills of the farmer and vice versa.

AI technologies in Agriculture Crop or seed selection

The key to maximizing yields and assuring uniformity in production has always been seeds with high vigor, good germination, and a high seedling emergence rate that have always guaranteed emergence even under a variety of agricultural situations. A phenotyping tool called SeedGerm was created through machine learning-based phenotypic analysis and automated seed imaging. SeedGerm can evaluate seed batch success by measuring morphological changes and scoring germination, which in turn rates seedling vigor. Officials may use these characteristics when issuing germination certificates (Colmer *et al*., 2020). Kumar *et al*. (2015) proposed the crop selection method (CSM), a brand-new methodology.

Crop management practices

Sensors and embedded systems have been developed that support the growth conditions in a growth chamber, such as light intensity, humidity, and O_2 and CO_2 levels. In real time, they can adjust crop conditions to match optimized parameters based on the most recent crop growth data (Lakhiar *et al*., 2018). A technical company called Trace Genomics uses soil samples from agricultural lands to harvest DNA and count the bacteria living there. Machine learning methods are used to analyse the soil data. The biological and chemical characteristics of the soil sample are integrated to provide the farmer with recommendations that are finally evidence-based on historical occurrence data. This would assist in deciding which crop would be better for the land or vice versa.

Crop production requires a steady supply of water that is also easily accessible. It is strongly encouraged not to use more water resources than the crop actually needs because freshwater is so scarce. As a result, AI technologies that capture real-time data on the quantity of soil moisture and the weather could adjust the amount of water required and automate the beginning and ending of the water supply (Talaviya *et al*., 2020). A couple of these AI-powered automated irrigation techniques were enumerated by Kumar *et al*. (2015). According to Mahmood *et al*. (2016), excessive pesticide use poses dangers to human health, biodiversity, and the ecosystem by posing eutrophication risks to the streams and endangering human health. The amount of pesticide typically sprayed can be reduced by up to 55% thanks to the invention of the "Rover" by Facchinetti *et al*. (2021), which also improves crop coverage.

Weather Forecasting

For many different industries, including agriculture long-term weather forecasts are essential. AI technologies are assisting in the solution of this problem. Farmers can learn about weather analysis and prepare for the type of crop to grow, the seeds to sow, and the crop to be harvested by using artificial intelligence (AI) weather forecasting (Naik *et al*., 2023). Machine learning algorithms can examine enormous volumes of data and find minute patterns that can point to long-term trends in the weather. These detailed and more precise long-term projections made possible by AI can offer useful information for planning and decision-making. More accurately than ever, meteorologists can use AI to forecast the occurrence, severity, and course of extreme weather phenomena.

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Yield Prediction

Given that yield and profit are the primary goals of all forms of agriculture, prediction models are one of the top AI strategies that farmers are most likely to accept. Before predicting the yield, soil type, soil nutrient concentration, crop data, and weather variables are examined (Van Klompenburg *et al*., 2020).

Pest and Weed Management

In order to limit the waste of weedicide and crop exposure to agrochemicals, Partel *et al*. (2019) offer a strategy for creating automated machines that might specifically recognize weeds and spray them with agrochemicals. Pest management programs include Pasqual and Mansfield, SMARTSOY, and CORAC (Bannerjee *et al*., 2018).

Storing and Marketing Products

Before reaching the consumer, agricultural products must be stored in the right conditions to maintain quality. In storage chambers, several sensors have been designed to extend the shelf life of these items after harvest. Traditional farmers only have a basic understanding of the conventional markets for their products, but market data can suggest the next round of crops to farmers by accurately analysing current market trends, pricing decisions, and consumer consumption information (Talaviya *et al.*, 2020). By employing price forecasting to obtain accurate information about the price of crops for the future few weeks, farmers may increase their profit (Naik *et al*., 2023).

Internet of Things (IoT)

New scientific advancements like IoT-based technologies are becoming more and more necessary in a variety of agricultural systems for a wide range of applications (Table 2) as we move toward more cultured and urban farming. They contribute to the improvement of several farming techniques that increase productivity while preserving or reducing the influence on the product's originality. IoT smart agricultural solutions are made to help monitor crop fields using sensors and by automating watering systems. As a result, farmers and related enterprises may conveniently and hassle-free monitor field conditions from anywhere.

Table 2: IoT application in agriculture

IoT technology	Application
IoT- based soil sampling	AgroCares 'Lab- in- a- Box' soil testing toolbox is regarded as a complete laboratory in and of itself because of the extensive services it offers. It may be used by any farmer, independent of lab experience, to analyze up to 100 samples each day without having to go to a lab.
IoT- Based Disease and Pest Monitoring	By precisely identifying crop pests with IoT-based smart technologies, such as wireless sensors, drones, and robots, farmers may significantly reduce their use of pesticides. IoT-based autonomous traps may gather, tabulate, and even describe different pest species before uploading the information to the cloud for thorough study. This Internet of Things-based pest monitoring device can help restore the natural climate while lowering overall costs.
IoT-Based Fertilization	With little labor required, new IoT-based fertilization systems help with the precise assessment of spatial patterns of fertilizer requirements. For instance, the normalized difference vegetation index (NDVI), which assesses crop nutrition, is solely dependent on the reflection of visible and near-infrared light from plants. Such precise execution can significantly increase fertilizer effectiveness while simultaneously preventing negative environmental effects. Variable rate technology (VRT), geo-mapping, GPS precision, autonomous cars, and other IoT-

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	based technologies are now influencing smart fertilization.
IoT-Based Irrigation	It is anticipated that adoption of impending IoT technology may alter current watering practices. Crop efficiency is anticipated to significantly increase as a result of the use of IoT-based solutions, such as irrigation management based on the crop water stress index (CWSI). CropMetrics' variable rate irrigation (VRI) optimization, which takes into account topography or the heterogeneity of the soil, improves the efficiency of water use.

Various multipurpose technologies such as mobile applications, cloud computing, communication technologies, etc., are being utilized in IoT- based farming in agriculture. In order to use the IoT in advanced farming, communication technologies such Wi-Fi, LoRaWAN, mobile communication, Zigbee, and Bluetooth can be employed (Jawad *et al.*, 2017). With the help of these technologies, the entire agricultural process may be automated, speeding up and improving agriculture.

Robotics in Agriculture

Due to advancements in technology, interest in robotics applications in agriculture has increased. These applications transform mundane fieldwork into inventive technical activities that are highly advantageous. Even though many of the current crop of agricultural robots are still in the prototype stage, they can already do a variety of tasks like planting, field inspection, data collection, weed control, precise spraying, and harvesting. Some of the robots being used in this sector for various tasks are recorded in Table 3.

Planting

The process of planting necessitates a great deal of uniformity and precision, and it frequently involves a sizable agricultural area, so it requires a big amount of time and effort. Autonomous systems have been developed to address the challenges with human planting for several crops, including corn, wheat, sugarcane, and vegetables (Shi *et al.*, 2019). An autonomous seeding robot was developed using the Agribot platform. In this research, an infrared (IR) sensor was used to both identify the rows and check the integrity of the seed tank, and it achieved reasonable results in terms of accuracy in the spacing between the seeds (Naik *et al.*, 2016). The automated planting method would therefore be significantly more effective and suitable for farmers in the near future with better planting quality (Mahmud *et al.*, 2020).

Weed Control and Spraying

Weed management and accurate spraying are two of the most common farm tasks performed by field robots. Robotic targeted spraying for weed management has produced good results and reduced pesticide use to as little as 5- 10% as compared to blanket spraying (Pinheiro & Gusmo, 2014). As a result of interdisciplinary collaboration initiatives across numerous international research organizations, various possible weed robots have been introduced and put into use during the past ten years; nevertheless, they have not yet been fully commercialized. According to some reports, these robots can cut the use of weed herbicides by 80–90% (Molina *et al.*, 2011).

Field Inspection and Data Collection

The use of automation in agricultural inspection necessitated the creation of a system that could conduct the inspection process without the need for human eyesight. Because of this, computer vision is rapidly being used to replace human eyesight while inspecting plants for agriculture. Ayaz *et al.* (2019) claim that computer vision, a cutting-edge image processing technique, has the potential to take the role of human eyesight in some inspection activities. A camera mounted in a fixed location on a mobile robot or a drone is often used for autonomous inspection. The self-governing strategy and its implementation in the inspection method will improve the accuracy and efficacy of disease prevention and commodity quality testing, ensuring future food security. For improved farming, scouting robots for data collecting entails a significant use of cutting-edge sensors (Patmasari *et al.*, 2018).

Harvesting

The yield and affordability of modern food production will be guaranteed by increased harvesting efficiency and decreased labor expenses. As a result, implementing autonomous harvesting using robots should be thought of as a different solution to the problem of costs and labor shortages. The autonomous recognition of fruits from multiple images or based on the fusion of color and 3D features (Barnea *et al.*, 2016), multi-template matching algorithms (Bao *et al.*, 2016), symmetry analysis, combined color distance method, and RGB-D data analysis for apples (Garrido-Novell *et al.*, 2012), and sweet-peas (Lavanya *et al.*, 2020), apple detection using stereo vision, fruit recognition and obstacle avoidance in dense foliage using convolutional neural networks (Zhao *et al.*, 2016).

Drones in agriculture: Various farming activities, including crop monitoring, crop spraying, soil analysis, and mapping, are improved and optimized. In fact, one of the key industries to use drones is agriculture. Farm imaging, farm mapping, and farm surveying are all done using drones that include sensors and cameras. Both aerial and ground-based drones are available. Ground drones are mobile robots that survey fields. Aerial drones are flying robots, also referred to as unmanned aerial vehicles (UAVs) or unmanned aircraft systems (UAS). Drones can be operated remotely or they can fly automatically thanks to flight plans that are software-controlled and coordinated with sensors and GPS in their embedded systems. Information about crop health, irrigation, spraying, planting, the soil and field, plant counts, yield forecast, and much more may be gleaned from the drone data. Drone surveys can be planned in advance (drone as a service) or drones can be purchased and kept close to farms where they can be repaired and recharged. After the surveys, the drones must be transported to neighbouring labs for data analysis, which will improve the use of IoT in agriculture.

Table 3: Robotics application in agriculture

Robots	Applications	References
VinBot	Autonomous image acquisition. 3D data collection for yield estimation	Shamshiri *et al.* 2018
BoniRob	Weed control for row crops. Field mapping	Bakken *et al.* 2019
AgBot	Autonomous fertilizer application. Weed detection and sorting. Chemical or mechanical weed control.	Redhead *et al.* 2015
MARS	Optimizing plant- specific precision agriculture.	Fountas *et al.* 2020
Ladybird	Surveillance and mapping. Classification and detection of differentvegetables.	Bender *et al.* 2019
SMP S4	Bird and pest control.	Shamshiri *et al.* 2018
Vine agent	Health monitoring of plants.	Arguenon *et al.* 2006
Mantis	Field data collection.	Stein *et al.* 2016
GRAPE	Plant detection. Health monitoring. Manipulation of small objects.	Roure *et al.* 2017

AI and robots in agriculture: Advantages

Improves decision-making: The agriculture sector benefits greatly from predictive analytics. It assists farmers in resolving significant farming issues, including market demand analysis, price forecasts, and determining the best window of time to plant and harvest a crop.

Cost savings: AI helps farmers make informed decisions at every stage of farming by giving them real-time knowledge. With this wise choice, there will be less product and chemical loss and more effective use of both time and money.

Labour scarcity is less of a problem: The agriculture sector has long experienced a labour shortage. The issue of a labour scarcity is resolved by AI-based harvesting robots, driverless tractors, intelligent irrigation and fertilization systems, smart spraying, vertical farming software, and these technologies.

AI and Robotics challenges in agriculture

Implementing this technology may seem like an obvious move for every farmer after realizing the benefits of AI for sustainable farming. There are, however, still some significant obstaclesin its way.

Lack of knowledge with AI and Robotics: Despite the many advantages of employing AI in agriculture, most people in the world are unfamiliar with the use of AI-enabled products and machinery. To address the problems, AI businesses should first give farmers the fundamental tools, and then, as they become accustomed to them, advanced machinery.

Lack of expertise with emerging technology: For underdeveloped nations, implementing AI and other emerging technologies in agriculture might be difficult. Selling such technologies in regions where such agricultural technology is not currently employed may be difficult. Farmers require assistance in these areas in order to use these technologies.

Issues with privacy and security: Because there are still unclear rules and guidelines for employing AI, there may be a number of legal problems. Additionally, because of software and internet usage, privacy and security problems like cyberattacks and data leaks may emerge. For farm owners or farmers, all of these problems may pose serious difficulties.

CONCLUSION

A variety of agricultural practices are being transformed and optimized thanks in large part to AI and Robotics. Precision agriculture, crop and soil monitoring, autonomous farming, livestock management, supply chain optimization, disease and pest control, and other industries are clearly affected by AI. AI and Robotics in agriculture has the potential to raise production, decrease resource waste, increase sustainability, and improve food security by giving farmers useful information and decision-making tools. These technologies have decreased the need for labour in the processes, which has decreased the amount of errors caused by humans and improved the processes, leading to high production efficiency and yield. Adopting AI solutions will play a significant role in farming communities. The success of AI and Robotics is also attributed to the development of prediction solutions to address current issues in farming. Future research and development is necessary to address the drawbacks of these intelligent farming systems, though.

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CHAPTER 2

ROLE OF MICRONUTRIENTS IN VEGETABLE CROP PRODUCTION

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ABSTRACT

Micronutrients, though required in trace amounts, are indispensable for the growth and productivity of vegetable crops. This abstract delves into the pivotal role of micronutrients such as iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), boron (B), and molybdenum (Mo) in vegetable crop production, highlighting their significance in ensuring food security and sustainable agriculture. Micronutrients are essential for a wide range of biochemical and physiological processes within vegetable plants. Iron, for instance, is a crucial component of chlorophyll, the green pigment responsible for photosynthesis, while zinc plays a role in enzyme activation and protein synthesis. Copper aids in electron transport during photosynthesis, and manganese is involved in oxygen release during this process. Boron is essential for cell wall formation and membrane integrity, and molybdenum facilitates nitrogen metabolism. The availability of these micronutrients in the soil directly impacts the health and yield potential of vegetable crops. Micronutrient deficiencies can lead to stunted growth, reduced fruit or vegetable quality, and increased susceptibility to diseases. Conversely, optimal micronutrient levels enhance crop resilience, nutrient uptake, and overall productivity.

Keywords: micronutrients, pivotal role, food security, pigment, metabolism

INTRODUCTION

Micronutrients, despite their name, are microscopic elements that hold a macroscopic importance in the realm of vegetable crop production. These essential trace elements, including iron, zinc, copper, manganese, boron, and molybdenum, may be required in smaller quantities compared to macronutrients like nitrogen, phosphorus, and potassium, but their role is far from insignificant. In fact, these micronutrients are the unsung heroes of agriculture, serving as critical catalysts in countless biochemical reactions within vegetable plants. They are the keys that unlock the plant's potential for growth, nutrient absorption, and disease resistance, ultimately determining the success and sustainability of vegetable crop yields.

Micronutrients play a pivotal role in vegetable crop production, serving as the essential building blocks that facilitate the growth and development of these plants. These minute yet crucial elements, including iron, zinc, copper, manganese, boron, and molybdenum, are essential for various biochemical and physiological processes within vegetables. They are responsible for enzymatic reactions, photosynthesis, and the overall nutrient uptake and utilization, thereby influencing the quality, yield, and resilience of vegetable crops. In this intricate interplay between soil, plants, and nutrients, the role of micronutrients emerges as a linchpin in ensuring the health and productivity of vegetable crops, underscoring their significance in sustainable agriculture and food security.

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Balanced micronutrient management is crucial in modern agriculture. Soil testing and targeted micronutrient application help prevent deficiencies and excesses, ensuring that vegetable crops receive the nutrients they require for optimal growth. Sustainable practices, such as crop rotation and organic matter incorporation, can also improve micronutrient availability in the soil.

What are micronutrients?

Micronutrients are part of the enzyme systems of plant. They play an important role in photosynthesis. They are also important in essential reactions such as nitrogen fixation, protein synthesis etc. There are seven essential micronutrients such as Boron, Zinc, Molybdenum, Copper, Manganese, Iron and Chlorine.

Forms of micronutrients absorbed by plants: Depending on different types of elements plants absorb micronutrients in both ionic and non- ionic forms.

Mobility of micronutrients

The mobility of micronutrients refers to their ability to move within the plant from one part to another, which is essential for overall plant growth and development.

Mobility of micronutrients in plants

In plants, nutrients are categorized as either mobile or immobile. Mobile nutrients can be transported within the plant and redistributed to areas with higher demand. Immobile nutrients, on the other hand, remain fixed in the tissues where they were initially absorbed.

Some micronutrients, such as nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg), are considered mobile in plants. These nutrients can be translocated from older leaves to younger leaves or other growing parts of the plant when deficiencies occur. This helps ensure that essential nutrients are available where they are needed most. Other micronutrients, including iron (Fe), boron (B), copper (Cu), zinc (Zn), and calcium (Ca), are immobile in plants. Once these nutrients are taken up by the plant's roots, they tend to remain in the specific tissues where they were initially absorbed. Deficiencies in immobile nutrients often manifest as localized symptoms in newer leaves.

Mobility of micronutrients in soil

Micronutrients in soil, such as iron, zinc, copper, manganese, boron, and molybdenum, have different mobility characteristics compared to macronutrients. The mobility of micronutrients in soil depends on several factors:

a) **Soil pH:** Soil pH plays a significant role in micronutrient mobility. Most micronutrients are less mobile in alkaline (high pH) soils and more mobile in acidic (low pH) soils. For example, iron and manganese become more available in acidic conditions.

b) **Organic Matter:** Organic matter can affect the mobility of micronutrients. It can chelate or bind to micronutrients, making them more available for plant uptake. Soils with high organic matter content tend to have better micronutrient availability.

c) **Soil Texture:** Soil texture influences the movement of micronutrients. Sandy soils tend to have lower micronutrient retention, making them more mobile, while clay soils can retain micronutrients better, reducing their mobility.

d) **Redox Potential:** Micronutrient mobility can also be influenced by the redox potential (oxidation-reduction potential) of the soil. Changes in redox conditions can affect the solubility and availability of certain micronutrients.

e) **Competitive Interactions:** Micronutrients can compete with each other and with macronutrients for uptake by plants. Imbalances in nutrient availability can affect the uptake

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of specific micronutrients.

f) **Microbial Activity:** Microorganisms in the soil can influence micronutrient availability by either immobilizing or mobilizing these nutrients.

g) **Fertilization:** Micronutrient fertilization can directly influence their availability. Applying micronutrient fertilizers can help correct deficiencies or improve their availability to plants.

Understanding these factors is crucial for proper soil management and nutrient balance in agriculture. Soil testing and analysis can help determine micronutrient levels and guide appropriate corrective measures, such as adjusting pH, organic matter, or applying micronutrient fertilizers.

Table 1: Optimum range of micronutrients in different vegetable crops:

Vegetables	**Fe**	**Mn**	**Zn**	**Cu**	**B**
Beans	50-300	50-299	20-200	9-28	22-78
Beet root	50-200	50-200	20-200	6-14	-
Brinjal	50-300	40-250	20-250	7-58	27-76
Cabbage	30-200	25-200	20-250	4.5-17	23-77
Carrot	50-300	60-200	25-250	6-18	33-98
Cauliflower	30-200	25-250	25-100	5-16	35-102
Onion	60-300	50-250	25-100	14.8-32	24-62
Peas	50-300	30-400	19-150	8-23	-
Radish	50-200	50-250	20-250	7-26	27.6-127
Tomato	40-200	40-250	20-55	3-22	27-62
Turnip	40-300	40-250	20-245	8-25	45-101

Source: Anjaneyulu, K. and Raja, M.E. (1999). Micronutrient disorders in vegetable cropsand their correction. *Indian Horticulture.* (Jan.-March). pp 15-16.

Deficiency symptoms of micronutrients and their management:

Boron

Boron deficiency symptoms in plants typically include:

a) Stunted Growth: Plants may appear stunted, with reduced stem and root growth.

b) Deformed New Growth: Young leaves and stems may become distorted or misshapen.

c) Brittle Stems: Stems can become brittle and may break easily.

d) Discoloration: Leaves may show discoloration, often appearing yellow or brown along the edges or between veins.

e) Reduced Flower and Fruit Production: Boron deficiency can lead to poor flower and fruit development, and in severe cases, fruit may be misshapen.

Some deficiencies of boron in vegetables are:

1. Browning of cauliflower curd.
2. Cauliflower - hollow heart.
3. Black heart in black.
4. Turnip internal browning.
5. Potato heart- brown or black.
6. Radish – water damaged areas and a hollow heart.

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7. Pitted, corky, and irregular ripening of tomato fruits.

Management practices of Boron

- Boron shortage is most common in soils with a coarse texture
- More severe during dry spells when root activity is constrained.
- For appropriate growth and development of vegetable crops, boron must be supplied often and continuously to the young tissue or buds because it is very immobile in plants.
- If the B value in the soil test is less than 0.5 mg/kg soil, the soil is deemed inadequate. Copper

a) Onion bulbs soften and develop thin, immature, pale scales.

b) The death of stems and twigs, yellowing of the leaves, reduced growth, and readilywilting pale green leaves.

Management Practices

- The most typical soil types with copper deficit include sandy soil, calcareous soil, and soil with a high level of organic matter.
- With an increase in soil clay concentration, the level of Cu rises.
- Reduced copper uptake by plants is caused by increased phosphorus and iron availability in soils.
- A single treatment may be useful for several years because of the long-lasting residual action of copper in the soil.
- However, soils with a lot of organic matter need to be fertilized with copper every year.
- Some fungicides also contain copper, and regular application will raise the soil's copper content.
- The primary fertilizers with copper are composed of copper sulfate (35% Cu) and copper oxide (75% Cu). We can use copper foliar spray of 0.1-0.2% and soil application of 5–10 kg/ha to the vegetable crops.

Iron

a) The juvenile leaves have distinctive green veins and golden interveinal regions.

b) The leaf's points and margins retain their green color for a very long time. In severe cases, the veins and interveinal portions of the leaf turn yellow and occasionally bleach.

c) Due to low quantities of chlorophyll, Fe deficiency is primarily exhibited by yellowleaves. The younger top leaves in interveinal tissues are the first to yellow.

Management Practices

- On soil with a pH above 6.8, calcareous soil, and soil with a significant amount ofsodium and calcium, iron deficiency occurs.
- The major treatment for iron chlorosis is foliar application of ferrous sulfate @ 0.4%, a micronutrient that contains iron.
- Fe should not be applied to the soil since it quickly reverts to forms that are inaccessibleto plants.
- To avoid yield loss, iron chlorosis must be treated at an early stage of crop development.
- To enhance leaf adhesion and Fe absorption, the solution needs to contain a surfactant. Manganese

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a) Marsh spot, an interveinal chlorosis in pea.

b) Onion leaves with a thin, yellow stripe.

c) Bean leaves exhibit chlorosis, followed by necrosis and fading.

d) The cabbage has small, yellowish leaves with yellow interveinal mottling.

e) Leafy tomato with chlorotic and forward-rolled leaves.

Management Practices

- In sandy, calcareous, and soils with pH levels above 6.7, shortage of manganese is observed.
- Increased soil pH and high quantities of accessible iron in soils have a negative impacton Mn uptake.
- Along with having a low pH and being poisonous to Mn, acidic soils may also have lessP and Mo available.
- Vegetables are susceptible to too much Mn. Manganese insufficiency and high pH havea correlation with interveinal chlorosis and its relationship to excessive liming.

Molybdenum

a) Cauliflower whiptail leaf (failure of leaf lamina to form).

b) Turnip with mottle and whiptail.

c) Tomato young leaves turn purple.

d) Radish leaf discoloration and death of the developing tip.

e) Granulation and decomposition in chilli veins.

f) Deep blue onion leaves with pronounced yellow and green striations.

g) Cabbage leaves develop cup-like shapes and chlorotic mottling.

Management Practices

- Acidic soils with a pH below 5.2 and sandy soils that have been heavily leached are linked to Mo deficiency.
- In contrast to the other micronutrients, Mo is more readily absorbed by plants as soil pH rises.
- The availability of Mo in the soil was decreased by the high Mn concentration andnitrate-nitrogen fertilizers.
- Cauliflower, broccoli, spinach, lettuce, radish, and beans are among the crops that are particularly vulnerable to a lack of molybdenum.
- The two most popular Mo fertilizers on the market are ammonium molybdate (54% Mo), and sodium molybdate (38% Mo), can be used @2–5 kg/ha as oil applications or 0.03–0.05% as foliar sprays.

Zinc

a) Small reddish brown spots on cotyledonary leaves of beans.

b) In beet, interveinal yellowing and marginal burning occur.

c) Potato fern leaf disorder.

d) Tomato leaves shrink, get chlorotic, and curl inward.

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e) Yellowing of onion leaves.

f) In garlic, the entire plant becomes yellow.

g) Cucurbit middle leaves are golden yellow in colour.

Management Practices

- Most affected by Zn deficiency are calcareous soils and neutral to alkaline sandy soils.
- It is commonly known that at least 50% of the soils in India are deficient in zinc. If the test value is less than 0.6 mg DTPA-extractable Zn/kg soil, Indian soils are typically thought to be zinc deficient. Plant Zn uptake declines with zinc shortage. In tomato, greater soil pH and higher quantities of phosphorus and iron available in the soils had a negative impact on the uptake of zinc. Zinc sulphate (21 and 33% Zn) and zinc-EDTA (12% Zn) are the most widely used fertilizers. Based on the native Zn availability of the soil, zinc sulphate (ZnS04) should be applied to the soil at a rate of 5 to 25 kg per ha, whilst zinc EDTA should be applied topically at a rate of 1%.

Different forms of applying micronutrients in vegetable crops:

The application of micronutrients in vegetable crops is essential to ensure proper growth, development, and yield. Here are some common methods for applying micronutrients:

1. Soil Application:

a) **Broadcasting:** Micronutrient-containing fertilizers can be broadcasted evenly over the entire vegetable field. This method is effective for correcting widespread micronutrient deficiencies.

b) **Banding:** Concentrated bands of micronutrient fertilizers can be placed near the base of plants or along rows. This method is suitable when a specific area requires micronutrient supplementation.

2. **Foliar Spraying:** A micronutrient solution is diluted and sprayed directly onto the leaves of the vegetable plants. This method is especially effective for providing quick nutrient uptake and correction of deficiencies. It is crucial to avoid spraying during extreme weather conditions, like high temperatures or strong sunlight.

3. **Seed Treatment:** Micronutrients can be applied directly to seeds before planting. This ensures that young seedlings have access to essential micronutrients from the moment they germinate.

4. **Drip Irrigation:** Micronutrient solutions can be injected into the irrigation system, allowing for a controlled and uniform application directly to the root zone of the plants. This is particularly efficient for managing micronutrient levels over time.

5. **Fertigation:** Micronutrients can be mixed with liquid fertilizers and applied simultaneously with regular irrigation. Fertigation ensures a constant and precise supply of micronutrients to the crop.

6. **Organic Matter Incorporation:** In cases of mild micronutrient deficienciesorganic matter rich in micronutrients (e.g., compost or well-rotted manure) can be incorporated into the soil during land preparation.

7. **pH Adjustment:** Soil pH can affect the availability of micronutrients to plants. Adjusting soil pH to the recommended range can improve the plant's ability to access micronutrients naturally present in the soil.

8. **Chelated Micronutrients:** Chelated micronutrient fertilizers contain micronutrients bound to organic molecules, which enhance their availability to plants. They can be applied through

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various methods mentioned above.

It is important to note that the choice of application method should be based on the specific nutrient requirements of the crop, the type and severity of micronutrient deficiencies, and local conditions. Soil tests and regular monitoring of plant health are essential for determining the need for micronutrient supplementation and the appropriate application method.

Table 2: Source and rate of micronutrients for soil application

Micronutrient	Source	Quantity required (kg/ha)
B	Borax- 10.5% Boron	2-5
Cu	Copper sulphate- 35% Cu	5-10
Fe	Iron sulphate- 20% Fe	10-15
	Iron chelate (EDTA)-12% Fe	15-20
Mn	Manganese sulphate-28% Mn	5-10
Mo	Sodium molybdate-38% Mo	2-5
	Ammonium molybdate-54% Mo	2-5
Zn	Zinc sulphate-21 & 33% Zn	5-25

Recommended concentration of micronutrients for foliar application in vegetable crops

The recommended concentration of micronutrients for foliar application in vegetable crops can vary depending on the specific crop, its growth stage, and the current nutrient status of the soil

Table 3: Recommended concentration of micronutrients

Micronutrient	Concentration
B	0.5-0.6% borax
Cu	0.1-0.2% copper sulphate + 0.5% lime
Fe	0.4% ferrous sulphate + 0.2% lime
Mn	0.4-0.6% manganese sulphate + 0.2-0.3% lime
Mb	0.05% sodium or ammonium molybdate
Zn	0.4-0.6% zinc sulphate + 0.1-0.3 % lime

CONCLUSION

In conclusion, micronutrients play a crucial role in vegetable crop production. They are essential for plant growth, development, and overall health. Proper micronutrient management is necessary to ensure optimal yields, quality, and nutritional value of vegetables. Deficiencies or excesses of micronutrients can have detrimental effects on crop performance. Therefore, a balanced approach to micronutrient application is essential for sustainable and successful vegetable production. The nutritional value of crops is a growing concern, thus applying micronutrients to preserve soil health and crop productivity in addition to preserving the quality of vegetables is of utmost importance. Micronutrients help increase fruit setting, production, quality, and post-harvest life as well as build resilience to biotic and abiotic challenges.

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CHAPTER 3

UNDERUTILIZED VEGETABLE CROPS AND THEIR IMPORTANCE

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INTRODUCTION

With more than 70% of agricultural livelihood, India is one of the most populated countries inthe world, making up nearly one-fifth of the global population. While the global demand for foodis projected to increase by 3% or more annually in the near future, the yearly growth rate is only about 1.8%. To fulfill the rising demand for food, the region's food output needs thus increase annually by around 3.5%. To address the different difficulties, synergistic interactions between better technology, institutional supports, favourable governmental policies, and awakening among the farmers are required. Self-sufficiency may not always imply adequate nourishment. In actuality, there are still significant discrepancies in the availability of calories, proteins, minerals, and vitamins. Malnutrition issues are also fairly common in the nation. By making more veggies available, these inadequacies might be significantly reduced. Being good sources of nutrients, vitamins, and minerals, vegetables are essential to a healthy human diet and the major force behind achieving global nutritional security. Vegetable production accounts for 58.73% of the whole horticulture output in India. According to Arora *et al.* (1980), India produced 162.89 million tonnes of vegetables from an area of 9.39 million ha. This phenomenal rise in vegetable output improved productivity to 16.45 t/ha and increased per-capita availability to 280 g. The development of better varieties, hybrids, production, and protection methods via methodical study together with widespread acceptance by the farmers made it feasible for this wonderful expansion. However, just a small number of significant crops contributed to this amazing yield. Although India's varied agro-climatic conditions allow for the cultivation of more than 60 farmed and approximately 30 lesser-known vegetable crops, underutilised vegetables have not received much attention. According to Jaenicke and Hoeschle (2006), underutilised plant species and crops are "those species with underexploited potential to contribute to food security, health (nutritional/medicinal), income generation, and environmental balance. Although they are important locally or regionally, underutilized vegetables rarely receive national notice or admiration. Although they are important locally or regionally, underutilized vegetables rarely receive national notice or admiration. The plant species that are traditionally employed for their food, fiber, fodder, oil, or medicinal characteristics are the underutilized vegetable crops. However, those species have untapped potential to provide environmental benefits, nutrition, health, income, and food security.

Common Perception

There are numerous underutilized vegetable crops that go by a variety of names. Some of these labels for underutilized species include orphan, abandoned, new, neglected, lost, underused, local, minor, traditional, forgotten, alternative, niche, promising, and underdeveloped. A plant must possess the following qualities in order to be categorized as one of the "underutilized vegetable crops":

a) The crop must have scientific or ethno botanical evidence of its nutritional benefits.

b) Crop must have been grown, whether currently or in the past, and only in a certain region.

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c) It must be grown less frequently right now than other traditional crops.

d) Crops must have a poor or nonexistent formal seed supply system, be recognized as having indigenous uses in localized areas, receive little attention from research, extension services, farmers, policy and decision makers, and technology providers, and possibly have multiple uses in addition to being highly nutritious.

Importance

Utilizing underutilized veggies more frequently and successfully is helping to combat economic prosperity, poverty, and malnutrition. They are a vital part of the rural poor's biological resources and can help the millions of tribal people in the world live happier, healthier lives. Underutilized veggies have strong antioxidant activity and are a good source of vitamins, minerals, and other health-promoting ingredients. They are crucial in ensuring that diets are varied, which results in better balanced sources of micronutrients. Underutilized vegetable crops can also give sustenance to the poor by satisfying the nutrient needs of vulnerable groups. Furthermore, underutilized vegetables have a high level of tolerance to biotic and abiotic stress. Those undervalued vegetables offer a natural and abundant source of vitamins, minerals, and antioxidants. Unused vegetables have a significant impact on rural life; they are a vital component of the local population's diet and nutrition because many of them have long been valued for their medicinal, therapeutic, and nutritional benefits. They are consumed either raw or cooked as traditional delicacies, and the sales of their surplus help many rural families supplement their income. Malnutrition and associated food shortages are evident among the underprivileged rural population. They have the potential to help reduce poverty by creating jobs and generating revenue, as well as by increasing the productivity and profitability of agricultural household labor in both rural and urban settings.

There is a technique to lessen the risk of over-reliance on a very small number of important cropsby using underutilized vegetable crops. By increasing the variety of edible foods, they can support sustainable lives by ensuring the food security of households. For low-income city dwellers, they sometimes serve as convenience food and contribute nutrients to the diet.

They can help maintain the stability of agro ecosystems since they are adapted to vulnerable conditions, especially in arid and semi-arid plains, mountains, steppes, and tropical forests.

Potential Role of Underutilized Vegetables

Food security and better nutrition: Numerous unused and underutilized vegetables are nutrient-dense and well-suited to low-input farming. The security of food and the well-being of the poor can be immediately impacted by the extinction of these species, whether they are wild, managed, or cultivated. Their increased use may result in better nutrition. For instance, compared to widely available commercial species and variants, several underused vegetables have higher levels of vitamin C and pro-vitamin A. In order to maintain a diverse and healthy diet and fight against micronutrient deficiencies, the so-called "hidden hunger," and other dietary deficiencies, attention should be paid to neglected and underutilized vegetables, especially among the rural poor and more vulnerable social groups in developing countries.

Ecosystem stability: Climate change and the deterioration of land and water resources have increased interest in crops and species that are suited to tough conditions such as desert borders, areas with low soil or degraded vegetation, or areas prone to drought.

Income growth for rural poor: New market niches are being created for neglected and underutilized vegetables as a result of the increased demand from consumers in developed and emerging nations for variety and novelty in cuisine. The comparative advantages that these crops offer over important staples or commercial crops can help impoverished farmers in less favorable areas create more income. Additionally, the ability of contemporary technologies to

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turn plants and other agricultural products into a variety of goods and to lengthen their shelf lives has opened up new possibilities for the creation of novel uses for these species and the marketing of their products.

***Alternanthera sessilis* (Ponnanganni Greens, Gudrisag)**
The leaves are utilized to cool down the body and are consumed as a herb for diarrhea, fever, anemia, etc. The leaves, blossoms, and fragile stalks are eaten as vegetables in Tamil Nadu and Karnataka. Ponnanganni greens are high in carotene, vitamin C, riboflavin, niacin, fiber, protein, carbohydrates, fat, and a number of minerals. Vegetables are made from the leaves and delicate shoots. It is primarily spread through seed.

***Sesbania grandiflora pers* (Agathi)**
Due to their great nutritional content, notably in terms of vitamin A and minerals, leaves, flowers, and fragile fruits are prized as vegetables or included in curries and salads in many nations. Flowers and leaves both have nutritional and therapeutic qualities. It is not, however, widely farmed for vegetable purposes. It is primarily spread through seed. In T.N., plants are cultivated around coconut seedlings to provide shade and as a wind break for banana trees. Italso serves as food, fodder, and ornamentation. According to Duke and Wain (1981), agathi is a traditional treatment for bruising, catarrh, diarrhea, eyes, fevers, headaches, smallpox, sores, sorethroat, and stomatitis.

***Portulaca oleracea* (Common Purslane)**
A succulent prostrate or erect annual (Portulaca oleracea) belonging to Portulacaceae with green or purple stem. It is found throughout India as a weed, ascending up to an altitude of 1500 m in the Himalayas, also cultivated as vegetable. It is rich in β carotene, folic acid, Vitamin C and essential fatty acids. One hundred grams of fresh purslane leaves (one serving) contain about 300-400 mg of omega-3 fatty acids, 12.2 mg of alpha-tocopherol, 26.6 mg of ascorbic acid, 1.9 mg of beta-carotene, and 14.8 mg of glutathione (Simopoulos *et al,*. 1992) it is mainly propagated by seed.

***Talinum triangulare* (Water leaf)**
Water leaf, a soft, mucilaginous leafy vegetable cultivated in the tropics and a member of the Portulacaceae family. It has carotenoids like lutein and zeaxanthin, which function as stimulants and in certain ways affect the immune cells of the eyes (Shakuntala and Shadaksharaswamy, 1985), just like other vegetables do. Consuming these vegetables helps prevent heart disease, some types of cancer, blood pressure control, cholesterol levels, diverticulosis, a painful digestive condition, and cataract and muscle degeneration, two frequent causes of visual loss. According to Disu (2010), waterleaf is consumed as a pot herb and in soups, as a side dish in sauces, or raw in salads as a scurvy preventative. Cutting/Division is the main method of propagation.

***Ipomoea aquatica* (Water spinach)**
It is an herbaceous aquatic or semi-aquatic trailing species known as water convolvulus or kangkong, its fragile twigs and leaves are utilized as vegetables or as an ingredient in sauces and soups as reported by Westphal (1994). Seeds and herbaceous cuttings are the major methods of propagation addressing diabetes. Scorpion venom antidote as described by Malalavidhane *et al.* (2001), was used by Jayaweera (1982) to treat liver problems and debility by acting as an emetic, diuretic, and purgative. People in Indonesia think it has a relaxing effect when used as a sleeping aid. Due to the high Fe content, doctors suggest it to anemic patients.

***Sauropus androgynus* (Chekurmanis)**
The plant is said to have a high nutritional value, earning it the nicknames "multivitamin green" and "multi mineral packed leafy vegetable" in popular culture. Chekkurmanis is a fantastic source of vitamins, minerals, and carbohydrates. Most often, semi-hard wood stem

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cuttings are used for propagation. Chekkurmanis leaves are crushed with pomegranate roots to make juice, and jasmine leaves are used to treat eye problems. In Tamil Nadu and Kerala, the delicate shoots and leaves are utilized as vegetables. The Dutch East Indies used leaves to color fermented rice and give pastries a light green hue. Java uses leaves to make soup because they are extremely high in protein, minerals, and vitamins A, B, and C. Vegetables are shaded by it since it is grownas a living fence in garden beds.

***Solanum torvum* (Turkey berry, Wild eggplant)**

The South Indian people consider the edible fruits of *S. Torvum*, which are used as a vegetable, to be a vital component of their nutrition. It is primarily spread through seeds. As a poison antidote and a treatment for fever, wounds, tooth decay, reproductive issues, and arterial hypertension, it is widely utilized in traditional medicine across the globe (Ndebia *et al.*, 2007).

***Psophocarpus tetragonolobus* (Winged bean)**

It is a sturdy, climbing, perennial herbaceous tree that can grow to a height of 5 meters. The blossoms might be blue, white, or purple, among other colors. The four-sided pods have distinctive wings and range in length from 6 to 36 cm (up to 50 cm), with 5 to 20 seeds per pod (Sahoo *et al.*, 2002).The shiny, spherical seeds range in size from 0.06 to 0.5 grams and can be white, yellow, brown, black, or speckled. All plant parts, including the seeds, flowers, leaves, pods, and roots that resemble tubers, are edible. You can stew, boil, fry, roast, or make milk out of the young, sensitive pods. The roots and seeds both have about 20% and 40% protein content, respectively, which is ten times higher than what is found in potatoes or yams. It is primarily spread through seeds. Additionally high in carbs and vitamin A (300 to 900 IU), winged beans are. Its delicate leaves produce flavorful sauces and curries. The tuber-like roots are cooked or fried before consumption. The plant makes excellent cattle feed. The winged bean has the potential to significantly reduce the issue of protein deficiency in the humid tropics. Unknown asof yet are the plant's potential benefits for enhancing human diet.

***Canavalia gladiata and C. ensiformis* (Sword bean and Jack bean)**

Young Sword bean pods and seeds are consumed as a green vegetable. Sword bean (SB) (*Canavalia gladiata* Jacq.) is a tropical food legume that is widely cultivated in South India's Eastern and Western Ghats as reported by Jana (2007). Jack bean has a high protein content of 23% to 34% and a high carbohydrate content of 55%. After being cooked, the mature jack bean seeds are eaten by the Dravidian tribes of India, including the Kurumba, Malyali, and Irula. Bothare spread through seeds.

***Vigna umbelata* (Rice bean)**

Rice bean, also known as Climbing bean, Mountain bean, Oriental bean, Haricot bean, Red bean and Jerusalem pea, is a highly branched annual with erector semi -erect stem tending to be viny. In India, it is known by different vernacular names such as moth, rajmoong and satrangi mash. It has axillary raceme inflorescence with bright yellow flowers occurring in clusters. Pods are slender and somewhat curved. Among all the traditional pulses, rice beans have reportedly the highest nutritious value (Arora et al., 1980) because it contains a lot of protein and significant amounts of the limiting amino acids tryptophan and methionine. It is primarily spread through seeds.

Constraints for the Development of Underutilized Vegetable Crops

i. Lack of knowledge among farmers on the therapeutic and dietary benefits of underutilized vegetable crops.

ii. Insufficient research

iii. A lack of planting materials and acceptable seeds.

iv. Limited use of cutting-edge agricultural techniques on farms

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v. Lack of use of novel and creative technologies for increasing productivity, such as biotechnology and plastics.

vi. Lack of knowledge about post-harvest management techniques.

vii. Limited And Insufficient Infrastructure Facilities For processing, storage, and transportation.

viii. These crops receive little attention in campaigns to promote gardening.

ix. Inadequate institutional arrangements and a limited role for finance institutions in the establishment of horticulture- and agro-based industrial units.

Strategies for the Development of Underutilized Vegetable Crops:

To prevent over-exploitation of natural resources, domestication of potential wild species through homestead farming should be promoted. Supports are needed for planting material distribution and multiplication in addition to opening up markets for perishables through marketing networks. Vegetable crops that go unharnessed are nutrient-dense and well-suited to low input horticulture. Increased research and development in these areas will significantly improve human wellbeing in terms of food security and nutrition. By national programs focusingon their conservation and usage, a small number of species need to be prioritized for in-depth research and development in underutilized vegetable crops. The majority of varied ethnic cultures' traditional agricultural systems are used to raise and manage vegetable crops. Increased effort is needed to record indigenous knowledge, for example through ethobotanical studies. A focus on value ads will be possible if more native diversity is used for many purposes. Particularly at the national and regional levels, strategies must be developed to create and make available potential selections/varieties while overcoming challenges with the production of high- quality seed material, planting material, in-vitro/tissue culture material, etc. It is necessary to carry out systematic localized crop planning in accordance with the region's agro-climatic appropriateness. It is necessary to rapidly expand infrastructural facilities with a focus on market development, transportation, and communication. These crops have a low yield and poor quality, which reduces productivity. Therefore, some standards for the economic use of underutilized vegetable crops must be devised. High productivity, market demand, lack of harmful insects, illnesses, and ease of postharvest management, high nutritional value, and availability of production are possible requirements. According to Singh (2003) making the farming community aware of the nutritional value of underutilized food crops, such as fruits, vegetables, and medicinal plants, is essential from the beginning.

CONCLUSION

Underutilized veggies that are high in nutrients and have the ability to withstand harsh weather conditions may benefit growers, consumers, and environmentalists if they are properly controlled. Despite their acknowledged value, underutilized vegetables are sometimes not used to their full potential due to a shortage of planting materials, a lack of knowledge about their nutritional and therapeutic benefits, or a lack of information on the methods used to grow them.

To maintain future food and nutritional security, it is necessary to start a program on genetic resource investigation, management, usage, and enhancement of underutilized vegetable crops. Vegetables that go unharnessed are crucial to India's national economy. India's climate and soil are ideal for growing a variety of underused veggies. As a result, the Indian government has been making efforts to promote the underutilized veggies. To enhance the production of underused vegetables, some GOs and NGOs have been working on development programs. Finally, it canbe concluded that underutilized vegetable production will address the shortage of

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per capita consumption availability and thereby address nutritional issues. Additionally, it will create jobs, raise rural residents' incomes, and ultimately contribute to the nation's economy.

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CHAPTER 4

COMMERCIAL APPLICATION OF PLANT GROWTH REGULATORS(PGRS) IN FRUIT CROPS

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INTRODUCTION

In plants, growth and other physiological functions are mediated by chemical messengers called Plant hormones or Phytohormones. Thimmann, in 1948, proposed the term 'Phytohormone' as these hormones are synthesized in plants. Besides natural phytohormones, it is possible today to find synthetic and biotechnological commercial products, referred as plant growth regulators, which are well known for their regulatory effects.

Plant growth regulators (PGRs**)** are organic compounds, other than nutrients, that affect physiological processes of plants when applied in small concentrations. It refers to either natural or synthetic compounds that are applied directly to a target plant to alter its life processes or its structure to improve quality, increase yields, or facilitate harvesting. Plant hormones affect gene expression and transcription levels, cellular division, and growth. They are used to regulate the growth of cultivated plants, weeds, and in vitro-grown plants and plant cells. PGRs have been widely used in various agricultural activities. The powerful role of plant growth control in the various physiological and chemical processes of plants is well-known, right from changing plant phenotype by accelerating germination or growth to increase yield and post-harvest handling of the produce, thereby increasing market value. In addition, the unusual use of plant growth controllers is known to bring about changes in tree conversion, growth and distribution of assimilates (source - sink balance) and the number and quality of the desired economic products of horticultural plants.

The main classes of Plant Growth Regulators are Auxin, Gibberellins, Cytokinins, Ethylene and Abscisic acid. Furthermore, few novel growth regulators, *viz.*, Brassinosteroids, Jasmonic acid, Salicylic acid and Strigolactones are added to the list, which alone or in combination with the main phytohormones plays crucial role in growth and development processes, especially in plant defense mechanism. Apart from these, growth retardants are also included in synthetic PGRs. Most of the growth retardants such as AMO 1618, Phosphon -D, Alar, CCC (Cycocoel), Mepiquat Chloride, Paclobutrazol, etc are called 'anti-Gibberellins' as they hamper the synthesis of Gibberellic acids.

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Table 1: Precursor product, natural and synthetic form of some Phytohormones

Phytohormones	Precursors	Natural	Synthetic
Auxin	Tryptophan	IAA (Indole acetic acid)	IBA (Indole Butyric Acid),NAA (Naphthalene AceticAcid), Methyl ester of Naphthalene acetic acid (MENA), 2 -methyl- 4-chlorophenoxy acetic acid (MCPA), 2, 4-D (2, 4-Dichloro Phenoxy Acetic Acid) and 2,4,5-T (2,4,5-Trichloro Phenoxy Acetic Acid)
Gibberellins	Acetyl coA	Gibberellic acid	-
Cytokinins	Isopentyl Group (5-AMP)	N6- substitutedAdenine derivatives. Zeatin (common)	6-benzylaminopurine (BAP) and6-furfurylaminopurine or kinetin, Benzyl Adenine (BA), Diphenyl Urea, CPPU
Ethylene	methionine	Ethylene	Ethrel/ethephon ((2-chloroethyl) phosphonic acid)
Abscisic acid (ABA)	Mevalonic acid	ABA	(±)-cis, trans-Abscisic Acid forms
Salicylic acid	Chorismic acid	Salicylic acid	Aspirin (not used as PGR)
Brassinosteroids	Campesterol	Brassinolide	Brassinazol
Jasmonates		Jasmonic acids, Methyl jasmonate,JA-Isoleucine	Coronatine

Auxin:

Auxin is the first plant hormone discovered and studied extensively, produced in the shoot and root apices. In 1881, Charles Darwin and his son published the book "The Power of Movement in Plants", where they studied the phenomenon of phototropism in plants. Frits Went continued with the study and in 1926 isolated auxin from the Avena coleoptile tips by a method called Avena coleoptile or curvature test and concluded that no growth can occur without auxin.

Site of synthesis: Meristem, young leaves and developing seeds and fruits. Major functions of auxin are:

- Cell division and elongation.
- Apical dominance.
- **Root initiation:** Cuttings of plants which do not readily root, form abundant roots when treated with auxins. Synthetic auxins like IBA, NAA are particularly very effective. In general cuttings of herbaceous plants readily respond to auxins while those of woody perennials like eucalyptus, mango and others fail to respond to auxin application
- **Prevention of abscission:** Abscission is a balance between the inhibition of auxin and promotion of substances like ABA, Ethylene etc. Several auxins (2,4-D, IAA, NAA) inhibit the abscission of both leaves and fruits.
- **Parthenocarpy:** Application of auxin causes development of ovary into the fruit in several plants such as tomato, brinjal and others. Such fruits are seedless as these have developed without the normal process of fertilization these are known as parthenocarpicfruits.

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- Callus formation.
- **Eradication of weeds:** 2,4- D and 2,4,5-T are effective weedicides at higher concentration of 1 to 3 percent. 2,4- D is selective weed killer. It is highly toxic to broadleaved plants or dicotyledons while relatively non-toxic to narrow leaved plants or monocot.
- **Flowering and sex expression:** Pineapple can be made to bloom promptly with the application of NAA or 2,4-D. However, in this plant the effect of auxin is not direct but is mediated through ethylene formation. Application of auxin also alters the sex ratio of flowers.

Table 2: Commercial application of Auxin in fruit crops:

Fruit crop	PGR Concentration	Response/effect	Reference
Guava cv. Sardar)	NAA 600 ppm	Maximum winter crop yield (359.3 q/ha)	Suleman *et al*.2006
Mango cv. Sunderja	Urea + NAA6%+ 150 ppm	Increasing the total flower number per panicle and percentage of hermaphrodite flowers	Baghel and Tiwari, 2003
Mango cv. Bombai	NAA 40 ppm	Maximum fruit retention	Gupta and Brahmachari, 2004
Apple	NAA+BA 7.5+75 ppm	Good thinning and good increase in fruit size	Robinson, 2000
Guava cv. L-49	NAA 10 ppm	Greatest fruit diameter (5.03 cm),fruit weight (88.9 g), flesh weight (83.6 g), number of fruits per tree (666) and fruit yield (56.9 kg)	Yadav, 2002
Guava cv. Sardar)	NAA 600 ppm	Maximum winter crop yield (359.3 q/ha)	Suleman *et al*. 2006
Mango cv. Sunderja	Urea + NAA6%+ 150 ppm	Increasing the total flower number per panicle and percentage of hermaphrodite flowers	Baghel and Tiwari, 2003
Mango cv. Bombai	NAA 40 ppm	Maximum fruit retention	Gupta and Brahmachari, 2004
Apple	NAA+BA 7.5+75 ppm	Good thinning and good increase in fruit size	Robinson, 2000
Guava cv. L-49	NAA 10 ppm	Greatest fruit diameter (5.03 cm),fruit weight (88.9 g), flesh weight (83.6 g), number of fruits per tree (666) and fruit yield (56.9 kg)	Yadav, 2002

Gibberellins:

Gibberellins (GAs) are plant hormones, discovered by Kurosawa in 1926 that regulate various developmental processes. There are over 125 different molecular forms of gibberellin and they are identified Gibberellic acid (GA1, GA2, . . . Gan). The common gibberellic acid is GA3.

Gibberellins plays a major role in breaking of dormancy and promoting germination by increasing the α-amylase activity. This enzyme converts starch to reducing sugars resulting in an increase of osmotic pressure, causing entry of water into the cells and cell enlargement. The most important effect of GA is the stem elongation when GA is applied the stem elongates markedly. As a result, such plants grow taller. Enhanced stem growth is not due to rapid elongation of internodes. GA promotes flowering in long day plant, floral initiation and sex

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determination, Prevention of genetic and physiological dwarfism and tolerance to chilling. Many plants require a period of low temperature for flowering. Application of GA replaces the vernalization (0-5 °C) requirement for the flowering of carrot, beetroot, chicory and others. Therefore, low temperature requirement of plants can be replaced with GA. In many cases e.g., pome and stone fruits where auxins have failed to induced parthenocarpy the gibberellins have proven to be successful.

Site of synthesis: Young leaves, roots, and developing seeds and fruits.

Commercial application of Gibberellic acid in fruit crops:

1. Germination:

- Papaya seeds treated with 200ppm GA gave better germination.
- Guava, GA3 @ 1000- 8000 ppm.

2. Fruit setting

- GA3 @ 40 ppm fruit setting in grape.
- GA3 @ 50ppm in sour lime
- Phalsa, GA3 @ 60 ppm
- Sweet lime, GA3 @10 ppm

3. Spraying of GA3 @50-75 ppm reduce fruit drop in sweet oranges (Var. Jaffa).
4. Mature green guava fruits treated with 100-200 ppm GA 3 retarded the weight lossesand helped in extending storability of fruits.
5. GA3 treatment in grapes by NRC Grape, Pune (Table 3):

Table 3

Stages	GA3 Dose
Berry elongation in grapes	
10% flowering	10 ppm
50% flowering	15 ppm
90% flowering	20 ppm
Increase in berry size	
3-4 mm berry stage	40 ppm along with CPPU @2 ppm
6-7 mm berry stage	40 ppm along with CPPU @2 ppm

Cytokinins:

They are a family of related adenine-like compounds. Skoog and Miller discovered the first Cytokinins, i.e., Kinetin (6-furfuryl amino purine) from autoclaved herring sperm DNA in the late 1940s. The term, cytokinin was proposed by Letham in 1963.

Site of synthesis: The natural cytokinin is synthesized in root apical meristem, inflorescences, young leaves, developing fruits and seeds.

Major role: Cell division and enlargement, delay of senescence (Richmand - Lang effect), accumulation and translocation of solutes, flower induction in short day plant, provide resistance to high temperature, cold and diseases. Auxin: cytokinin ratio regulates morphogenesis in cultured tissue. More concentration of auxin promotes roots while more concentration of cytokinin promotes shoot proliferation. However, when both are present in equal concentration, callus formation takes place. Cytokinins useful for increasing shelf life of fruits, fruit thinning quickening of root induction and producing efficient root system. Certain

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Cytokinins have been found to be the constituent of certain transfer RNA molecules in a number of different organisms. They are also involved in stimulation of organ formation

Table 4: Application of cytokinin in various fruit crops:

Crop	Role of cytokinin	Reference
Mango	Application of CPPU @10 ppm promotes highest fruit retention, number of fruits per cluster, fruit weight and leaf area.	Notodiamedio, 2000
Citrus	1. Maximum number of flowers per culture achieved by MS medium supplement with kinetin 0.2mg/l in Kinnow explant culture. 2. Application of BA @ 30g/l and kinetin at the time of fruit setting shows positive impact of fruit juice in Kinnow	1. Singh *et al*. 2006 2. Khalid *et al*. 2012
Litchi	Spraying of kinetin @ 25mg/l improves the fruit weight, in addition to delaying fruit ripening by reducing ethylene production.	Dhua *et al*. 2003
Grape	1. CPPU @ 5 and 10mg/l promote better berry diameter	Zabadal *et al*. 2006
Fig	CPPU (25mg/l) at the time of anthesis promotes parthenocarpy fruit.	Chai *et al*. 2019
Apple	1. Application of CPPU @ 10mg/l or BA @50mg/l after 2weeek of full bloom shows positive impact on fruit size with no negative impact on yield, fruit shape, seed number 2. application of BA in apple increase the endogenous cytokinin (zeatin) which promoted maximum cell division	Stern *et al*. 2006 Yuan and Greene, 2000
Pomegranate	Foliar spray of CPPU 5ppm in month ofApril increase fruit size, juice content of pomegranate	Sharma and Belsare, 2011
Guava	1. Treatment with 100ppm BA increases ascorbic acid and TSS 2. MS medium containing BAP @ 3mg/l promotes shoot bud proliferation.	Debnath *et al*. 2011 Mishra *et al*. 2005

Ethylene:

Ethylene is the gaseous hormone discovered by Dimitry Neljubow that stimulates growth and development. Ethylene production is closely associated with fruit ripening in many species, and is the plant hormone that regulates and coordinates different aspects of the ripening process. Ripening includes: 1. Changes in carbohydrate composition, resulting in sugar accumulation and increased sweetness; 2. Change in colour 3. Flesh softening and textural change; 4. Formation of aroma volatiles; 5. Accumulation of organic acids with associated development of flavour.

Ethylene involves in regulating and stimulating the opening of flowers, fruit thinning in apple to eliminate biennial bearing and also to improve fruit size and quality, callus formation and initiation of adventitious roots on the stem cuttings, leaf epinasty during stress, fruit ripening and shedding of leaves.

Table 4: Commercial application of Ethylene in fruit crops

Fruit	Application of ethylene	Reference
Pear	The optimum ripening and acceptable quality were achieved after 8 days of ripening period in 'Patharnakh' at 20°C with 1000 ppm ethephon solution and 100 ppm ethylene gas treatment.	Dhillon and Mahajan, 2011
Kiwi fruit	1000ppm ethephon with 3-5% glycerine showed remarkable role on ripening and improving quality	Bal and Demir, 2007
Plum	An ethylene dose of 100 mg/l increased TSS content, firmness and fresh mass loss in Horvin cultivar	Romero *et al.* 2015
Citrus	50-100 µl/l of 1-MCP effectively inhibit ethylene-induced fruit de-greening	Pora *et al.* 1999
Mango	• Fruits treated with 150 ppm of ethylene for 25h at 23 ± 2° C induced uniform ripening without impairing the taste and flavour • 100 ppm ethylene gas in ripening chamber for 18 hrs. and storage at ambient condition recorded the maximum shelf lifeof 6 days	Deepa *et al.* 2016 Doke *et al.* 2018

Abscisic acid

Abscisic acid (ABA), initially discovered by Frederick Addicott, is the hormone that is usually associated with major plant responses to stress. It is a sesquiterpenoid containing 15 carbon atoms, often described as an inhibitor. ABA plays a dominant role in fruit ripening of non-climacteric fruits. ABA triggers the closing of stomata during stress. During drought stress, ABA levels in leaves rise dramatically, causing closure of stomata and the production of proteins known to protect membranes and other cellular structures during dehydration. Proteins also reduce the osmotic potential of the cytoplasm, further preserving the water left in the cell. ABA application can mimic drought stress responses by plants, namely reduced bud and shoot growth, stomatal closure, and reduced photosynthesis. Proteins which form in response to the stress can be induced with an application of ABA. It promotes desiccation tolerance in the embryo Seed dormancy**.**

Site of Synthesis: Mature leaves and roots; developing seeds Application in fruit crops:

- In Mango, ABA induced fruit ripening through ethylene biosynthesis. Dipping of fruits in 1Mm ABA had shown higher total sugars and sucrose as well as degradation of total organic acids, and citric and fumaric acids (Zaharah *et al*., 2012).
- In Pineapple ABA reduced the intensity of internal browning, moisture loss and malic acid content in the crown leaves (Nanayakkara *et al*., 2005).
- The induction of callus formation in cultured buds of Shamouti orange (*Citrus sinensis*) was observed by incorporation of abscisic acid (ABA) (Goren *et al*.,1979).

Salicylic acid

It is a ubiquitous plant phenolic compound, regulates a number of processes in plants It is most widely known for its roles in signalling for plant defense against pathogens, thermogenicity in plants, and flowering in certain species. Exogenous application of Salicylic acid at nontoxic concentrations to susceptible plants could enhance their resistance to fungal pathogens. It also acts as a potential non-enzymatic antioxidant as well as plant growth regulator.

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Role in disease resistance: Disease resistance: SA is the signalling hormone in plant resistance to pathogens and plays a key role in regulating systemic acquired resistance (SAR) and the hypersensitive reaction (HR) in disease-resistant plants. SAR is where a pathogenic attack on one part of a plant induces resistance to pathogens in other parts of the plant. The intra-plant signal for the development of SAR is SA. HR is a response to pathogen attack seen in some disease-resistant plants. In plants which have HR, a necrotic lesion develops around the initial point of pathogen attack via death of cells in the necrotic area. This HR may lead to SAR. As part of the physiological development of both HR and SAR a number of low molecular weight PR (pathogenesis related) proteins are often produced by the plant.

Application in fruit crops:

- Pre-harvest treatment with salicylates, and especially at 10 mM concentration improve fruit quality, ascorbic acid, phenolics, and anthocyanins at harvest and during storage of pomegranate (Garcia *et al.,* 2020).
- The pre harvest applications of salicylic acid (4 mM) was done at flowering stage, fruit setting, 30, 20 and 10 days before fruit harvest. significantly improved the plant growth parameters and fruit yield
- Application of salicylic acid @ 2 mM at 3-4 leaf stage showed maximum growth in vegetative characters of strawberry
- SA has been reported to reduce chilling injuries in banana seedlings. SA enhances the chilling tolerance by regulating H2O2 metabolism and strengthening the antioxidant defense system

Brassiosteroids:

They are considered plant hormones because of their ability to cause dramatic changes in growth and differentiation at low concentrations. It covers a wide range of functions such as Stimulation of stem elongation, Pollen tube elongation, Stimulation of cell division (with auxin and cytokinins), Seed germination, inhibition of root elongation, etc. BRs application was effective in increasing the number of flowers in autumn but reduced flowering in late winter crops of grapes.

- Kumari and Thakur (2018) have also observed enhanced growth of apple seedlings due to BRs application
- In Navel orange (*Citrus sinensis* L.) cv. Morita, the brassinolide spray at a concentration of 0.01 ppm increased fruit set (Sugiyama and Kuraishi, 1989).
- Watanabe *et al*. (1997) also observed an increase in fruit set of Fuyu (Persimmon) by BRs application at 0.01 ppm. The fruit set was also improved by 76.2% and 70.60%, respectively, when applied seven days before blooming and at the full bloom stage
- Rajan *et al*. (2017) found that post-shooting spray of banana bunches with brassinosteroid at the rate of 2.0 mg L-1 resulted in a yield of 114.46 t ha^{-1} in cultivar Grand Naine as against 84.24 t ha^{-1} in control
- In grapes, Bhat *et al*. (2011) concluded that exogenous application of CPPU and 0.4 mg/liter BR enhanced berry size, berry length and diameter, and berry number considerably in grapes
- Application of GA3 at 50 ppm together with 1 ppm BRs at fruit set found to increase the fruit sugar content
- 10 µM brassinolide (BL) capability in enhancing tolerance of fruits to cold temperature stress in mango

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- Apart from germination, BRs have been reported to influence seedling growth and help in maintaining plant height and branch number in nursery plants.

Jasmonates:

Jasmonates are phospholipid-derived hormones that regulate plant development and responses to environmental stress. Jasmonates induce plant defense responses upon pathogen or insect attack, mechanical wounding or abiotic and biotic stresses such as drought, salinity, low temperature, etc

- Application of MeJA (0.5 mM) in two plum cultivars namely Black Splendor and Royal Rosa, at pit hardening stage, initial colour development and onset of ripening, improved the fruit quality, antioxidant enzyme activity and delayed ripening and thereby improving the shelf life (Zapata *et al.* 2014).
- MeJA in apples showed a significant increase in red colour, total phenols (cyanidin3-galactosides, chlorogenic acid, phlorizin, flavanols and flavanols) in peel and lead to production of more export-grade fruits (Shafiq *et al.* 2013).
- MeJA, in addition, stimulates defense responses in plants against biotic and abiotic stresses. It has been reported that *Colletotrichum acutatum* and *Botrytis cinerea* were effectively controlled by MeJA by inducing systemic acquired resistance in plants (Yu *et al.* 2009). MeJA stimulates the pathogenesis related gene expressions, antioxidant systems and also helps with emission of repellent volatile compounds against insects and herbivore.
- Sweet cherry treated with 0.4 mM MeJA at fruit set had lesser percentage of fruit cracking during harvest. It also maintained the fruit firmness and other quality parameters (Balbontín *et al.*, 2018).
- Exogenous MeJA applications not only results in better postharvest life of fruits butalso enhance resistance towards postharvest diseases through preventing pathogenic attack. In guava, when mature green and ripe fruits were treated with MeJA, it was observed that MeJA had lightly influenced the ethylene synthesis and ripening process while did not control the anthracnose (Silva *et al.* 2017).

Paclobutrazol:

Paclobutrazol is probably the most widely used PGR in the production of fruit crops. because of its wide range of efficacy and moderate- to long-lasting response. It is commercially used to overcome alternate bearing problem in Mango. It prevents Kaurenoic acid conversation to GA12-aldehyde by blocking the enzyme Kaurenoic acid oxidase and hence inhibit Gibberellic acid synthesis. The post-harvest application of a small amount of paclobutrazol to the soil significantly promotes flowering and fruiting in the following year. Recommended Dose is 4 ml/ m diameter of canopy (12 o'clock shade) preferably in more than 8-year-old trees within July 15 – Aug 15.

CCC: It is commercially used to increase fruit set in Grapes. NRC-Grape, Pune recommended application of 6BA @ 10 ppm along with CCC @ 250 ppm to increase panicle size.

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CHAPTER 5

WIDE HYBRIDIZATION IN VEGETABLE CROPS

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INTRODUCTION

The Green Revolution has had a profound impact on India, transforming it from a country with a food grain deficit to one with a surplus. Few endeavors have influenced agricultural development to such an extent as the Green Revolution. This transformation has also left its mark on the breeding and production of vegetable crops. However, there have been unintended consequences, primarily seen in reduced varietal diversity within major cultivated crop species and increased uniformity in the appearance and harvestable products. This homogeneity has made agriculture more vulnerable to natural disasters. The emergence of new pathogen races has led to disease outbreaks and pest infestations, causing yield losses of up to 50 percent. Changing climatic conditions, such as drought, floods, salinity, and high temperatures, have further resulted in reduced crop yields and quality. In order to address the challenges of feeding the ever-growing population and combating malnutrition, wild species offer opportunities for enhancing the quality of vegetable cultivars. To restore ecological sustainability and mitigate the effects of biotic and abiotic stresses in cultivated vegetable crops, wide hybridization has been recommended as a potent tool for plant breeders. Wild species serve as a rich source of valuable traits, improved quality, processing characteristics, and resistance to biotic and abiotic stresses.

Hybridization has played a pivotal role in fostering diversity among angiosperm species, with approximately 25% of plant species, particularly the more recent ones, participating in hybridization and the introgression of their genetic material with other species. This phenomenon unfolds when distinct populations, subspecies, or species encounter each other to interbreed and merge their gene pools. Such interactions often culminate in the establishment of a hybrid zone or a hybrid swarm. The outcome of hybridization can manifest as swift genomic alterations, potentially giving rise to advantageous new traits. The process of hybridization between individuals from distinct species within the same genus, referred to as interspecific hybridization, or individuals from two separate genera within the same family, is known as intergeneric hybridization. These processes are commonly referred to as distant hybridization or wide hybridization. For many decades, crop wild relatives have been instrumental in breeding, particularly in the transfer of genes that confer resistance or tolerance to pests, diseases, and abiotic stress to cultivated species. Wide hybridization encompasses both efficient conventional breeding techniques and modern molecular methods as effective toolsfor crop improvement.

Importance of wild hybridization

- Creation of genetic variability
- Development of lines with wider adoptability
- Potential genetic materials for biotic and abiotic stresses
- Yield enhancement line

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- Transfer of sterile cytoplasm for hybrids production
- Breeding for rootstock
- Quality improvement

Barriers to wild hybridization

The challenges encountered during the distant hybridization program are mainly due to cross-incompatibility, which can be broadly categorized into two types: prezygotic and postzygotic barriers. Prezygotic incompatibility pertains to issues that manifest before fertilization, causing an inability to successfully cross, such as a lack of recognition between pollen and stigma, hindrance in pollen germination, pollen tube growth arrest within the stigma or stylar tissue, or failure of pollen tubes to penetrate the ovule. In contrast, postzygotic incompatibility arises after fertilization, leading to problems like the development of hybrid seeds that are either weak or nonviable, as well as sterility in F_1 hybrids or subsequent generations. These postzygotic barriers can include factors like abnormal embryo development resulting from irregular endosperm growth, the occurrence of lethal or sublethal traits in hybrid seedlings, hybrid sterility due to chromosomal or genetic distinctions, and hybrid breakdown in F_2 or later generations.

In the context of pre-zygotic barriers, when attempting to crossbreed *Solanum khasianum* and *Solanum melongena*, it is observed that the pollen from *Solanum melongena* is unable to successfully reach the ovary of *Solanum khasianum*. In the case of a cross between *Lycopersicon peruvianum* and *Lycopersicon esculuntum*, the use of *Lycopersicon esculuntum* as the male parent is precluded due to the impediment of pollen tube growth from *Lycopersicon esculentum* in the style of *Lycopersicon peruvianum*. The post fertilization barriers manifest in wide hybridization and their offspring, often referred to as post-syngamic barriers. These barriers encompass events such as embryonic breakdown, zygote development failure, anomalous fertilization, as well as the hindrance of endosperm and embryo development. Hybrid sterility in further generations of wide hybrids arises from the expression of lethal genes, genetic imbalance resulting from non-homologous chromosomes, the elimination of chromosomes, and the abortion of endosperm. Numerous interspecific hybrids formed by crossing *Abelmoschus esculentus* with *A. ficulneus* and *Abelmoschus esculentus* with *A. tuberculatus* exhibit notably limited seed production. Furthermore, a notable concern in wide hybridization is the phenomenon of linkage drag, wherein substantial segments of the donor chromosome persist even after several backcrosses. This persistence is problematic due to the presence of undesirable donor genes that exert adverse effects on the overall agronomic performance.

Table 1: Potential genetic resources for biotic stress resistance for vegetable crop breeding

Crop/biotic stress	Resistance
Melon	
CGMMV	*C. africanus, C. ficifolius, C. anguria, Cucumismelo var. momordica*
Powdery mildew	*Cucumis ficifolius, C. anguria C. anguria var. anguria , C. dinteri* and *C. sagittatus*
Gummy stem blight	*C. myriocarpus, C. zeyheri* and *C. anguria*
Fusarium wilt	*C. figarei*
Fruitfly	*C. callosus*
Nematode	*C. metuliferus*
Whitefly	*C. asper, C. denteri, C. dipsaceus, C. sagittatus*
Cucumber	

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Powdery mildew	*C. hardwikkii*
Gummy stem blight	*C. hystrix*
Watermelon	
Fusarium wilt and Anthracnose	*Citrullus naudinianus*
Pumpkin	
PM and Viruses	*C. lundelliana, C. martenezii*
ZYMV, WMV	*C. ecuadorensis, C. foetidissima, C. martinezii*
Downy mildew	*Cucurbita argyrosperma, C. foetidissima*
Okra	
YVMV	*A.enbeepeegeearense, A. caille,*
OELCV	*A.enbeepeegeearense, A. crinitus, A.ficulneus, A.moschatus, A. angulosus*
Tomato	
Fusarium wilt	*Solanum hirsutum*
Nematode	*S. peruvianum*
Brinjal	
Bacterial Wilt	*S. torvum*
Shoot and fruit borer	*S. incanum*
Potato	
Late blight, Early blight, Potato virus-x	*S. demissum*

Techniques to overcome barriers to wild hybridization

Chromosomal Number Manipulation

The successful hybridization of cultivated and wild species with varying ploidy levels presents inherent challenges. To overcome these hurdles, the process can benefit from inducing chromosome doubling in one of the potential parental plants or in the resulting F_1 offspring. When the interspecific crosses are made between *Abelmoschus esculentus* and *Abelmoschus manihot*, the resultant F_1 hybrid show hybrid sterility. This can be overcome by treatment of seedling of interspecific hybrids with colchicine 0.2 % in order to allow chromosome doubling. The resultant colchiciploid are fertile in nature.

Similarly in potato most of the wild relatives which are source of biotic and abiotic stresses are diploid in nature but the cultivated potato exhibit tetraploidy making an inhibitory factor for the cross compatibility. This crossability can be achieved by making the tetraploid cultivar to diploid through dihaploid and double haploid development.

Fig.1: Flow chart representing method to overcome hybrid sterility in okra Bridging Species Technique

In cases where it proves challenging or unfeasible to achieve direct interbreeding between two species possessing either similar or disparate ploidy levels, a third species, referred to as a "bridging species," is employed to facilitate the generation of such inter-species crosses. *Solanum bulbocastanum*, which possesses valuable traits, is incapable of hybridization with *S. tuberosum*. Therefore, *S. pinnatisectum* has been employed as an bridging specie. Currently, *S. phureja* (2x) and *S. acaule* (4x) are also utilized as bridging species to facilitate the transfer of late blight resistance to cultivated potato species. Resistance to potato virus Y has been introduced from the non-tuberous species *S. etuberosum* through the bridging species *S. verrucosum* and *S. pinnatisectum*.

Effect of nutrients and growth regulators

Plant growth regulators and essential nutrients have been observed to enhance the elongation of pollen tubes and foster embryonic development. Furthermore, they extend the duration of stigma receptivity while impeding premature detachment of pollinated flowers. Application of NAA and potassium gibberelate applied to the pedicle of the pollinated flower of *Phaseolus vulgaris* and *P. aculifolius* improves seed set

Mentor pollen utilization

In certain instances, pollen grains from one species may fail to initiate germination when placed on the stigmas of a different species. When these non-compatible pollen grains are combined with inactivated maternal pollen grains, germination of the former is achieved. By employing ethanol to deactivate compatible pollen and then combining it with non-compatible pollen for pollination, the protein-based recognition factors emanating from the walls of the inactivated compatible pollen grains serve to obscure the rejection response of the recipient stigma, thereby facilitating the germination of foreign pollen grains. This inactivated maternal pollen is commonly referred to as recognition or mentor pollen.

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Protoplast fusion

Several species exhibit such formidable obstacles to interbreeding that the prospect of sexual hybridization remains unattainable. In such cases, one viable approach for surmounting these barriers involves the pursuit of protoplast fusion, followed by the subsequent regeneration of somatic hybrids.

Embryo rescue technique

Embryo abortion may manifest at various developmental phases, contingent upon the genomic relationship between two parental species. These abortive embryos can be dissection from the maturing seed, subsequent cultivation in laboratory receptacles filled with nutritive medium, and subsequent maturation into hybrid plants. Cucumber species *Cucumis hystivus* is developed by embryo culture of species *C. hystrix* and *C. sativus.*

Table 2: Successful crop improvement through wide hybridization

Crop	Wide hybrid	Parentage	Special trait
Tomato	Hissar Anmol	*S. lycopersicon x S. hirsutum f.sp. glabratum*	Resistant to ToLCV
	Pusa Red Plum	*S. lycopersicon x S. pimpinellifolium*	Rich in Ascorbic acid
Potato	Kufri Kuber	*(Solanum curtilobum x S. tuberosum)*	High tuber yield
		x S. andigenum	
Okra	Arka Anamika	*Abelmoschus esculentus x A. tetraphyllys*	YVMV and Fruit Borer Resistant
	Arka Abhay	*Abelmoschus esculentus x A. tetraphyllys*	YVMV and Fruit Borer Resistant
	Parbhani Kranti	*Abelmoschus esculentus (Pusa Sawani) x A. manihot*	YVMV resistance
	Pusa A 4	*Abelmoschus esculentus x A. manihot ssp. manihot*	YVMV resistance
	Punjab -7	*Abelmoschus esculentus (Pusa Sawani) x A. manihot ssp. manihot*	YVMV resistance
	Punjab Padmini	*Abelmoschus esculentus (Rashmi) x A. manihot ssp. manihot*	YVMV resistance
Cucumber	*Cucumis hystivus*	*Cucumis hystrix x C. sativus*	Downey mildew, Nematode, Gummy stem blight
Raphanobrassica		Radish x Cabbage	1st intergeneric cross Fodder crop
Hakuran		Cabbage x Chinese Cabbage (developed by embryo culture)	Leafy vegetable, resistant to bacterialsoft rot, drought, and Heat
Caulicob		Cabbage x Cauliflower	
Nabicol		Kale x Turnip	
Swede		Turnip x Cabbage	Cruciferous root vegetable
Solanopersicon		*Solanum tuberosum x Solanum lycopersicum*	

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CONCLUSION

In summary, wild species serve as repositories of unique genes that have the potential to be harnessed for wide hybridization endeavors. Consequently, wild species constitute the central core of extensive hybridization programs. Wide hybridization represents a potent tool for effecting genetic enhancements in vegetable crops, requiring a high level of technical expertise and knowledge. Notwithstanding the numerous obstacles associated with wide hybridization, these challenges can be surmounted by employing both conventional and biotechnological methodologies. To expand the genetic diversity, contemporary approaches involving in vitro techniques and biotechnology are being employed in extensive hybridization. This approach is invaluable for breeding resistance to diseases and insects, as well as enhancing the quality of cultivars, which is currently an URGENT NECESSITY.

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CHAPTER 6

PLANT GROWTH AND DEVELOPMENT: PHASES AND REGULATION

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ABSTRACT
This chapter delves comprehensively into the fascinating world of plant growth and development. It elucidates the intricate processes dictating a plant's life cycle, emphasizing the critical roles that plants play in the biosphere. As the foundation of food webs, they are essential for supporting life on Earth. Moreover, plants significantly contribute to mitigating climate change by absorbing and storing carbon dioxide. The dynamic interplay between internal factors, such as hormonal control, and external elements, including sunlight and temperature, that orchestrate plant growth. The significance of understanding and managing these processes in agriculture, as they inform optimal timing for planting, fertilization, and irrigation, ultimately enhancing crop yields while minimizing losses to pests and diseases. The practical applications of understanding plant growth, notably in agriculture, where it informs optimal planting times, nutrient management, and pest control for enhancing crop yields. Furthermore, in the context of ecosystem management, knowledge of plant growth is pivotal for selecting appropriate species and ensuring biodiversity conservation. From the initial germination of a seed to the eventual formation of flowers and fruits, each stage of a plant's life is meticulously dissected. Key events and their ecological significance are detailed, providing insights into the profound impact of plant science. In essence, this chapter highlights the pivotal role of plant growth and development in addressing global challenges such as climate change, food security, and the preservation of biodiversity.

Keywords: mitigating climate change, hormonal control, enhancing crop yields, ecosystem management, ecological significance.

Overview of Plant Growth and Development
The plant kingdom is one of the most crucial in the whole biosphere. Multicellular creatures are capable of producing their own sustenance from atmospheric carbon dioxide. All other forms of life depend on plants for survival on Earth since they form the basis of food webs. Hormonal control and environmental signals are only two examples of the dynamic interaction between internal and exterior elements in plant growth and development. Each step of a plant's life cycle is essential to its continued existence, adaption, and reproduction, from germination, when a dormant seed awakens, through the reproductive phase, when flowers assist pollination and seed generation.

Proper plant growth and development are basic requirements for optimum production in agriculture. Knowledge of plant development factors allows farmers to improve crop yieldsvia more precise timing of planting, fertilization, and watering (Taiz and Zeiger, 2010). it is important to know how vulnerable crops are at various phases of development to various pests and diseases to reduce crop losses and chemical interventions, (Oerke, 2006).

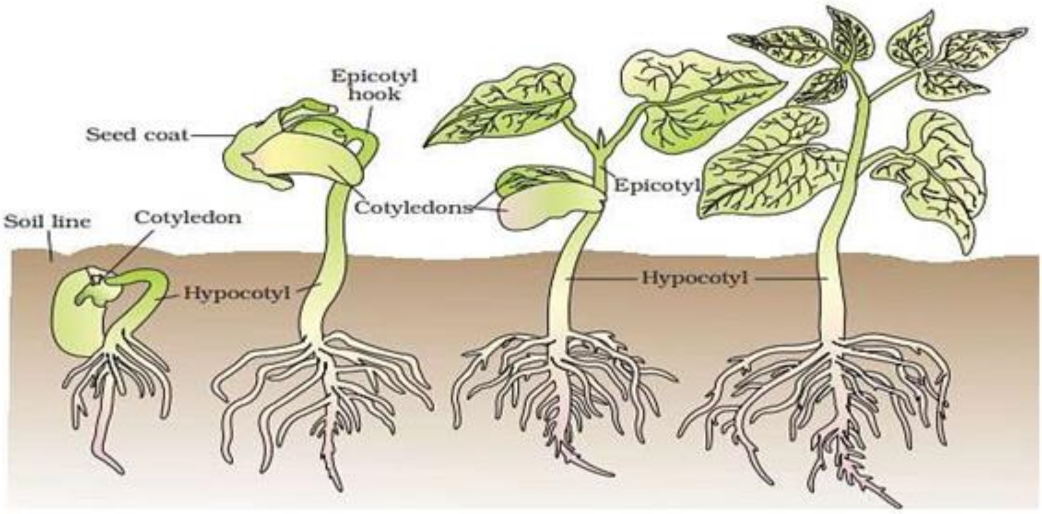

Fig. 1. Plant Growth and Development. (Source: edurev.in)

It is important to know how plants grow and change is also crucial for managing ecosystems. If you want to restore degraded ecosystems or preserve biodiversity, you need to know which species to plant and how to care for them (Suding *et al*., 2004). Plants have a pivotal part in carbon sequestration, which mitigates the impacts of climate alteration, since of the sum of carbon dioxide they assimilate and store amid photosynthesis (Field *et al.*,1998).

From germination to regenerative development, this chapter will take you on a travel through the lifecycle of a plant and into the administrative frameworks that keep it all in check. As our information on plant science extends, we are going to be superior able to utilize plants to combat issues like climate alter, starvation, and the misfortune of biodiversity.

Germination

Definition and Importance of Germination

A seed germinates when it breaks its dormant state and begins to grow into a plant. It's a crucial time period since it starts the growing phase and prepares the ground for a healthy living root system in the young plant. By kicking off the development of new individuals from seeds (Bewley *et al.,* 1994), the process of germination guarantees the survival of plant species.

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Fig. 2. Seed germination. (Source: https://www.istockphoto.com/)Factors Influencing **Germination**

Germination is influenced by a complex interplay of internal and external factors. Some of the key factors that affect germination include:

1. **Water Availability:** Adequate water is essential for seed germination. It triggers the activation of enzymes, initiating metabolic processes necessary for the growth of the embryo.
2. **Temperature:** Seeds have specific temperature requirements for germination. Optimal temperatures vary among plant species, and some seeds require exposure to cold temperatures (stratification) to overcome dormancy and germinate, while others require warm temperatures.
3. **Oxygen:** Germination is an aerobic process, and oxygen availability is critical for respiration and energy production during seedling growth.
4. **Light:** Light can be an important factor in seed germination. Some seeds require light to germinate (photoblastic seeds), while others are inhibited by light (photodormant seeds).
5. **Seed Coat and Dormancy:** The seed coat can act as a physical barrier to germination. Some seeds have specialized dormancy mechanisms that delay germination untilfavourable conditions are met (Finch-Savage *et al*., 2006).

Key Events During Germination

Germination involves a series of key events that transform a quiescent seed into an actively growing seedling:

- ❖ ***Water Absorption****:* Water is taken up by the seed through imbibition, leading to the swelling and softening of the seed coat.
- ❖ ***Activation of Enzymes****:* With the availability of water, enzymes within the seed are activated, catalyzing the breakdown of stored nutrients (such as starch) into simple sugars that fuel the growing embryo.
- ❖ ***Cell Expansion and Growth****:* As the embryo absorbs water and nutrients, its cells undergo rapid expansion and elongation, leading to the emergence of the radicle (embryonic root) and the plumule (embryonic shoot).

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- ***Radicle Emergence**:* The radicle elongates and emerges from the seed, anchoring the seedling in the soil and absorbing water and minerals.
- ***Plumule Emergence**:* The plumule emerges next, growing towards the light and air, and developing into the seedling's shoot system.
- ***Photosynthesis Initiation**:* As the plumule emerges from the soil, the first set of true leaves develop and photosynthesis begins, providing the seedling with a source of energy for further growth.

Examples of Germination in Different Plant Species

Germination is a universal process that occurs in a wide variety of plant species. Here are some examples of germination in different plant families and genera:

- *Maize (Zea mays):* Maize seeds germinate well under warm soil temperatures and require adequate moisture for successful germination.
- *Arabidopsis (Arabidopsis thaliana):* Arabidopsis seeds serve as a model system for studying germination. They require light to break dormancy and initiate germination through photo morphogenesis. (Koornneef and Meinke, 2010).
- *Bean (Phaseolus vulgaris):* Bean seeds are common in horticulture and agriculture. They require warm temperatures and well-drained soil for optimal germination.

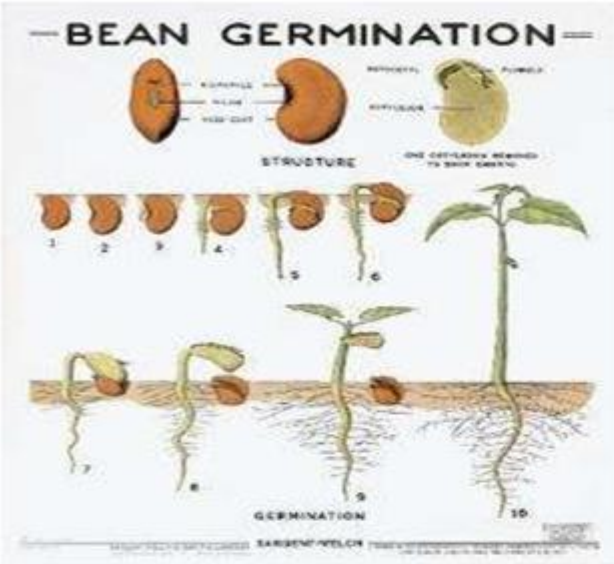

Fig. 3. Bean germination chart. (Source: sargentwelch.com)

- *Pine (Pinus spp.):* Pine seeds have specific germination requirements. Some pine species, like lodgepole pine (Pinus contorta), have serotinous cones that require heat from wildfires to release their seeds and initiate germination.

Seedling Establishment

Stages of Seedling Establishment

After successful germination phase, the next step in a plant's life cycle is the establishment of its seedlings. A young seedling that can grow on its own is developed. There are many distinct phases during seedling establishment:

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Emergence: During this stage, the radicle (embryonic root) emerges from the seed and elongates downward into the soil. The radicle is the first organ to emerge and plays a vitalrole in anchoring the seedling and absorbing water and nutrient. (Mastrangelo and Guzmán, 2004).

Cotyledon Unfolding: Cotyledons are the first leaves that emerge from the seed and provide energy for the initial growth of the seedling. In monocots, such as grasses, the cotyledon remains within the seed, and the first leaf emerges directly from the coleoptile. (Poethig, 1987).

Plumule Growth: As the cotyledons unfold, the plumule (embryonic shoot) elongates and grows upward towards the soil surface. The plumule eventually gives rise to the first true leaves, which will perform photosynthesis and support the seedling's energy requirements (McCormick and Yang, 2001).

Root System Development

Root system development is a critical aspect of seedling establishment as it enables the seedling to anchor itself in the soil and access essential water and nutrients. The process of root system development involves the following stages:

Fig. 4. Root system development in pine. (Ono *et. al.*, 2021)

Primary Root Growth: The primary root, derived from the radicle, is the first root to emerge from the seed and is essential for anchoring the seedling It plays a crucial part in improving the soil's capacity to absorb water and nutrients. (Benfey and Scheres, 2000).

Root Branching: As the primary root elongates, it starts to produce lateral roots through branching. Lateral roots extend laterally from the primary root and contribute to the overall root system's efficiency in water and nutrient uptake (Péret *et al*., 2013).

Formation of Root Hairs: Root hairs are tiny extensions of root epidermal cells that greatly increase the surface area of the root system. They play a crucial role in enhancing water and nutrient absorption from the soil (Gilroy *et al.,* 2018).

Shoot System Development and Cotyledon Function

As the plumule grows, the shoot system develops, and the cotyledons play a crucial role in supporting early seedling growth and development:

- ***Cotyledon Function:*** Cotyledons are essential storage organs that contain nutrients transferred from the endosperm or seed coat during germination. These stored nutrients provide the seedling with a source of energy until it can establish a functional root system and begin photosynthesis. (Taiz and Zeiger, 2010).

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- ***Development of True Leaves:*** The plumule elongates and produces the first true leaves, which are the seedling's primary photosynthetic organs. True leaves are characterized by their distinct shape, vascular system, and chlorophyll content, allowing the seedling to synthesize its own food through photosynthesis (Raven *et al.*, 2013).

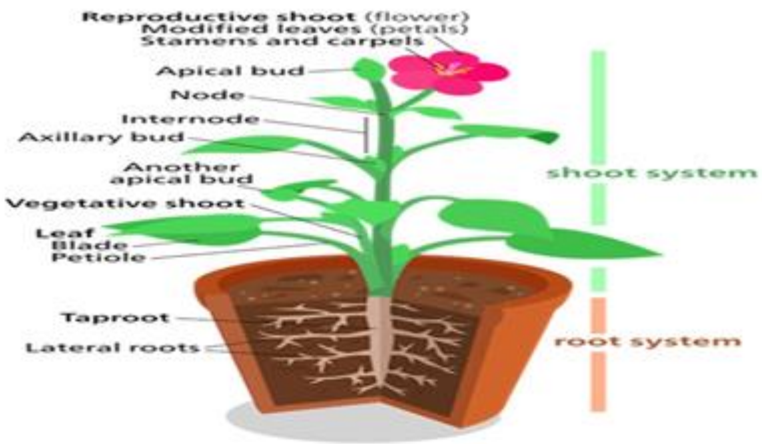

Fig. 5. Plant shoot system. (Source: study.com)

Dependence on External Resources for Survival

During seedling establishment, young seedlings are highly dependent on external resources for their survival and growth. They rely on the following external factors:

Water and Nutrients: Seedlings require an adequate supply of water and essential nutrients from the soil to support their physiological processes and growth. Water is essential for maintaining turgor pressure and nutrient transport within the plant (Marschner, 2011).

Light: While cotyledons can provide energy for early seedling growth, the seedling becomes increasingly dependent on light for photosynthesis as the true leaves develop. The seedling's development and well-being depend critically on access to light. (Folta and Childers, 2008).

Protection from Herbivores and Pathogens: Seedlings are vulnerable to herbivores and pathogens during their early stages of growth. They depend on external factors, such as beneficial microbes or physical barriers, for protection against potential threats (Pineda *et al.*, 2010).

The germination and establishment of a seed is an essential first step in every plant's life cycle. It is very necessary to have a grasp of the processes involved in the formation of the root and shoot system, the role of the cotyledons, and the seedling's dependence on external nutrients in order to effectively propagate and establish plants in their natural habitats or in agricultural settings.

Vegetative GrowthDefinition

The botanical phenomenon referred to as "vegetative growth" pertains to a specific stage in a plant's life cycle whereby the plant primarily focuses on developmental processes unrelated to reproduction. During this specific period, the plant is predominantly directing a substantial amount of its energy into the physiological process of enhancing its biomass and size via the growth and development of its vegetative organs, such as the roots, stems, and leaves stated differently, the botanical organism is undergoing growth.

The process of vegetative growth is of utmost importance as it serves as a crucial prerequisite for the subsequent reproductive phase, during which the plant allocates its resources towards

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the development of flowers and fruits. Characteristics of vegetative growth include continuous cell division and elongation, resulting in the expansion and differentiation of various plant tissues (Poethig, 2007).

Characteristics of Vegetative Growth Root Growth and Nutrient Absorption

Vegetative development cannot occur without root expansion, as roots are the plants' major route for absorbing water and nutrients from the soil. The following steps make up the root development process:

- **Cell Division and Elongation:** Root tips contain meristematic cells that continuously divide, leading to root elongation. Roots grow longer so that they may reach water and minerals in the soil more deeply. (Benfey and Scheres, 2000).
- **Root Hairs and Nutrient Absorption:** Root hairs are extensions of root epidermal cells that significantly increase the root's surface area. They are the main sites of nutrient and water absorption, facilitating the uptake of essential minerals and ions from the soil (Gilroy *et al.*, 2008).

Shoot Growth, Branching, and Leaf Development

Shoot growth is a critical component of vegetative growth, contributing to the above-ground biomass and the expansion of the plant canopy. Key processes involved in shoot growth include:

1. **Stem Elongation:** Shoots elongate through cell division and elongation in the apical meristems. This upward growth allows the plant to compete for sunlight and space in its environment. (Poethig, 1990).
2. **Branching and Lateral Shoots:** As the plant grows, lateral buds can become activated, leading to the development of lateral shoots or branches. Branching increases the plant's capacity for light capture and enhances overall growth and biomass production. (Berger and Altmann, 2000).
3. **Leaf Development:** Leaves are the primary sites of photosynthesis, where sunlight is converted into chemical energy. During vegetative growth, leaves continuously develop and expand, increasing the plant's capacity for photosynthesis and assimilation of carbon dioxide, phototosynthesis and Biomass Production. (Evans and Poorter, 2001).

Photosynthesis is vital for physiological process of plant during vegetative growth.Growth and development occur through photosynthesis by generating biomass. The process of photosynthesis involves the following:

- **Carbon Fixation:** Carbon dioxide from the atmosphere is fixed by the enzyme RuBisCO (Ribulose-1,5-bisphosphate carboxylase/oxygenase) in the chloroplasts of leaf cells, leading to the formation of organic compounds, primarily sugars (Sage and Zhu, 2011).
- **Biomass Accumulation:** The sugars produced during photosynthesis are utilized as building blocks for the synthesis of complex molecules, such as cellulose and proteins. total biomass production. is promoted by these chemicals that help in tissue development (Schulze *et al*., 2005).

Reproductive Growth

Transition from Vegetative to Reproductive Phase

Moving from the growth and development of vegetative organs to the formation of reproductive structure is a major event in a plant's life cycle, known as the transition from the vegetative phase to the reproductive phases. This transition is orchestrated by complex interactions between environmental cues, genetic factors and hormonal signals (Amasino, 2010). It culminates in the formation of flowers, which are the reproductive organs of angiosperms (flowering plants).

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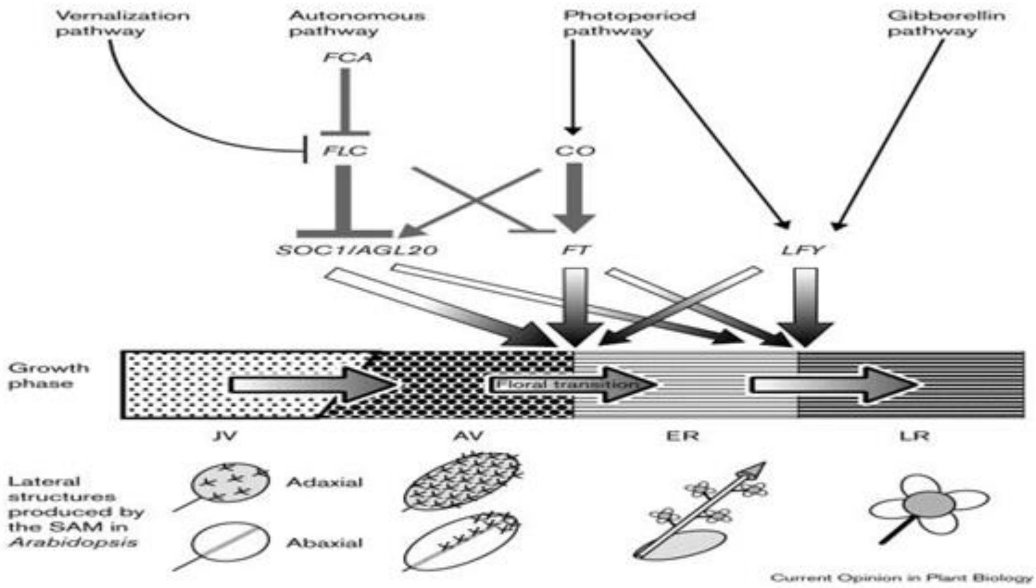

Fig. 6. Transition from Vegetative to Reproductive Phase. (Akari, 2001)

Environmental and hormonal triggers are responsible for flowering in plants.

Flowering is regulated by a combination of external environmental cues and internal hormonal signals. Key factors influencing the transition to the reproductive phase include:

Photoperiod: Day length, or photoperiod, is a critical environmental cue that triggers flowering in many plant species. Photoreceptors perceive changes in day length, influencing the expression of flowering-related genes (Song *et al*., 2015).

Temperature: Temperature fluctuations, especially the difference between daytime and nighttime temperatures, play a role in the timing of flowering. Cold temperatures (vernalization) or exposure to specific temperature ranges can induce flowering in some plants (Ibanez *et al*., 2010).

Hormones: Plant hormones, such as gibberellins, cytokinins, and auxins, play essential roles in regulating flowering. The balance and interaction of these hormones influence the transition from vegetative to reproductive growth (Wigge, 2013).

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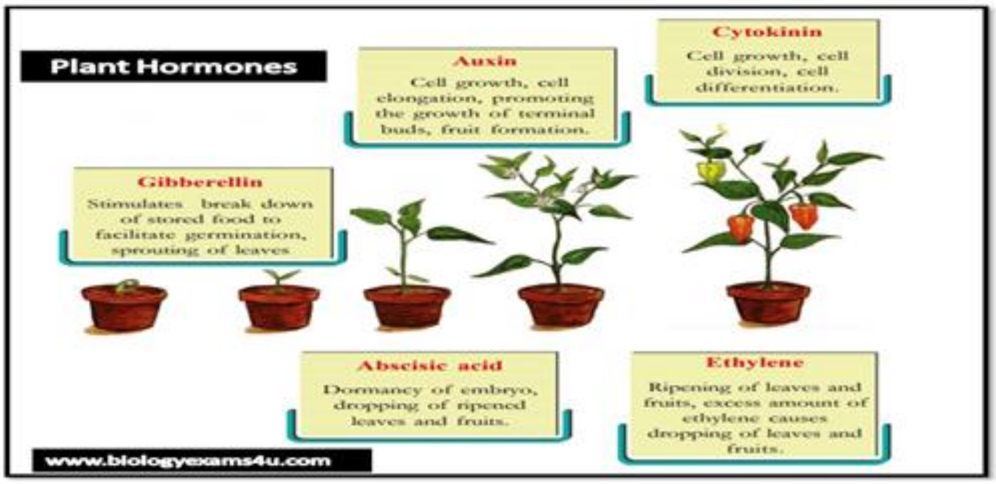

Fig. 7. Effect of plant hormonesStructure and Function of Flowers

Flowers are complex structures that serve as the reproductive centers of flowering plants. A typical flower consists of several parts, each with distinct functions:

Sepals and Petals: Sepals are outermost floral organs that protect the developing bud, whilepetals are often brightly coloured and attract pollinators.

Stamens: Stamens are the male reproductive organs of the flower, consisting of an anther anda filament.

Carpels: Carpels are the female reproductive organs, each comprising an ovary, a style, and astigma. The ovary contains ovules, where female gametes are produced.

Pollination, Fertilization, and Fruit Development

Pollination, the transfer of pollen from the anther to the stigma, is a crucial step in sexual reproduction.

Fertilization: Pollen grains germinate on the stigma and grow down the style to reach the ovary, where fertilization occurs. Within the seed, an embryo develops from a zygote created when male and female gametes fuse.

Fruit Development: Following fertilization, the ovary develops into a fruit, enclosing and protecting the developing seeds.

Seeds can be dispersed by fruits which can play a vital role in reproduction and seed propagation.

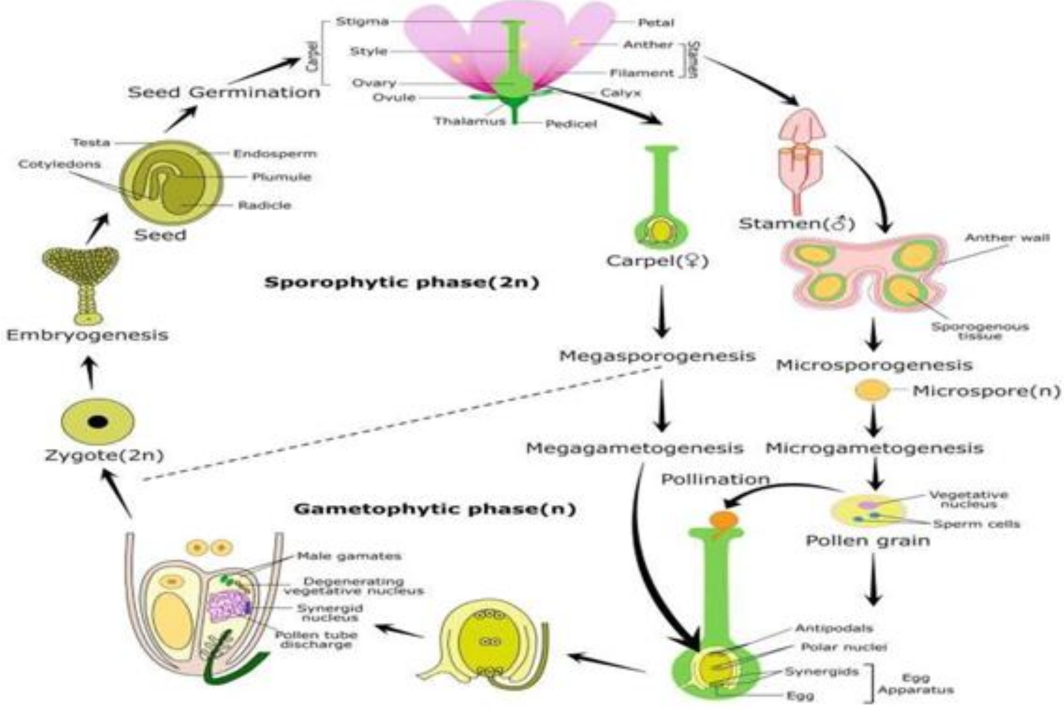

Fig. 8. Pollination, Fertilization and Seed Development. (Bhatia *et. al.*, 2018)

Controlling the Development and Growth of Plants:

Plant growth and development are finely orchestrated processes governed by a complex interplay of internal and external factors. A plant's life cycle is shaped in large part by internal control, which is mediated by plant hormones. The function of several plant hormones in coordinating growth and development is explored here.

Internal Regulation: Plant Hormones

Plant hormones, also known as phytohormones or growth regulators, are chemical messengers that govern diverse physiological and developmental processes in plants (Woodward and Bartel, 2005). The effects of these hormones on development, differentiation, and sensitivity to environmental cues are significant despite their low-level of activity. (Kieber and Schaller, 2018). In this article, we will discuss the main hormones in plants and their roles:

Plant hormones collectively control a wide array of processes, including cell division, elongation, differentiation, flowering, fruiting, and responses to stressors(Santner and Estelle, 2009). Their integrated actions ensure proper coordination and adaptation to varying environmental conditions.

Role of Auxins in Cell Elongation and Tropisms:

Auxins, primarily represented by indole-3-acetic acid (IAA), regulate cell elongation, tropic responses, and apical dominance (Hobbie and Estelle, 1995). They stimulate elongation by loosening cell walls and promoting water uptake. Auxins also mediate phototropism (growth towards light) and gravitropism (response to gravity) by their unequal distribution in plant organs.

Gibberellins and Their Impact on Stem Elongation and Seed Germination:

Gibberellins (GAs) are key regulators of stem elongation, seed germination, and flowering (Hedden and Thomas, 2012). They promote cell division and elongation, leading to increased

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plant height. In seed germination, GAs break seed dormancy and trigger the synthesis of hydrolytic enzymes.

Cytokinins in Cell Division and Lateral Bud Growth:
Cytokinins are essential for cell division, influencing shoot and root development. (Sakakibara, 2006). They antagonize auxins in apical dominance and promote lateral bud growth, leading to the formation of branches.

Abscisic Acid and Its Role in Seed Dormancy and Stress Responses:
Abscisic acid (ABA) primarily functions as a stress hormone, regulating responses to drought, salinity, and cold stress (Finkelstein *et al*., 2002). It also plays a pivotal role in seed dormancy, inhibiting germination under unfavourable conditions.

Ethylene and Its Involvement in Fruit Ripening and Senescence:
Ethylene is a gaseous hormone responsible for various physiological responses, includingfruit ripening and leaf senescence (Johnson and Ecker, 1998). As a result, the cell walls of the fruit relax, the colour shifts, and aromatic chemicals are released more quickly. Plants are able to successfully adapt to new settings because of the dynamic interaction of these hormones**.**

External Regulation: Environmental Factors
The growth and development of plants are intricately shaped by a multitude of external environmental factors. This section explores the diverse ways in which external factors impact plant growth and development.

Influence of Light on Photosynthesis and Photomorphogenesis:
Light serves as a crucial environmental factor that governs photosynthesis and photomorphogenesis – the process of growth and development in response to light stimuli (Chen and Fankhauser, 2004). Photoreceptor proteins such as phytochromes and cryptochromes perceive light quality, quantity, and duration, influencing processes like seed germination, stem elongation, and flowering.

The effect that temperature has on the biochemical reactions that take place in plants and their Growth
Temperature has a considerable impact on the metabolic processes, enzyme activity, and overall development of plants, to a greater or lesser degree depending on the specific situation. (Hänninen, 2006). Temperature has a direct impact on photosynthesis, respiration, and other vital functions because biochemical reactions that are mediated by enzymes are temperature dependant. •Changes in temperature may lead plants to behave in an adaptive manner, such as by acclimating to colder conditions or becoming more resistant to heat stress.

Water and Nutrient Availability and Their Impact on Plant Growth:
Water and nutrient availability are critical determinants of plant growth and development (Marschner, 2012). It is necessary to have an appropriate absorption of water in order to properly maintain turgor pressure and ensure that nutrients are transported. The reproduction of cells, the expansion of root systems, and the opening of flowers are all instances of such processes**.**

Interactions with Other Organisms and Their Effects on Growth and Development:
Plants exist within complex ecosystems where interactions with other organisms, including pathogens, symbiotic partners, and competitors, significantly influence their growth and development (Pieterse *et al*., 2014). These interactions can trigger defence mechanisms, alter resource allocation, and even impact reproductive success**.**

Role of Gravity in Geotropism and Gravitropism:

Gravity is a fundamental external cue that guides plant growth in relation to the Earth's gravitational field. (Leopold and Kriedemann, 1975). Geotropism (response to gravity) includes positive gravitropism in roots and negative gravitropism in shoots.

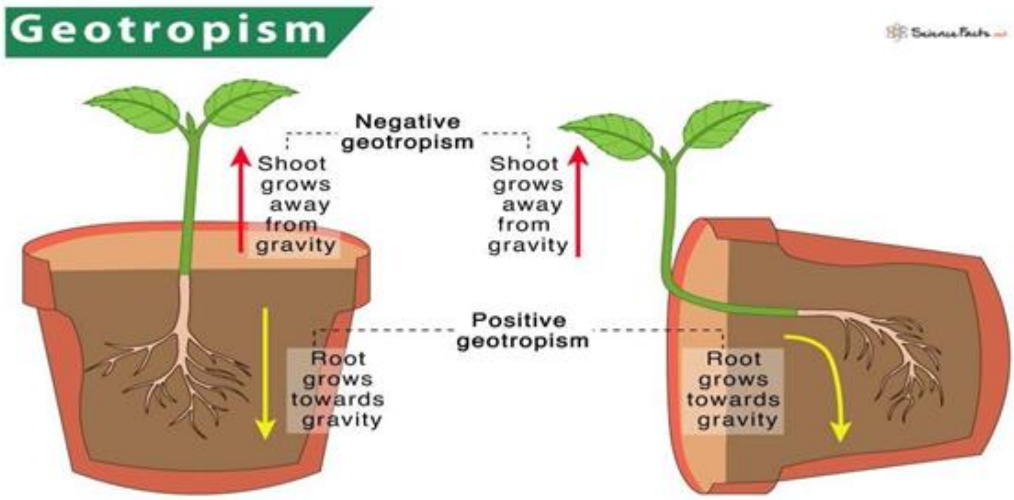

Fig. 9. Geotropism. (Source: sciencefacts.ne)

CONCLUSION

On the contrary, understanding plant growth and development has highlighted complex processes that control plant life cycles. A meticulously structured sequence, each crucial for a plant's overall health and resilience, is formed during the various stages of seed germination, seedling establishment, vegetative growth or reproductive growth. The internal regulatory mechanisms, guided by a complex network of plant hormones, coordinate growth responsesin an intricate way. As a result, agricultural output and quality can be improved the regulatory mechanisms. As a result of this understanding, plants are better able to adjust to shifting environmental conditions. As this improvement proceeds, we are mindful that there's more to memorize. Innovative scientific approaches and hardware thrust us to memorize more around the biochemical and physiological forms that maintain plant improvement. The think about of botany is an unending field with no limits to what may be learned.

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CHAPTER 7

THE IMPACT OF CLIMATE CHANGE ON HORTICULTURE

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ABSTRACT

Agroecological regions in India with diversified soil and climate offers a lot of opportunity for the cultivation of a wide range of horticultural crops. Recently, climate change accelerates at an alarming rate and causing serious issue. The adverse effects of climate change include global warming, seasonal pattern changes, heavy rain, ice cap melting, flood, rising sea level, drought, and other extreme events. Due to climate change crop productivity and yield will be decreased as a result of in sufficient chilling hours, shifting of crop belt, physiological disorder, pest and disease incidence, and so on. Climate change can be managed to some extend through mitigation strategies and some adaptation measures. Mitigation strategies include carbon sequestration through fruit crops, efficient energy usage, fertilizer and manure management and soil management practices. Crop-based adaptation methods must be developed, incorporating all available choices to maintain productivity, depending on the susceptibility of each crop in an agro-ecological region and the growing season.

Keywords: Climate change, horticultural crops, loss, mitigation, adaptation

INTRODUCTION

India is a country with several agro-ecological regions due to its diversified soil and climate, which offers a lot of opportunity for the cultivation of a wide range of horticultural crops like fruits, vegetables, flowers and ornamentals, spices, condiments, plantation crops, medicinal and aromatic plants, root and tuber crops. India is the 2nd largest producer of fruits and vegetables production in the world next to China. The estimated total production of horticulture in India for the agricultural year 2023 was 350.9 million tonnes, with 107.7 million tonnes of fruits and 212.5 million tonnes of vegetables (1st Advance Estimate-2023, Ministry of Agriculture and Farmers Welfare, India). Recently, we are experiencing the effects of climate change and it is accelerating at an alarming rate. It's possible that this is the most serious issue that society has ever facing. In India the impact of climate change on four economic sectors like agriculture, water, natural ecosystems and biodiversity, and health, in four climate-sensitive regions namely the Himalayan region, the Western Ghats, the Coastal Area, and the North-East Region is very high. The current difficulties, such as global climate change, water and soil contamination, limited water availability, urbanisation, and so on, aggravate the situation. Climate change wouldvery certainly result in more food shortages, as well as higher loss of life and infrastructure due to coastal inundation and riverine flooding. The main factors influencing crop production are soilfertility, soil temperature, soil moisture, and sunlight. The average global temperature is predicted to rise over the course of this century, along with seasonal and yearly precipitation patterns changing and the frequency and severity of extreme weather events increasing. Through the CO_2 fertilisation effect, increased atmospheric carbon dioxide levels may potentially have an impact on crop production. Crop yields and the distribution of agricultural/horticultural production will be significantly changed by these factors.

The adverse effects of climate change include global warming, seasonal pattern changes, heavy rain, ice cap melting, flood, rising sea level, drought, and other extreme events. According to the IPCC assessment, crop production in India is expected to decline by 10-40% by 2080-2100 as a result of global warming. Climate change poses a significant threat to human food security. Around 12% of the world's population is already at risk of being without food, but if temperatures raise just 2 to 3°C, that number may climb by up to 200 million. A drop in prospective yields is most likely caused by a shortening of the growing season, a decrease in water availability, and poor vernalization. The unusual monsoon may prevent the Western Ghats and the adjacent areas from receiving their usual amount of precipitation. Other effects include the vulnerability, rarity, and quick extinction of plant species. The plains of India will encounter similar challenges. According to Nobel Laureate Pachauri, (who won the Nobel Peace prize for climate change), the amount of agricultural land will decrease, and the available land may eventually no longer be suitable for the current crops. Farmers must look into options for changing their crops to fit the conditions. He also stated that climate change could cause severe food security challenges in a country like India.

Impacts of Climate Change

- Higher temperatures prolongs the duration of heat waves and increase the potential evaporation.
- More sporadic rainfall patterns and unpredictable high temperature periods will impair crop yield.
- Winter rainfall has significantly decreased, which has caused a serious water shortage in the early summer months.
- Temperature increases will cause a shift in crop production time. Temperature increases may cause photoperiods to become less variable. Therefore, photosensitive crop will mature more quickly.
- More stronger floods will affect the horticulture crops particularly in the flood plains of the eastern Himalayan rivers, their major tributaries, and the delta regions.
- More severe droughts across a larger area have a negative impact on crop production.
- The areas which are presently suitable for the cultivation of crops become unsuitable.
- In temperate places, the length of winter and the chilling period will shorten, impacting crops that require a chilling period particularly fruit crops like apple, pear, plum, cherry, apricot and temperate nut crops.
- Coastal flooding and saline intrusion due to sea level rise, along with the amplified storm surges from more potent tropical cyclones in the Bay of Bengal will destroy the crops and also make the soil more saline.
- The increasing temperature will have a negative impact on pollination. Floral abortions, flower and fruit drop will occur often.
- Himalayan glaciers are rapidly melting, initially increasing river flows and then causing sedimentation and reduced flow, especially during the drier months.
- Climate change will also lead to more pest and disease outbreak
- The agro-ecological zones are gradually shifting
- Several indigenous cultivars aren't yielding as planned and are on the verge of extinction.

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1. **Impact on Fruit Crops**

Insufficient chilling hours and soil moisture:

In the last century, the temperature in the North West Himalayas has risen by 1.6°C (IPCC, 2018). This will affect most of the temperate fruit crops like apple, cherry, pear, peach and plum. The loss of snow cover in Himachal's lower hills has a significant impact on fruit bearing conditions. Snowfall was occurring less frequently and at different times, which lowered the chilling hours and ultimately led to a poorer-quality crop of certain apple cultivars (Rana, 2010). Apples require a chilling hours between 1000 - 1600 hours at or below 7°C, but at the moment this requirement is not met due to an increase in the earth's surface temperature brought on by climate change. Warmer climatic circumstances were found to have a substantial impact on flowering, fruit set, yield, and quality in peach cultivars. Peach trees have abnormal patterns of phonological stages, including late flowering and a longer flowering period, as a result of lack ofchilling.

Shifting of crop belt

Due to insufficient chilling conditions in the mid hills (Rajgarh, Theog and Kotkhai in Himachal), the apple belt has been moved to a higher hill location (Kinnaur, Lahaul and Spiti in Himachal Pradesh) to achieve the required amount of chilling hours. Snowfall and rainfall have decreased in the mid-hills, creating drought-like conditions that will impede tree development. This has an effect on the flowering and fruit set period by interfering with pollination and directly causing yield loss.

Physiological disorder

- Several physiological disorders of the fruit crop have become more prominent as a resultof the high temperature.

Example: Spongy tissue in mango, fruit cracking, black spot in custard apple, flower andfruit abscission, and so on.

- Additionally, air pollution increased some physiological problems like black tip of the mango which is due to ethylene, sulphur dioxide, carbon monoxide, carbon fume gases and fluoride.
- Sunburn and cracking in apples, apricots, and cherries are due to high temperatures and moisture stress, while an increase in temperature at maturity leads to fruit cracking and burning in litchi.
- Choke throat in banana due to low temperature stress.

Effect on Pollination Activity

Temperature stress has a major impact on pollination activities, which accounts for 35% of global food supply. Interactions between plants and pollinators are hampered by temporal (phenological) and spatial (distributional) inconsistencies. Temporal alterations are already evident as *Apis mellifera* has accelerated their activity period earlier than the flowering peaks of their preferred forage species, and spatial-shifting of areas in developing countries. Crop plants that are pollinator-specific, pollinator-limited, or self-incompatible are particularly susceptible tothis issue. The number of days available for successful pollination during the formation of the mango panicle can be decreased as a result of rising temperatures, which can also speed panicle growth. A floral bud might change into a vegetative one during a warm night.

Affect Quality of Fruits

In order to fetch a high price on the export market, quality factors are crucial to consider. Changes in climatic conditions have an impact on the ideal conditions for producing secondary metabolites and pigmentation, both of which are essential for growing high-quality fruits. Heat shocks (over 35°C) resulted in the loss of 50% of the berries due to browning and berry burn.

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According to (Jones and Davis, 2011) each degree increase in the average growing season's temperature results in a 10-15 day earlier maturation of grapes, and warmer temperatures resultin a drop in anthocyanin and acidity in French wine grape varietals. Rising temperatures have a negative effect on the quality of grape wine production by hastening the maturity period of the grapes and lowering acidity and colour. In citrus, grapes, and litchi, higher temperatures are predicted to speeds the development of fruitlets and maturity. Due to quicker maturation and ripening, the fruit's availability period may be decreased. The marketing of apple fruits depends mainly on the red colour of the fruit. Temperature is one of the most important factors influencing the development of red colour in apple fruits. At 30°C anthocyanin development willbe very poor in apple.

Pest and Disease Incidence

Climate change has impacted pest and disease occurrence in fruit crops. Changes in flowering time and temperature variations can bring in new pests, make minor pests into significant pests, and break pest resistance. Seasonal variations, particularly variations in temperature and rainfall patterns, have a direct impact on the lifecycle of a variety of insect pests. Geographic distribution, population growth rates, generation numbers, overwintering, developmental seasons, crop-pest phenology synchronicity, increased risk of invasion by migrating pests, and interspecific interactions could all change as a result of climate change.

Stormy rains cause an increase in bacterial gummosis in pome and stone fruits. In mango cv. Chausa, fruit fly development increased as temperature rise from 20 to 35°C. Future climatic conditions may influence codling moth prevalence in apples as well as the life cycle phases that are critical for pest control. In Switzerland, the potential risk for the third generation was also significantly increasing. In order to suppress a third generation of codling moth, it would be essential to expand and broaden protective measures (such as pesticides), which would raise the risk of pesticide residual effects on fruits.

Favourable conditions for pest incidence under climate change scenario

Fruit Crop	Pest	Reference
Apple	Every 1°C Increase reduces winter stink mortality bug by 15%. (*Halyomorpha halys*)	Kiritani, 2007
Apple	A 2 °C increase in temperature will cause an additional 5 generations of woolly aphids every year.	Harrington *et al*. 2007
Banana	Drier climates will exacerbate the severity of burrowing nematode (*Radopholus similis*).	Villanueva, 2005

2. Impact on Vegetable CropsHigh temperature:

As many physiological, biochemical, and metabolic activities in plants are dependent on temperature, fluctuations in daily mean maximum and minimum temperature are the principal effect of climate change that negatively affects vegetable production.

- Potato is the fourth most significant non-cereal staple food in the world. The most sensitive crop to climate change is the potato due to its well-known specific temperature and day length requirements for tuber formation and flowering. Long days and cool temperatures are necessary for potato flowering. It allows for the breeding of potatoes by heterosis or hybridization at high altitudes in Himachal Pradesh. The potato breeding area is moving to higher altitudes as a result of the rising temperature. Potato is quite specific about the temperature required for tuber formation. 20°C is the ideal temperature for tuber development. At temperatures exceeding 21°C, the yield of potato tubers is sharply reduced, and at 30°C, tuber formation is completely inhibited (Sekhawat, 2001).
- Fruit colour is very important in determining tomato marketability. The ideal temperaturefor

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tomato lycopene pigment formation is 25-30°C. Lycopene begins to degrade above 27°C, and above 40°C, it is fully destroyed. Similarly, temperatures over 25°C have an impact on tomato pollination and fruit set (Kalloo *et al*., 2001).

- Watermelon, summer squash, winter squash, and pumpkin seeds will not germinate at 42° C, while melon and cucumber seeds will be significantly suppressed at 45° C respectively (Kurtar, 2010).
- Bolting is caused by high temperatures in cole crops, which is undesirable when cultivated for vegetable purposes.
- DBM (Diamond Back Moth) survival rates increase in warm climates. Climate change can have an impact on the areas that produce brassicas, especially in the subtropical and increasingly in the temperate zones. In the future thrips will multiply and live more easily in arid environments . Higher temperatures are detrimental to the survival and reproduction of some important parasitoid and predators, such as Trichogramma in vegetables.

Low temperature:

Crop plants that develop in tropical regions may suffer substantial freezing injury, even if little freezing conditions occur, although most crops that originate in colder climates often survive with minimal freezing if the freezing situation is not too severe. Low temperatures of 8 to 12°C hinder tomato seed germination, pollen tube growth, and the percentage of fruit set. Beans seed are very sensitive to low temperature especially during imbibition, so the seeds do not germinate. Dull, gray-green with limp tips in asparagus, pitting and russetting in bean, water soaked lesions in cucumber, seed blackening in brinjal, discolouration in okra and poor colour development in tomato are due to low temperature.

Frost injury symptoms (Caplan, 1988)

Crop	Symptom
Garlic	Thawed cloves have a greyish yellow and water soaked appearance
Celery	Wilted appearance
Cauliflower	When cooked, curds turn brown and emits off flavour
Carrot	Blistered appearance, jagged length-wise cracks
Broccoli	Curd turns brown
Artichoke	Epidermis detach and develop whitish to light tan blisters.
Onion	Water soaked appearance
Potato	Grey or bluish-grey patches beneath the skin and the tuber becomes soft
Sweet potato	Root become soft and susceptible to decay

Drought

Drought conditions are mainly due to climate change phenomenon like irregular and insufficient rainfall. Tomatoes are very sensitive to drought during immediately after transplanting, at flowering and fruit development. The yield of root and bulb crops like potato, carrot, and onion mainly depend on the translocation of carbohydrates from leaf to bulb or root. Drought stress during storage organ enlargement lowers yield and quality. Since leafy crops like spinach, amaranth, and palak are naturally succulent, the drought condition lowers the water content of the leaf, which results in poor quantity and quality.

Salinity

According to the United States Department of Agriculture (USDA), among the major crops, tomatoes, cucumbers, eggplants, and peppers are moderately sensitive to saline soils, whereas onions are more sensitive. The effects of salt stress on plants include loss of turgor, reduced growth, wilting, leaf curling and epinasty, leaf abscission, reduced photosynthesis, respiratory modifications, loss of cellular integrity, tissue necrosis, and possibly death of the plant.

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- Many crops undergo anatomical changes as a result of salt stress, and bean leaves develop thick epidermis and mesophyll cells.
- Salt stress reduces intercellular gaps in spinach leaves and increases stomatal density in peas.
- Salt stress reduces intercellular gaps in spinach leaves and increases stomatal density in peas.
- In cucurbits due to salt stress there will be a reduction in fresh and dry weight, relative water content, and overall chlorophyll content.

Flooding

The majority of vegetables are extremely sensitive to floods, and tomato in particular exhibits minimal genetic diversity in this regard. In general, flooding damage to vegetables is caused by a decrease in oxygen in the root zone, which limits aerobic processes. Tomato plants that have been flooded build up endogenous ethylene, which harms the plants. Low oxygen levels encourage the roots to produce more 1-aminocyclopropane-1-carboxylic acid (ACC), a precursor to ethylene. The quick development of epinastic growth of leaves is a typical tomato response to waterlogging, and the involvement of ethylene buildup has been identified. With rising temperatures, flooding symptoms become more severe; even a short period of flooding at high temperatures, tomato plants typically wilt quickly and die.

3. Impact on Plantation Crops

The yield of coconuts dropped by roughly three lakh nuts annually for four years due to a consecutive drought. Increased CO_2 caused higher biomass production in coconut, arecanut, and cocoa. However, at higher air temperatures, biomass production decreased slightly. Due to high air temperature net photosynthesis is reduced. According to research on the "Impact of Climate Change in Cashew" undertaken at the Directorate of Cashew Research in Puttur, India, the rainfed cashew crop is highly vulnerable to changes in temperature and weather vagaries, particularly during the reproductive phase. For abundant flowering, cashew needs a dry environment with mild winters (15–20°C) and moderate dew at night. Flowers dry out in the afternoon due to high temperatures (over 34.4°C) and low relative humidity (20%), which affects the yield. During the flowering and fruiting phase, heavy dew and unseasonal rains increased theprevalence of pests and illnesses. All of these circumstances led to yield reductions of up to 50 to65%. Coffee requires summer shower for fruit setting during flowering but due to climate changeraining doesn’t occur during flowering. Most of the plantation crops are grown under rainfed condition, prolonged drought will hinder the growth and yield.

4. Impact on Spice Crops

India is a country with all major, minor, tree and seed spices. The effects of climate change are particularly severe for spice crops. Temperature, rainfall, photoperiod, wind, and other abiotic factors all have an impact on distinct physiological growth phases of spice crops, including flowering, fruit setting, fruit development, seed setting, and final reproductive or vegetative production. Black pepper plants lose their spikes when the temperature is too high, cardamom flowers may abort if the dry season is too lengthy, and vanilla plants suffer from arid circumstances and strong winds. The crops most vulnerable to frost are cumin, coriander, nigella, and ajowan. Onion bolting is caused by sudden temperature drops during the early vegetative period. The majority of seed spices, such as coriander, fenugreek, cumin, etc., are susceptible to disease like powdery mildew and pests like aphid due to high rainfall and humidity. Theenvironment's stress effect also has an impact on spice crop seed production and storage life.

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5. Impact on Flower Crops

The melting of the Himalayan ice cover will reduce the chilling requirement for the flowering of many ornamentals such as Rhododendron, Orchid, Tulipa, Alstromerea, Magnolia, Saussurea, Impatiens, Narcissus, and others. They will either fail to bloom or produce less flowers. Flowers produced commercially, especially in open fields, will be adversely affected, resulting in poor flowering, improper floral growth, and colour. High temperature leads to fading ofcolour in petals. Jasmine's flowering is prevented by a low temperature (19°C), which also causes a reduction in flower size. Where temperatures fall below 15°C, tropical orchid flowers do not fully bloom. When temperatures continue above 35°C, tropical orchids experience floral bud lossand unmarketable spikes.

Mitigation strategies for climate change

Climatic change is a reality, and there is sufficient data to prove that greenhouse gas emissions have caused global warming and accompanying climatic change. The process of reducing or sequestering greenhouse gas emissions is known as mitigation. Improved crop management techniques can significantly reduce greenhouse gas emissions by reducing the requirement for energy, and intensifying perennial horticultural crops will aid in removing carbon dioxide from the environment. The ways to mitigate climate change through orchard crops are as follows

- **Carbon Sequestration:** Terrestrial sequestration is the process of storing CO2 in soil and plant biomass through photosynthesis. Fruit orchards play a significant role in terrestrial carbon sequestration through photosynthesis and storage of carbon in tree biomass, such as trunks, foliage, branches, roots, and soil, as well as providing food and income to farmers. The trees with dense foliage, broad leaves, and clustered leaves were found to be more effective in storing CO2. Santol plantation had the most carbon sequestration with 203.62 t/ha, followed by mango and rambutan.
- **Efficient Energy Use:** Increase the efficiency of energy consumption through using solarand wind energy, little or no tillage, enhancing the fuel efficiency of agricultural machinery etc..
- **Fertilizer and Manure Management:** Fertilizer, manure, and biomass management by reducing the use and manufacturing of synthetic fertilisers, avoiding leaching and volatilization of N from fertilizers during storage and application, using slow-release fertilizers, Nitrification inhibitors, and so on. Dicyandiamide (DCD) a potential nitrification inhibitors, efficiently mitigate nitrous oxide emission (13-42%) followed by coated Ca-carbide, nimin, neem cake, neem oil and thiosulphate. Whereas the cumulativeN2O emission is reduced by 18 to 32.5% when dicyandiamide is used in combination with organic manures and urea.
- **Soil Management:** Organic fertilizers, decreased tillage, avoiding soil compaction, the use of biochar, cover crops, intercropping, and other cropping systems are some of the soil management techniques used to increase the percentage of soil carbon.

Adaptation Strategies

Potential effects of climate change rely on the system's capacity to adapt to change as well as the climate itself. How successfully the crops adjust to the concurrent environmental challenges brought on by climate change will determine the potential. Crop-based adaptation methods must be developed, incorporating all available choices to maintain productivity, depending on the susceptibility of each crop in an agro-ecological region and the growing season. In order to deal with extreme events like high temperatures, frost, and conditions of restricted and excessive moisture stress, scientists have already developed a number of methods. The agricultural sector can implement a number of adaptation strategies to deal with upcoming climate change, some of them are as follows

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i. Using rootstock or crops that are adapted to the climate

ii. Cropping patterns include cropping systems, intercropping, alternative crops, crop diversification, and crop relocation in alternative places.

iii. Cultivar/variety-based adaptation

- Development of climate-tolerant or resistant cultivars/varieties/rootstock.
- Planting many cultivars or crop species

iv. Modifications of crop management techniques

- Changing the timing of planting or sowing, modifying cropping season, and off-season production and marketing of horticulture crops
- Applying sustainable, specialised, or liquid fertilizer
- Using zero-tillage techniques to increase soil drainage, etc.
- Implementing new or enhancing existing irrigation systems such as drip irrigation
- Changes in land use management practises and improvements in crop residue and weed management
- Effective resource management
- Adopting innovative farming practises and resource-saving technologies (such as fruit bagging and fertigation etc.). Mango fruits were bagged when they were in the marble stage using brown paper and a scurting bag, which resulted in the highest fruit retention (%); newspaper bags resulted in the highest fruit weight; and the fruit in both bags was free of spongy tissue. Pomegranate fruit bagging reduce the cracking and fruit fly damage.
- Pest and disease management strategies
- Mulching improves the soil's microclimate, microbial activity, and health. It also helps to conserve soil moisture.
- Use of anti-transpirants such as chitosane, kaolin, and other compounds that reflect heat radiation from plant parts, reducing water losses by transpiration and the temperature of fruit and leaf surfaces. In comparison to other treatments, the anti-transpirant chitosane treatment at 2% significantly increased average finger weight, average hand weight, and bunch weight in bananas (Ahmed *et al.*, 2014)

v. Wind breaks or shelter belts that change the microclimate of the orchard as well as the soil. It also provide shelter for pollinating insects, protect the orchard from wind erosion and other natural disasters, and so on. The lowest percentage of frost-damaged fruitplants was seen in orchards of fruit crops enclosed by wind breaks.

vi. Using water harvesting technology and recycling waste water and solid waste in agriculture

vii. Use crop modelling techniques for suitability analysis.

viii. Crop insurance schemes and weather forecasting for farmers

CONCLUSION

Global horticultural practises are already under a lot of stress from the changing environment, which affects crop yields, quality, and sustainability in general. Traditional growing seasons are being disrupted by warming temperatures, altered precipitation patterns, and a rise in the frequency of extreme weather events, which is changing plant growth and distribution, pest and disease dynamics, and water availability.

In order to ensure the resilience of horticulture systems in the face of these difficulties, adaptation and mitigation methods are crucial. To create and implement cutting-edge practises like drought-resistant crop varieties, precise irrigation systems, agroforestry techniques, and climate-resilient agricultural methods, farmers, researchers, governments, and communities mustwork together. Additionally, initiatives to minimise greenhouse gas emissions a can help tolessen the effects of climate change on horticulture.

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CHAPTER 8

INTRODUCTION TO INDIAN AGRICULTURE AND CHANGING LANDSCAPE

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ABSTRACT

Agriculture, frequently celebrated as the cornerstone of the Indian economy, occupies a crucial position, and is expected to maintain this central role in the foreseeable future. Observing the transformative shifts within the Indian agricultural domain, it becomes abundantly clear that markets, institutions, and technology all had important roles to play. Particularly during the beginning of the Green Revolution in the late 1960s and early 1970s, the public sector played a crucial and catalytic role. In this capacity, novel seeds were imported, their coordinated distribution and presentation, as well as price and market assistance, were all performed with a "not-for-profit" perspective. Additionally, the government supported and encouraged the cooperative sector, which also had a "not-for-profit" mentality, helping Operation Flood happen in the 1970s and 1980s to succeed in the White Revolution in milk. Thus, the introduction to Indian agriculture and its changing landscape provides a glimpse into the multifaceted nature of this vital sector of the Indian economy.

INTRODUCTION

The Indian economy is heavily dependent on agriculture, which is sometimes referred to as the country's backbone. The need for agriculture will continue for the next few years. Despite using just 2.3% of the planet's geographical area and just 4.2% of its water resources, this sector must support close to 17% of the global population.

Early 1990s economic changes in India were crucial in getting the nation's economy moving in the direction of faster development. Notably, the yearly growth in GDP has increased from about 6% in the early years of these changes to over 8% in more recent years. The non-agricultural sector's explosive growth has been the main force behind this amazing economic advancement. Between the years 1980-81 and 2006-07, there has been a marginal decrease in the agricultural workforce, with their percentage declining from 60.5 percent to 52 percent. This shift underscores the changing employment landscape, as more individuals have sought opportunities in non-agricultural sectors.

The current cropping intensity stands at 137%, reflecting a 26% growth since 1950-51. Thetotal cultivated land is 142 million hectares (Mha), with 58.87 Mha being under irrigation in 2004-05. Currently, irrigation is used on 45.5% of the net planted land while rain-fed agriculture is used on the remaining 54.5%. Land degradation and excessive groundwater as well as surface water resource use are causing the soil health to quickly deteriorate. Both biotic (insect diseases, insect pests, weeds) and abiotic (drought, salt, heat, cold, etc.) factors cause around one-fourth of the value of agricultural product to be lost. The transportation, storage, processing, value addition, along with marketing of farm products must be improved urgentlyto improve family nutrition, food safety, and livelihoods.

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Indian agriculture exhibits a rich diversity in agro-ecological factors, including variations in soil types, rainfall patterns, temperature ranges, and cropping systems. In addition to benefiting from abundant solar energy, the country receives a substantial annual rainfall of approximately 3 trillion cubic meters, includes 55 small rivers in addition to 14 large rivers and 44 medium-sized rivers collectively contributing to around 83 percent of the drainage basin. An estimated 210 billion cubic meters of groundwater resources are also available. However, the availability of irrigation water is diminishing, making it a scarce resource. Consequently, the proper collection and efficient utilization of water resources have become crucial priorities.

High-yielding cultivars were first introduced in the middle of the 1960s, which resulted in intensive farming that required more energy inputs and better management techniques. Key agricultural operations such as land preparation, harvesting, threshing, and irrigation consumed most energy resources. From 92% in 1950–51 to only 20 percent in 2000–01, the share of animate power utilized in agriculture experienced a sharp reduction. Depending mainly existing remain energy sources was no longer adequate for field operations to meet the requisite cropping intensity and timeliness. To supplement their animate energy supplies, farmers began to use mechanical power sources.

The requirement for an excess that may be sold on the market increases with the size of the farm. To make sure that farmers on a small scale can make sufficient income, this is essential. To do this, we must concentrate on creating and promoting ecotechnologies that are based on the values of economics, environment, equal opportunity for all women, and job creation. This shows the route to achieving an agriculture "ever-green revolution" that is sustainable. It is apparent that demand for food grains is expected to increase to 240 million metric tons in 2020 along with 300 million metric tons in 2025 to kept up with present population growth along with consumption patterns. This is based on estimates of India's food requirements and the total yield of major crops. About 6.7 percent yearly agricultural growth rate must be maintained to satisfy these demand estimates. The largest number of holdings, operating area, and average holding size are displayed in Tables -1, 2 and 3.

When examining historical transformations within the agricultural sector, it becomes clear that technology, institutions, and markets have played crucial roles in driving change. These shifts have been accompanied by evolving roles of the public, cooperative, and private sectors. In the initial stages, the public sector actively provided price and market support during the green revolution era in collaboration with the Consultative Group of International Agricultural Research (CGIAR) network, all on a "not-for-profit" basis. Over time, the government shifted towards an indirect interventionist role, facilitating the establishment of new institutions, and encouraging private sector involvement. As the private sector has taken the lead in agricultural markets, particularly in revolutions related to cotton and horticulture crops, a new phase focusing on "for-profit" approaches has begun. This development raises intriguing questions about its impact on the principles of CISS, which encompass competitiveness, inclusiveness, sustainability, and scalability of the growth process.

The rationale behind India's departure from a protective regime and its embrace of market forces has been a subject of prolonged debate. The economic liberalization of the early 1990s facilitated deeper integration with the global economy, but disagreements persist regarding whether India should fully liberalize its agricultural sector and adopt a more aggressive market-driven approach. These discussions stem from the pressing issues of poverty and hunger, which present significant developmental challenges for India. While economic growth alone cannot guarantee food security for the masses, it remains imperative to streamline the food grain management system, enhance targeting accuracy, and establish social safety nets and protection networks to optimize the welfare of the impoverished. Consequently, food security will

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continue to hold a prominent place on the policy agenda, requiring Indian policymakers to skillfully balance food security concerns with the objective of achieving higher growth.

This paper aims to analyse various issues within the Indian agricultural sector, focusing on significant shifts (referred to as "revolutions") and examining the factors that led to their success or failure. The study delves into the impact of public sector involvement, technological advancements, high-value commodity markets, and enhanced connections between farms and businesses in the evolving landscape of Indian agriculture. Furthermore, it discusses how these factors contributed to sectoral growth, acknowledging that although some successes were initially promising, they proved to be short-lived. The paper also addresses the integration of agricultural markets on both regional and global scales, along with the structural changes within the Indian agricultural system. Additionally, it outlines crucial policy reforms and institutional adjustments that still require attention.

Table 1: Number of holdings (in '000) all social groups

Sl.No.	Size Groups	Number of Holdings (in '000)									
		1970-71	1976-77	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16
1	Marginal (below 1.00 ha.)	36200	44523	50122	56147	63389	71179	75408	83694	92826	100251
2	Small (1.00 - 2.00 ha.)	13432	14728	16072	17922	20092	21643	22695	23930	24779	25809
3	Semi-Medium (2.00 - 4.00 ha.)	10681	11666	12455	13252	13923	14261	14021	14127	13896	13993
4	Medium (4.00 - 10.00 ha.)	7932	8212	8068	7916	7580	7092	6577	6375	5875	5561
5	Large (10.00 ha & above)	2766	2440	2166	1918	1654	1404	1230	1096	973	838
6	All Sizes	71011	81569	88883	97155	106637	115580	119931	129222	138348	146454

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Table 2: Operated area (in '000 ha.) all social groups.

Sl. No.	Size Groups	Operated Area (in '000 ha.)									
		1970-71	1976-77	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16
1	Marginal (below 1.00 ha.)	14599	17509	19735	22042	24894	28121	29814	32026	35908	37923
2	Small (1.00 - 2.00 ha.)	19282	20905	23169	25708	28827	30722	32139	33101	35244	36151
3	Semi-Mediu m (2.00 - 4.00 ha.)	29999	32428	34645	36666	38375	38953	38193	37898	37705	37619
4	Mediu m (4.00 - 10.00 ha.)	48234	49628	48543	47144	44752	41398	38217	36583	33828	31810
5	Large (10.00 ha& above)	50064	42873	37705	33002	28659	24160	21072	18715	16907	14314
	All Sizes	162318	163343	163797	164562	165507	163355	159436	158323	159592	157817

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Table 3: Average (in ha.) all social groups.

Sl. No.	Size Groups	Average (in ha.)									
		1970-71	1976-77	1980-81	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16
1	Marginal (below 1.00 ha.)	0.40	0.39	0.39	0.39	0.39	0.40	0.40	0.38	0.39	0.38
2	Small (1.00 - 2.00 ha.)	1.44	1.42	1.44	1.43	1.43	1.42	1.42	1.38	1.42	1.40
3	Semi-Medium (2.00 - 4.00 ha.)	2.81	2.78	2.78	2.77	2.76	2.73	2.72	2.68	2.71	2.69
4	Medium (4.00 - 10.00 ha.)	6.08	6.04	6.02	5.96	5.90	5.84	5.81	5.74	5.76	5.72
5	Large (10.00 ha & above)	18.10	17.57	17.41	17.21	17.33	17.20	17.12	17.08	17.38	17.07
	All Sizes	2.28	2.00	1.84	1.69	1.55	1.41	1.33	1.23	1.15	1.08

The nation is actively striving to discover effective methods to ensure ample nourishment for its rapidly growing population. On one side, it grapples with the issue of decreasing productivity, while simultaneously facing challenges brought about by liberalization. The most effective plan of action in this situation is to use the infrastructure that already exists and the natural resources that are already accessible to satisfy the demands. The essential necessity of the hour is to manage the present infrastructure effectively while working in harmony along with natural processes. A full awareness of the scope of the current infrastructure and natural assets is a crucial requirement for effective and sustainable usage of these resources.

The development of technology that increase productivity and lower cultivation expenses is the focus of the discipline of agricultural engineering. In the past, field work and processing tasks were mostly carried out by human and animal power. The use of mechanical power, however, has greatly increased agricultural engineering activity. By 2025, an estimated population of 1.363 billion individuals is expected, which would need an agricultural productivity growth of 100% from the present level. According to estimates, agriculture would require an increase in energy input from the current level of 1.3 - 2.4 kW/ha.

Governments at all levels have made the rapid growth of agriculture a priority because of the knowledge that agricultural output is limited. Farmers' adopting high-yielding cultivars, higher fertilizer use, and dependable irrigation by using tube wells has accelerated this development. The country is expected to produce 315.72 million tons of foodgrains for the period from 2021 to 2022 based according to Fourth Advance Estimates. Comparing this amount to the foodgrain output in the year prior, 2020–2021, there has been a rise of 4.98 million tons. The output for 2021–22 also represents a large 25 million tons increase above the average production for the preceding five years (2016–17 to 2020–21).

In particular, the total quantity produced of rice is projected to reach a new record 130.29 million tonnes in 2021–22, which would represent a significant increase of 13.85 million tonnes above an average yield of 116.44 million tonnes during the preceding five years. The output of wheat is predicted to reach 106.84 million tonnes in 2021–2022, above the average

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production over the previous five years of 103.88 million tonnes by 2.96 million tonnes. Nutri/coarse cereal output is anticipated to reach 50.90 million tonnes in 2021–22, an increase of 4.32 million tonnes over the average for the last five years production of 46.57 million tonnes. Additionally, a record 27.69 million tonnes of pulses are expected to be produced in 2021–22, which is 3.87 million tonnes greater than the total production average of 23.82 million tonnes over the preceding five years. According to projections, the nation will produce a record number of oilseeds 37.70 million tonnes in 2021–22, about 1.75 million tonnes from the 35.95 million tonnes produced during 2020–21. Additionally, this year's oilseed production is 5.01 million tons higher than the norm. In a similar line, the country is expected to produce 431.81 million tonnes of sugarcane, a record, in 2021–22, exceeding the average output of 373.46 million tonnes by substantial 58.35 million tonnes.

Production estimates for cotton and jute and mesta are 31.20 million bales of cotton (each weight 170 kilograms), and 10.32 million bales of jute and mesta (each weighing 180 kg).

Table 4, provides an extensive description of the primary crop acreage, production, and yield statistical analysis from 2019–20 through 2021–2022.

Table 4: Production and productivity in agriculture (Area, production and yield of majorCrops)

Crops	Area (Lakh hectare)			Production (Million Tonnes)			Yield(kg/hectare)		
	2019-20	2020-21	2021-22*	2019-20	2020-21	2021-22*	2019-20	2020-21	2021-22*
Rice	436.62	457.69	463.79	118.87	124.37	130.29	2722	2717	2809
Wheat	313.57	311.25	304.69	107.86	109.59	106.84	3440	3521	3507
Nutri / Coarsecereals	239.88	241.18	226.52	47.75	51.32	50.90	1991	2128	2247
Pulses	279.87	287.83	310.30	23.03	25.46	27.69	823	885	892
Foodgrains	1269.95	1297.95	1305.3	297.50	310.74	315.72	2343	2394	2419
Oilseeds	271.39	288.33	291.67	33.22	35.95	37.70	1224	1247	1292
Sugarcane	46.03	48.51	51.48	370.50	405.40	431.81	80497	83566	83887
Cotton	134.77	132.86	119.10	36.07	35.25	31.20	455	451	445
Jute & Mesta	6.73	6.62	6.86	9.88	9.35	10.32	2641	2542	2709

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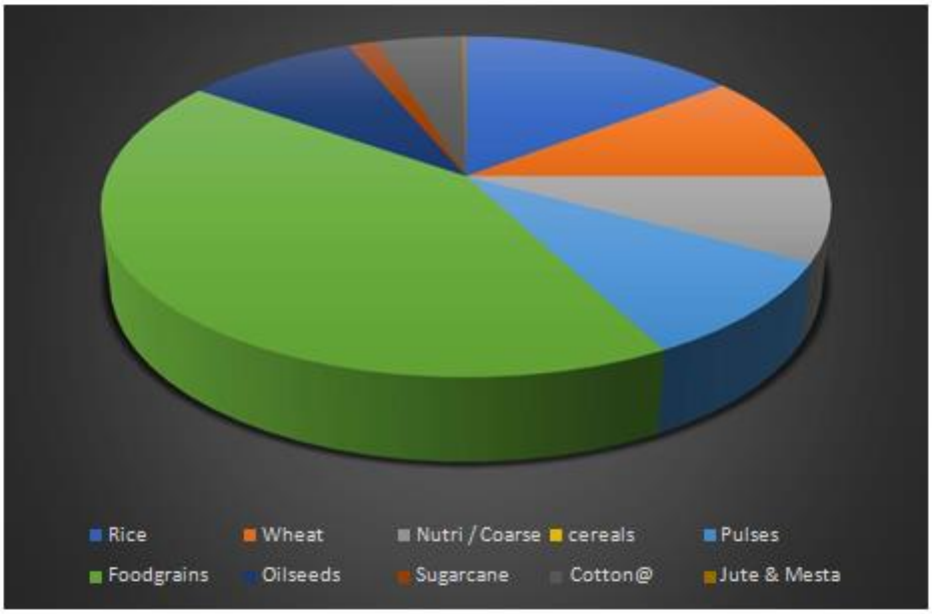

Fig. 1: Production and productivity in agriculture (Area, production and yield of major Crops)

The Indian Agriculture Industry's Changing Landscape

The Green Revolution and subsequent developments:

India had many droughts from the early 1960s onward, which added to concerns about food security. The Bengal Famine, which occurred in 1943, was the primary cause of these issues. Inadequate home output and low foreign exchange reserves made the situation worse such that it was more difficult to buy grains on the world market. Consequently, there was an escalating reliance on foreign aid, which carried its own political implications. The government's main objective at the time was to attain long-term food grain self-sufficiency, and the most practical solution was to increase local production. The Green Revolution was brought about as a result of this necessity, which also spurred a substantial technical advance. The advent of "miracle seeds" coming from Mexico transformed Indian agriculture and prompted the widespread use of high-yielding cultivar seeds for many different crops. In response to the urgent demand for greater productivity, this change led to a significant rise in the output of wheat and rice. The agricultural landscape of India did improve generally, especially in regions such as Punjab and Haryana, but the success was not widespread. The cycle of the "revolution of green" was notable completed in Punjab in 1966–1967 because of increased infrastructure, improved irrigation systems, and the tenacity of the farmers (Singh, 2001). Because wealthy farmers and resource-rich areas mostly benefited from the green revolution's success, this fact drew criticism.

The government formed a partnership with the CGIAR network to adopt high-yield technology since the achievement of the Green Revolution depended on a strong political commitment. But with expanded production came the need for sensible pricing and marketing strategies, which forced government agencies to have a prominent role once more in delivering these services. The Agricultural pricing Commission (APC) along with the Food Corporation of India (FCI) were founded in 1965 to guarantee "remunerative prices" for producers and to make the marketing and sale of food grains easier. The public sector's "not-for-profit" approach drove import substitution policies, enabling India to attain self-sufficiency in cereals, with only occasional grain imports in some years. However, the positive outcomes of the Green Revolution started to decline by the late 1970s and slowed down by the end of the 1980s.

The growth rate of the cereal industry then underwent major variations, notably with a notable fall in the 1999–2000 national period in India. While many academics have voiced worry about the stagnant output of rice and wheat, it has received less attention since, from the middle of the 1980s, consumer preferences have been changing away from grains in response to rising income levels. As a result, despite slower rise in production rates, grain inventories have accumulated.

As an instance, in the month of July 2002, India discovered that it had 63 million tonnes of grain such as rice and wheat on hand, far more than the 24.3 million tons buffer requirement, and had to get rid of them through subsidized exports. Currently, in the month of July 2009, inventories have risen to approximately 53 million tonnes, more than double the buffer stock's minimum need of 26.9 million tonnes, due to food grain output more than 230 million tonnes in the year 2007-2008 and roughly the same in 2008/09. As a result, rather than concentrating exclusively on raising output, it is imperative to address challenges connected to better grains management and marketing.

The high-yielding seed types released in the Green Revolution required a lot of input, whichhad a negative impact on the environment. As a result, the governments that led the revolution are currently dealing with serious problems, such as the deterioration of soil and water as a result of excessive application of pesticides and fertilizers, as well as the significant groundwater depletion (Sud, 2009). It could be wise to take into account moving the principal cultivation of cereals from the northern regions of Punjab, Haryana, and portions of the state of Uttar Pradesh towards the eastern area given the residual effects of these effects.

The White Revolution: Operation Flood's achievements:

The expansion of liquid production of milk, sales and marketing, and delivery in India was propelled by the "White Revolution," which has been credited to the accomplishment of Operation Flood, which was initiated in the 1970s and carried out in three stages until 1996. India became the world's top producer of liquid milk during this historic time as milk output increased dramatically from 21.2 million tonnes in 1968/69 to an astounding 104.8 million tonnes in 2007/08. Additionally, the daily supply of milk per person climbed from a meager 112 grams in 1968–1969 to a considerable 252 grams in 2007–2008.

With a little 1.2% rise between 1960/61 and 1973/74, milk output first grew slowly. It then picked up steam, peaking at 5.5% between 1981–1982 and 1990–1991; however, it did so after gaining speed. Every 1000 urban customers saw an increase in daily milk supply from cooperatives between 1991 and 2007 from 37.3 - 66.3 liters. In India, there are 177 milk union spread out across 346 districts that are jointly held by close to 13.4 million farmers members, with women making up 28% of this population. At the village level, the introduction of amenities like bulk vending, automated milk collection devices, and volume milk coolers has transformed the procedures for collecting and preserving milk. Today, milk travels 2,200 kilometres to reach deficit milk regions, utilizing rail and road milk tankers (NDDB 2009).

Mr. Verghese Kurien spearheaded a remarkable revolution that witnessed three key factors vital to its triumph: the conversion of milk value chains into cooperative entities, the infusion of technology to enhance the acquisition, storage, and distribution of milk to distant markets, and the creation of expansive milk markets capable of accommodating the surging production. Within the conventional milk procurement and marketing system, village intermediaries wielded control, leading to diminished earnings for farmers. The unstructured value chain left milk producers with no choice but to vend their product to intermediaries, primarily due to milk's highly perishable nature.

Operation Flood, consisting of three distinct phases, unfolded over the following timeframes: Phase I spanned from 1970 to 1980, Phase II from 1981 to 1985, and Phase III from 1985 to

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1996. The funding for this initiative was sourced from multiple avenues, including grants from the European Commission (provided through the World Food Program in the form of skimmed milk powder and butter oil), loans from the World Bank, and the internal resources of the National Dairy Development Board (NDDB). Its inception involved the connection of 18 prominent milk sheds with the four major metropolitan cities, namely Delhi, Mumbai, Kolkata, and Chennai. By the conclusion of the 1995/96 timeframe, the initiative had expanded significantly, with an impressive network of 72,744 dairy collection centers (DCS) established in 170 milk sheds across the country, ultimately catering to the needs of 9.3 million milk farmers.

While the public sector was instrumental in facilitating grants for the advancement of the dairy sector, it refrained from offering direct assistance. Sustainability and scalability were primarily driven by technology and market dynamics. Cooperatives, operating under a licensing framework during Operation Flood and its aftermath, shielded themselves from private sector rivalry. Nonetheless, the revision of the Milk and Milk Products Order in 2002 marked the opening of the door for private sector engagement, which is anticipated to surpass cooperatives in the foreseeable future.

In 2012, it was estimated that the private corporate sector would handle approximately 20% of milk production, while cooperatives would manage about 10%. Together, these entities were projected to process only 30% of India's milk production. The next notable advancement was expected in the value-added sector, as the private sector's financial resources were well-positioned to capitalize on economies of scale, owing to the limited processing taking place through organized supply chains.

CONCLUSIONS

In conclusion, the introduction to Indian agriculture and its changing landscape provides a glimpse into the multifaceted nature of this vital sector of the Indian economy. We have touched upon the historical significance of agriculture in India, its role in food security, and the diverse crops and farming practices that have sustained the nation for centuries.

Furthermore, we have acknowledged the transformative changes that Indian agriculture has undergone in recent years. The adoption of modern technology, government policies, and shifting consumer preferences are reshaping the sector. These changes bring both opportunities and challenges for Indian farmers, the rural economy, and the entire nation.

As we delve deeper into the study of Indian agriculture, we will explore the complexities of these changes, including the Green Revolution, the role of biotechnology, and the challenges of sustainable and inclusive growth. Understanding the evolving landscape of Indian agriculture is not only crucial for policymakers but for all of us as consumers and global citizens.

This introduction serves as a foundation for the in-depth analysis that follows, as we seek to grasp the intricacies of Indian agriculture and the forces shaping its future.

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CHAPTER 9

BIOLOGICAL CONTROL OF PLANT PATHOGENS

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ABSTRACT
Plant pathogens pose a significant threat to global agriculture, causing yield losses, economic damage, and environmental concerns. In recent years, there has been a growing interest in the useof biological control methods as an eco-friendly and sustainable approach to manage plant diseases. This abstract explores the concept of biological control of plant pathogens, emphasizing the use of beneficial microorganisms, parasites, and predators as natural antagonists against destructive pathogens. This method aims to reduce the reliance on chemical pesticides while promoting natural ecological balances.

Keywords: Biological Control, Plant Diseases, Management

INTRODUCTION
The global agricultural sector is being severely impacted by plant diseases, which can result in considerable yield losses and financial losses. Chemical pesticides have historically played a significant role in the management of these diseases, but despite their effectiveness, they are additionally contributing to adverse effects on the environment, the emergence of pathogen resistance, and the accumulation of pesticide residues in food. In response to these challenges, there has been a growing interest in adopting more sustainable and eco-friendly approaches to disease management, with biological control emerging as a promising alternative.

Utilizing the ability of organisms to prevent the growth, reproduction, or spread of plant pathogensis known as biological control. Unlike chemical pesticides, which often have broad-spectrum effects and may harm non-target organisms, biological control agents are typically specific to thetarget pathogen.

Definition
Biological control is defined as the reduction of inoculum density or disease producing activities of a pathogen or parasite in its active or dormant stage by one or more organisms accomplished naturally or through manipulation of the environment, host or by introduction of one or more antagonists or by mass introduction of one or more antagonists.

Stephen Denis Garrett (1970) defined biological control of plant diseases as any condition or practice, which reduced the survival or activity of a pathogen through the agency of any other living organisms other than man resulting in reduced disease incidence.

Baker and Cook (1974) defined the term as the reduction of inoculum density or disease producingactivities of a pathogen or a parasite in its active or dormant state by one or more organisms, accomplished naturally or through manipulation of the environment, host or antagonists or by massintroduction of one or more antagonists.

Baker and Cook (1983) shortened the definition that it is the reduction of the amount of inoculumor disease producing activity of a pathogen accomplished by or through one or more organisms other than man.

In comparison to other strategies used to manage diseases, biological control offers numerous advantages. The benefits include the following:

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Advantages of Biological Control

1. Biological control is less costly and cheaper than any other methods.
2. Bio control agents give protection to the crop throughout the crop period.
3. They are highly effective against specific plant diseases.
4. They do not cause toxicity to the plants.
5. Application of bio control agents is safer to the environment and to the person who applies them.
6. They multiply easily in the soil and leave no residual problem.
7. Bio control agents can eliminate pathogens from the site of infection.
8. Bio control agents not only control the disease but also enhance the root and plant growth by way of encouraging the beneficial soil microflora. It increases the crop yield also. It helps in the volatilization and sequestration of certain inorganic nutrients. For example Bacillus subtilis solubilizes the element, phosphorous and makes it available to the plant.
9. Biocontrol agents are very easy to handle and apply to the target.
10. Biocontrol agents can be combined with biofertilizers.
11. They are easy to manufacture.

Although biological control is advantageous in many aspects, it has the following disadvantages.

1. Biocontrol agents can only be used against specific diseases.
2. They are less effective than the fungicides.
3. Biocontrol agents have slow effect in the control of plant diseases.
4. At present, only few bio control agents are available for use and are available only in few places.
5. They are unavailable in larger quantities at present.
6. This method is only a preventive measure and not a curative measure.
7. Biocontrol agents should be multiplied and supplied without contamination and this requiresskilled persons.
8. The shelf life of bio control agents is short. Antagonists, Trichoderma viride is viable for fourmonths and Pseudomonas fluorescens is viable for 3 months only.
9. The required amount of population of bio control agents should be checked at periodical intervaland should be maintained at required level for effective use.
10. The efficiency of biocontrol agents is mainly decided by environmental conditions.
11. A bio control agent under certain circumstances may become a pathogen.

BIOCONTROL AGENTS

A biological agent that reduces the number or disease producing activities of the pathogen is calledas antagonist or biocontrol agent. The important biocontrol agents used in plant disease management includes fungi, bacteria, actinomycetes, mycorrhizal fungi, viruses, protozoa, bdellovibrios, etc. Among them, fungal and bacterial antagonists especially species of Trichoderma, Gliocladium, Pseudomonas and Bacillus are most widely used against plant

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diseases. They act on the pathogen through one or more of the following mechanisms like competition, parasitism, antibiosis, lysis, etc.

Characteristics of the Ideal bio control agent:

An ideal bio control agent should have the following features / characteristics.

1. It should not be pathogenic to plants, human beings, animals and microorganisms.
2. It should have broad spectrum of activity in controlling many types of diseases and must begenetically stable.
3. It should have fast growth and sporulation.
4. It must be cultured under artificial media.
5. The inoculum must be capable of abundant production using conventional methods such asliquid fermentation and withstand long term storage until application.
6. It should be amenable for inexpensive mass multiplication and economically viable.
7. It should have long shelf life.
8. It must be efficacious under different environmental conditions.
9. It should be compatible with bio fertilizers.
10. It should have least susceptibility to the action by the seed treating chemicals.
11. It should not be toxic to beneficial organisms in or on the target area.
12. It should be easily formulated and methods of application must be convenient and compatiblewith common cultural practices.
13. It should easily establish in the soil with high persistence and survival capacity.
14. It should be biologically competitive with other microorganisms.

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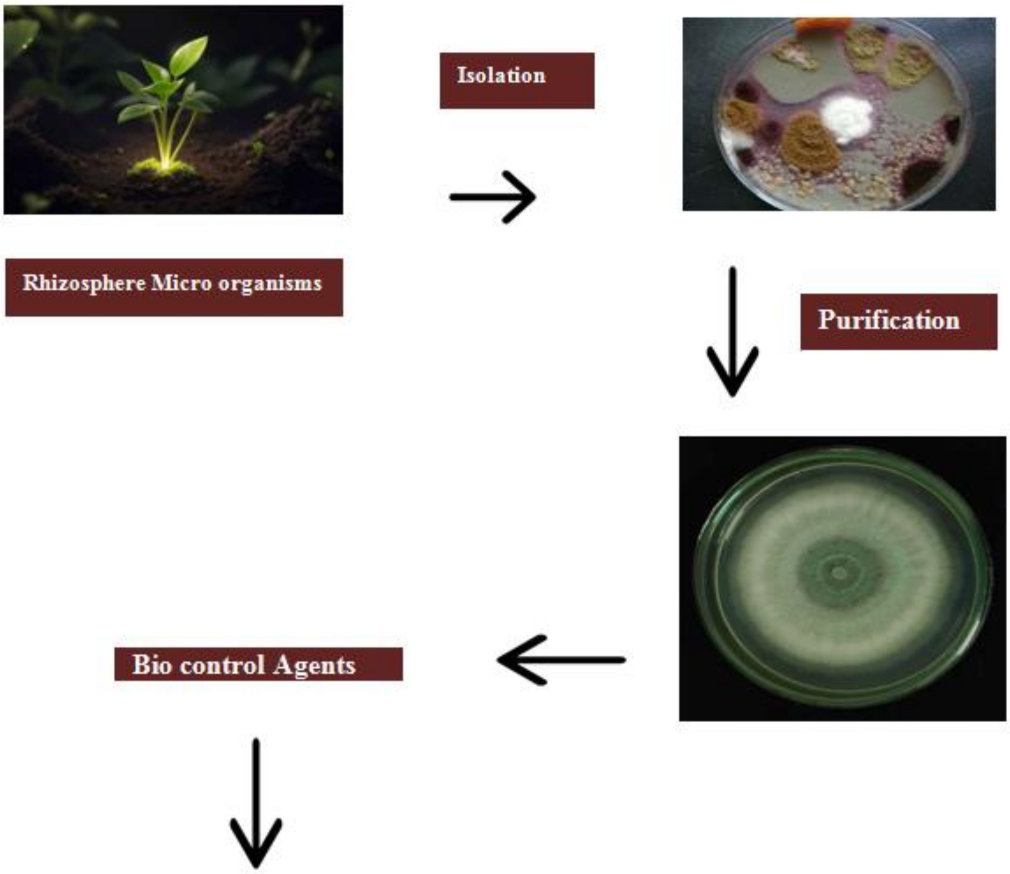
Mechanism involved in biological control:



Antibiotics	**Toxins**	**Siderophores**	**HCN**
Volatiles	**Lytic Enzymes**	**Induced Systemic Resistance**	

1. **Parasitism:** Parasitism is a valuable mechanism employed by bio control agents to manage andcontrol pathogen populations in an environmentally friendly and sustainable manner. It is a mechanism employed by certain bio control agents to manage plant pathogens. These bio control agents are typically microorganisms that can infect, colonize, and ultimately kill or suppress plantpathogens. The bio control agent parasitizes the pathogen by coiling around the hyphae.

Trichoderma and Beauveria species are well known bio control agents that parasitize and kill fungal plant pathogens. They can colonize the pathogen, secrete enzymes to degrade its cell wall,and compete for resources.

Examples: *Tricoderma viride* parasite derives its nutrition from the pathogen by puncturing the host hyphae and kills them. Various bacteria and fungi secrete hydrolytic enzymes for the degradation of cell wall of pathogen.

Certain bacteria, like *Pseudomonas* and *Bacillus* species, produce antimicrobial compounds and toxins that can parasitize and inhibit the growth of plant pathogens.

Viruses, called mycoviruses, can parasitize and infect fungal pathogens. They interfere with the replication and virulence of the pathogen, ultimately reducing its ability to cause disease.

2. **Lysis:** The lysis mechanism is a common strategy used by bio control agents to combat plant pathogens. It involves the bio control agent producing compounds or enzymes that can break

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downnor disrupt the cell walls or membranes of the target plant pathogens.

Many bio control agents produce lytic enzymes, such as chitinases, glucanases, and proteases. These enzymes degrade the structural components of the pathogen's cell wall or membrane, weakening it and ultimately causing its death.

Chitinases: Chitinases are enzymes that break down chitin, a major component of the cell walls of fungus. Bio control agents that produce chitinases can target fungal pathogens effectively.

Glucanases: Glucanases target glucans, which are another component of fungal cell walls. They can weaken the cell walls of fungal pathogens.

Proteases: Proteases are enzymes that break down proteins. Some bio control agents produce proteases that can disrupt the protein structures in fungal cell membranes, leading to cell lysis.

Examples: *Bacillus spp*. Causes hyphal lysis of *Gaumanomyces gramini* var *tritici* (Take-all disease of wheat)

The chitinolytic enzymes of *Serratia marcescens* caused cell wall lysis of *Sclerotium rolfsi*

Tricoderma spp. produces chitineses and B 1-3 glucanases which lysis the cell wall of *Rhizoctoniasolani*.

3. **Antibiosis:** Antibiosis is a mechanism employed by certain bio control agents to manage plant pathogens. In this mechanism, bio control agents release secondary metabolites or substances that inhibit the growth and development of plant pathogens. These secondary metabolites can be toxic to the pathogens or interfere with their metabolic processes. The antibiotic compounds secreted bythe bio control agent suppress the growth of the pathogen.

Examples: *Trichodema spp*. Produces antibiotics Viz, Trichodermin, Gliotoxin and Viridian.

Some fungal bio control agents, like species of *Trichoderma* and *Gliocladium*, are known for theirability to produce antibiotics and enzymes that can suppress fungal plant pathogens.

Certain bacteria, such as *Pseudomonas* and *Bacillus* species, are also capable of producing antibiotics and other antimicrobial compounds that inhibit the growth of plant pathogens.

Phenazine-1-carboxylic acid (PCA) produced by *Pseudomonas fluorescence* play an importantrole in suppressing the take all disease of wheat.

4. **Competition:** Competition is one of the mechanisms employed by bio control agents to manageplant pathogens. In this mechanism, bio control agents compete with the target plant pathogens foressential resources, such as nutrients, space, and moisture, ultimately reducing the pathogen's ability to cause disease. The bio control agent competes for food and essential elements with the pathogen thereby displacing and suppressing the growth of pathogen. This mechanism reduces disease incidence by limiting pathogen access to essential resources.

Examples: The competition for nutrients between *Pythium aphanidermatum*, *P. ultimum* and bacteria suppress the damping off disease in cucumber.

Fluorescent iron chelator siderophores such as Pseudutiactins and pyoverdins produced by *P.fluorscence* chelate the iron available in the soil thereby, depriving the pathogen of its Fe (Iron)requirement.

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Table 1: List of antagonistic organisms and plant pathogens controlled by them

Sl. No	Antagonist	Pathogen controlled
I.	**Bacteria**	
1.	*Agrobacterium radiobacter*	*Agrobacterium tumefaciens*
2.	*Azotobacter chrococcum*	*Rhizoctonia solani*
3.	*Bacillus subtilis*	*Fusarium* spp., *Pythium* spp., *Rhizoctonia* spp., *Sclerotium rolfsii*, *Streptomyces scabies* and *Verticillium spp.*
4.	*Bacillus thuringiensis*	*Alternaria alternate* and *Hemileia vastatrix*
5.	*Erwinia herbicola* pv. *herbicola*	*Erwinia amylovora*
6.	*Pseudomonas fluorescens*	*Fusarium* spp., *Macrophomina phaseolina*, *Pyricularia oryzae*, *Pythium* spp. and *Rhizoctonia solani*
7.	*P. cepacia*	*Cercospora* spp.
8.	*Streptomyces diastaticus*	*Pythium aphanidermatum*
9.	*S. griseoviridis*	*Alternaria brassicola*, *Fusarium oxysporum* f. sp. *dianthi* and *Rhizoctonia solani*
II.	**Fungi**	
1.	*Trichoderma hamatum*	*Pythium spp*. and *Rhizoctonia solani*
2.	*T. harzianum*	*Botrytis cinerea*, *Fusarium spp*., *Pythium spp*., *Rhizoctonia spp.* and *Sclerotiumrolfsii*
3.	*T. koningii*	*Sclerotinia sclerotiorum*
4.	*T. polysporum*	*Phytophthora cinnamomi*
5.	*T. viride*	*Armillaria mellea*, *Botrytis cinerea*, *Fusarium spp*., *Phytophthora spp*., *Pythiumspp*., *Rhizoctonia solani* and *Sclerotium rolfsii*
6.	*Verticillium hemileiae*	*Hemileia vastatrix*
7.	*V. lecanii*	*Puccinia arachidis* and *Uromyces appendiculatus*
8.	*Gliocladium catenulatum*	*Sclerotinia sclerotiorum*
9.	*G. roseum*	*Phytophthora* spp. and *Verticillium dahliae*
10.	*G. virens* (syn. *Trichoderma virens*)	*Botrytis cinerea*, *Pythium spp*., *Rhizoctoniasolani* and *Sclerotium rolfsii*
11.	*Penicillium islandicum*	*Puccinia arachidis*
12.	*P. oxalicum*	*Pythium* spp.

Table 2: List of commercial preparations of bio control agents available worldwide

Sl. No	Antagonist	Commercial product and source	Pathogen controlled
I.	**Bacteria**		
1.	***Pseudomonas fluorescens***	Conqueror (Australia)	*Pseudomonas tolaasi*
		Dagger – G (USA)	*Pythium* spp. and *Rhizoctonia solani*
2.	***Pseudomonas cepacia***	Intercept (USA)	*Cercospora* spp., *Fusarium* spp., *Pythium*

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			spp. and *Rhizoctonia spp.*
3.	***Bacillus subtilis***	Kodiak, Kodiak HB, Kodiak At (USA)	*Aspergillus flavus* and *A. parasiticus*
		Quantum 4000 (USA)	*Fusarium spp.*, *Rhizoctonia spp*. and *Sclerotium rolfsii*
		Gus 4000 (USA)	*Gaeumannomyces graminis* var *tritici*
II	**Fungi**		
1.	***Trichoderma spp.***	Ecofit (India)	*Macrophomina phaseolina* and *R. solani*
		Biofungus (Belgium)	*Fusarium spp., Phytophthora spp., Pythium spp., Rhizoctonia solani, Sclerotinia spp*. and *Verticillium spp.*
		Trichoderma2000 (Israel)	*Fusarium spp., Pythium spp., Rhizoctonia solani* and *Sclerotium rolfsii*
		Trichodermin (Bulgaria and Russia)	*Botrytis cinerea, Pythium spp., Sclerotinia sclerotiarum,* and *Verticillium spp.*
2.	***Trichoderma harzianum***	BINAB –T (Sweden and UK)	*Armillaria mellea, Ceratocystis ulmi, Chondostereum purpureum, Endothia parasitica,Fusarium spp., Gaeumannomyces graminis* var *tritici* and *Rhizoctonia spp.*
		Root-Pro (Israel)	*Fusarium spp,Pythium spp., R. solani,* and *Sclerotium rolfsii*
		F-Stop (USA)	*Pythium spp.*
		Root Shield (USA)	*Fusarium spp., Pythium spp.,* and *R. solani*
		Supresivit (Czech Republic, Denmark and USA)	*Fusarium spp., Pythium spp*. and *R. solani*
		Trichodex T 39 (Israel and USA)	*Botrytis cinerea, Colletotrichum spp.,*

			Erysiphe spp. and *Uncinula necator*
		Trichopel (New Zealand)	*Armillaria spp., Fusarium spp., Phytophthora spp., Pythium spp.* and *Rhizoctonia spp.*
3.	***Trichoderma viride***	Tricontrol (India)	*Fusarium spp. and Rhizoctonia spp.*
		Antagon-TV (India)	*R. solani* and *M. phaseolina*
		Basderma (India)	*Fusarium spp.* and *Rhizoctonia spp.*
		Bio-atom (India)	*Fusarium spp.* and *Rhizoctonia spp.*
		Bioderma (India)	*Fusarium spp.* and *Rhizoctonia spp.*
		Niprot (India)	*Fusarium spp.* and *Rhizoctonia spp.*
		Sun-derma (India)	*Fusarium spp.* and *Rhizoctonia spp.*
		Trichodowels, Trichoject andTrichoseal (New Zealand)	*Armillaria spp., Fusarium spp., Phytophthora spp., Pythium spp.* and *Rhizoctonia spp.*
4.	***Trichoderma virens* (Syn. *Gliocladium virens* strainGL - 21)**	Gliogard (USA)	*Pythium ultimum* and *Rhizoctonia solani*
		Soilgard (USA)	*Pythium spp.*

CONCLUSION

In conclusion, the biological control of plant pathogens is a promising and environmentally sustainable approach to safeguarding agricultural crops. By harnessing the natural mechanisms of beneficial microorganisms, we can reduce the reliance on chemical pesticides while effectively managing plant diseases. The multifaceted benefits of biological control, such as minimized environmental impact, decreased pesticide residues in food, and the potential for long-term diseasesuppression, make it a compelling solution for modern agriculture.

However, it is essential to acknowledge that biological control is not a one-size-fits-all solution. Effectiveness can vary depending on factors like crop type, pathogen species, and environmental conditions. To maximize its potential, integrated pest management (IPM) strategies that combine biological control with other pest management methods should be employed. Furthermore, ongoing research and development are crucial to identifying and optimizing the most effective biological agents and their application techniques.

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CHAPTER 10

CLIMATE CHANGE AND ITS IMPACT ON THE PROLIFERATION OF PLANT PATHOGEN

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INTRODUCTION

Climate change has emerged as one of the most critical global challenges of our era, bearing profound implications for both ecosystems and human societies. According to the Sixth Assessment Report released by the Intergovernmental Panel on Climate Change (IPCC) in 2021, emissions of greenhouse gases from human activities, such as the combustion of fossil fuels and deforestation, have contributed to an average global temperature increase of 1.1℃ since 1850- 1900. It is projected that within the next two decades, this rise will reach or even surpass 1.5℃. This increment in global warming is anticipated to bring about a heightened occurrence of heatwaves, prolonged warm seasons, and shortened cold seasons. With a 1.5℃ increase in global temperatures, heat extremes will more frequently surpass the critical thresholds essential for agriculture and human health, particularly when compared to a 2℃ rise.

The far-reaching repercussions of climate change extend beyond elevated temperatures and extreme weather events; they also encompass profound implications for ecosystems and agriculture. A lesser-known yet substantial consequence of climate change is its impact on plant diseases, which is gaining increased attention as a significant threat to global food security in the 21st century (Boonekamp, 2012). As temperatures rise and weather patterns become increasingly erratic due to climate change, conducive conditions for the proliferation and dissemination of plant pathogens are created, resulting in heightened incidence and severity of diseases in cropson a global scale.

Plant diseases represent dynamic processes wherein morphological and physiological alterations result from the interaction between a host plant and a pathogen, closely entwined with their environment. The classic disease triangle underscores the significance of a susceptible host, a virulent pathogen, and a favorable environment as prerequisites for disease development (Gaumann,1950). Climate change has the potential to impact the life cycle phases and rates of pathogenic organisms, as well as the physiology and resilience of host plants, as elucidated by (Chakraborty *et al.*, 1998).

Furthermore, crucial factors governing disease growth and development, namely temperature, light, and water, are also influenced by changing climatic conditions, thereby affecting the type and condition of host plants (Rosenzweig *et al.*, 2001). Elevated levels of carbon dioxide (CO_2)in the atmosphere, as a result of climate change, are expected to enhance photosynthesis and water use efficiency in most crops, potentially leading to increased yields, as discussed by (Goudriaan *et al.*,1995).

The reality of climate change is widely acknowledged, characterized by rising global temperatures and an escalation in the frequency of extreme weather events. Additionally, shifts

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in precipitation patterns are anticipated, including increased rainfall in far northern, far southern, and equatorial regions, coupled with decreased precipitation in most other areas. It is crucial to recognize that certain regions may also experience variations in seasonal precipitation, as indicated by average annual projections, as outlined by (Stern, 2006; Semenov, 2009).

This, in turn, poses a significant threat to agricultural productivity and food supplies, underscoring the pressing need for immediate attention and mitigation efforts to address this alarming consequence of climate change.

Plant- host relationship

The disease triangle is a key concept in plant pathology, emphasizing the interplay of three factors: a virulent pathogen, a susceptible host plant, and favorable environmental conditions. When these factors align, plant diseases can develop, and plants respond to changing conditions by regulating gene expression (Gaumann, 1950;Garrett *et al.*, 2006).

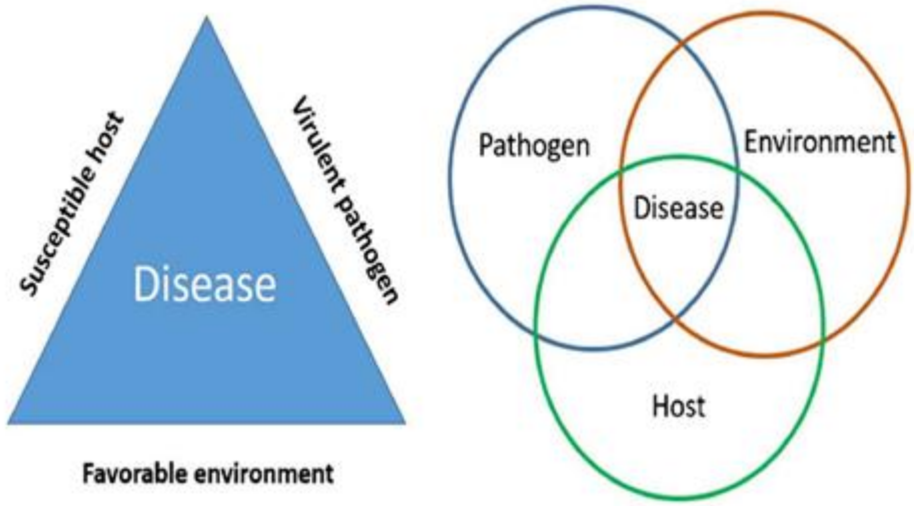

Fig. 1: Disease triangle: The disease triangle represents the interaction between a host, a pathogen, and environmental conditions that lead to disease development

Increasing CO_2 concentrations and temperatures can either enhance or hinder metabolic processes and impact leaf physiology, morphology, and crop production (Ainsworth and Rogers, 2007). Elevated CO_2 levels affect both the host and pathogen in various ways, leading to changes in factors like leaf count, area, branches, plant height, and yield (Bowes, 1993; Pritchard *et al.*, 1999; Eastburn *et al.*, 2011). Elevated CO_2 can increase the pathogen load in C3 grasses, possibly due to extended leaf longevity and higher photosynthetic rates (Mitchell *et al.*, 2003).

Rising temperatures and their duration significantly influence the severity of plant diseases due to climate change. Temperature changes, especially ambient temperature (Li *et al.*, 2013), impact microbial pathogens, hosts, and disease incidence. Temperature plays a crucial role in plant and pathogen growth, affecting penetration, survival, development, reproduction rates, and dispersal of many pathogens. Higher temperatures can modify pathogen growth and reproduction rates (Ladanyi and Horvath, 2010) such as spore germination in the rust fungus *Puccinia substriata.*

Elevated temperature, combined with sufficient soil moisture, creates a humid environment, favoring pathogens that thrive in such conditions, potentially leading to diseases with increased virulence (Mcelrone *et al.*, 2005). Conversely, lower moisture conditions can favor pathogenic fungal species causing powdery mildew disease (Coakley *et al.*, 1999).

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Altered Temperature

Climate change exerts a direct and profound influence on the dynamics of plant diseases, primarily by disrupting established temperature patterns. This phenomenon is multifaceted, as rising temperatures intricately interplay with both plants and their pathogens, yielding complex consequences for ecosystems. It is essential to dissect these effects for a comprehensive understanding of their ecological implications.

The impact of climate change on plant diseases manifests in various ways. Warmer winters, for instance, contribute to a reduction in winter pathogen mortality rates, allowing them to endure and perpetuate infections year-round. Conversely, extreme heat events inflict stress upon plants, compromising their defense mechanisms and rendering them more susceptible to diseases. In northwestern India, research indicates that the concurrent occurrence of water scarcity and heat stress threatens wheat yields, even when factoring in the positive influence of elevated carbon dioxide levels, known as the 'CO_2 fertilization effect,' in the future (Lal *et al.*,1998).

These temperature fluctuations disrupt the delicate equilibrium in plant-pathogen interactions, leading to heightened disease occurrence and severity. Elevated temperatures may favor one stage of the host-pathogen interaction while impeding another, yielding complex and sometimes unexpected outcomes. For instance, projections indicate that each 1℃ increases in the minimum temperature during the dry season could lead to a 10% decrease in rice yield in the Philippines, illustrating the potential ramifications of elevated temperatures on agricultural plant yield (Peng *et al.,* 2004).

Climate change, through alterations in temperature and other environmental factors, also influences the behavior and survival of pathogens. This, in turn, impacts the timing and intensity of disease outbreaks within plant populations. A poignant example is the emergence of potatolate blight, caused by *Phytophthora infestans*, occurring earlier in the growing season in the Fenno-Scandia region due to rising springtime temperatures (Lehsten *et al.,* 2017). While much research has concentrated on climate change's effects during epidemic seasons, off-season environmental conditions must not be overlooked, as they directly influence the survival of dormant pathogen stages, which, in turn, have profound implications for subsequent epidemic seasons. This phenomenon is exemplified by powdery mildew (*Podosphaera plantaginis*) infecting *Plantago lanceolata*, where milder winter conditions enhance the pathogen's winter survival, culminating in increased disease prevalence across the metapopulation (Penczykowski *et al.*, 2015).

Both pathogens and plants are intimately tied to temperature, with changes in this climatic factor impacting the virulence mechanisms of pathogens and the susceptibility of hosts. Temperature influences the entire infection cycle, from spore germination to host tissue colonization, affecting pathogen proliferation and survival, consequently altering the disease's severity (Campbell *et al.,* 1990). Moreover, higher temperatures can create a more conducive environment for the survival and proliferation of various plant pathogens, including fungi, bacteria, and viruses, leading to longer growing seasons and milder winters that facilitate year-round infections. For instance, the sensitivity of plants to Tobacco mosaic virus (TMV) is temperature-dependent, with temperatures above 27ºC rendering plants susceptible to this pathogen (Wright *et al.*, 2000).

In conclusion, climate change, particularly the alteration of temperature patterns, has far-reaching consequences on the intricate interplay between plant diseases, pathogens, and their host plants. These effects span from the seasonal dynamics of disease outbreaks to the fundamental physiological processes underlying pathogen growth and host susceptibility. Understanding these intricate relationships is crucial for predicting and mitigating the ecological and agricultural impacts of climate change on plant diseases.

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Effect of increased CO_2 concentration

Elevated levels of carbon dioxide (CO_2) play a significant role in shaping the interactions between plants and pathogens. While increased CO_2 levels can boost plant growth and productivity, a phenomenon known as the "CO_2 fertilization effect," they can also make plants more vulnerable to certain diseases. This susceptibility occurs because plants allocate more resources to growth at the expense of their defense mechanisms when CO_2 levels are elevated (Manning *et al.*, 1995). These effects have far-reaching consequences, impacting factors like virus transmission, disease severity, and human nutrition (Myers, 2014; O'Leary, 2015; Trebick and Finlay, 2019; Vassiliadis, 2016).

Although elevated CO_2 levels can indeed promote the growth of plants, improve their water use efficiency, and increase the yield of C_3 crops (Kimball, 2016; Leakey, 2009) they also lead to reduced concentrations of essential nutrients such as nitrogen, sulfur, iron, and zinc in plant tissues and grains (Myers, 2014).

Kobayashi *et al.* (2006) conducted a study investigating the impact of elevated atmospheric CO_2 levels on the susceptibility of rice to blast and sheath blight infections. They discovered that higher CO_2 concentrations made the plants more susceptible to these diseases.

In a study by Osozawa *et al.* (1994), the effects of CO_2 in the gaseous phase on two types of soil were examined: one that suppressed clubroot disease in cabbage and another that promoted it. The study concluded that increased CO_2 concentration promoted the occurrence of the disease in the conducive soil when soil moisture levels were high. This effect was attributed to CO_2 causing a decrease in soil water pH, which, in turn, activated the germination of resting spores and hindered crucifer root activity. In contrast, in the suppressive soil, these alterations were not significant because other physical and chemical mechanisms played a role in inducing disease suppressiveness.

Altered precipitation Pattern

Changes in precipitation patterns can exert profound effects on plant diseases, encompassing a complex interplay between moisture availability and the behavior of various pathogens. The augmentation of rainfall and humidity levels can instigate conducive environments for the proliferation of fungal pathogens, exemplified by rusts and mildews. Notably, the fungus *Rhizoctonia bataticola* has seen an escalating prevalence in tropical and humid regions, where elevated temperatures and soil moisture deficits have become prevalent (Sharma and Ghosh, 2017).

Conversely, drought-induced stress can render plants more susceptible to bacterial and fungal infections, signifying a shift in disease prevalence in regions experiencing prolonged droughts due to climate change. A noteworthy example is *Phytophthora cinnamomi*, a mycelial oomycete with a dual lifestyle as a saprophyte or root parasite targeting woody plant roots. This pathogen has garnered significant attention in Australia for its destructive impact on biodiversity. The expected detrimental effect of droughts on pathogens closely linked to moisture presence is well-documented (Weste and Marks, 1987; Harham, 2005; Sturrock *et al.*, 2011).

Intriguingly, elevated drought conditions have been linked to reduced corn yields due to increased water deficits promoting the proliferation of *Aspergillus flavus*, a fungus responsible for aflatoxin production. This compound diminishes corn quality and poses health risks to humans due to its concentration in drought-affected crops (Rosenzweig *et al.*, 2000).

Furthermore, soil moisture levels play a pivotal role in the life cycles of many plant pathogens, albeit with varying requirements among different types of pathogens (Boland *et al.*, 2004;

Agrios, 1997). For instance, certain fungal diseases, like dry rot in beans caused by *Fusarium solani*, thrive in conditions characterized by lower moisture levels.

Moisture, particularly through rain or irrigation, can serve as a vector for the spread of plant pathogens. Rain can splash pathogens from infected plant parts onto healthy ones, facilitating new infections. Wind-driven rain can carry pathogens over longer distances, further exacerbatingthe spread. Elevated moisture levels provide ideal conditions for the development of infections, spore formation, and support spore release and germination in various fungi (Agrios, 1997). Fungal activity varies with temperature, peaking in the moderate temperature range of 18–24 °C. The ongoing shift toward warmer and drier summers is expected to decrease fungal-induced plant diseases, particularly during these warmer and drier periods (Boland *et al.,* 2004).

The behavior and impact of insects and pathogens during and after a drought event are contingent on factors such as food source, feeding habits, stress duration, and host defense mechanisms (Kolb *et al.,* 2016). Drought-stressed plants exhibit a spectrum of biochemical responses, including the production of distinct chemical compounds and modified volatile organic compounds. These biochemical alterations can influence interactions with pathogens and pests. Some compounds act as attractants or repellents, affecting organism behavior, and may also impact pathogen virulence. These changes in plant biochemistry encompass fundamental metabolic processes, including carbohydrate, protein, lipid, amino acid synthesis, phytohormone levels, secondary metabolism pathways, and the generation of reactive oxygen species (Hsiao, 1973; Cruz de Carvalho, 2008; Xu *et al.*, 2010; Niinemets, 2015).

Additionally, the infection of wheat foliage by downy mildew *(Sclerophthora macrospora*) necessitates free water, whereas the infection by powdery mildew (*Blumeria graminis f. sp. tritici*) doesn't require the presence of water on leaf surfaces (Wakelin *et al.*, 2018). These distinctions underscore the intricate relationship between moisture and disease in plants, with varying requirements and responses among different pathogens.

Altered Geographic Distribution

The ongoing phenomenon of rising global temperatures is poised to bring about a substantial transformation in the distribution patterns of climatic regions, consequently exerting a profound influence on the prevalence and severity of plant pathogens. As eloquently articulated by Shaw *et al.,* 2011, the advent of warmer temperatures and shifting precipitation patterns has ushered in novel habitats conducive to the proliferation of disease vectors and pathogens, while concurrently rendering certain regions less hospitable for their persistence. The ramifications of these alterations extend to the emergence of diseases in areas that were hitherto untouched by such afflictions. A striking illustration of this phenomenon is the expansion of tropical plant diseases beyond their historical equatorial confines, venturing into higher latitudes and altitudes as a direct consequence of temperature elevations. A compelling case in point is the catastrophic impact of coffee rust disease, instigated by the fungal agent *Hemileia vastatrix,* on coffee crops in Central and South America, regions previously safeguarded from its ravages by cooler temperatures (Kushalappa, 1989).

When the introduction of plants to novel regions for agricultural or other purposes occurs, these plants may come into contact with native pathogens indigenous to the newfound habitat. In certain instances, these native pathogens may succeed in infecting and inflicting harm upon the introduced plant species, giving rise to the phenomenon widely recognized as "pathogen spillover" or "pathogen host shift" in the realms of agriculture and ecology. Once a pathogen is introduced to a fresh locale, its ability to establish and attain endemic status hinges on the suitability of the environmental conditions. Such endemism signifies the pathogen's persistence and propagation within the local ecosystem, a development that can have adverse repercussions

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for both agriculture and native plant species. A vivid example is the Moko disease afflicting banana plants, caused by the bacterium *Ralstonia (Pseudomonas) solanacearum*. Originating in Heliconia species in Central America, this bacterium was unwittingly disseminated to new territories, including parts of Australia, due to the movement of plants and plant materials across regions via imports (Woods, 1984).

The emergence of potato late blight, attributed to the pathogen *Phytophthora infestans*, is believed to be the result of coevolution with wild potato (Solanum) species. Its transition into a significant threat for cultivated potatoes, particularly *Solanum tuberosum*, transpired when *P. infestans* was inadvertently transported from the South American Andes to Mexico. This parasitesubsequently spread to fresh regions and encountered host plants that had previously not been exposed to its malevolence, progressively assuming a more devastating role as a potato disease. Its incursion into the northeastern United States around 1840 and subsequent proliferation in Europe culminated in the harrowing Irish potato famine (Woodham-Smith, 1962; Niederhauser

,199).

Another vivid illustration is the insidious citrus canker, a bacterial ailment attributed to *Xanthomonas axonopodis pathovar. citri*, which induces the formation of canker lesions and premature shedding of fruit and leaves in citrus species, including oranges and grapefruits. Originating in Southeast Asia or India, this disease has traversed borders and is now present in over 30 countries (Civerolo, 1994).

It is worth noting that the introduction of pathogens into new territories does not always result in the emergence of diseases; rather, the introduction of secondary factors, such as the introduction of vectors like arthropods, can be the catalyst for the propagation of plant diseases. Pierce's Disease of grapes, incited by *Xylella fastidiosa*, serves as a compelling example. Despite its presence in California, USA, for over a century, it was not until 1997 when the arrival of a new vector, the blue-green sharpshooter *Graphocephala atropunctata*, precipitated a rapid and extensive spread of Pierce's Disease. This emergent situation wrought substantial economic losses, exceeding a staggering $6 million in Southern California alone in 1999 (Anderson *et al,* in 2004).

Strategies for Mitigation and Adaptation

The dual pillars encompassing the domains of mitigation and adaptation represent pivotal facets in addressing the multifaceted challenges posed by climate change in the context of agriculture. Within these realms, two primary strategies emerge: (i) the pursuit of mitigation and adaptation through the application of innovative technologies in crop production and management, tailored to accommodate the anticipated climate change scenarios, and (ii) the imperative role of sound governmental policies and political determination to counteract the foreseen adverse consequences of climate change on agricultural systems (Venkateswarlu and Shanker, 2009).

The ramifications of climate change on plant diseases constitute a formidable obstacle to agriculture and food security. In response, farmers and agricultural experts find themselves compelled to recalibrate their approaches to confront the evolving disease patterns. This recalibration necessitates the adoption of novel crop varieties, adjustments in planting schedules, and the implementation of innovative disease management strategies. In the forthcoming decades, farmers will be obliged to embrace a spectrum of agronomic methodologies to accommodate the shifting climate dynamics. These methodologies encompass optimizing planting and harvesting timetables, transitioning to crop varieties better suited to the emerging climatic conditions, and, when required, modifying or entirely reimagining their cropping systems. Evidently, these techniques have already demonstrated their efficacy under prevailing climate conditions (Rosenzweig *et al.*, 2004).

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As climate patterns and seasons continue their inexorable transformation, there arises an unmistakable imperative for the adoption of eco-friendly agricultural practices and disease management strategies. These initiatives are instrumental in ensuring the sustainability of crop production. They hinge upon indispensable tools such as weather-based disease monitoring, meticulous tracking of inoculum (with particular emphasis on soil-borne diseases), and the swift deployment of diagnostic tools. These elements are essential for adeptly adapting to evolving disease scenarios and facilitating judicious decision-making in crop management (Gupta *et al.,* 2018).

To bolster the resilience of crop varieties against the escalating stressors of both abiotic and biotic nature, while concurrently upholding the imperative of high yields to satiate the demands of a burgeoning global populace, crop breeding strategies have integrated cutting-edge technologies, including genomics. However, the advancement in crop improvement endeavors has been marked by a gradual pace. To expedite the breeding cycle and catalyze progress, substantial investments are indispensable in both plant genomics and phenotypic resources. These resources assume a pivotal role in deciphering the genetic underpinnings of agricultural traits and expediting the development of enhanced crop varieties (Anderson *et al.,* 2020; Parmar *et al.,* 2017; Lamaoui *et al.,* 2018).

CONCLUSION

This chapter highlights the significant impact of climate change on plant diseases, resulting in increased disease incidence and severity, alterations in host susceptibility and pathogen virulence, and the emergence of new diseases. It emphasizes the need for region-specific and adaptable disease management strategies that consider climate predictions and crop vulnerabilities. Collaboration, innovation, and global commitment are crucial for mitigatingclimate change's adverse effects on agriculture and preserving our planet's well-being.

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CHAPTER 11

ENVIRONMENTAL FACTORS THAT CAUSE PLANT DISEASES

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INTRODUCTION

Plant diseases are caused by a variety of factors, including biotic (living) and abiotic (non-living) factors. Plants are susceptible to a wide range of diseases caused by pathogens such as bacteria, fungi, viruses, nematodes, and parasitic plants. These pathogens are prevalent in the environment and can cause significant economic losses to crop production. The environment plays a critical role in the development and spread of plant diseases. Environmental factors such as temperature, humidity, rainfall, wind, and soil quality can affect the susceptibility of plants to pathogens. Understanding these environmental factors can help growers and farmers take preventative measures to protect their crops from disease. In this article, we will focus on the abiotic factors that contribute to the development of plant diseases.

TEMPERATURE

Temperature is a crucial environmental factor that affects the growth and development of plants and their susceptibility to diseases. Temperature can directly affect the growth and development of pathogens as well. High temperatures can reduce the effectiveness of plant defense mechanisms, making plants more vulnerable to disease. Conversely, low temperatures can slow down the growth of plants and make them more susceptible to diseases.

Temperature also affects the activity of insects and other pests that transmit plant diseases. For example, the spread of potato virus Y, a viral disease that affects potato plants, is affected by temperature. The virus can only be transmitted by aphids when temperatures are above 15°C.

Therefore, controlling temperature can be an effective way to manage plant diseases (García et al., 2016).

1. High Temperature

High temperature can cause a range of plant diseases. One of the most common diseases that result from high temperatures is bacterial wilt. Bacterial wilt is caused by the bacterium Ralstonia solanacearum and affects a wide range of plants, including tomatoes, potatoes, and eggplants. The disease is more prevalent in warmer climates and is spread through contaminated soil, water, or equipment.

High temperatures can also lead to the development of powdery mildew, which is caused by the fungus Erysiphe cichoracearum. Powdery mildew can affect a wide range of plants, including cucumbers, pumpkins, and squash. The fungus thrives in warm, humid conditions, and the sporescan be easily spread through the wind.

Another disease that can be caused by high temperatures is grey mold, which is caused by the fungus Botrytis cinerea. Grey mold affects a wide range of plants, including grapes,

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strawberries, and lettuce. The fungus thrives in warm, humid conditions and can cause the flowers, fruits, and leaves of the plant to rot.

2. Low Temperature

Low temperature can also cause a range of plant diseases. One of the most common diseases that result from low temperatures is frost damage. Frost damage occurs when the temperature drops below freezing, and ice crystals form inside the plant cells, causing them to rupture. Frost damage can lead to the development of diseases such as grey mold and powdery mildew.

Another disease that can be caused by low temperatures is blackleg, which affects members of the cabbage family. Blackleg is caused by the bacterium Erwinia carotovora and is more prevalent in cooler temperatures. The disease can cause the stems of the plant to rot, leading to stunted growth and reduced yields (García et al., 2016). In addition to these diseases, low temperatures can also weaken the plant's immune system, making it more susceptible to infection by other pathogens.

3. Temperature Fluctuations

Temperature fluctuations can also cause plant diseases. Rapid changes in temperature can cause stress to the plant, which can weaken its immune system and make it more susceptible to infection by pathogens.

For example, sudden changes in temperature can cause the plant to wilt, making it more susceptible to infection by soil-borne pathogens such as Fusarium and Rhizoctonia. These fungi thrive in soil that is too moist or too dry and can cause root rot and other diseases (Anderson et al., 2004).

Temperature fluctuations can also lead to the development of blossom-end rot, which affects tomatoes and other fruiting plants. Blossom-end rot is caused by a calcium deficiency in the plant and can be triggered by sudden changes in temperature, as well as fluctuations in soil moisture levels.

In summary, temperature is a critical environmental factor that can cause a range of plant diseases. High temperatures can cause diseases such as bacterial wilt, powdery mildew, and grey mold, while low temperatures can cause frost damage, blackleg, and weaken the plant's immune system. Temperature fluctuations can also lead to a range of diseases and weaken the plant's immune system.

HUMIDITY

Humidity is another critical environmental factor that affects plant diseases. High humidity provides a suitable environment for the growth and spread of fungal and bacterial pathogens. Fungi, in particular, thrive in humid conditions and can cause a wide range of plant diseases. High humidity can also increase the severity of disease symptoms in plants. Low humidity can also cause problems for plants. Dry conditions can stress plants, making them more susceptible to diseases. When plants are stressed, they produce less of the chemicals that help protect them from pathogens.

Humidity can affect plant diseases in several ways:

1. Influence on Pathogen Growth and Reproduction:

Humidity can affect the growth and reproduction of plant pathogens. Many fungal and bacterial pathogens require high levels of moisture to grow and reproduce, and high humidity can provide the ideal conditions for their development.

For example, powdery mildew, a fungal disease that affects many plant species, thrives in high humidity conditions. The spores of powdery mildew need moisture to germinate, and they can

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spread rapidly under humid conditions. Similarly, bacterial leaf spot, a disease caused by the bacterium Xanthomonas campestris, can spread rapidly in high humidity conditions, as the bacteria require moisture to infect and colonize plant tissues (Gill, 1966).

2. Influence on Host Plant Susceptibility:

Humidity can also affect the susceptibility of host plants to disease. High humidity can lead to increased leaf wetness, which can make plants more susceptible to infection by plant pathogens. When leaves remain wet for extended periods, it provides an ideal environment for pathogens to germinate and infect the plant.

Additionally, high humidity can cause water stress in plants, which can weaken their defenses against disease. When plants experience water stress, they may allocate less resources towards defense mechanisms, making them more susceptible to infection.

3. Influence on Disease Transmission:

Humidity can also influence the transmission of plant diseases by insect vectors. Many insect vectors, such as aphids and whiteflies, are attracted to high humidity conditions, and their behavior and feeding patterns can be influenced by humidity levels (Eastburn et al., 2010).

For example, whiteflies, which are common insect vectors of plant viruses, are attracted to high humidity conditions. In humid conditions, whiteflies may reproduce more quickly and feed morefrequently, increasing the chances of virus transmission.

In summary, humidity is a critical environmental factor that can influence the development and severity of plant diseases. It can affect the growth and reproduction of plant pathogens, the susceptibility of host plants to disease, and the transmission of plant diseases by insect vectors. Understanding the effects of humidity on plant diseases is important for effective disease management strategies

RAINFALL

Rainfall is essential for plant growth, but it can also contribute to the development and spread of plant diseases. Excessive rainfall can lead to waterlogging of soil, which can cause root rot and other fungal diseases. Rain can also dislodge spores of fungal and bacterial pathogens, causing them to spread from plant to plant (Chakraborty et al., 2000).

Rainfall can affect plant diseases in several ways:

1. Influence on Pathogen Growth and Survival:

Rainfall can influence the growth and survival of plant pathogens. Some pathogens require moisture for their growth and reproduction, and rainfall can provide the necessary moisture for their development. However, excessive rainfall can also create waterlogged conditions, which can lead to anaerobic soil conditions that are detrimental to many plant pathogens.

For example, the fungal pathogen Pythium sp. requires moisture for its growth and reproduction, and excessive rainfall can provide favorable conditions for its development. In contrast, the fungal pathogen Fusarium oxysporum can be inhibited by excessive moisture, and prolonged periods of rainfall can lead to soil saturation, which can limit its growth and survival.

2. Influence on Host Plant Growth and Defense Mechanisms:

Rainfall can also affect the growth and defense mechanisms of the host plant. Adequate rainfall can promote plant growth and photosynthesis, leading to increased biomass production and improved plant defenses. However, excessive rainfall can cause waterlogging and nutrient leaching, which can lead to reduced plant growth and weakened defense mechanisms.

Additionally, rainfall can influence the distribution of plant pathogens within a field or landscape. For example, wind-driven rain can disperse fungal spores over long distances,

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leadingto the spread of plant diseases. Similarly, water runoff from infected plants or fields can carry plant pathogens downstream, leading to the contamination of healthy plants(Rumbolz et al., 2002).

3. Influence on Disease Development:
Rainfall can also affect the development of plant diseases. Rainfall can create favorable conditions for the development of some diseases, while inhibiting the development of others. Forexample, cool, moist conditions are favorable for the development of many fungal diseases, suchas powdery mildew and downy mildew.

Conversely, dry conditions can inhibit the development of many plant diseases. For example, thebacterial pathogen Xylella fastidiosa requires moisture for its growth and reproduction, and dry conditions can limit its development and spread.

In summary, rainfall is an important environmental factor that can influence the development and severity of plant diseases. It can affect the growth and survival of plant pathogens, the growth and defense mechanisms of the host plant, and the distribution and development of plant diseases. Therefore, understanding the effects of rainfall on plant diseases is important foreffective disease management strategies.

WIND
Wind can also contribute to the spread of plant diseases. Wind can disperse fungal spores and other pathogens.

Wind is another environmental factor that can influence the development and spread of plant diseases. Wind can have both direct and indirect effects on plant pathogens and host plants, leading to increased disease incidence and severity.

1. Mechanical Damage:
One direct effect of wind on plants is mechanical damage. Strong winds can cause physical damage to plant tissues, such as breaking stems or branches, or tearing leaves. This damage can create entry points for plant pathogens, allowing them to invade and infect the plant (Clarkson et al., 2014).

2. Dispersal of Pathogens:
The dispersal of pathogens is a significant factor in causing plant diseases. Pathogens can be dispersed in various ways, including by insects, water, wind, soil, and human activities. Here are some ways that the dispersal of pathogens can cause plant diseases:

i) Insects:
Insects, such as aphids, thrips, and whiteflies, can transmit pathogens from infected plants to healthy plants. These insects feed on plant sap, and as they move from plant to plant, they can carry pathogens on their mouthparts and spread them to new hosts. Some pathogens can also be transmitted by insect eggs or through insect feces.

3. Water:
Water can also disperse pathogens, particularly those that live in the soil or on plant surfaces. Pathogens can be spread by rainfall, irrigation, or natural water sources. For example, Phytophthora root rot and Pythium damping-off are soil-borne diseases that can be spread by irrigation water that carries the pathogen from infected soil to healthy plants.

4. Wind:
Wind can also disperse pathogens, particularly those that produce spores or other propagules that can be carried by the wind. Fungal diseases, such as powdery mildew and rust, can be spread by wind-dispersed spores that land on new hosts and infect them. Some bacterial and

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viral diseases can also be spread by wind, particularly if infectedplant tissues are shredded or broken by the wind, releasing pathogens into the air.

5. Soil:

Soil can also disperse pathogens, particularly if soil particles adhere to plant surfaces, tools, or footwear. Soil-borne diseases, such as Verticillium wilt and Fusarium wilt, can be spread by soil particles that are carried from infected soil to healthy plants or by tools or equipment that have come into contact with infected soil.

6. Human activities:

Human activities, such as pruning, harvesting, and planting, can also disperse pathogens. For example, pruning tools that have been used on infected plants can spread pathogensto healthy plants if not disinfected properly. Similarly, planting infected plant material or using contaminated soil can introduce pathogens to new areas and lead to disease outbreaks.

In summary, the dispersal of pathogens is a significant factor in causing plant diseases. To minimize the risk of disease outbreaks, it is essential to manage the movement of pathogens by implementing good sanitation practices, avoiding the use of infected plant material, selecting disease-resistant plant species, and implementing integrated pest management strategies that target both insect vectors and plant pathogens.

ENVIRONMENTAL STRESS:

Wind can also cause environmental stress in plants, making them more susceptible to infection by plant pathogens. Wind can increase transpiration rates in plants, leading to water stress and dehydration. This can weaken plant defenses, making them more vulnerable to infection.

1. Interactions with other Environmental Factors:

Wind can interact with other environmental factors, such as temperature and humidity, to influence plant disease development. For example, high wind speeds can increase evapotranspiration rates, leading to reduced humidity levels. This can create favorable conditionsfor some plant pathogens, such as powdery mildew, to infect host plants.

In summary, wind can have direct and indirect effects on plant pathogens and host plants, leading to increased disease incidence and severity. It can cause mechanical damage, disperse pathogens over long distances, create environmental stress in plants, and interact with other environmental factors to influence disease development. Therefore, understanding the effects of wind on plant diseases is important for effective disease management strategies (Xin et al., 2016)

LIGHT

Light is an essential environmental factor for plant growth and development, but changes in light intensity or quality can affect plant physiology and defense mechanisms, making them more susceptible to infection by plant pathogens. Here are some ways that light can cause plant diseases:

1. UV Radiation:

Ultraviolet (UV) radiation can cause DNA damage in plants and alter their physiological processes, leading to reduced plant growth and defense mechanisms. This can make plants more vulnerable to infection by plant pathogens. Some plant pathogens, such as fungi, are sensitive to UV radiation and may be inhibited by it, while others, such as viruses, may be less affected.

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2. Intensity and Quality of Light:

Changes in the intensity and quality of light can affect plant physiology and defense mechanisms, making them more susceptible to infection by plant pathogens. For example, high light intensity can cause photoinhibition, leading to reduced photosynthesis and weakened plant defenses. Low light intensity can also reduce plant growth and defense mechanisms, making them more vulnerable to infection.

3. Shade:

Plants grown in shaded environments may have reduced photosynthesis rates and lower levels of plant defense compounds, making them more susceptible to infection by plant pathogens. Shade can also create favorable conditions for some plant pathogens, such as fungi, to infect host plants.

4. Photoperiod:

Changes in photoperiod, or the length of light and dark periods, can affect plant growth and defense mechanisms. For example, short-day plants may have reduced growth and defense mechanisms under long-day conditions, making them more vulnerable to infection.

5. Blue Light:

Blue light has been shown to stimulate the growth of some plant pathogens, such as Botrytis cinerea, which can cause grey mold in a variety of crops, including tomatoes and strawberries. Blue light can also reduce the production of plant defense compounds, making them more susceptible to infection (Sharma and Verma 2019).

In summary, changes in light intensity, quality, photoperiod, and shade can affect plant physiology and defense mechanisms, making them more vulnerable to infection by plant pathogens. UV radiation and blue light can also directly influence the growth and survival of some plant pathogens. Therefore, understanding the effects of light on plant diseases is importantfor effective disease management strategies

SOIL pH

Soil pH is a critical environmental factor that can influence the development and severity of plant diseases. The pH of the soil affects the availability of nutrients and the growth of plant pathogens. Some plant pathogens prefer acidic soils, while others prefer alkaline soils. Here are some ways that soil pH can cause plant diseases:

1. Nutrient Availability:

Soil pH can affect the availability of nutrients for plant growth and development. Changes in soilpH can lead to nutrient imbalances that can weaken the defense mechanisms of host plants, making them more susceptible to infection. For example, at low soil pH, aluminum and manganese can become more soluble and toxic to plants, while at high soil pH, iron and phosphorus can become less available.

2. Microbial Activity:

The pH of the soil can also influence the microbial communities present in the soil. Changes in soil pH can alter the balance of microbial communities, leading to changes in disease incidence and severity. For example, some plant pathogens, such as Rhizoctonia solani, prefer acidic soils and may be more prevalent in soils with low pH.

3. Aluminum Toxicity:

At low soil pH, aluminum can become more soluble and toxic to plants. This can cause damage to the roots of plants, leading to reduced plant growth and weakened defense mechanisms. Aluminum toxicity can also create favorable conditions for some plant pathogens, such as Phytophthora spp., to infect host plants.

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4. Manganese Toxicity:
At low soil pH, manganese can become more soluble and toxic to plants. This can cause damage to the roots of plants, leading to reduced plant growth and weakened defense mechanisms. Manganese toxicity can also create favorable conditions for some plant pathogens, such as Fusarium spp., to infect host plants.

5. Calcium Deficiency:
At low soil pH, calcium can become less available to plants. Calcium is important for cell wall formation and strengthening, and its deficiency can weaken plant defense mechanisms, making them more vulnerable to infection by plant pathogens. Calcium deficiency can also increase the susceptibility of plants to physiological disorders, such as blossom end rot in tomatoes.

In summary, soil pH can influence the availability of nutrients, microbial activity, and the toxicity of certain elements in the soil, all of which can affect the growth and defense mechanisms of host plants, making them more vulnerable to infection by plant pathogens. Therefore, understanding the effects of soil pH on plant diseases is crucial for effective disease management strategies

NUTRIENTS
While nutrients are essential for plant growth and development, imbalances or deficiencies in nutrient levels can weaken plant defense mechanisms, making them more vulnerable to infectionby plant pathogens. Here are some ways that nutrients can cause plant diseases:

1. Nitrogen:
Excessive nitrogen application can lead to rapid plant growth, which can create favorable conditions for some plant pathogens, such as fungi, to infect host plants. Additionally, high nitrogen levels can reduce the production of plant defense compounds, making them more vulnerable to infection. Conversely, nitrogen deficiency can weaken plant defense mechanisms and make them more susceptible to infection by pathogens.

2. Phosphorus:
Phosphorus deficiency can weaken plant defense mechanisms, making them more vulnerable to infection by pathogens. Additionally, some plant pathogens, such as Phytophthora spp., can thrive in soils with high phosphorus levels.

3. Potassium:
Potassium deficiency can lead to weaker cell walls and reduced production of defense compounds, making plants more susceptible to infection by pathogens. Additionally, some plant pathogens, such as fungi, can thrive in soils with high potassium levels.

4. Calcium:
Calcium deficiency can weaken cell walls and reduce the production of defense compounds, making plants more susceptible to infection by pathogens. Additionally, some plant pathogens, such as Phytophthora spp., can thrive in soils with high calcium levels.

5. Magnesium:
Magnesium deficiency can reduce the production of defense compounds, making plants more susceptible to infection by pathogens. Additionally, some plant pathogens, such as Sclerotinia spp., can thrive in soils with high magnesium levels.

In summary, imbalances or deficiencies in nutrient levels can weaken plant defense mechanisms, making them more vulnerable to infection by plant pathogens. Excessive levels of certain nutrients can also create favorable conditions for some plant pathogens to infect host plants. Therefore, understanding the effects of nutrients on plant diseases is important for

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effective disease management strategies, which may include optimizing nutrient levels and using fertilizers carefully to minimize the risk of plant diseases.

WATER AVAILABILITY

Water availability is a critical environmental factor that can affect the development and severity of plant diseases. Both too much and too little water can create conditions that favor the growth of plant pathogens and weaken the defense mechanisms of host plants, making them more vulnerable to infection. Here are some ways that water availability can cause plant diseases:

1. **Waterlogging:**

Waterlogging occurs when soil becomes saturated with water for an extended period of time, leading to reduced oxygen availability in the soil and around plant roots. This lack of oxygen can have several negative effects on plants and create conditions that favor the growth and spread of plant pathogens. Here are some ways that waterlogging can cause plant diseases:

2. **Reduced oxygen availability:**

Waterlogging leads to reduced oxygen availability in the soil and around plant roots, which can lead to anaerobic conditions that are harmful to plant growth and development. Lack of oxygen can weaken plant defense mechanisms, making them more vulnerable to infection by pathogens. Additionally, some plant pathogens, such as Pythium spp. and Phytophthora spp., thrive in waterlogged soils and can infect host plants under these conditions.

3. **Nutrient imbalances:**

Waterlogging can cause nutrient imbalances in the soil, as nutrients may become less available to plants in anaerobic conditions. This can lead to deficiencies or excesses of certain nutrients that can weaken plant defense mechanisms and make them more susceptible to infection by pathogens.

4. **Root rot:**

Waterlogging can cause root rot, a disease caused by various plant pathogens, including Pythium spp., Phytophthora spp., and Fusarium spp. Root rot leads to the decay of plant roots and can cause wilting, stunting, and death of infected plants. Root rot is a significant problem in waterlogged soils, as these conditions create favorable environments for the growth and spread of these pathogens.

5. **Increased susceptibility to other diseases:**

Waterlogging can weaken plant defense mechanisms and increase susceptibility to other diseases. For example, waterlogged soils can create favorable conditions for foliar diseases, such as downy mildew, powdery mildew, and rust, which thrive in humid conditions and can infect plants with weakened defense mechanisms.

In summary, waterlogging can create conditions that favor the growth and spread of plant pathogens and weaken plant defense mechanisms, making them more susceptible to infection by other pathogens. Therefore, it is essential to prevent or manage waterlogging to minimize the risk of plant diseases. Strategies to manage waterlogging may include improving soil drainage, selecting plants that are tolerant to waterlogged conditions, and avoiding over-irrigation or heavy rainfall events.

DROUGHT

Drought stress is a common environmental factor that can cause plant diseases. Drought stress occurs when plants experience water deficits, either due to low rainfall or insufficient irrigation, leading to reduced plant growth and development. Here are some ways that drought stress can cause plant diseases:

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1. Weakened plant defense mechanisms:

Drought stress can weaken plant defense mechanisms, making them more vulnerable to infection by pathogens. For example, drought stress can reduce the production of defense compounds, such as phytohormones, secondary metabolites, and proteins, which are essential for the plant's ability to defend against pathogens.

2. Increased susceptibility to other stresses:

Drought stress can increase the susceptibility of plants to other environmental stresses, such as heat stress, cold stress, and nutrient deficiencies, which can also weaken plant defense mechanisms and make them more susceptible to infection by pathogens.

3. Physiological changes:

Drought stress can lead to physiological changes in plants that can increase susceptibility to infection by pathogens. For example, drought stress can reduce stomatal conductance, leading to decreased gas exchange and increased susceptibility to foliar pathogens, such as powdery mildew.

4. Fungal infections:

Drought stress can create favorable conditions for the growth and spread of some fungal pathogens, such as Fusarium spp., which can infect plants that are under water stress. Additionally, drought stress can increase the incidence of some foliar diseases, such as Botrytis spp., which thrive in dry conditions.

5. Insect infestations:

Drought stress can also increase the incidence of insect infestations, which can transmit plant pathogens or directly damage plant tissues, creating entry points for pathogens. For example, spider mites and thrips are known to increase in population under dry conditions and can damage plant tissues, making them more vulnerable to infection by pathogens (Panchal et al., 2017).

In summary, drought stress can weaken plant defense mechanisms and create conditions that favor the growth and spread of plant pathogens, making plants more susceptible to infection by diseases. Therefore, it is important to manage drought stress to reduce the risk of plant diseases. Strategies to manage drought stress may include optimizing irrigation practices, selecting drought-tolerant plant species, and improving soil water-holding capacity through mulching or soil amendments.

FLOODING:

Sudden and severe flooding can cause plant diseases in several ways. Flooding occurs when there is an excessive amount of water in the soil, which can lead to a lack of oxygen in the root zone and create favorable conditions for the growth and spread of plant pathogens. Here are some ways that sudden and severe flooding can cause plant diseases:

1. Reduced oxygen availability:

Flooding can lead to reduced oxygen availability in the soil and around plant roots, leading to anaerobic conditions that can be harmful to plant growth and development. Lack of oxygen can weaken plant defense mechanisms, making them more vulnerable to infection by pathogens. Additionally, some plant pathogens, such as Pythium spp., Phytophthora spp., and Fusarium spp., thrive in waterlogged soils and can infect host plants under these conditions.

2. Nutrient imbalances:

Flooding can cause nutrient imbalances in the soil, as nutrients may become less available to plants in anaerobic conditions. This can lead to deficiencies or excesses of certain nutrients that

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can weaken plant defense mechanisms and make them more susceptible to infection by pathogens.

3. Physical damage:

Sudden and severe flooding can cause physical damage to plants, such as uprooting or breaking of stems or branches, which can create entry points for pathogens to infect the plant. Additionally, flooding can cause soil erosion, which can expose plant roots and increase their vulnerability to infection by pathogens.

4. Spread of plant pathogens:

Flooding can also lead to the spread of plant pathogens through the movement of water, which can carry pathogens from one location to another. This can increase the incidence of plant diseases in areas that were previously unaffected.

5. Increased susceptibility to other diseases:

Flooding can weaken plant defense mechanisms and increase susceptibility to other diseases. For example, flooding can create favorable conditions for foliar diseases, such as downy mildew, powdery mildew, and rust, which thrive in humid conditions and can infect plants with weakened defense mechanisms.

In summary, sudden and severe flooding can create conditions that favor the growth and spread of plant pathogens and weaken plant defense mechanisms, making them more susceptible to infection by other pathogens. Therefore, it is essential to prevent or manage flooding to minimize the risk of plant diseases. Strategies to manage flooding mayinclude improving soil drainage, selecting plants that are tolerant to waterlogged conditions, and avoiding over-irrigation or heavy rainfall events.

6. Poor irrigation practices:

Poor irrigation practices can cause plant diseases in several ways. Irrigation is essential for plant growth and development, but when not managed properly, it can create conditions that favor the growth and spread of plant pathogens. Here are some ways that poor irrigation practices can cause plant diseases:

WATERLOGGED SOILS:

Over-irrigation or poor drainage can lead to waterlogged soils, which can reduce oxygen availability in the root zone and create anaerobic conditions that are favorable for the growth andspread of plant pathogens. This can weaken plant defense mechanisms and make them more susceptible to infection by pathogens, such as *Pythium spp., Phytophthora spp., and Fusarium spp*. (Reddy et al., 2019)

1. Nutrient imbalances:

Poor irrigation practices can lead to nutrient imbalances in the soil, which can weaken plant defense mechanisms and make them more susceptible to infection by pathogens. For example, over-irrigation can cause leaching of nutrients from the soil, leading to deficiencies in essential nutrients, such as nitrogen, phosphorus, and potassium.

2. Foliar diseases:

Poor irrigation practices can increase the incidence of foliar diseases, such as powdery mildew and downy mildew, which thrive in humid conditions. Overhead irrigation can create a favorable environment for these diseases by keeping the foliage wet for extendedperiods.

3. Root diseases:

Poor irrigation practices can also increase the incidence of root diseases, such as Fusarium wilt, Verticillium wilt, and root rot. Over-irrigation can lead to waterlogged soils, as mentioned

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earlier, which can create anaerobic conditions that are favorable for the growth and spread of these diseases.

4. Spread of plant pathogens:
Poor irrigation practices can also contribute to the spread of plant pathogens through the movement of water. For example, overhead irrigation can splash water onto neighboring plants, spreading pathogens from infected plants to healthy plants.

In summary, poor irrigation practices can create conditions that favor the growth and spread of plant pathogens, weaken plant defense mechanisms, and increase susceptibility to infection by diseases. Therefore, it is essential to manage irrigation properly to reduce the risk of plant diseases. Strategies to manage irrigation properly may include selecting the appropriate irrigation method for the plant species, monitoring soil moisture levels, avoiding over-irrigation, and improving soil drainage.

HUMIDITY:
Humidity can cause plant diseases in several ways. High humidity levels can create a favorable environment for the growth and spread of plant pathogens, particularly those that thrive in moist conditions. Here are some ways that humidity can cause plant diseases (Jones et al., 2016):

1. Fungal diseases:
High humidity levels can create a favorable environment for fungal diseases, such as powdery mildew, downy mildew, and rust. These diseases thrive in moist conditions and can infect plants with weakened defense mechanisms. Humid conditions can also promote the growth and spread of fungal spores, increasing the incidence of these diseases.

2. Bacterial diseases:
Humidity can also increase the incidence of bacterial diseases, such as bacterial leaf spot and bacterial wilt. Bacterial diseases can spread rapidly in humid conditions, particularly when plants are wet for extended periods. These diseases can infect plants through wounds, natural openings, or directly through the leaf surface.

3. Viral diseases:
Humidity can increase the incidence of viral diseases, such as cucumber mosaic virus and tomato spotted wilt virus. Viral diseases are typically transmitted by insect vectors, such as aphids and thrips, but high humidity levels can promote the survival and transmission of these vectors, increasing the risk of infection in plants.

4. Reduced transpiration:
High humidity levels can reduce transpiration in plants, leading to reduced water uptake and nutrient availability, which can weaken plant defense mechanisms and make them more susceptible to infection by pathogens.

5. Physiological disorders:
High humidity levels can also cause physiological disorders in plants, such as blossom end rot in tomatoes and peppers. These disorders are typically caused by calcium deficiencies, which can be exacerbated by high humidity levels that can interfere with calcium uptake.

In summary, high humidity levels can create a favorable environment for the growth and spread of plant pathogens, weaken plant defense mechanisms, and increase the incidence of plant diseases. Therefore, it is essential to manage humidity levels to minimize the risk of plant diseases. Strategies to manage humidity levels may include improving air circulation around plants, reducing water on plant foliage, selecting plant species that are tolerant to high humidity levels, and avoiding over-fertilization, which can promote vegetative growth and increase susceptibility to diseases.

In summary, water availability can affect the growth and defense mechanisms of host plants, making them more vulnerable to infection by plant pathogens. Both too much and too little water can create conditions that favor the growth of pathogens and weaken plant defense mechanisms. Therefore, understanding the effects of water availability on plant diseases is crucial for effective disease management strategies, which may include optimizing irrigation practices and improvingdrainage to minimize the risk of plant diseases.

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CHAPTER 12

ROBOTIC FARMING: REVOLUTIONIZING AGRICULTURE WITH AUTOMATION

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ABSTRACT

Robotics is the branch of technology that deals with the design, construction, operation, structural depositions, manufacture and application of robots. Robotics brings together several very different engineering areas and skills. Robots and drones are being deployed in farmlands for many farm purposes particularly in fruit picking, chemical spraying, plant analysis, plant protection and many more. With the revolutionary rise in the implementing of precision farming and sustainable agriculture, the use of agri-bots, short for agricultural robots, should be encouraged and made available for the farmlands at a global level.

Keywords: Farm machinery, IOT in agriculture, Precision farming, Robotic agriculture, Sustainable agriculture

INTRODUCTION

Agriculture has been practiced since the prehistoric era, at least thousands of years. Since day one, agriculture has undergone a lot of advancements from domestication and introduction of crops, producing of high yielding varieties and hybrids to using nanotechnology and even indoor farming. Robotic farming and the application of IOT in agriculture is one of the modern concepts in the trend of crop production. Robotics is the branch of science and technology that deals with the application of robots. Robotics brings together several very different engineering areas and skills. Robots are being utilized in agriculture for many purposes like monitoring, incorporation of inputs, sowing seeds, harvesting, analysis and detection, forecasting, etc. The main objective of robotic farming is to increase efficiency and reduce the dependency of human labor.

With the rise of population there is a tremendous increase in food demand and decrease in farmlands, to make up with the needs of food, injudicious use of farm inputs is being practiced like excessive use of chemical inputs and intensive use of farm machineries, lack of labor and manpower and uncertain climate problems are being faced in agricultural production. Agriculture has a serious impact on the environment due to deforestation and chemical use. Intensive pesticides and fertilizers lead to degradation of the farm ecosystem eradicating beneficial soil micro- organisms as well as causing several health hazards, excessive use of farm machinery leads to soil compaction, air pollution, and requires skilled labor. With urbanization, many rural lands are also converted into urban areas which resulted to the decline in farm areas, but still with the high demand of foods. All these factors lead to the high demand for food, with low productivity. A way out of these problems can be by practicing extensive farming following the principles of precision agriculture.

Precision agriculture is the science of improving crop yields and farm management using precise amounts of inputs utilizing high technology tools. Drones, irrigation technologies, GPS/GIS, etc., are some examples of tools being used in precision agriculture. Robot farming

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system is necessary that can be applied from seeding or planting stage to harvesting. There are many developed robot tractors and robot vehicles for agricultural purposes, examples are intra-row mechanical weed control tractor, automated rice transplanter, etc. Using these light weighted machineries in seeding/planting stage and other intercultural operation may lead to reduction of using of heavy machineries which reduces major constraints like soil compaction, use of fossil fuels, optimum use of inputs, reducing post -harvest losses, avoid labor costs and labor scarcity problems.

Needs of robotic farming

Robots and such machineries are utilized in farming to reduce and target inputs in more efficient ways. The approach of such systems gives us the opportunity to develop a new range of agricultural equipment based on machines with artificial intelligence that reduce waste, are economical, eco-friendly and increases food sustainability. There is also other considerable potential for robotics technologies for their applications, such as, being able to work on wet soils, work at night, herding cattle, milking cattle, reducing labor costs in harvesting and reduce post-harvest losses, etc.

Sensory data collected by robotic platforms in the field can further provide information regarding soil, seeds, livestock, crops, costs, farm equipment and the use of water and fertilizer. The Internet of Things (IoT) technologies and analytics are helping farmers analyze data on weather, temperature, moisture, prices and provide knowledge how to optimize yield, improve planning, make smarter decisions about the amount of input needed, and decide the right time to distribute those resources in order to minimize waste and increase yields. Future telecommunications availability is likely to enhance IoT capacity, with agri-tech test beds already under development.

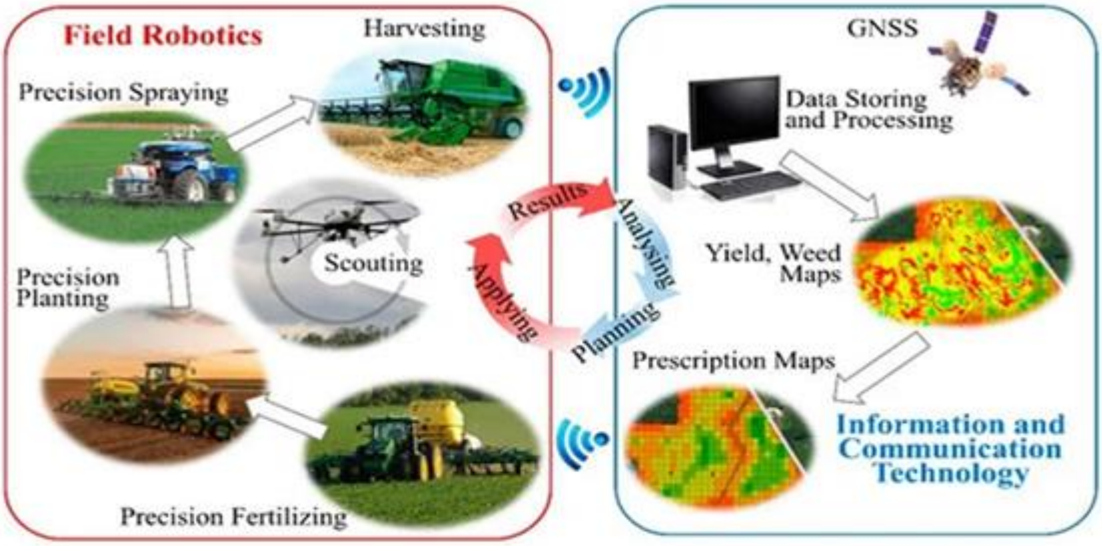

Fig 1: Components of precision farming, the involvement of automation and robots are an important aspect in precision farming.

Source: Field Robots for Intelligent Farms—Inhering Features from Industry (Gonzale-de-Santos et al, 2020)

Scope of Robotic Farming

Data collection at different stages of crop growth such as nutrient availability, soil moisture, pest incidence, weed density, crop maturity, water stress and others. It improves the productivity and quality of the produce as well as the effortless cultivation process. Precision farming needs an application accurate input at accurate time. Crop monitoring would be less

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expensive, less complicated, and less time-consuming if a system could remain within the crop area for continuous monitoring. Management of inputs at optimum rate could be achieved by sensing the situation of the crop measured in the field by using a microprocessor. Continuous monitoring the crop canopy using the robot would make it easier to identify crop diseases and pest attack at an early stage.

Agricultural robots play an important part in reducing environmental chemical contamination and crop chemical residues. Micro spraying can be practiced using agri-bots, it is the concept of spaying inputs closer to the target area, spraying the optimum amount directly on the leaves without disturbing the crop or the soil resulting in less input-loss through air flow, soil leaching, etc.

Weed control is a very hectic job to do in intercultural operations, causing farmers to use weedicides in an excessive manner, thereby causing contamination of water sources as well as the environment. Agricultural robots can be deployed to survey the field and perform weed control methods either by spraying weedicides/herbicides and/or spinning rotary blades.

Harvesting of crops are done in a bulk manner in agronomical crops but in horticultural crops like fruits and vegetables there is uneven maturity among the harvest, these results to immature picking as well as overmature harvesting, causing post-harvest losses. Post-harvest losses of horticultural commodities in India are about 5-40 % of total produce. Utilizing agricultural robots in fields with sensors and data regarding fruit/vegetable maturity will help the harvesting much easier, reducing labor costs as well as post-harvest losses caused by harvesting injury and immature/overmature harvesting.

Problems faced in Traditional Framing

Major problems faced in traditional farming are:

1. **Practicing intensive farming –** As we have discussed above, the farms must produce more for the demanding population farmers practice intensive farming causing yield losses, environment degradation, health hazards.
2. **Less education among farmers/ less skilled labor –** Farmers in India are mostly from a poor background, so they are less educated/ don't have time to get educated running the farms to earn money for the family.
3. **Lack of labor –** Nowadays there are lesser number of labors due to change in professions of many farmers due to crop losses, debts, land losses, etc. Due to these the wage of labor also becomes higher causing disagreement among the laborers and the farmers/landowners.
4. **Most farmers in India are poor –** In India, even if the backbone of economy if agriculture, the farmers are mostly poor. Also, the farmers face land tenure issues which can lead to difficulties for the long term.
5. **High capital requirements in inputs –** High costs of implements, nutrients and fertilizers, chemicals cause the farmers to fall into debt. Many farmers lack investment and credit, making it challenging to purchase farm inputs such as seeds, fertilizers, machinery, etc.
6. **Technology barrier –** Most of the farmers who practice small scale farming or rural farmers lack access to modern technology which causes a challenge in their production, limiting their produce.
7. **Cropping system –** Most of the farmers practice monocropping, i.e., continuous cultivation of a single type of crop on their farms, which can lead to increased incidence of pests and diseases.
8. **Post-harvest loss –** Lack of proper knowledge in harvesting and maturity stage and post-

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harvest handling, transportation and storage causes a major loss to the farm produce and the farmers' financials.

Types of Agricultural robots

1. **Demeter Robots –** Used in navigation, harvesting acres of crop, land survey, etc.
2. **Weed Control Robots –** It is used in weed identification and detection as well as weed control.
3. **Forester Robots –** Used in foraging timber.
4. **Fruit picking Robots –** Used to harvest fruits and vegetables in the right maturestage using image/visual recognition system.
5. **Drone Robots –** It has many applications in farming starting from drones which are used to spray fertilizers, weedicides, pesticides, herbicides, etc, to drone which are usedfor soil mapping and herding of cattle.
6. **Auto-Irrigation systems –** It uses sensors and real time data to ensure optimized irrigation and efficient water use.
7. **Monitoring robots –** Used to analyze plant health, detect diseases, pests and nutrient deficiencies.

Fig 2: AI generated images of robots which are deployed in the fields, starting from first image shown robotic weeder, scouting drone, smart irrigation system and robotic harvesters.

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Advantages

Following the problems of traditional farming scenario in India, robotic farming may help reduce many as mentioned below.

- Reduction in labor - Weeding, spraying chemicals, harvesting, etc., as we have discussed above can be done by machinery reducing labor cost as well as minimizing human errors and time consumption.
- Employment of skilled but unemployed youth and make farming an easy occupation. This ensures a good socioeconomic status of the youth.
- The use of fertilizer, pesticides, insecticides, herbicides, and water consumption can be reduced in very large percentage through micro spraying resulting in reduction of costs as well as reduce environmental contaminations.
- Productivity and crop quality will be increased with the precise and timely input given. Crops require accurate timing mainly at harvesting and other purpose such as application of PGRs which may be performed using an accurate dose and timing by application of robots.
- Robots can work anytime regardless of whether it is night or day. Continuous monitoring and real time data may be obtained by deploying robots, may it be day or night which ensures us to make well informed decisions.
- They are light weight and avoid soil compaction as compared to usage of tractors or other heavy machinery. Many purposes which are done by tractors and others such as harvesting, large scale spraying of fertilizers or pesticides are now performed using drones and robots.

Drawbacks

In spite of having a number of advantages, robotic farming faces limitations too, mainly the need for skilled and trained farmers. A few drawbacks and limitations we need to consider regarding robotic farming are as follows.

- It is costly to buy and to maintain. The initial cost of carrying out robotic farming system i.e., buying and maintenance of machinery like tractors and drones are expensive and can be a burden to carry for small farmers.
- Machinery is complicated. Robotic farming involves the use of technology like sensors, GIS, and AI. Farmers need to be trained to operate these systems, which is quite challenging. The machinery is also crop or task specific and there will be a need to purchase equipment for each different task.
- Requires skilled labor which can result to loss of jobs among uneducated/unskilled labor. This may cause an effect on employment and the socioeconomic status of the rural population. Plus, robots may be limited to their programming in times of weather aberrations or some other challenges, while farmers may adjust according to their decisions easily.
- It requires power, whereas in India we face a lot of problems regarding power shortage in farmlands. A high-speed internet connectivity is also required to carry out the operations and real time decision making which makes it very limited in farmlands in remote areas, where most of farms are in India.
- Pest and disease detection and deficiency detection cannot always be relied on the data of the robots and we need to monitor the plants as well.

Future of Agriculture with Robots

In the near future the world population is expected to rise to almost 10 billion, but the amount of cultivable land as well as the availability of labor for agricultural production will either remain

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the same or reduce as it is today. The farmers are already opting for practices which will be giving increment in yields as well as environment and health concerned and economical.

Precision farming will be very much revolutionized deploying the agri-bots gaining high yields as well as reduction in input costs by getting more information of crops and the inter and intra farm-system through plant environment analysis which will also help in further research and development in the agricultural sector. Post-harvest losses will be reduced in a great manner providing quality food on the table.

Table 1: Common agricultural robots that are used in agricultural purposes and their functions.

Sl. No.	Robot name	Functions
1	Agrobot SW601	Robotic strawberry harvesting
2	AgJunction AutoCart	Autonomous tractor for grain carting
3	Bear Flag Robotics	Autonomous tractor for vineyard tasks
4	Blue River See & Spray	Precision spraying for weed control
5	Dogtooth Technologies	Autonomous tomato harvesting
6	Ecorobotix Weed-It	Precision spraying for weed control
7	Fendt Xaver	Autonomous planting and weeding in rows
8	Naio Technologies Oz	Weeding, planting and harvesting for small farms
9	Octinion Rubion	Robotic strawberry harvesting
10	Ripe Robotics	Robotic apple picking and sorting
11	Robotriks Max 1	Autonomous weeding in various crops
12	Vitirover	Autonomous vineyard mowing and weed control

CONCLUSION

Precision agriculture can be performed with ease with the application of agricultural robots performing monitoring of farmlands continuously by using different sensing technology, which provides different crop parameters like nutrient availability, pest and disease incidence, water stress, harvesting and maturity indices etc. for better remedies of crops. With continuous increasing of population and decreasing of agricultural workers creating limitations to farming, agricultural robots have the potential ability to reduce the pressure of labour shortage and increment of productivity. Various technologies like vision and image processing, mechanics and electronics can be fit together in a single system named agricultural robot which can provide optimum solution for various agricultural operations.

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CHAPTER 13

BIOCHAR: ENHANCING CROP YIELD AND SOIL QUALITY

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ABSTRACT

The chemical compounds such as pesticides, fertilizers, heavy metals, acidic substances etc. are major concern that pollute the soil resulting in phytotoxicity and threats to soil biota. Recently, application of biochar has been suggested as an eco-friendly and multi-functional method to improve the soil properties, yield production, carbon sequestration, plant disease management, pollutants remediation etc. Biochar is a carbon-based material formed by the pyrolysis of biomass in absence of oxygen. Several studies proved biochar as a sustainable solution for mitigation of climate change, agricultural productivity and soil amendment. Addition of biochar in soil also aids in increasing the nitrogen and phosphorus mineralization by preventing the nutrient loss due to leaching. The application of biochar in the soil could be a sustainable approach for improving the soil fertility. This book chapter will discuss and highlights the role of biochar in soil quality and fertility and the significant effect of biochar in crop productivity and yields.

Keywords: biochar, carbon sequestration, pollutants remediation, carbonaceous, microflora

INTRODUCTION

Degradation of soil health due to rapid development of industry and high intensity of human activities has become a major threat to environment, human health and agricultural productivity. The long-term application of inorganic fertilizers may also proliferate the acidity of soil, affecting the soil microflora, which affects the soil fertility, thus led to decrease in crop production (Pietri *et al,* 2008). Amendment of biochar in soil could maintained the sustainability of soil organic matter and preserve the soil fertility. The word “biochar” is derived from the Greek word; ‘bios’ meaning life and ‘char’ short for charcoal. Basically, it means charcoal which can be used in certain applications. Biochar is as porous carbonaceous materials made by thermal decomposition (pyrolysis) of biomass (wood, leaves, manure and other waste materials) in the absence of oxygen. It has a great potential in increasing the soil fertility, plant growth, cation exchange capacity, plant disease management, bioremediation of contaminants and pesticides. It also has the ability to increase carbon sequestration, which helps in reducing greenhouse gas emissions and nitrogen leaching (Fig. 1). Amendment of biochar and compost in poor soil will lead to increase the fertility of soil and ultimately enhances the growth of plants. Presently, biochar has increasingly found to be the most suitable soil amendment process due to its larger specific surface area, porosity and surface hydrophobicity.

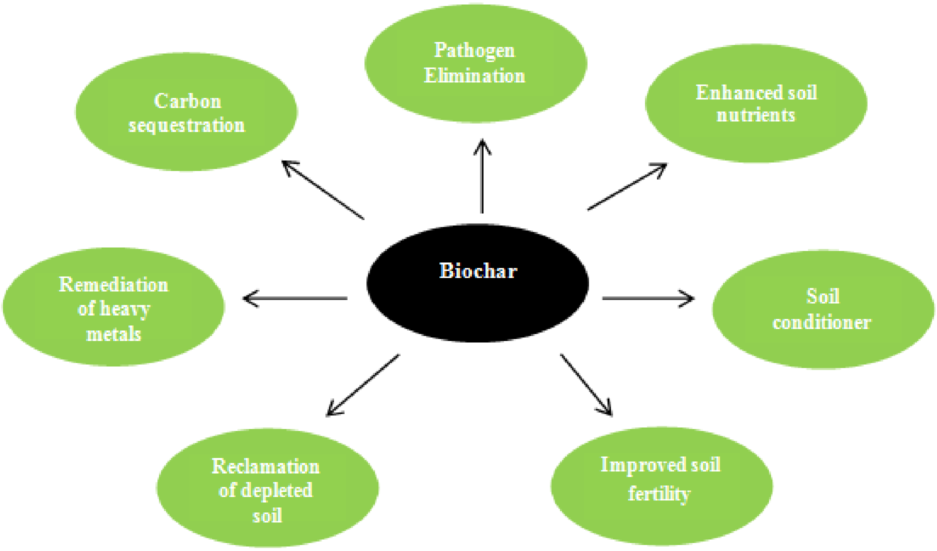

Figure 1: Benefits of Biochar

Preparation of Biochar

Biochar can be prepared from any biomass such as crop residues, livestock and poultry manures, kitchen waste, sludge, fruit skin etc. through thermo-chemical treatments including rapid pyrolysis, slow pyrolysis, torrefaction, carbonization viz., hydrothermal or flash and gasification methods

(Tan *et al*, 2017; Meyer *et al*, 2011). The properties of biochar varies with raw materials used,methods and process employed (Table 1).

Table 1: Properties of Biochar prepared by different methods and process.

Raw material	**Temperature deg. C**	**PH**	**Surface area (m^2 g^{-1})**	**Pore volume (Cm^3g^{-1})**	**Reference**
	400	10.2	49.2	0.042	
Herb residue	600	10.1	51.3	0.051	Lian *et al*, 2014
	300	7.3	5.6	-	
Soybean	700	11.3	420	0.2	Ahmed *et al*, 2014
Corn straw	600	10.0	61.0	0.036	Song *et al*, 2014
Rice husk	450-500	7.0	34.4	0.028	Van *et al*, 2015
Pine wood	600	-	209.6	0.003	Wang *et al*,2015
	400	-	28.1	0.0409	
Orange peel	700	-	501	0.390	Chen *et al*, 2011
	400	8.0	20.7	0.027	
Municipal solid waste	500	8.5	29.1	0.039	Jin *et al*, 2014
	700	9.0	29.8	0.038	
Rice straw	700	-	369.26	0.23	Chen *et al*, 2018
Swine manure	700	-	227.56	0.14	Chen *et al*, 2018
Corn straw	500	-	32.85	0.0148	Tan *et al*, 2017
Wheat straw	600	-	38.1	0.051	Sun *et al*, 2016
Rice straw	600	-	27.4	0.040	Sun *et al*, 2016
Raw sugar beet	600	9.45	2.6	-	Yao *et al*, 2011

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tailing					
Tea waste	700	-	342.22	0.0219	Rajapaksha *et al*, 2014
	700	-	421.31	0.0576	

Crop yield

The addition of biochar in soil can improve the plant growth and enhances crop yield, thereby increasing food production and sustainability in areas with limited resources. Several studies haveshown the significant effect of biochar application in soil. Amendment of biochar in soil increase the nutrient content, which results in higher crop productivity (Helal *et al*, 2019). Application of biochar in sandy soil and heavy acidic soil helps in improving the capability of nutrient uptake, leads to improve plant growth, root elongation and yield production of red chilli and maize (Hanpattanakit *et al,* 2021; Uzoma *et al,* 2011). It was also observed that the use of combination of fertilizer, compost and biochar could increase the vegetative growth, biomass and total phenolicresponse of *Labiniapumela* var. alata seedlings as compared with the application of sole NPK fertilizers (Vijayanathan *et al*, 2019). Treatment of soil with mixture of biochar and plant growth- promoting microorganisms is considered as the best combination for the growth and production ofFrench beans (Saxena *et al,* 2013). The application of biochar in the soil also increase the retention of nutrients in soil. In recent years, addition of biochar in soil shows effectivity in the crop productivity. The several positive effect of biochar application on crop yield is summarized in table 2.

Table 2. Effect of biochar application on crop yield.

S.No.	**Biomass & process**	**Application rate**	**Crop grown**	**Effect on yield**	**Reference**
1	Hardwood 500 °C	10, 20, and 30 t/ ha	Cocoyam	Increase yield 8.1, 7.8, and 5.5 %,respectively	Adekiya *et al*, 2020
2	Willow wood pyrolysis, 600°C	10-25 t/ ha -1 crop cycle	Papaya, Banana	Reduced Banana yield by 18-24% and neutral for papaya	Bass *et al*, 2016
3	Rice straw BC (RBC) 550 °C	4.5 t /ha for two crop season	Rice	Grain yield increases by 8.5–10.7%	Liu *et al*, 2016
4	Acacia biochar 400–500 °C	25- 50 t/ ha	Maize	Increased yields in 1st year by 20% and after 2nd year by 12.5%.	Arif *et al*, 2016
5	Pine needle And Lantana Biochar slow pyrolysis	2 and 5 t / ha	Wheat,rice	Increased wheat yield by 6.2–24.2%. Neutral rice yield.	Bhattacharjya *et al*, 2016
6	Orchard pruning PY, 500 °C.	22 - 44 t / ha for 4 years.	Grape	Increases productivity by up to 66%	Genesio *et al*, 2015
7	Hardwood biocharat pyrolysis temp 500 °C	30 and 60 t/ha 2 crop cycle	Durum wheat	Increased up to 30% biomass productionand yield	Vaccari *et al*, 2011
9	Mixed hardwood	10 t/ha for 1 crop cycle	Durum wheat and	Increase yield by 10%	Baronti *et al*, 2010

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	pyrolyzed 500 °C		maize	and maize by 6 %	
10	*Eupatorium adenophorum*pyrolysed at 680-700°C	750 kg/ha for 17 weeks	Pumpkin	Increase fruit yield(85-300)%	Schmidt *et al*, 2015
11	Rice Straw and Corn Stalk	1, 2, and 4 t/ha	Corn, peanut, and sweetpotato	Increase yield by 5-15 % when biochar is applied 1 or 2 t/ha. 20% by applying 4 t/ha	Yang *et al*,2015
12	Zambia, Maize cob, and mixed softwood pyrolysis at , 400 °C	4 t/ ha 2 crop cycles	Maize	Biomass yield by 233-322%	Cornelissen *et al*, 2013
13	Cow Manure 6000 °C	0, 10, 15, and 20 ton/ha	Maize	Increased Maize crop yield	Azeem *et al*, 2019
14	ConocarpusPyrolysed at 400 °C	Apply 4-8% (w/w) for 11 weeks	Tomato	Increase tomato yield by 14-43%	Usman *et al*, 2016
15	Rice Husks450 °C	0, 10, 25, and 50 t/ha in	Rice and wheat	Increased rice and wheat yield by 12% and 17%, respectively	Wang *et al*,2012
16	Cow manure pyrolysis at 500 °C	0, 10, 15, and 20t/ha 12 weeks	Maize	Increased maize grain yield by 150 and 98% by applying 15 and 20 t/ha rate biochar, respectively.	Uzoma *et al*, 2011
17	Natural grass-cutting pyrolysis at400 °C	10 t /ha 8 weeks	Red clover, redfescue, and plantain	Increase biomass (8-30)% in single crop & 28-50% in mixed cropping	Oram *et al*,2014

Role of Biochar in Soil Quality

Enchances soil nutrients

Since biochar itself is prepared from wood waste materials, it contains high levels of soluble potassium (K) and variable concentrations of phosphorus (P) and calcium (Ca). It also increase thesoil net nitrogen (N) mineralization rate and ammonium ($NH4^+$) concentration (Gundale *et al,* 2016). Hence, biochar enhances the soil nutrient content and bioavailability for plants.

Remediation of soil

Biochar produced from woodchips and cotton straw through pyrolysis can significantly decrease the uptake of pesticides by the plants grown in contaminated soils (Yu *et al*, 2009). Moreover, it can also act as an efficient sorbent for removing organic and inorganic pollutants from soil.

Promotes soil health

Biochar positively promotes the soil health by retaining soluble nutrients in soil, thus increasing crop yield. Nitrogen and phosphorus, the key nutrients for plant growth, can be increased by amending the biochar in soil (Zeng *et al*, 2013; Rawat *et al*, 2019). Thus, biochar helps in improving the plant and soil nutrient management.

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Increases activity of soil biota

Several studies have shown the potential of biochar in stimulating the soil microflora, which helpsin increasing the soil fertility. The release of various organic molecules from biochar may lead to improve the abundance and activity of soil microbiota. Biochar increases the soil texture, cation exchange capacity, moisture-holding capacity, soil pH and microbial flora (Mensah *et al*, 2018). In addition, it provides a suitable habitat for bacteria, actinomycetes and fungi due to its larger porosity and surface area (Thies *et al*, 2009).

Modification of Biochar

Biochar are modified into physical, chemical and biological treatments. Nanobiochar has the greatabsorbing capacity due to its larger surface area and nano-porosity.

Physical Modification

Physical biochar modification are regarded as environmental friendly and cost effective as compared with chemical modification. It also helps in improving the physiochemical properties ofbiochar such as porosity, permeability and controlled treatments (Islam *et al*., 2021). Fan *et al.* (2016) reported that biochar production through ball milling is considered to be the most common and suitable method. In ball milling, the pristine biochars are grinded into powder or nanoparticles which significantly increase the surface area and absorption capacity (Lyu *et al*., 2018).

Chemical Modification

Biochars can be modified through chemical reaction to make them more effective at performing specific applications by improving their physiochemical characteristics (Mihoub *et al.*, 2022). Chemical modification of biochar can be done by chemical oxidation, CO_2 activation, acidic/alkali treatment, steam/impregnation and nanocomposite synthesis. Sajjadi et.al (2019) observed that the biochar modified with oxidizing agents i.e. $KMnO_4$ and Fe(III) can increase the pore size and specific surface.

Biological Modification

Biological modification of biochar can be obtained by pre-heating the feedstock with anaerobic digestion and developed a film on internal and external surfaces of biochars (Li *et al.*, 2021). Muhummad *et al* (2021) also reported that the modified wheat straw biochar in soil with soil-indigenous microorganisms have higher biosorption capacity (14.42 mg g^{-1}) as compared to pristine biochar (6.28 mg g^{-1}) and wheat straw (4.20 mg g^{-1}) indicating that biological modified wheat straw has the tendency of reducing the Cd leaching more efficiently and also achieved superior stabilizing performance. Table 3 represents the positive effects of biochar application in improving the soil health.

Table 3: Effectiveness of biochar in improving the soil health

Modified biochar	Biochar dose	Soil properties	Reference
Poultry manure	5% (w/w)	Reduction of toxic Cr (VI) in soil	Mandal *et al.,* 2017
Sheep manure	5% (w/w)	Reduction of toxic Cr (VI) in soil	Mandal *et al.,* 2017
S-modified rice husk	5% (w/w)	Leachate total Hg concentrations decreased while increased Leachate total Hg removal	O'Connor *et* 2018
Fe-Mn	2%(w/w)	Decreased soil pH. Moreover increasedsoil enzymes (CAT, POD, UE, ALP/AKP)and abundance of Firmicutes and Proteobacteria.	Lin *et al.,* 2019
Fe-Mn	2%(w/w)	Decreased pH, Cadmium, bioavailable of antimony while increases EC, available P,	Wang *et al.,* 2019

		available K, total N and organic matters. UE and CAT were not affected.	
MgO	4.5 Mg Ha^{-1}	Increased available P	Wu *et al.,* 2019
S-Fe	1% (w/w)	Decreased Cd concentrations while increased soil organic matter content and microbial community	Wu *et al.*, 2019
Carrot pulp	8% (w/w)	Increased oxidizable fraction of Cu and reducible fraction of Cu while decreased acid soluble fraction of Cu. Decreasedacid soluble fraction of Zn while increasedreducible fraction of Zn, residual fraction of Zn and oxidizable fraction. Increased soil pH, soil organic carbon,CEC and EC.	Gholami *et al.,* 2021
Composite modified biochar	1% (w/w)	Soil soluble Na^+ and Na^+ adsorption ratio decreased while soil soluble K^+ , Mg^+ andCa^+ increased	Duan *et al.*, 2021
Particle	1%(w/w)	Soil soluble Na^+ and Na^+ adsorption ratio decreased while soil soluble K^+ , Mg^+ andCa^+ increased	Duan *et al.*, 2021
Lolium perenne	0.6% (w/w)	EC and soil pH increased and $CaCl_2$ extractable Cd decreased	Zhang *et al.*, 2021
Brassica napus BC-UV	0.6% (w/w)	EC and soil pH increased and $CaCl_2$ extractable Cd decreased	Zhang *et al.*, 2021
Rhamnolipid	2% (w/w)	Reduced emission of N_2O and increased bacterial community, dehydrogenaseactivity, fungal diversity indices, emissionof CO_2 and CH_4	Zhen *et al.*, 2021

CONCLUSION AND FUTURE PERSPECTIVES

The application of biochar are known to improve the physical and chemical properties of agricultural and horticultural soils thereby providing a good solution to cropland deterioration which are mainly caused by acidity, salinity and lack of nutrients in the soil. Biochar can be made from a variety of plant-based materials in absence of oxygen and has the potential to substitute for fertilizer and soil amendment. Overall, biochar application in the soil could be a sustainable approach for improving the soil enzyme activity thereby enhancing soil fertility. Hence, biochar can be recommended for sustainable soil health improvement leading to enhancement of crop productivity and yields.

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CHAPTER 14

EMPOWERING WOMEN AND YOUTH IN AGRICULTURE THROUGH EXTENSION

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ABSTRACT
Youth are the backbone of a nation. The importance of youth in nation-building cannot be overstated. To take advantage of the potential of youth and get the full benefits of the demographic dividend, the Government of India has announced a slew of initiatives. These initiatives are focused on the concepts of social inclusion, gender equality, and rural development that is sustainable. To inspire youths to pursue agricultural occupations, we need a multifaceted approach which addresses the problems they confront while also emphasizing the benefits available. Women bear almost all of the responsibility for meeting the basic needs of the family, but they are systematically ignored in terms of utilizing the resources, information, and freedom of action needed to fulfil this responsibility. Several studies have revealed that when women are involved, supported, and empowered in society, the entire society flourishes and communities become more resilient. Women account for approximately forty-three percent of the worldwide agricultural labour force. Women possess a promising future in agriculture because it is an evergreen vocation with a lot of potential. Science and technology in agriculture have a significant impact and will empower women in agriculture. There are many schemes or programmes which uplift women in many ways such as Mahila Kisan Shakshtikaran Pariyojana etc.

Empowerment
Empowerment is the process of enhancing an individual's or a community's spiritual, political, social, racial, educational, gender, or economic strength. It frequently includes the empowered gaining faith in their own abilities.

Youth and agriculture
The more emboldened the youth are, the more advanced the country will be. Countries that channel youth potential in the correct way are more advanced.

Youth are very significant resources for any nation, particularly for maintaining agricultural output, which is a vital area for development. The youthful population is an important stakeholder in the development process, especially given their remarkable assets of resiliency, creative thinking, and perseverance. Youth participation in agriculture is low (Mangal, 2009), despite the fact that this age group is the most productive in any society since it contains people in the prime of their lives, both physically and cognitively. Agriculture, as one of the fundamental pillars of any civilization, can only function as such if youth engagement is increased. Improving youth production in agriculture, for example, and investigating effective livelihood diversification are critical.

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Several recommendations for boosting youth involvement in agriculture are as follows:

- ❖ Enhancing accessibility to training and capacity development.
- ❖ Strengthening training at the primary and secondary school levels through the use of innovative techniques.
- ❖ Integrating school agricultural operations into the general curriculum.
- ❖ More options for youngster's on-farm training.
- ❖ Increasing accessibility to resources including land, capital, technology, and knowledge.
- ❖ Making market opportunities more accessible.
- ❖ By revising rules and programs, we may provide focused marketing possibilities forthe primary and value-added agricultural products generated by young entrepreneurs through specific partnerships with schools, hotels, and so on.
- ❖ By changing policies and programs, we can provide motivation and improve the image of agriculture.
- ❖ Agriculture graduates need to get involved in advocating for agricultural policy, programs, and issues. Promoting networking among youngsters through offering incentives to stimulate youth participation and group activities.
- ❖ To improve agriculture's sustainability, states, local governments, and the private sector should all be involved in its development.

Strategies for Enhancing Youth Participation in Agriculture

To inspire youths to pursue agricultural occupations, we need a multifaceted approach which addresses the problems they confront while also emphasizing the benefits available.

- **Raising awareness:** Conduct awareness campaigns and career exhibitions to highlight the variety of agricultural career possibilities as well as the sector's potential for growth and innovation.
- **Providing resources and support:** Implementing programs and policies which provide young agripreneurs access to land, finance, and other resources, for example theAgri-Clinics and Agri-Business Centres Scheme (ACABC) Pradhan Mantri Kisan Samman Nidhi (PM-KISAN).
- **Investing in education:** Redesigning agricultural training and agricultural education courses to embrace new technology, techniques and agribusiness management skills that appeal to the interests of youth.
- **Leveraging technology:** Advocating for the implementation of new agricultural technologies and digital tools in order to make the industry more interesting and efficient to young people**.**

Government initiatives to attract youth towards Agriculture: (Krishi Jagat portal)

The Indian government has launched a number of efforts to encourage young people to work in agriculture. These projects seek to overcome youth interest in farming by providing them with options for decent livelihoods. An example is to reorient agriculture from a crop-based strategy to a farming systems mode, stressing a more efficient, demand-driven, and lucrative "plough to plate" approach. Development of skill is also seen as a crucial approach for engaging farmers and youth in successful livelihood projects, hence raising rural living standards. Furthermore, the government has concentrated on supporting agricultural

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entrepreneurship, seeing it as a stronger proposition for attracting and retaining farmers and youngsters in the sector.

The Department of Agriculture and Farmers Welfare (DA&FW), Ministry of Agriculture and Farmers Welfare, Government of India, executes the followingschemes/programs to encourage youth to pursue careers in agriculture and other related industries, as well as to foster entrepreneurship:

1. Establishment of Agri-Clinics and Agri-Business Centres (AC&ABC)
2. Skill training programmes (minimum 200 hours' duration) for Rural Youth andFarmers including women farmers
3. Skill Training of Rural Youth (STRY)
4. Sub Mission on Agricultural Mechanization (SMAM)
5. Remunerative Approaches for Agriculture and Allied Sectors Rejuvenation (RKVY-RAFTAAR) to promote Agri-Startups
6. Certified Farm Advisor/Certified Livestock Advisor programme
7. Post Graduate Diploma in Management (Agri Business Management) [PGDM (ABM)The Department of Agricultural Research and Education (DARE) runs the following schemes/programs through the Indian Council of Agricultural Research (ICAR) to attract youth to agriculture and other related industries and to foster entrepreneurship:

1. Technology Assessment and Demonstration for its Application and CapacityDevelopment through Krishi Vigyan Kendras (KVKs).
2. **Attracting and Retaining Youth in Agriculture (ARYA)**

"ARYA," an ICAR pilot project, is investigating several approaches to recruit and retain youth in agriculture by identifying their reasons for dissatisfaction, such as lack of participation in policy making, access to land and credit, and, most importantly, parental and societal support. The Role of Government Initiatives in Youth Agriculture Each KVK would train 200 to 300 youngsters in agricultural auxiliary and connected sectors such as poultry raising, dairying, and fishing.

Women Empowerment

It refers to the provision of authority to women who would not otherwise have it. This includes giving women effective decision-making power/authority and the ability to influence other people's decisions, as well as economic, social, and civil freedom.

In the context of women's development, empowerment is a process of defining, challenging, and overcoming limitations in a woman's life in order to strengthen her ability to affect her life, surroundings, and community. It is a multifaceted active process that should enablewomen to embrace their full individuality and authority in all aspects of life.

Introduction

Women account for approximately forty-three percent of the worldwide agricultural labor force (FAO, 2011). In India, women account for forty-eight percent of the population, with seventy percent of them living in rural communities. In a changing agricultural situation, where the role of women in agriculture is becoming increasingly seen as crucial and required (Farmar-Bowers, 2010) in ensuring global food security, equipping them with the requisite knowledge and skills has become critical. Rural women's empowerment entails preparing them to be economically independent and self-sufficient, as well as encouraging them to participate in the development activities of the society in which they reside.

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New programs must be developed with enough resources to mobilize women, create groups, and improve capacity and capability in the technical, organizational, and commercial (business microenterprises) sectors, as well as support systems (loans, inputs, and markets). These should be developed in collaboration with women and other organizations (public, private, and non-profit) that can potentially complement and enrich the State Department of Agriculture's efforts. Approximately 36% of female students are enrolled in various programmes at State Agricultural Universities. They must be properly trained, have their capacity increased, and be encouraged to work as facilitators in order to empower women in agriculture.

Agriculture in many developing countries is underperforming for a variety of reasons. Among these include the fact that women lack the resources and opportunity necessary to make the most use of their time. Women are farmers, workers, and entrepreneurs, but virtually everywhere women confront more barriers to productive resources, markets and amenities than men. This "gender gap" limits their productivity and contributions to agriculture as well as the fulfilment of broader social and economic goals. Closing the agricultural gender gap will benefit society significantly by boosting agricultural output, reducing poverty and hunger, and fostering economic prosperity.

Women in Agriculture

Women contribute significantly to agriculture and rural economic development in all emerging countries. Their functions vary greatly within and within areas, and they are fast changing in numerous regions of the world where economic and social factors are reshaping the agriculture sector. Contract farming and contemporary supply networks for high-value agricultural goods, for example, present women with different opportunities and problems than men. These distinctions stem from women's various roles and duties, as well as the limits they confront.

Women engage in agriculture as self-employed farmers, as unpaid employees on family farms, and as paid or unpaid laborers on other farms and agriculture-related businesses. They are interested in both subsistence and commercial agriculture and livestock farming. They grow food and cash crops and manage diversified agricultural operations that frequently include crops, livestock, and fish farming. All of these women are classified as agricultural laborers (FAO, 2010). India dominates the Southern Asian average, with women accounting for somewhat more than 30% of the agricultural labor force.

Focus areas for empowering women in agriculture include:

1. Education

Women possess a promising future in agriculture because it is an evergreen vocation with a lot of potential. Science and technology in agriculture have a significant impact and will empower women in agriculture. Education will be critical in ensuring that science and technology are used effectively. As a result, there is an unavoidable need to focus on women's education in order to empower them. The real issue is that the young ladies with promising farming careers were illiterate. These illiterate young women are forced to work in agriculture and other non-agricultural industries like as masonry work, road construction, and so on. As a result, there is an urgent need to launch rigorous functional literacy programs to assist target groups of women farmers to ensure they can read, write, figure out, and comprehend agricultural technological concepts.

2. Land rights

Women in most Indian families do not possess property in their own names and do not receive a share of the assets of their parents. Women continue to have limited access to land and property as a result of inadequate enforcement of laws protecting them. The Hindu

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Succession Amendment Act 2005, a recent Central Government legislation, has also advanced women's property rights closer to equality. It formally equalizes Hindu women's rights to inherit in agricultural land with the same as men.

3. Capacity building

It is another vital area that should be prioritized by establishing training programs, exposure tours, vocational trainings, group talks, and incorporating them in national and international trade fairs, among other things, to help them to acquire technical abilities and create self-confidence. Special training programs for rural and disadvantaged women should also be developed in light of their locally available and demand-oriented industries.

4. Self-help groups

In India, this strategy has shown remarkable results. It must also be sustained and developed by encouraging women to participate. Self-help groups have emerged as an essential method for women's empowerment and poverty alleviation. SHGs are founded on the concept of dialogic small groups that will act to create collective consciousness.

5. Access to ICT tools

Women have an excellent future in agriculture because it is an evergreen vocation with plenty of opportunities. Science and technology in agriculture have a significant impact and will empower women in agriculture. ICT (Information and Communication Technology) is playing a significant role in the development of communication and human relation skills within women, which leads to improved efficiency in their activities.

Approaches for empowering women in agriculture

1. Providing agricultural education and training, as well as financial management and entrepreneurship.
2. Gender equity and the prevention of violence based on gender in agricultural settings.
3. Providing women with safe ownership and constitutional safeguards for their landrights.
4. Providing financial services that are targeted to the requirements of women andsupporting the adoption of relevant technologies.
5. Increasing market access and market information.

Need for promotion of women farmer:

In India, the agriculture support system reinforces women's exclusion from their rights as agricultural laborers and farmers.

1. Farm women are the most productive workers in the economies of the majority of developing countries, including India. More than 80% of rural women earn their living through agricultural pursuits.
2. Due to widowhood, desertion, or male emigration, around 20% of agricultural livelihoods are headed by women.
3. Most households led by women lack access to extension services, farmer support organizations, and production resources like as seed, water, financing, and subsidies. Women are paid less than males as agricultural laborers.

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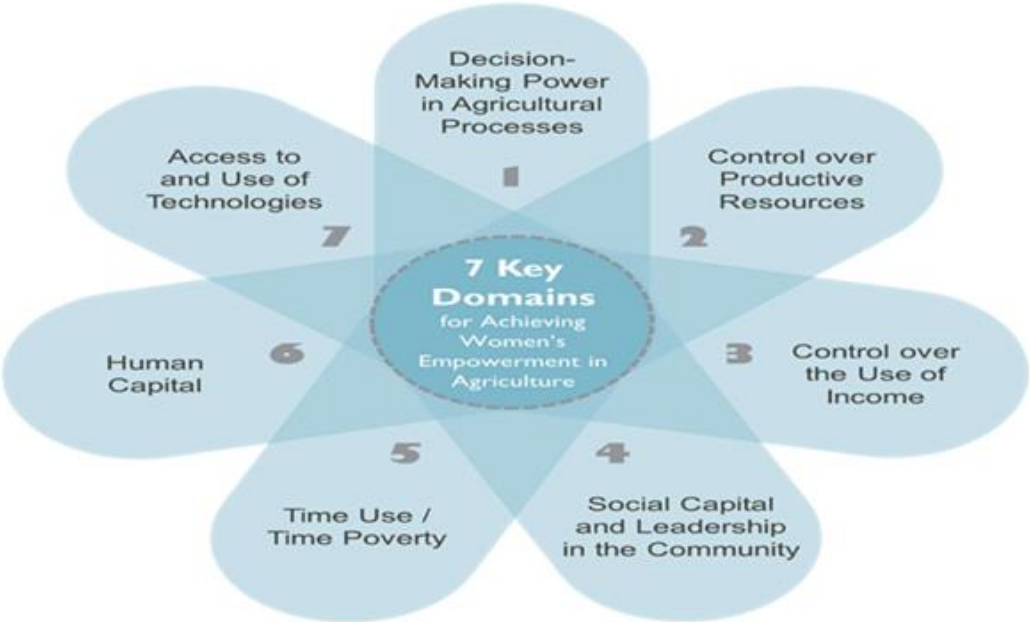

Fig 1: Key Domains for achieving Women's Empowerment in Agriculture Empowering Women Farmers: Skill and Capacity Building

Several inter-ministerial efforts launched by the Government of India have assisted women farmers in gaining access to resources that will improve their livelihood, social and economic benefits. The guidelines of the Department of Agriculture, Cooperation, and Farmers Welfare (DAC&FW)'s different beneficiary-oriented schemes require states and other implementing agencies to spend at least 30% of their budgets on women farmers.

- The Ministry of Rural Development launched the Mahila Kisan Sashaktikaran Pariyojana (MKSP) project to provide skill development and capacity building programs for rural women. This scheme was developed as a component of the DAY-NRLM (Deendayal Antyodaya Yojana — National Rural Livelihoods Mission) and is being implemented across India through State Rural Livelihoods Missions (SRLM). The main objective of this scheme is to strengthen women by making deliberate investments to increase their involvement and productivity, as well as to provide rural women with sustainable livelihoods. Trainings on the use of current agriculture, associated techniques, and agro-ecological best practices are provided to women farmers through community resource persons and extension organizations under the DAY-NRLM initiative. Specific women farmer training programs are organized on topics such as household food security through kitchen gardening and nutrition gardening, the development and design of low/minimum cost diets, design and development of high nutrient efficiency diets, processing and cooking, gender mainstreaming through SHGs, storage loss prevention techniques, value addition, women empowerment, location specific labor reduction technologies, rural crafts, and women and child care.
- The Pradhan Mantri Kaushal Vikas Yojana (PMKVY), which is run by the Ministry of Skill Development and Entrepreneurship, offers many short-term skill training programs, such as Short-Term Training (STT) and Recognition of Prior Learning (RPL), to help rural youth and women make a living. The Deen Dayal Upadhyaya Grameen Kaushalya Yojana (DDU-GKY) is a placement-linked skill development initiative for rural youngsters seeking paid employment.

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- Farmers Producer Organizations (FPOs) and women self-help groups (SHGs) also played important roles in the dissemination of these programs among rural women. The Mahila Shakti Kendra (MSK) developed by the Ministry of Women and Child Development has strengthened rural women by community participation and increasing recognition on girl education, maternal care and health, and so on.
- ICAR Central Institute for Women in Agriculture, Bhuvneshwar, is leading parallel research projects on the introduction of new interventions in organizing women's involvement in the farming sector, technology testing and refinement, gender sensitive extension approaches, and reduction, among other things, to increase women's participationin agriculture.
- The Department of Biotechnology (DBT) initiated the Biotech-Krishi Innovation Science Application Network (Biotech-KISAN) Program to provide scientific solutions to farmers in the north east region by linking available innovative agriculture technologies to the farm with small and marginal farmers, particularly women farmers in the region (Ministry ofScience and Technology, 2021).

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CHAPTER 15

CLASSIFICATION OF CROPS

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ABSTRACT

The classification of crops is a fundamental aspect of agriculture, essential for understanding, managing, and optimizing agricultural practices. This abstract provides an overview of the methods and significance of crop classification. We explore the various approaches to categorizing crops, including taxonomic, Phenological, and economic classifications, and the role of technological advancements, such as remote sensing and machine learning, in crop classification. Furthermore, we discuss the importance of crop classification in sustainable agriculture, food security, and biodiversity conservation. This abstract highlights the interdisciplinary nature of crop classification and its central role in shaping the future of agriculture

Key-words:

INTRODUCTION

Agriculture is the backbone of India's economy. The history of agriculture dates back to several centuries. Since time immemorial, crops and plants were grown and domesticated by the people, in several parts of the world. Plants which are fully useful for human and animal consumption have been segregated and cultivated in farms and fields. In Geographic studies, the area of cultivation of crops and plants, factors of their growth, their distribution and yield are analyzed with reference to space and time. Crop classification is a fundamental aspect of agriculture, as it provides a systematic way to categorize and understand the diverse array of plants cultivated for various purposes. This chapter delves into the principles, methods, and significance of crop classification. It explores how crops are categorized based on various criteria, such as their use, growth characteristics, and botanical features. Understanding crop classification is essential for effective agricultural management, crop selection, and sustainable farming practices.

Types of Crop Classification

Globally, major crop classifications are defined by the Food and Agriculture Organization (FAO) of the United Nations. For a better understanding of agricultural crops and their distribution in India and the globe, knowledge of the classification of plants and crops is needed. Crop classification can be approached from different angles. This section discusses various classification criteria:

Descriptive Classification of Crops The descriptive classification of crops is based on five criterions:

A. **Mode of Reproduction:** The method adopted according to the Mode of Reproduction, has classified the crops into two major divisions as sexual and asexual reproducing plants. The Sexual category of plants are developed from a seed or spore after undergoing union of male and female gametes. The typical examples include palms and ferns. The Asexual category of plants undergo reproduction by any vegetative means without the union of the sexual gametes or by apomixis.

B. Mode of Pollination: This criteria divides plants into three categories as:

i. **Naturally self-pollinated crops:** In the Naturally self-pollinated plants, both pollen and embryo sac are produced in the same floral structure or in different flowers but within the same plant. Typical Examples include: rice, most pulses, okra, tobacco, tomato.

ii. **Naturally cross-pollinated crops:** In the Naturally cross-pollinated crops, the pollen transfer is done from one flower to the stigma of another flower in a separate plant. Typical examples include, corn and many grasses, avocado, grape, mango, many plants with unisexual or imperfect flowers.

iii. **Both self- and cross-pollinated crops:** In both self- and cross-pollinated crops, plants are largely self-pollinated but varying amounts of cross-pollination also occur. Examples include, cotton and sorghum.

C. Life Span: According to Life Span, crops are classified into annuals, biennial and perennial categories.

i. **Annual:** The Annuals are plants which live within a short period of time, for a few weeks or months, perpetuated by seed, and which die soon after producing seeds. Examples include: rice, corn, cowpea, etc.

ii. **Biennials:** The Biennials are plants which requires two growing seasons to complete its life cycle, the first for vegetative growth and accumulation of food reserves, and the second for the production of reproductive parts. Examples include: onion, cabbage, carrot, celery, and raddish.

iii. **Perennials:** The Perennials include, a plant that lives indefinitely, including all trees and shrubs and many herbaceous plants with underground stems (e.g. corm, rhizome, tuber) like banana and clump-forming grasses. The Perennial plants continue growing and produce seeds year after year, either from a single plant or, in herbaceous plants, from succeeding regrowth.

D. Growth Habit: Based on Growth Habit crops classified into Herbs, Vines, Lianas, Shrubs and Trees.

E. Leaf Retention: According to Leaf Retention, plants are classified into Evergreen plants and deciduous plants.

i. **Evergreen plants:** The Evergreen plants are those that maintain their leaves throughout the year. Abscised leaves are continually replaced by new flushes. Examples include pines, banana, papaya, palms and most tropical plants.

ii. **Deciduous plants:** The Deciduous plants are those which naturally shed off or lose leaves annually for extended periods. Natural leaf shedding is pronounced in deciduous trees of temperate regions.

Classification of Crops based on the Ecological Adaptation or Habitat

Geography and ecology are two inter-related subjects. Most of the ecosystems are studied under geographic contexts, The plants are also classified according to their ecological adaptation and habitat. The major classes of plants are:

i. **Aquatic / hydrophytic plants:** The Aquatic/ hydrophytic plants are adapted to growing in water or waterlogged soil. They grow entirely in submerged, partly submerged or floating, or conditions. Examples: lotus and water lily.

ii. **Epiphyte or epiphytic plants:** The Epiphyte or epiphytic plants grow above ground on another plant but is not parasitic, usually deriving only physical support from the host and

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obtaining nourishment from the air and other sources. The most common epiphytes belong to the pineapple, orchid, and fern families.

iii. **Halophyte or halophytic plants:** The Halophytes grow in habitats excessively rich in salts or under saline conditions. Mangrove vegetation are good examples. Coconut, cashew and tamarind have varying levels of tolerance to saline conditions.

iv. **Lithophyte or lithophytic plants:** The Lithophytes are adapted to grow on rocks or in rocky terrain with little humus, absorbing nutrients from the atmosphere, rain, and decaying matter which accumulate on the rocks.

v. **Mesophyte or mesophitic plants:** The Mesophytes are terrestrial plants which are adapted to moderate conditions for growth, i.e. not too dry and not too wet (e.g. corn and most commercially-grown crops).

vi. **F) Parasite or parasitic plants:** The Parasite or parasitic plants grow on another plant from which it takes part or all nourishment. (e.g. cuscuta, loranthus, orobanche, striga etc.)

vii. **Saprophyte or saprophytic plants:** The Saprophyte or saprophytic crops grow on decaying organic matter and has no green tissue. This classification applies to the mushrooms, which are fungi.

viii. **Sciophyte or sciophytic plants:** The Sciophytes grow in low light intensity or shade, e.g. most ferns and mosses, black pepper, coffee, hot pepper, gingers, and many orchids can tolerate or require shade.

ix. **Terrestrial or land plants:** The Terrestrial or land plants grow on land. Most agricultural crops are terrestrial plants. They are further subclassified into various groups such as halophytes, mesophytes, etc.

x. **Xerophyte/ xerophytic plants:** The Xerophytes are adapted to conditions with little or no water. Examples: cacti and many succulents.

Agricultural Classification

A crop is any useful plant, or a plant which is grown for any purpose. It is utilized by people directly or indirectly, raw or processed. These plants are intentionally grown or managed for various uses.

On the basis of tradition, extent of cultivation and intensity of culture, agricultural crops are classified into two main divisions: agronomic and horticultural.

Based on Use/Agronomic classification: The Agronomic crops are also called as “field crops”. They are mostly annual herbaceous plants that are grown under extensive or large-scale culture. The agronomic classification of plants/crops based on their primary uses include the following classes:

i. **Food Crops:** The Food Crops are plants grown primarily for the harvesting of any part which is used by people as food or processed into food product.

ii. **Cash crops:** The Non-food Crops are mainly cash crops. These are plants grown for the production of non-food products such as fiber, fodder, alcohol and tobacco.

iii. **Staple crops:** The Staple Crops are food crops. These are regularly consumed in a traditional diet and from which people obtain a major proportion of their energy and nutrient requirements. Examples of other staple crops: wheat and millet.

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iv. **Cereal or Grain crops:** The Cereal or Grain Crops are mainly annual, herbaceous plants belonging to the grass family which are grown for their seeds or grains. Examples: corn, millet, rice, sorghum, wheat.

v. **Legume or Seed crops or Pulses:** The Legume Seed Crops or Pulses are leguminous plants which produce edible, protein-rich seeds. Examples: cowpea, peanut and peas.

vi. **Root and Tuber Crops or Tuberous Crops:** The Root and Tubers crops are plants with modified, swollen root or underground stem. These organs are rich sources of carbohydrate and are commonly used as staple, livestock feed, or as raw materials for industrial purposes, such as starch and alcohol production, or processed into various food products.

vii. **Oilseed Crops:** The Oil Seed Crops are plants grown for their seeds which are rich source of edible and industrial oil. Example: sunflower.

viii. **Sugar and Sweetener Crops:** The Sugar and sweetener Crops are plants grown primarily for the production of sugar or other sweet tasting products. Various forms of sugar are derived from various parts of certain plants such as from stems, bulb and other underground organs, leaves, flowers, fruits, seeds, sap and resin. These are called as sugar crops.

ix. **Beverage Crops:** The Beverage Crops are plants which are sources of various drinks including fruit juices. Examples: coffee and tea.

x. **Rubber Crops:** The Rubber Crops are another major type of plants that are grown for the production of latex which is processed into the industrial product called rubber.

xi. **Latex and Gum Crops:** The Latex and Gum Crops are very typical plants. These plants are grown for the collection of latex which is processed into chewing gum, inelastic rubber and other industrial products such as surgical tapes and dental supplies, insulation, splints, pipes, golf balls, waterproofing, adhesives, etc.

xii. **Dye and Tannin Crops:** The Dye and Tannin Crops are special kinds of plants. These plants are grown as sources of tannin and coloring substances. Tannin is an aromatic, phenolic substance which is obtained from barks and other plant organs and variously used in tanning, medicines, dyeing, ink manufacture, etc.

xiii. **Fiber Crops:** Fiber Crops are plants grown as sources of fiber used in making textiles, ropes, twine and similar materials. The fiber is extracted from the bark, leaves, or other organs including the husk of coconut.

xiv. **Pasture and Forage crops:** The Pasture and Forage Crops are very essential varieties of plants. These plants are grown or managed as vegetable feed for grazing animals. Soilage Crops are the grasses grown, cut and directly fed to animals. Silage Crops are the grasses grown, cut, fermented and preserved before being fed to animals. The Biofuel Crops are special type of crops.

xv. **Biofuel Crops:** These plants are grown for the production of fuel that is used as additive or replacement for petroleum products. Examples: sugarcane, corn, coconut, castor bean and Jatropha.

Horticultural Crops/ Plants: Horticultural crops have been referred to as “garden crops”. Horticultural crops are annual and perennial plants which are grown under an intensive system of agriculture.

The following are the major kind of horticultural crops:

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Olericultural or Vegetable Crops

Vegetable Crops are (except mushroom) grown for their succulent and edible parts such as the roots, stems, leaves, young tops, fruits or seeds for use in culinary preparations either fresh or preserved in the fresh state. Vegetables are classified based on their edible parts, into several varieties. They are:

i. **Leafy Vegetables:** Leafy Vegetables are crops that are grown mainly for their leaves. Examples: amaranth, lettuce, and raddish.

ii. **Shoot Vegetables:** Shoot Vegetables are plants grown primarily for their edible shoot, mainly the young, succulent stem. Examples: asparagus and celery.

iii. **Pod and Seed Vegetables:** Pod and Seed Vegetables are generally members of Leguminosae or Fabaceae family. These plants are grown for their young pods and seeds. Examples: beans and sweet corn.

iv. **Root and Bulb Vegetables:** Root and Bulb Vegetables are plants grown for their swollen underground roots and stems. Examples: carrot, potato, onion and raddish.

v. **Flower Vegetables:** Flower Vegetables are plants with edible flowers. Examples: rose and sunflower.

vi. **Fruit Vegetables:** Fruit Vegetables are grown for their fleshy, succulent fruits. Examples: eggplant, tomato, peppers and melons.

Vegetables are also classified according to their families, into the following groups:

i. **Cole Crops or Crucifers:** These vegetable crops belong to the Cruciferae or Brassicaceae (Mustard) family. They possess edible leaves or heads. Examples: cabbage, cauliflower, mustard, and raddish.

ii. **Cucurbits:** belong to the Gourd and Squash family. They are grown mainly for their fruits but some have edible young shoots and flowers; also called Vine Crops. Examples: bottle gourd, cucumber and melons.

iii. **Legume Vegetables:** Legume Vegetables are the members of the Leguminosae or Fabaceae (Bean) family. The seeds are rich in protein. Examples: kidney beans, pea and pole sitao.

iv. **Liliaceae:** Lilies are members of the Liliaceae (Lily) family. Examples: asparagus, garlic and onion.

v. **Solanaceous Crops:** belong to the Solanaceae (Nightshade or Eggplant) family and, with the exception of white potato, are also called Fruit Vegetables. Examples: eggplant, tomato, peppers and white potato.

vi. **Mushrooms** are edible fungi belonging to the division Basidiomycota (club fungi). The edible part commonly consist of an upright stalk and an umbrella- shaped cap.

Fruit Crops and Nuts: The Fruit Crops and Nuts include plants that are grown primarily for their edible fruits. Nuts are grown for their fruits which are high in fat. The nut is a simple, dry, indehiscent fruit with a hard outer covering. Example is the cashew.

Spice Crops: The Spice Crops are grown for the production of aromatic substances which are used as food flavoring, fragrance or preservative qualities. Spices are in solid or liquid forms. Examples: black pepper, garlic, ginger, hot pepper, onion and turmeric.

Essential-oil Crops: The Essential-oil Crops are plants grown for the extraction of essential oils which are volatile, aromatic substances for perfumery and other uses. Examples: eucalyptus, peppermint, etc.

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Ornamental and Other Plantation Crops

Gardening is a part of agriculture. Horticultural cultivation of garden plants is a major area of economy. The Ornamental Crops are plants that are grown primarily for decoration or landscaping or to be appreciated because of their attractive flowers or foliage. They also include floricultural crops.

Floricultural crops are valued for their attractive flowers, foliage ornamentals for their leaves.

The Lawn or Turf Grasses are grasses grown for aesthetic purpose in the landscape or for any outdoor recreational use. They are usually maintained at a low height. Example: Bermuda grass. The ornamental plants are further classified into several varieties, based on their usage, as:

i. **Cut flowers:** The Cut flowers are obtained from plants that are grown for their attractive flowers with long shelf life. Example: anthurium.

ii. **Cut foliage:** The Cut foliage are obtained from plants that are grown for their attractive foliage which are cut for floral decoration. Example: ferns.

iii. **Edge Crops:** The Edge Crops are the short- statured plants that are grown to serve as barrier between the lawn and garden, to highlight gardens, or to create standalone gardens; also called border plants. Examples: mondo grass and dwarf cucharita.

iv. **Groundcovers:** The Groundcovers are low-lying, aesthetically appealing plants grown in the landscape primarily to suppress weed growth and to control, retard or prevent soil erosion by covering and binding loose, bare soil. It is used to produce a carpeting effect.

v. **Hedges:** The Hedges are plants grown at the edges of pathways or boundaries and continuously pruned to knee - high height or upper but below eye level.

vi. **Accents:** The Accents are plants with showy features distinct from the rest of the other plants. It immediately attracts attention and becomes a focal item in the landscape garden and at the same time provides the contrast which gives attention to other plants.

vii. **Specimens:** The Specimens are obtained from plants that have showy features, or with unique characteristics which make them pieces of conversation or botanical curiosity, or otherwise desired as collector’s item.

viii. **Screens:** The Screens are plants grown to serve as barrier against sun rays, to conceal certain parts of the landscape, or to obstruct view.

ix. **Shade crops:** The Shade crops are generally trees, shrubs, trellised vines and lianas which are grown mainly to provide shade singly or with supporting trellis.

x. **Avenue Trees:** The Avenue Trees are mainly trees and shrubs grown, more or less equidistant, beside roads and streets. Palms are also used.

In addition to these, there are two more categories of plantation crops. One is Biocidal Crops and another Industrial Crops.

Biocidal Crops: The Biocidal Crops are plants containing organic compounds with pesticidal or anti-microbial properties. The effective parts are either directly applied or seeped in water for foliar spray.

Industrial Crops: The Industrial Crops are plants grown to provide materials for industrial processing and production of non-food products, including drugs. The crop names which we use in the farmland are also included under the plantation crops category. They include:

i. **Main Crop:** Any crop which is intended by the grower to become his main source of revenue is called as the Main Crop.

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ii. **Nursery Crop:** A plant which is temporarily grown in the nursery and later planted in the field or garden or used for ornamental display, when it reaches the proper age and size, is called as a Nursery crop.

iii. **Intercrop:** The Intercrop is any crop which is planted simultaneously with or before the flowering season of the main crop in intercropping.

iv. **Filler Crop:** The Filler Crop is any crop which is planted to fill a gap. The Relay Crop is the crop which is planted after the flowering period or harvest of the main crop in relay cropping.

v. **Companion Crop:** The Companion crop is any crop which is planted close to the main crop to complement the latter's growth and production, or to maximize utilization of space because they do not compete.

vi. **Cover Crop:** The Cover crop is a crop grown mainly to control soil erosion, regulate soil temperature, control weeds and reduce evaporative losses.

vii. **Green Manure Crop:** The Green manure crop is a leguminous crop grown to be ploughed under the soil to increase organic matter and serve as organic fertilizer. Mung bean (mungo) is ideal for this purpose.

viii. **Trap Crop or Decoy Crop:** The Trap crop or Decoy crop are plants grown to attract certain insect pests or parasites because they are favorite hosts. They act as decoys to lure pests away from the main crop.

ix. **Insect pest repellant crops:** The Insect pest repellant crops are plants grown along the borders and at strategic places in the farm to repel insect pests because of their strong aroma and anti-herbivory properties.

x. **Natural enemies attractant crops:** The Natural enemies attractant crops are flowering plants grown at strategic places in the farm to attract natural enemies of insect pests.

Classification based on Cultural Method/Water

i. **Rain fed:** crops grow only on rain water. E.g. Jowar, Bajra, Mung etc.

ii. **Irrigated crops:** Crops grows with the help of irrigation water. E.g.Chili, sugarcane, Banana, papaya etc.

Classification based on Root System

i. **Tap root system:** The main root goes deep into the soil. E.g. Tur, Grape, Cotton etc.

ii. **Adventitious/Fiber rooted:** The crops whose roots are fibrous shallow & spreading into the soil. E.g. Cereal crops, wheat, rice etc.

Classification based on Economic Importance

i. **Cash crop:** Grown for earning money. E.g. Sugarcane, cotton.

ii. **Food crops:** Grown for raising food grain for the population and & fodder for cattle. E.g. Jowar, wheat, rice etc.

Classification based on No. of Cotyledons

i. **Monocots or monocotyledons:** Having one cotyledon in the seed. E.g. all cereals & Millets.

ii. **Dicots or dicotyledonous:** Crops having two cotyledons in the seed. E.g. all legumes & pulses.

Classification based on Photosynthesis' (Reduction of CO_2 /Dark Reaction)

i. **C_3 Plants:** Photo respiration is high in these plants C_3 Plants have lower water use efficiency. The initial product of C assimilation in the three 'C' compounds. The enzyme involved in the primary carboxylation is ribulose-1,-Biophospate carboxylose. E.g. Rice, soybeans, wheat, barley cottons, potato.

ii. **C_4 plants:** The primary product of C fixation is four carbon compounds which may be malice acid or acerbic acid. The enzymes responsible for carboxylation are phosphoenol Pyruvic acid carboxylose which has high affinity for CO_2 and capable of assimilation CO_2 event at lower concentration, photorespiration is negligible. Photosynthetic rates are higher in C_4 than C_3 plants for the same amount of stomatal opening. These are said to be drought resistant & they are able to grow better even under moisture stress. C_4 plants translate photosynthates rapidly. E.g. Sorghum, Maize, napier grass, sesame etc.

iii. **CAM plants:** (Crassulacean acid metabolism plants) the stomata open at night and large amount of CO_2 is fixed as a malice acid which is stored in vacuoles. During day stomata are closed. There is no possibility of CO_2 entry. CO_2 which is stored as malice acid is broken down & released as CO_2 . In these plants there is negligible transpiration. C_4 & CAM plant have high water use efficiency. These are highly drought resistant. E.g. Pineapple, sisal & agave.

Classification based on Length of Photoperiod Required for Floral Initiation

Most plants are influenced by relative length of the day & night, especially for floral initiation, the effect on plant is known as photoperiodism depending on the length of photoperiod required for floral ignition, plants are classified as:

i. **Short-day plants:** Flower initiation takes plate when days are short less then ten hours. E.g. rice, Jowar, green gram, black gram etc.

ii. **Long day's plants:** require long days are more than ten hours for floral ignition. E.g. Wheat, Barley etc.

iii. **Day neutral plants:** Photoperiod does not have much influence for phase change for these plants. E.g. Cotton, sunflower. The rate of the flowering initiation depends on how short or long is photoperiod. Shorter the days, more rapid initiation of flowering in short days plants. Longer the days more rapid are the initiation of flowering in long days plants.

CONCLUSION

The extent of cultivation of these crops vary from place to place and depends on such factors as the level of mechanization, adoption of technological advances, farm size, market stability and availability of capital.. This classification serves as the cornerstone for informed decision-making in agriculture, enabling farmers and researchers to optimize resource allocation, implement sustainable practices, and enhance food security. The integration of advanced technologies, such as remote sensing and machine learning, has revolutionized crop classification, increasing its accuracy and efficiency. Furthermore, the adaptability of crop classification to address contemporary challenges like climate change, precision agriculture, and global food security underscores its ongoing significance. As agriculture continues to evolve, crop classification remains a key tool for fostering innovation, sustainability, and resilience in the face of changing agricultural landscapes.

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CHAPTER 16

ROLE OF BIOFERTILIZERS IN NURTURING SOIL CONSERVATION

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ABSTRACT

Biofertilizers play a pivotal role in soil conservation by directly and indirectly enhancing soil health and preventing degradation. They achieve this by improving soil fertility, reducing erosion, and increasing water retention capacity. Biofertilizers contribute to balanced nutrient supply, reduce the need for chemical fertilizers, and promote sustainable agriculture. By fostering beneficial microorganisms, they promote microbial diversity, support nutrient cycling, and enhance soil structure. Moreover, they aid in disease suppression and the decomposition of organic matter. This collective action ensures soil resilience, which is essential for sustainable agriculture and ecosystem health. The future of biofertilizers in India is promising, driven by a shift towards sustainable agriculture, government support, and increasing environmental awareness. Ongoing research and development are enhancing their efficacy, while economic benefits and alignment with global trends are increasing adoption rates. As India seeks to address soil degradation and reduce the environmental impact of agriculture, biofertilizers are positioned to play a vital role in improving soil health, conserving natural resources, and ensuring long-term food security.

Keywords: Biofertilizers, Soil Health, Sustainable Agriculture, Microbial Diversity

INTRODUCTION

The concept of biofertilizers represents a remarkable evolution in sustainable agriculture and soil conservation (Mahanty *et al*., 2017). As human populations continue to grow, the need for increased food production has put tremendous pressure on our agricultural systems. Historically, the solution to higher yields often involved the heavy application of chemical fertilizers, which, while initially effective, has had detrimental long-term effects on soil health and the environment (Singh *et al*., 2016). In response to these challenges, the concept of biofertilizers has emerged as a vital and progressive approach to address the dual objectives of enhancing crop productivity while preserving and even rejuvenating the health of our soils.

Biofertilizers, fundamentally, are living microorganisms, predominantly bacteria, fungi, and algae, as well as other natural substances like organic materials that are applied to agricultural fields to promote nutrient uptake by plants and improve soil structure. The evolution of this concept has been driven by a growing understanding of the complex interplay between soil, plants, and the microorganisms inhabiting the rhizosphere (Wendel *et al.*, 2022). These microorganisms form a mutually beneficial relationship with plants, aiding in nutrient acquisition, disease resistance, and overall crop vigor. Over time, researchers and farmers have recognized the ecological and economic advantages of harnessing the power of these naturally occurring allies in farming.

This evolution in our agricultural practices reflects a paradigm shift from a heavy reliance on synthetic fertilizers, which can lead to soil degradation and environmental pollution, towards a more harmonious and sustainable coexistence with nature. The role of biofertilizers in soil conservation cannot be understated, as they not only contribute to increased crop yields but also

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have the potential to mitigate soil erosion, reduce water pollution, and limit the release of greenhouse gases (Asoegwu*et al*., 2020). Biofertilizers have their pivotal role in the long-term fertility and vitality of our soils, thus securing a sustainable future for global agriculture.

Types of biofertilizers

Biofertilizers are natural products that contain beneficial microorganisms, which enhance soil fertility and promote plant growth. There are several types of biofertilizers, each with a specific role in improving soil and crop health. Here are the main types.

1. **Nitrogen-fixing biofertilizers**: These contain nitrogen-fixing bacteria, such as Rhizobium and Azotobacter, that convert atmospheric nitrogen into a plant-usable form. They are essential for leguminous crops like peas and beans.
2. **Phosphorus-solubilizing biofertilizers:** These biofertilizers contain phosphate-solubilizing microorganisms like Pseudomonas and Bacillus species. They help solubilize insoluble phosphates in the soil, making them available to plants.
3. **Potassium producing biofertilizers:** These biofertilizers, often based on potassium-solubilizing bacteria, facilitate the release of potassium from mineral sources in the soil.
4. **Micronutrient enhancing biofertilizers**: Some biofertilizers focus on improving the availability of essential micronutrients like iron, zinc, and manganese to plants. Microorganisms like mycorrhizal fungi play a vital role in this category.
5. **Growth promoting biofertilizers:** These contain beneficial microorganisms that produce plant growth-promoting substances such as auxins and cytokinins, leading to better root development and overall plant growth.
6. **Azolla based biofertilizers**: Azolla is a water fern that contains nitrogen-fixing cyanobacteria. It's used as a biofertilizer in flooded rice fields to enhance nitrogen availability.
7. **Vermicompost:** While not microorganism-based, vermicompost is an organic biofertilizer produced by earthworms. It's rich in nutrients and beneficial microorganisms.

These biofertilizers are eco-friendly alternatives to chemical fertilizers and play a significant role in sustainable agriculture by improving soil fertility, reducing the environmental impact, and enhancing crop yields.

Benefits of biofertilzers for soil conservation

Biofertilizers play a vital role in soil conservation, both directly and indirectly. They enhance soil fertility, reduce erosion, and increase water retention capacity. Moreover, biofertilization enhances soil quality, preventing degradation and minimizing environmental impact. The following section delves into these benefits.

A. Role of biofertilizers in improvement of soil fertility:

Biofertilizers contain beneficial microorganisms, which play a vital role in nutrient cycling. This improved nutrient availability results in enhanced soil fertility, promoting healthy plant growth and higher crop yields (Itelima*et al*., 2018). Biofertilizers can significantly improve soil fertility through various mechanisms as mentioned below:

i. **Nitrogen Fixation**: Some biofertilizers contain nitrogen-fixing bacteria like Rhizobium and Azotobacter. These microorganisms have the unique ability to convert atmospheric nitrogen (N_2) into ammonia (NH_3) and other forms of nitrogen that plants can readily use (Fasusi *et al.,* 2021). This process is known as nitrogen fixation. By making atmospheric nitrogen available to plants, biofertilizers enrich the soil with this essential nutrient, promoting healthy plant growth.

ii. **Phosphorus Solubilization**: Other biofertilizers consist of phosphate-solubilizing microorganisms, such as Pseudomonas and Bacillus species. These microorganisms solubilize insoluble forms of phosphorus in the soil, like calcium phosphate, making it accessible to plants. Phosphorus is a crucial element for plant growth, and biofertilizers help enhance its availability.

iii. **Potassium Mobilization**: Some biofertilizers are designed to release potassium from mineral sources in the soil. Potassium is essential for various plant functions, including photosynthesis and water regulation. Biofertilizers with potassium-solubilizing microorganisms help make potassium more accessible to plants.

iv. **Micronutrient Enhancement**: Biofertilizers can promote the availability of essential micronutrients like iron, zinc, and manganese. Certain microorganisms in biofertilizers can chelate or solubilize these micronutrients, ensuring that plants have an adequate supply. Micronutrients are vital for plant health and growth.

v. **Growth-Promoting Substances**: Some biofertilizers contain beneficial microorganisms that produce growth-promoting substances, such as auxins and cytokinins. These substances stimulate root development, increase nutrient uptake, and enhance overall plant growth. They also help improve soil fertility by creating healthier, more productive plants.

vi. **Organic Matter Addition**: Many biofertilizers contain organic materials that enrich the soil's organic matter content. Organic matter improves soil structure, water retention, and nutrient-holding capacity. It also supports the growth of beneficial soil microorganisms, contributing to long-term soil fertility.

In summary, biofertilizers enhance soil fertility by providing essential nutrients to plants, improving nutrient availability, promoting root development, and enriching soil with organic matter. By creating a more nutrient-rich and balanced environment for plant growth, biofertilizers play a crucial role in improving soil fertility and sustaining agricultural productivity.

B. Role of biofertilizers in reduction of soil erosion

Healthy plants with well-developed root systems help bind the soil particles together. Biofertilizers promote robust root growth, making the soil more resistant to erosion caused by wind and water. This reduction in soil erosion is crucial for maintaining soil structure and preventing the loss of fertile topsoil.The key processes of biofertilizers that contribute to soil erosion reduction are listed below.

i. **Stronger root systems**: Biofertilizers contain beneficial microorganisms that enhance root growth and overall plant health. Healthy plants with well-developed root systems help bind the soil particles together. The extensive root networks act as a natural anchor, making the soil more resistant to erosion by wind and water.

ii. **Increased vegetation density**: Biofertilizers contribute to increased plant growth and crop yield. Higher plant density results in a denser canopy that provides physical protection to the soil surface. This protection prevents the impact of raindrops and the force of wind from directly hitting the soil, reducing the potential for erosion.

iii. **Soil aggregation**: The microorganisms in biofertilizers can improve soil aggregation. They secrete organic substances that help bind soil particles together. This creates stable soil aggregates that are less prone to being carried away by water or wind. Enhanced soil structure is essential for erosion prevention.

iv. **Reduced runoff:** Healthy, well-nourished plants grown with the aid of biofertilizers have a more extensive root system that absorbs and retains water. This reduces surface runoff

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during heavy rainfall. Reduced runoff decreases the volume of water flowing over the soil surface, which is a significant cause of erosion.

v. **Enhanced water infiltration**: Biofertilizers improve soil structure and water-holding capacity. Soils enriched with biofertilizers have better water infiltration rates, allowing water to penetrate the soil rather than running off. Improved infiltration reduces the erosive power of water.

vi. **Plant cover and canopy**: Biofertilizers contribute to healthier plant growth and canopy development. A dense plant canopy shades the soil, reducing temperature fluctuations and evaporation. This helps to maintain soil moisture and reduce the drying effects of wind and sun, further preventing erosion.

vii. **Conservation tillage**: In some cases, biofertilizers are used in conservation tillage practices, which minimize soil disturbance. Reduced tillage helps maintain soil structure and reduces soil exposure to erosion forces.

C. Role of biofertilizers in enhancement of water retention

Soil enriched with biofertilizers is naturally proven to have better water-holding capacity through improved status of organic matter and soil structure (El-Hamid*et al.*, 2013). This water retention is beneficial for both water conservation and crop resilience, especially in regions prone to drought. The following are the mechanisms involved in improving water retention that are influenced by the use of biofertilizers.

i. **Improved soil structure**: Biofertilizers contain beneficial microorganisms that contribute to the development of stable soil aggregates. These aggregates create pore spaces in the soil, which act as reservoirs for water. The increased pore spaces allow the soil to hold more water, reducing the risk of water draining away.

ii. **Organic matter enrichment**: Many biofertilizers contain organic materials. When incorporated into the soil, these organic substances increase the soil's organic matter content. Organic matter acts like a sponge, capable of holding significant amounts of water. This results in improved water-holding capacity.

iii. **Reduced soil compaction**: Biofertilizers promote root development and overall plant health. Healthy plants with strong root systems help break up compacted soil. Compacted soil can limit water infiltration and retention. Biofertilizers aid in reducing compaction, allowing water to move more freely through the soil.

iv. **Enhanced capillary action**: The microorganisms in biofertilizers help improve soil porosity. This aids in capillary action, which allows water to move upward from deeper soil layers to the root zone. Improved capillary action helps maintain soil moisture, especially during dry periods.

v. **Drought resistance**: Biofertilizers stimulate healthy plant growth. Well-nourished and vigorous plants are better equipped to withstand drought conditions. They can access water stored in the soil for a longer duration, reducing the need for frequent irrigation.

vi. **Conservation of soil moisture**: Biofertilizers contribute to the development of a dense plant canopy. This canopy shades the soil, reducing water loss due to evaporation. Less evaporation means that more water remains available for plant use.

D. Role of biofertilizers in prevention of soil degradation:

Prolonged use of chemical fertilizers can lead to soil degradation, including nutrient imbalances and changes in soil pH. Biofertilizers are more sustainable and can prevent these adverse effects by fostering a more natural and balanced nutrient cycle, thus preserving the long-term health of the soil.Here's how biofertilizers help prevent soil degradation:

i. **Balanced nutrient supply**: Biofertilizers provide a balanced and sustainable supply of essential nutrients to plants. Unlike chemical fertilizers, which can lead to nutrient imbalances, biofertilizers release nutrients gradually, ensuring that plants receive what they need without overloading the soil with excessive nutrients. This balanced nutrient supply prevents soil nutrient depletion and degradation.

ii. **Organic matter enrichment**: Many biofertilizers contain organic materials. When incorporated into the soil, these organic substances contribute to the soil's organic matter content. Organic matter enhances soil structure, water retention, and nutrient-holding capacity. It also encourages beneficial microorganisms, which improve overall soil health.

iii. **Reduction of soil salinity**: Biofertilizers can help reduce soil salinity, a common issue in degraded soils. Some biofertilizers, like certain nitrogen-fixing bacteria, can improve the salt tolerance of plants and reduce soil salinity through increased plant growth and salt exclusion mechanisms.

iv. **Prevention of pH imbalance**: Continuous use of chemical fertilizers can lead to changes in soil pH, making it too acidic or alkaline. Biofertilizers do not alter soil pH significantly, helping to maintain a neutral pH range. Balanced soil pH is crucial for plant nutrient availability and overall soil health.

v. **Improved soil structure**: Biofertilizers enhance soil structure by creating stable soil aggregates. These aggregates are less prone to compaction and erosion. Enhanced soil structure promotes better aeration and water infiltration, reducing the risk of soil degradation caused by compaction and erosion.

vi. **Reduction in chemical residue**: The use of chemical fertilizers may leave behind chemical residues in the soil. Biofertilizers do not have this issue, ensuring a more natural and residue-free environment for plants and soil microorganisms.

E. Role of biofertilizers in reduction of environmental impact:

Chemical fertilizers can leach into water bodies, causing pollution and harm to aquatic ecosystems. Biofertilizers, being biologically derived, have a lower environmental impact (Asoegwu *et al.*, 2020). They do not contribute to soil or water pollution, making them a greener choice for agriculture. Here are several ways biofertilizers help to reduce environmental impact:

i. **Minimal chemical residues**: Unlike chemical fertilizers, biofertilizers do not leave chemical residues in the soil. This means that the soil and surrounding ecosystems are not exposed to harmful chemical compounds, reducing the risk of soil and water contamination.

ii. **Lower greenhouse gas emissions**: The production and application of chemical fertilizers are associated with significant greenhouse gas emissions, particularly nitrous oxide (N2O), a potent greenhouse gas. Biofertilizers, on the other hand, promote natural nitrogen fixation and nutrient cycling, reducing the need for energy-intensive fertilizer production and application. This helps lower greenhouse gas emissions associated with agriculture.

iii. **Reduction in soil erosion:**Biofertilizers support healthy plant growth and stronger root systems, reducing soil erosion. Soil erosion can lead to the loss of topsoil, which contains essential nutrients. By preventing erosion, biofertilizers help maintain soil fertility and reduce sediment runoff into water bodies, which can harm aquatic ecosystems.

iv. **Improved water quality**: The balanced nutrient supply and enhanced soil structure associated with biofertilizers reduce nutrient runoff into water bodies. Excessive nutrient

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runoff, often caused by chemical fertilizers, can lead to water pollution, including harmful algal blooms and aquatic dead zones. Biofertilizers help improve water quality by minimizing nutrient losses.

v. **Lower energy consumption**: The production and transportation of chemical fertilizers consume substantial energy resources. Biofertilizers, which primarily rely on naturally occurring microorganisms, have a lower energy footprint. This reduced energy consumption contributes to a smaller environmental footprint.

vi. **Enhanced soil health**: Biofertilizers foster a healthier and more diverse soil ecosystem. Beneficial microorganisms supported by biofertilizers can help control pests and diseases naturally, reducing the need for chemical pesticides. This promotes a more balanced and less harmful approach to pest management.

F. Role of biofertilizers in promotionof beneficial microorganisms:

Biofertilizers enhance the growth of beneficial microorganisms in the soil, such as mycorrhizal fungi and other soil bacteria (Mushtaq *et al*., 2021). These microorganisms contribute to pest control and disease suppression, reducing the need for chemical pesticides. This natural pest and disease management supports overall soil health. The following is how biofertilizers support the growth of beneficial microorganisms:

i. **Introduction of beneficial microbes**: Biofertilizers are intentionally inoculated with specific beneficial microorganisms, such as nitrogen-fixing bacteria, phosphorus-solubilizing fungi, and mycorrhizal fungi. When biofertilizers are applied to the soil, they introduce these beneficial microorganisms, thereby increasing their presence in the ecosystem.

ii. **Enhanced microbial diversity**: Beneficial microorganisms introduced by biofertilizers increase the overall microbial diversity in the soil. A diverse microbial community is more resilient and better able to carry out essential functions, such as nutrient cycling and disease suppression.

iii. **Symbiotic relationships**: Many of the microorganisms in biofertilizers form symbiotic relationships with plants. For example, nitrogen-fixing bacteria like Rhizobium form nodules on legume roots, where they convert atmospheric nitrogen into plant-usable forms. Mycorrhizal fungi form mutually beneficial relationships with most plants, aiding in nutrient uptake. These symbiotic interactions improve plant health and promote soil microbe populations.

iv. **Nutrient cycling**: Beneficial microorganisms in the soil play a key role in nutrient cycling. They break down organic matter, release nutrients, and make them available to plants. Biofertilizers enhance this natural process by fostering the growth of these microorganisms, ensuring efficient nutrient cycling.

v. **Disease suppression**: Some beneficial microorganisms in biofertilizers are known for their ability to suppress plant pathogens. They can outcompete harmful microorganisms or produce compounds that inhibit their growth. This natural pest and disease management reduces the need for chemical pesticides.

vi. **Decomposition of organic matter:**Microorganisms are responsible for the decomposition of organic matter in the soil. Biofertilizers enhance this decomposition process, which results in the release of nutrients from organic materials, further enriching the soil.

vii. **Improved soil aeration:** Beneficial microorganisms help improve soil aeration by creating channels and enhancing soil structure. Improved aeration allows for better oxygen penetration, which is essential for the growth and activity of beneficial microorganisms.

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viii. **Enhanced soil health**: The collective action of beneficial microorganisms promoted by biofertilizers contributes to overall soil health. Healthy soils support plant growth and sustainable agricultural practices.

G. Role of biofertilizers in sustainable agriculture:

Perhaps the most significant benefit is that biofertilizers promote sustainable agricultural practices. They ensure that the land remains productive over the long term while minimizing the negative environmental impact associated with chemical fertilizers. By conserving soil health and structure, biofertilizers help secure the future of agriculture. Biofertilizers can improve crop yields by 10-25% and supplement costly chemical fertilizer (N, P) by nearly 20-25% in most of the cases when used along with the chemical fertilizers (PIB, Ministry of Agriculture & Farmers Welfare, 2019).

CONCLUSION

Biofertilizers, in the context of Indian agriculture, have both advantages and disadvantages. On the positive side, they offer a sustainable approach to farming by enhancing soil fertility and reducing the dependence on synthetic fertilizers. One significant advantage of biofertilizers in India is their cost-effectiveness. They tend to be more affordable than chemical fertilizers, making them accessible to small-scale and resource-constrained farmers. In a country dealing with issues of soil erosion and water pollution, these benefits are highly relevant. Additionally, nitrogen-fixing biofertilizers, like Rhizobium and Azotobacter, are crucial in meeting India's high nitrogen fertilizer demand, mitigating environmental issues linked to excessive synthetic nitrogen use, including soil and water pollution. However, there are challenges to consider. Limited awareness and adoption among Indian farmers can hinder the potential benefits of biofertilizers. Additionally, ensuring the quality and effectiveness of biofertilizers can be challenging, requiring strict quality control and maintenance of microbial strains. Some biofertilizers may not be compatible with certain crops, soil conditions, or agro-climatic zones, limiting their applicability. Farmers may also experience an initial transition period when switching from chemical to biofertilizers, during which crop yields could be affected. In India's efforts to counteract soil deterioration and reduce the ecological footprint of farming, biofertilizers hold significant potential to enhance soil quality, preserve natural resources, and ensure food security in the long run.

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CHAPTER 17

THE ROLE OF ICT IN AGRICULTURAL EXTENSION AND FOOD SECURITY IN INDIA

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ABSTRACT

Information and Communication Technology (ICT) has emerged as a transformative force in various sectors, and its impact on agriculture and food security in India has been remarkable. This abstract delves into the pivotal role that ICT plays in enhancing agricultural extension services and ensuring food security in the country. India's economy is intrinsically linked to agriculture, with a significant portion of its population dependent on this sector. However, traditional agricultural practices often face challenges like lack of access to timely information, outdated techniques, and limited resources. ICT interventions have revolutionized agricultural extension services by bridging these gaps. Through mobile apps, websites, and SMS services, farmers gain access to real-time weather forecasts, market prices, pest and disease management strategies, and best farming practices. This democratization of information empowers farmers to make informed decisions, thereby increasing productivity and income. Furthermore, ICT has facilitated knowledge sharing and peer learning among farmers. Online forums and social media platforms enable farmers to connect, exchange experiences, and learn from each other's successes and failures. This communal learning fosters innovation and the adoption of modern techniques across diverse agro-climatic zones.

In the realm of food security, ICT contributes significantly to the entire food supply chain. From production to distribution, ICT-enabled systems enhance efficiency and reduce wastage. Digital platforms help link farmers directly to consumers and markets, minimizing intermediaries and ensuring fair prices. This not only benefits farmers but also enhances consumer access to diverse and nutritious food. However, challenges remain. Digital illiteracy, especially among older farmers, and inadequate rural connectivity hinder the complete integration of ICT. Moreover, sustaining these initiatives necessitates policy support, robust infrastructure, and continuous innovation.

Keywords- Agriculture, ICT, Extension, Food Security, Impact and Challenges

INTRODUCTION

The agricultural sector has been the backbone of India's economy, employing a significant portion of its population and ensuring food security for its vast populace. However, the sector has faced numerous challenges such as limited access to timely and relevant information, `insufficient technical knowledge, and inadequate market linkages. These challenges have hindered the sector's growth and its ability to contribute effectively to the nation's food security goals. In recent years, Information and Communication Technology (ICT) has emerged as a transformative force, playing a pivotal role in revolutionizing agricultural extension services and bolstering food security in India. Agricultural extension services have traditionally been the means through which farmers receive information, guidance, and training to enhance their agricultural practices. These services are crucial in disseminating knowledge about modern and

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sustainable farming techniques, crop management, pest and disease control, and market trends. However, the conventional extension approaches often faced limitations in terms of reach, timeliness, and customization. This is where ICT has stepped in as a game-changer.

The integration of ICT tools and platforms into agricultural extension services has redefined the way information is shared, accessed, and utilized in the farming community. Mobile phones, internet-based applications, social media, and community radio are among the tools that have gained prominence. These platforms enable real-time communication and knowledge exchange between agricultural experts, extension workers, and farmers, transcending geographical barriers. The potential of ICT to deliver tailored information, personalized recommendations, and instant feedback has transformed the efficiency and effectiveness of agricultural extension services.

Moreover, the role of ICT extends beyond merely improving extension services. It has demonstrated a significant impact on food security as well. Ensuring food security involves not only producing enough food but also managing the entire food supply chain efficiently. ICT has facilitated this by offering solutions that address challenges at every stage of the supply chain – from production and storage to distribution and consumption. By enhancing access to relevant information and empowering farmers with technical knowledge, ICT contributes to increased agricultural productivity and reduced post-harvest losses. Furthermore, ICT-enabled market linkages connect farmers directly to consumers, minimizing intermediaries and ensuring fair prices. This, in turn, leads to enhanced income for farmers and a more stable food supply for the population. While the benefits of ICT in agriculture and food security are evident, challenges remain. Digital literacy levels vary across regions, and there are concerns about the accessibility and affordability of ICT tools in rural areas. Bridging these gaps and ensuring equitable access to ICT solutions are essential for harnessing its full potential.

In recent years, the role of Information and Communication Technology (ICT) in agricultural extension has gained significant prominence in India, playing a vital role in enhancing food security and transforming the agricultural landscape. ICT refers to the integration of technologies that facilitate the creation, storage, processing, and sharing of information through various digital platforms. When applied to agricultural practices, ICT has the potential to revolutionize the way farmers receive information, access resources, and make informed decisions.

Agricultural Extension and Its Challenges-

Agricultural extension services are crucial for disseminating relevant information, modern farming techniques, and best practices to farmers. In India, where agriculture is a cornerstone of the economy and a primary livelihood source for millions, effective agricultural extension is vital for increasing productivity, improving crop yields, and ensuring food security. However, traditional extension methods faced challenges such as limited reach, information asymmetry, and delays in delivering critical information to farmers.

ICT's Contribution to Agricultural Extension-

ICT has addressed many of these challenges by providing innovative tools and platforms that enable efficient communication, knowledge sharing, and decision-making among farmers and agricultural experts. Some ways in which ICT has contributed to agricultural extension and food security in India include:

1. **Mobile Applications:** Various mobile apps provide real-time information on weather forecasts, pest and disease management, market prices, and crop management practices. These apps bridge the information gap and empower farmers to make informed decisions.

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2. **Online Portals and Websites:** Government and non-governmental organizations have established online portals that offer resources such as farming techniques, expert advice, market information, and government schemes. These platforms enable farmers to access valuable information without the need for physical presence.
3. **Interactive Voice Response (IVR) Systems:** IVR systems deliver audio-based agricultural advice to farmers' mobile phones. This technology is particularly useful for illiterate farmers or those with limited access to smart phones.
4. **Video Content and Webinars**: Videos and webinars provide visual demonstrations of agricultural practices, making it easier for farmers to understand and adopt new techniques. This mode of information delivery is especially beneficial in rural areas.
5. **Market Linkages:** ICT tools have facilitated direct access to markets for farmers, helping them connect with buyers and eliminating intermediaries. This leads to fairer prices for their produce and increased income.
6. **Precision Agriculture and Remote Sensing:** Technologies like remote sensing and Geographic Information Systems (GIS) help farmers monitor their fields' health, soil moisture, and crop conditions. This data-driven approach enhances resource management and optimizes yields.
7. **Remote Advisory Services:** Through ICT, agricultural experts and extension agents can provide real-time advice and guidance to farmers remotely. This is particularly beneficial in remote or inaccessible areas. Farmers can share images or videos of their crops or livestock, and experts can diagnose problems and recommend solutions without being physically present.
8. **Financial Services:** ICT has facilitated the provision of financial services to farmers, such as mobile banking, digital payments, and access to credit. This empowers farmers to manage their finances more efficiently and invest in their agricultural activities.
9. **Data Collection and Analysis:** ICT tools help gather and analyze agricultural data, including soil quality, weather patterns, and crop yields. This data-driven approach enhances decision-making for farmers and policymakers alike.
10. **Early Warning Systems:** ICT can be used to develop early warning systems for natural disasters like floods, droughts, and pest outbreaks. This allows farmers to take proactive measures to mitigate risks and minimize losses.
11. **Risk Mitigation:** Timely weather forecasts and pest outbreak alerts provided through ICT help farmers anticipate and mitigate potential risks to their crops. This minimizes losses and contributes to improved food security.
12. **Empowerment of Women Farmers:** ICT has played a pivotal role in empowering women farmers by providing them with access to information, resources, and markets, thereby contributing to their economic independence and social empowerment.
13. **Challenges and Considerations:** While ICT has immense potential, challenges such as limited digital literacy, access to reliable internet connectivity in rural areas, and the need for localized content and languages must be addressed to ensure equitable benefits for all farmers.

In essence, ICT has revolutionized agricultural extension by democratizing access to information, enabling personalized advice, enhancing collaboration, and promoting sustainable farming practices. However, it's important to consider that while ICT has immense potential, its effective implementation requires addressing issues of digital divide, connectivity, and ensuring that the technology reaches marginalized and resource-limited farmers.

Impact on Food Security:
The integration of ICT in agriculture has a profound impact on food security in India. By empowering farmers with timely and accurate information, ICT helps in mitigating crop losses due to unforeseen events such as weather fluctuations and pest outbreaks. Additionally, improved agricultural practices lead to increased productivity, which contributes to a more stable food supply. As farmers adopt modern techniques and gain access to markets, their income rises, reducing vulnerability to food insecurity.

Challenges and the Way Forward:
While ICT has made significant strides in improving agricultural extension and food security, challenges like limited internet connectivity in rural areas, digital illiteracy, and language barriers still exist. Addressing these challenges requires continued efforts from the government, private sector, and NGOs to provide training, develop user-friendly applications, and invest in digital infrastructure.

CONCLUSION

In conclusion, the role of ICT in agricultural extension and food security in India is transformative. It enhances the dissemination of knowledge, facilitates efficient resource utilization, and empowers farmers to make informed decisions. With continued advancements in technology and concerted efforts to bridge the digital divide, ICT will play an increasingly vital role in ensuring sustainable agricultural practices and food security for India's growing population. In conclusion, ICT has emerged as a powerful tool in agricultural extension, contributing significantly to improving food security in India. Its role in providing access to information, enhancing extension services, facilitating market access, enabling precision farming, and supporting data-driven decisions has been instrumental in transforming Indian agriculture. However, continuous efforts are required to overcome challenges and ensure that the benefits of ICT reach every farmer, contributing to a more sustainable, efficient, and secure food production system. The role of ICT in agricultural extension and food security in India is instrumental. It enhances the dissemination of knowledge, empowers farmers to make informed decisions, improves productivity, and strengthens market linkages. As India strives to ensure food security for its growing population, leveraging ICT in agriculture will be a crucial strategy in achieving sustainable and inclusive agricultural development.

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CHAPTER 18

BONSAI: THE ART OF MINIATURIZATION

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ABSTRACT

The cultivation of a miniature tree is known as bonsai art. It is the practise of cultivating trees in a small area in order to mimic specific environmental circumstances, including old age, extensive weathering, twisted landscapes and other variables. Bonsai needs many years to grow but with advancement in science the time for producing bonsai has been reduced with the aid of growth retardants. Bonsai can also be used as a technique for conservation of species. The art of bonsai honours the bond between the human heart and the tree. As urbanization and stress levels continue to rise, the calming effects of tending to these living artworks can offer solace, promote mindfulness and reduce anxiety. Bonsai can be beneficial as a therapeutic tool for mental health disorders when utilised as art therapy, and it can be promoted in a group setting in future rehabilitation centres. Participating in bonsai can aid individuals in fostering social connections and reducing stress brought on by the Covid-19-like pandemic. At present, the role of bonsai is not restricted to beautification of an area only but different bonsai techniques and processes also have health benefits and a powerful impact on human well-being.

Keywords: Bonsai; Miniature; Masterpieces; Gardening; Aesthetics; Artistry; Human well-being

INTRODUCTION

The term "bonsai" originally refers to the concept of planting a tree in a pot or tray. However, bonsai transcends this basic definition (Covello & Yoshimura, 1984). Bonsai artistry aims to convey a sense of immense size and age (Shukla et al., 2016). This is achieved through the cultivation of robust roots that spread in all directions, a substantial trunk that gradually tapers, a distinct apex, as well as well-formed and thoughtfully positioned branches (Halder et al., 2023). These elements harmoniously come together to craft a meticulous fusion of symmetry, equilibrium, and harmony (Sasi, 2017). Contrary to popular belief, age is not the most important factor in bonsai. If a very ancient bonsai's shape or appearance is not appealing, it will never be valued; but, if the bonsai's shape and branch arrangement are pleasing, it will be valued more (Pietraszko & Sobota, 2008). Although it is commonly linked to Japan, the bonsai art has Chinese origins. The first landscape miniatures, known as "pun-ching," were made there during the Han dynasty, which ruled approximately 200 BC, by arranging a few or several small trees implanted on a flat tray (Koreshoff, 1984; Hu, 1987). During Second World War the American soldiers started to bring miniature trees and the knowhow to the US (Iwasha, 1989; Faulkner, 1991; Yoshimura, 1993). Bonsai societies in metropolitan and larger cities made this art accessible (Koreshoff, 1984).

In a world that seems to be moving faster than ever, it's no wonder that people are seeking solace and tranquillity in various activities, one such practice that has gained significant attention for its positive impact on human health is bonsai cultivation. Plants have been documented to alleviate stress, foster feelings of serenity, boost self-esteem, and cultivate a

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sense of mastery over one's surroundings (Lewis, 1994). The incorporation of natural elements into living spaces seemingly has the potential to instigate favorable shifts in cognitive processes and emotions, which in turn can influence stress levels, health, and overall well-being. It becomes imperative to assess the projected benefits in order to rationalise the distribution of resources towards establishing more naturalistic environment (Grinde & Patil, 2009). In greater depth, exposure to nature has been associated with psychological benefits like stress reduction (Ulrich et al., 1991; Chang et al., 2005), positive effects on mental renewal (Kalpan and Kalpan 1989), improved attention (Harting et al., 2003; Van den Berg, 2007), and the management of attention deficits (Taylor et al., 2001; Taylor and Kuo, 2009). Beyond mental well-being, significant physical health advantages have also been shown to exist (Pretty, 2006), including longer life expectancy and improved self-perceived health (De vries, 2003; Mass et al., 2003). Green plants, particularly foliar plants, can have a good impact on health by stabilising prefrontal brain activity and the autonomic nerve system (Ikei et al., 2014; Hassan et al., 2017; Park et al., 2016; Park et al., 2017).

Classification of Bonsai:
Bonsai are classified based on their size into several categories (Table 1) (Taylor, 2008; Lewis, 2001; Lesniewicz, 1996). This classification plays a vital role in determining the care and maintenance required for each type of bonsai.

Table 1: Classification of bonsai based on size

Common name	Size	Dimensions
Miniature Bonsai Trees		
Kenshitsubo	Poppy sized eye	1–3 in
Shito	Fingertip sized	2–4 in
Shohin	Palm Sized	2–6 in
Mame	One handed	5-8 in
Komono	One handed	6-10 in
Medium Sized Bonsai		
Chiu	Two-handed	16–36 in
Chumono	Two-handed	16–36 in
Katade-mochi	One-handed	10–18 in
Large bonsai Trees		
Imperial bonsai	Eight-handed	60–80 in
Omono	Six-handed	40–60 in
Dai	Four-handed	30–48 in
Omono	Four-handed	30–48 in

Bonsai Styles: As the practice of bonsai advanced, it embraced classic styles that harmoniously incorporate the trunk, branches, and surface roots in a natural manner. Through the evolution from China to Japan, these designs gained sharper definition, accentuating not only aesthetics but also a profound sense of equilibrium. The styles which are suitable for different species are as follows (Sasi, 2017; Kimura, 2007; Kumar & Diwedi, 2011).

Formal Upright (Chokkan):
A bonsai tree nurtured in the formal upright style mirrors the development of a tree within its optimal surroundings. The trunk necessitates exacting straightness, exhibiting a gradual and uniform taper from base to apex—this stands as the style's most essential criterion. Eg: Larches, junipers, pines and spruces

Informal Upright (Moyogi): This bonsai style represents characteristic bend of a tree trunk in a defective situation. Eg: Maples.

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Slanting (Shakkan): The slanting style of bonsai bears a resemblance to the informal upright style, but in this approach, tree's apex is not positioned directly above its base.

Cascade (Kengai): In this style, the tree's growing tip protrudes from the bottom of its compartment. Eg: Conifer

The semi-cascade (Han-kengai): The cascading style and this Bonsai style are comparable. In this style, the tree rises above the container's rim while remaining above the base. Eg: Juniper

Broom (Hokidachi): Resembling an inverted, traditional handmade broom, the broom-style bonsai captures this distinctive form. Deciduous trees, particularly those adorned with delicate branches and leaves, are well-suited for this type of cultivation. Eg: Elm

Windblown (Fukinagashi): The windblown style in plants echoes the enduring battle for survival. These trees, exemplifying this resilient stance, are a rare sight in natural settings, often gracing cliffs or mountainsides. With their trunks and branches meticulously trained in a single direction, they evoke a powerful sense of wind's force and the tumult of a storm.

Driftwood Style (Shairimiki): A driftwood bonsai is a living tree that has been grafted onto a piece of driftwood. This design gives the normally youthful-looking bonsai an aged and elderly appearance.

Wall Bonsai: Elevate the art of tree miniaturization by guiding the tree to ascend a wall or vertical wooden surface. Showcasing innovation, train the tree to flourish vertically, presenting a novel expression of creativity. Wall bonsai is crafted by skillfully fashioning artistic and designer deadwood, seamlessly integrating with the wall's verticality.

The Clasped-to-stone (Ishisuki): In this style, the tree's roots are meticulously guided to embrace the contours of rocks. This cultivation method portrays the tree's resilience as it contends with limited space, leading the roots to cascade over the rocks and inhabit the stone's crevices. Plants clinging to the stones embody perseverance and the passage of time.

Forest (Yose-ue): A composition of multiple trees of the identical species is cultivated collectively within a single pot, forming a captivating forest-style bonsai arrangement. They are planted in odd number and gives the effect of a forest when viewed from outside.

When selecting a plant for bonsai, it's essential to consider certain characteristics that make it suitable for this unique art form. Plants with small leaves, compact growth habits, and a strong ability to adapt to shoot and root pruning. Plants enlisted in table 2, table 3 and table 4 along with their specification are suitable for bonsai making (Pessey & Samson 2014).

Table 2: Example of conifers suitable for bonsai

Species	Description	Pruning
Abies alba	Upright cones and short, spiky evergreen needles	Spring, before bud burst
Cedrus spp.	Dark green, short, spiky evergreen needles	Spring, before bud burst
Chamaecyparis spp.	Evergreen with varying habits, slow developer	Spring or autumn
Cryptomeria japonica	Slow-growing evergreen, turns red-bronze in autumn	Spring
Juniperus chinensis	Leafy evergreen, sea green in colour	Spring, autumn

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Juniperus rigida var. *nipponica*	Narrow, sharply pointed evergreen needles, cones in various colors	Spring
Larix spp. and cvs.	Deciduous needles, pale green in spring, gold in autumn	Spring, before bud burst
Picea spp. and cvs.	Erect evergreen needles, pendant cones	Spring, autumn
Pinus paviflora	Small fine bluish green needles	Spring, autumn
Pinus thunbergii	Strong, robust dark greyish-green needles	Spring, autumn
Taxus baccata	Dark green blunt evergreen needles, bright scarlet 'berries' (arils)	Spring, before bud burst summer

Table 3: Example of deciduous trees suitable for bonsai

Acer trifidum	Leaves with serrated edges, transitioning to vibrant orange in fall	Spring (branches), before bud burst; Autumn (leaves)
Acer palmatum	Minute leaves with 5 or 7 lobes, changing to fiery red or orange in fall	Spring, prior to bud burst
Betula nigra	Pale green foliage; trunk a reddish-brown hue with a white base	Spring, preceding bud burst
Carpinus laxiflora	Abundant, lush foliage emerging in spring	Spring, before the onset of bud burst
Fagus crenata	Leaves featuring rounded notches, shifting to brown in fall but persisting till spring	Spring, before bud burst; alternatively, in autumn
Ginkgo biloba	Leaves divided into two lobes, resembling a fan, green in summer and golden in autumn	Spring, preceding bud burst
Malus cerasifera	Blossoms flourish in spring, with relatively sizable leaves	Post-flowering; during autumn, trim back to a flower bud
Ulmus pavifolia	Diminutive glossy leaves, bark characterized by cracking and flaking	Spring, before the commencement of bud burst
Zelkova serrata	Tiny oval leaves, branches extending broadly, dense foliage	Spring, ahead of bud burst

Table 4: Example of ornamental shrubs and small trees suitable for bonsai

Species	Description	Pruning
Azalea	Glossy, sharp evergreen leaves, abundant spring flowers	Right after blooming
Camellia japonica	Lustrous evergreen leaves, blossoms spanning mid-winter to spring	Spring, prior to fresh leaf growth
Cotoneaster spp.	Small shiny leaves, green shifting to autumn red, red berries, upright growth	Spring, before new growth emerges
Cratagus spp. and cvs.	Thorny branches, small serrated leaves, white, pink, or red flowers, ornamental fruits in summer	Spring, before buds unfurl
Jasminum nudiflorum	Square-section green branches cascading with yellow winter flowers	Early spring, post flower bloom
Malus spp. and cvs.	Glossy oval leaves, white to deep pink flowers, cherry-sized red fruits	Spring maintenance
Prunus mume	Compact oval leaves, slender stems, vivid pink winter flowers	Spring, immediately following bloom
Japanese amygdalus	Pointed leaves with slight notches, white winter flowers	Spring, after flowering
Prunus serrulata	Oval leaves, mid to late spring white to pink blossoms	Spring, subsequent to flowering
Pyracantha angustifolia	Thorny evergreen leaves, white summer flowers	Late winter pruning
Rhododendron spp.	Lustrous sharp evergreen leaves, profuse spring flowers	Right after flowering

Easy to grow species: While the concept of a maintenance-free bonsai remains elusive, the trees mentioned here exhibit a lower degree of maintenance compared to many others. As such, they serve as great options for newcomers. Their simpler styling and care requirements do not diminish their elegance, nor do they hinder their potential to evolve into remarkable specimen trees. Warren (2014) enlisted some species which are easy to grow:

Portulacaria afra	*Muraya paniculata*	*Malphigia coccigera*
Crassula ovata	*Buxsus harlandii*	*Carissa carandas*
Ficus longisland	*Gmelina hystrix*	*Bauhinia roxburghii*
Ficus microcarpa	*Pyracantha coccinea*	*Ulmus paviflora*
Ficus virens	*Ficus ginseng*	

Succulent bonsai: Succulents are always a good choice for bonsai amateurs. Shirley and Larry (2014) gave the list of succulents which are suitable for bonsai making:

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Adansonia digitata	*Moringa ovalifolia*	*Senna meridionalis*
Adenium obesum	*Fouquieria splendens*	*Pachpodium saundersii*
Bursera microphylla	*Cyphostemma juttae*	*Portulacaria afra*
B. Fagaroides	*Crassula ovate*	*Opercularia decaryi*
Commiphora madagascariensis	*C. Africana*	

Bonsai pots: Terra cotta, cement ceramic, plastic, mica, and wood are the typical materials used to make bonsai pots. The fundamental function of bonsai pots are that the pot size should be able to comfortably house the tree and its framework of roots and should have a drainage hole in the bottom. They should have vertical sides and flat base so that the tree can be easily removed with its root mass for repotting. The style and shape of the pot matches the bonsai plant and does not dominate it. The length of bonsai pot should be 2/3 of the length of the bonsai plant (Relf, 2009; Joshi et al., 2020).

Techniques for growing Bonsai:

Pruning: This method involves pruning out extra growth in order to shape the bonsai. Pruning empowers you to reduce the tree's height and eliminate undesired branches. These are generally of 3 types; main branch pruning, general pruning and leaf cutting (Randhawa & Mukhopadhyay, 2010).

Wiring: Utilizing wire, you gain the ability to actualize your envisioned tree design, facilitating the crafting of organic, graceful contours as branches are repositioned (Wirley, 2006). The wiring has an impact on the bonsai's development and shape. Gauges 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24 and 26 are mostly used for bonsai. Application of wiring comes after leaf maturity, during early summer, with removal of wires in autumn to prevent bark damage (Warren, 2014). For coniferous trees, wiring in winter is preferred due to their longer adaptation time to new positions. There are two types of bonsai wires viz., aluminium wires (this material is suitable for amateurs and bonsai with thin bark) and copper wires (this material works well for mature and trees with thick bark).

Unwiring: The duration for which wire remains on the tree varies based on factors like species, age, health, and the extent of bending. It stays in place until the point of removal becomes necessary. When you observe wire beginning to dig into a particular area, focus on inspecting the branches that underwent the most significant bending before proceeding to remove the wire from the entire tree.

Defoliation: Defoliation is a technique to remove partial or all the leaves of a bonsai and influence proliferation of its branches to produce fresh, smaller and more number of leaves. Defoliation is carried out on deciduous and broad-leaved species (Shirley & Larry, 2002). It is done in late spring or early autumn.

Watering: With different plant types come different water needs. To prevent the midday heat in the summer, water trees in the early morning or late afternoon. Water early in the winter to allow any surplus to drain before the nighttime frost. Use of hard, or limy, water is not advised. Always use a fine rose to water bonsai to avoid damaging the delicate leaves or washing away the top layer of compost. (Kabir & Hawkeswood, 2021).

Fertilizer application: Fertilizer holds essential importance for Bonsai as these plants are cultivated in confined containers with limited soil, providing minimal nutrients. Despite these conditions, they need to foster robust trunks, branches, leaves, flowers, and fruits. Deprived of appropriate fertilizer usage, achieving substantial bonsai growth remains challenging. During the growth phase of bonsai, a primary fertilizer to consider is rapeseed cake. It encompasses a balanced mixture of Nitrogen, Phosphate, and Potash, with a proportion of 5:3:2 (Herb, 1995; Norman & Sutherland, 2005).

Repotting: The fast growing plants will need repotting every year while slow growing will need repotting after 2 to 3 years.

Growth Retardant: Growth retardants are used to control growth of bonsai. Some of the growth retardants which can be used in bonsai are Phosfon-D (2, 4-dichlorobenzyltributyl phosphonium chloride), cycocel or CCC (2-chloroethyl trimethylammonium chloride) and Bnine (N-dimethyl aminosuccinamic acid). In case of perennial plants, chemicals are used when new shoots on pruned plants attain 5-10 cm length (Rohith et al., 2021; Chaney, 2003).

Benefits of Bonsai: There are several benefits of bonsai are listed as follows:

- Therapeutic value of Bonsai: The therapeutic value of bonsai is indisputable. There are certain plants like Jade and *Ficus religiosa* that cure many diseases by sitting near to it (Sivaji & Ramamoorthy, 2017). Viewing bonsai trees can be used as a natural therapy as it allows for routine, self-induced mental relaxation. This therapy has been used to reduce physical and mental stress in the patients who are unable to walk more than a mile or doing vigorous activities to promote improved health (Ochiai et al., 2017; Dye, 2008)
- Removal of Indoor air pollution: Indoor air pollution is a concerning issue that can contribute to the emergence of numerous severe infections, lung conditions, and chronic illnesses. (Gonzalez-Martin, 2021; Zhang & Smith, 2003; Tran et al., 2020). Thus in urban areas where there is lack of space and pollution bonsai is always a good choice (Prophet et al., 2018; Cerro, 2022). A small plant can generate oxygen sufficient for one person. A three feet Tamarind Bonsai can give oxygen for four persons (Sivaji & Ramamoorthy, 2017).
- Conservation of Specie: By growing Bonsai, the plants which face the threat of extinction can be saved. For instance, the *Moringa hildebrandtii* tree has disappeared from its native Madagascar. However, horticulturists have preserved and grown it in numerous other nations as a bonsai, potted plant, and in the wild nature (Joshi & Joshi, 2009; Joshi & Joshi, 2005). Banyan and Peepal in India face a threat of extinction. Despite being a national tree and a native of India, there are only three large banyans in the country. If it is not protected, the Banyan can be seen only as a Bonsai by the future generations if it is grown as a Bonsai or as a potted plant. (Sivaji & Ramamoorthy, 2017).
- Stress reduction: Bonsai plants have beneficial effects on human physiology and psychology, particularly the positive psychology influences on enhancing learning and work efficiency (Raanaas et al., 2011), reducing distressing feelings (Yin et al., 2020), and assisting in the restoration of both physical and mental health (Park, 2009; Wang et al., 2016). Bonsai, regarded as a form of meditation, serves as a pathway to contemplation. Engaging with bonsai or immersing oneself in various facets of natural beauty can be likened to a meditative practice (Doyle, 2019)

Bonsai in the time of Covid: The COVID-19 pandemic has had a serious impact on the global landscape, leaving no aspect of life untouched. The pandemic has led to anxiety and fear, Depression and loneliness, Grief and loss, financial stress, disruptions to routines and lifestyles, ultimately having a significant impact on our mental health (Yan et al., 2022; Cullen et al., 2020; Gavin et al., 2020)

Bonsai is acknowledged as a deeply engaging pursuit with substantial positive effects on individuals' physical, emotional, and mental well-being, a notion frequently documented within the realm of leisure studies (for example, Kuykendall et al., 2015; Mansfield et al., 2020; Tian et al., 2020). Among the spectrum of leisure activities, serious leisure stands out due to its

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enduring personal and communal advantages. In contemporary times, bonsai has gained global popularity as a hobby that encompasses diverse dimensions, ranging from gardening to meditative and mindfulness practices. This multifaceted endeavor unites creativity, leisure, and art, contributing positively to the enhancement of mental and physical health (Hermann & Edwards, 2021). Generally, bonsai serves as a holistic pastime that instills individuals with profound curiosity and a sense of purpose in life (Mansourian, 2021). Engaging in the cultivation of bonsai as a form of dedicated leisure activity can provide valuable coping mechanisms during challenging periods such as recent pandemics and lockdowns. Observing bonsai plants generates physiological responses that induce feelings of comfort, relaxation, and simplicity while alleviating distressing emotions (Ochiai et al., 2017). The act of observing bonsai fosters a sense of relaxation. For those well-versed in bonsai techniques, the art form is intertwined with impactful healing experiences. Particularly, bonsai art encourages heightened awareness of ecological, spiritual, and emotional dimensions, encompassing various therapeutic attributes like artistic creativity, resilience, adaptability, and holistic well-being across social, physical, and individual aspects (Song et al., 2018). This intervention strategy is characterized by its simplicity, requiring minimal resources, and having limited environmental impact. Extensive instances have revealed that bonsai art ethically fosters well-being across diverse settings, including psychiatric institutions, retirement residences, rehabilitation centers, and correctional facilities (Hermann & Edwards, 2021). The practice of bonsai can function as a potent tool for mental health support, notably when employed as a medium for art therapy. Furthermore, its potential extends to group settings, where it could be a valuable component in rehabilitation initiatives.

CONCLUSION

Bonsai is an art or practice of cultivating which encourages the mindfulness and meditation. Bonsai is as precious as gold. Its profound ability to promote mindfulness, reduce stress, enhance ambiance, foster a sense of purpose and build community ties makes it a valuable tool in nurturing a holistic sense of well being. In an era of urban living, bonsai provides a unique opportunity for people to remain close to the nature. With advancements in biotechnology and precision agriculture, growers will harness genetic engineering to create new bonsai varieties with unique characteristics, while preserving the essence of traditional aesthetics. Additionally, as research advances, we may uncover more insights into the physiological and psychological benefits of engaging with bonsai, further solidifying its place as a valuable aspect of wellness practices for individuals worldwide.

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