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A HISTORIC LEAP FOR INDIAN AGRICULTURE: UNVEILING THE FIRST GENOME-EDITED RICE VARIETIES

Introduction

In a monumental stride towards sustainable agriculture and food security, India has unveiled its first-ever genome-edited rice varieties DRR Dhan 100 (Kamala) derived from Samba Mahsuri (BPT5204), a popular rice variety and Pusa DST Rice 1 derived from the popular fine grain variety MTU1010 (Cottondora Sannalu). Developed through CRISPR/Cas9 technology, these cultivars mark a paradigm shift in crop improvement strategies, moving beyond the constraints of conventional breeding and GMOs. The Environment (Protection) Act of 1986 exempts them from strict biosafety regulations, and they are approved under India's streamlined regulatory framework for genome-edited crops.

Several genome-edited crops are currently regulated for commercial cultivation in nations like Argentina, the United States, and Japan. Their findings demonstrate that genome editing can be an invaluable tool for agricultural sustainability if it is properly regulated. India strikes a compromise between innovation and biosafety with its prudent yet proactive strategy, allowing genome-edited crops according to the SDN-1 and SDN-2 categories. The secret to optimising the advantages will be to adapt global standards to the socioeconomic circumstances in India. The release of these varieties is not just a scientific milestone, it is a testament to India's emerging prowess in precision agriculture. These novel rice varieties have enhanced drought tolerance, high nitrogen utilisation efficiency, reduced water consumption and reduced greenhouse gas emissions, which boost rice yields by 20–30%. These varieties are expected to be vital in commencing the country's second green revolution.

An Overview of the Science of Genome Editing

CRISPR/Cas9 is often referred to as a molecular scissors. It enables researchers to precisely modify a plant's DNA (Fig.1). The changes are predictable and handed on to subsequent generations, just like any other mutation that happens naturally. Unlike genetically modified crops, which are often criticized and undergo complicated regulatory procedures, genome-edited crops provide a simpler path to the market. Furthermore, unlike traditional breeding, which could inadvertently transmit undesirable traits, CRISPR ensures targeted changes with less genetic damage.

In 2022, the Ministry of Environment, Forests, and Climate Change (MoEFCC) approved the SDN-1 and SDN-2 types of genome editing, thereby rendering it feasible to commercialize genome-edited crops that lack foreign genes. Such regulatory clarity enabled the introduction of DRR Dhan 100 and Pusa DST Rice 1, conceivably. It is projected that the regulation reform will spur development in both public and private research fields.

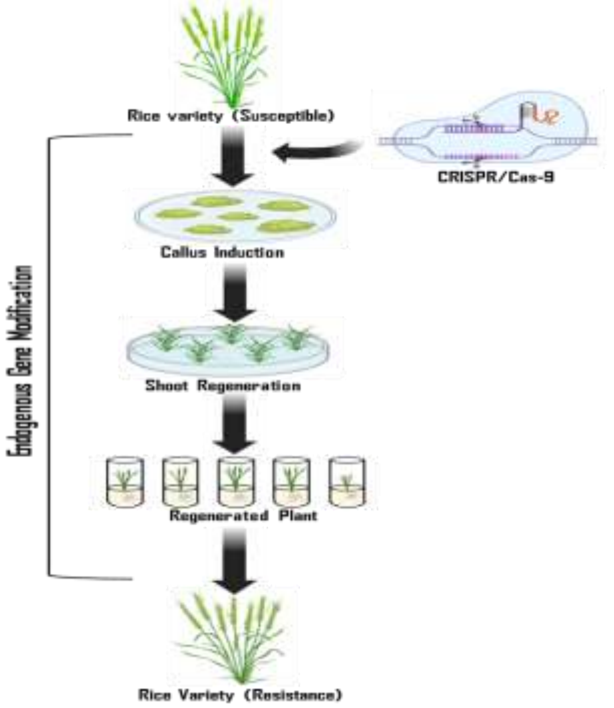

Fig. 1 Schematic Diagram showing the CRISPR/Cas Genome Editing in Rice

The Genesis of Genome Editing in India

India's tryst with genetic improvement began with the Green Revolution. However, despite major advances in molecular biology and plant breeding, challenges such as climate change, pest resistance and soil degradation persist. The revolutionary technology known as genome editing, especially via CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats), offers a targeted, faster and more acceptable alternative to traditional genetic modification. To speed up genetic advancement in the fields of biology, medicine and agriculture, countries across the globe have embraced CRISPR-Cas systems.

In the early 2000s, Indian scientists became acquainted with global advances in genetic engineering and biotechnology, which stipulated the foundation for genome editing in India. In March 2022, India announced an important policy reform by excluding genome-edited plants (SDN-1 and SDN-2 categories) from the laws concerning genetically modified organisms (GMOs) under the Environment Protection Act (EPA), 1986. India's regulatory strategy is now more in accordance with the policies of countries that promote gene editing without transgenesis, including the United States, Japan and Argentina. The decision is anticipated to shorten regulatory periods for innovations in the public and private sectors. It has paved the way for the more rapid and secure adoption of genome-edited crops in Indian agriculture.

Revolutionizing Rice: The Rise of DRR Dhan 100 and Pusa DST Rice 1

1. DRR Dhan 100 (Kamala): A Genome-Edited Milestone in Bacterial Leaf Blight Resistance

In collaboration with the Indian Council of Agricultural Research (ICAR), the Indian Institute of Rice Research (IIRR) developed DRR Dhan 100, also called Kamala. In Indian agriculture, genome editing technology has made significant strides. The rice variety resistance to bacterial leaf blight (BLB), a potentially fatal and prevalent disease that significantly reduces crop yields in rice-growing regions of India, has been improved via genetic editing utilizing the potent CRISPR-Cas9 technology.

The precise knockout of the OsSWEET11 gene, a known susceptibility gene that pathogens utilise to infect rice plants, is necessary to develop such resistance. By inactivating this gene, researchers managed to prevent the bacterial pathogen *Xanthomonas oryzae pv. oryzae* from obtaining plant nutrients and preventing the disease from replicating in the crop. Being a non-transgenic genome-edited crop, DRR Dhan 100 is noteworthy since this improvement was made without the addition of foreign genes or transgenes.

This differentiation is crucial as it could potentially play a role in getting beyond the legal constraints and public concern that frequently pertain to genetically modified organisms (GMOs). By offering farmers an environmentally beneficial, economical and sustainable alternative to chemical pesticides for BLB management, DRR Dhan 100 ultimately serves to increase food security and deliver safer food.

2. Pusa DST Rice 1: Climate-Resilient Rice for a Water-Stressed Future

In parallel, the development of Pusa DST Rice 1, another notable advancement in rice improvement using genome editing, was pioneered by the Indian Agricultural Research Institute (IARI). The enhanced drought resistance and early maturity of this variety constitute two of the foremost pressing challenges confronting rice growers, especially in India's rainfed and water-scarce regions.

The DST (Drought and Salt Tolerance) gene is an antagonist of drought response, and researchers at IARI exploited the CRISPR-Cas9 system to target and alter it. In rice, the DST gene inherently suppresses certain pathways that ultimately facilitate drought resistance. The plant's innate ability to more efficiently conserve water, regulate transpiration and sustain development in low-humidity environments was unlocked by researchers by modifying this gene.

In addition to exhibiting improved drought resistance, Pusa DST Rice 1 attains maturity earlier than traditional varieties, allowing farmers to harvest the crop earlier and reducing the probability of crop failure from extreme weather. Since this variety is a non-transgenic genome-edited crop, like DRR Dhan 100, it reinforces the concept that genome editing may offer a precise and widely accepted approach to develop crops that are climate-resilient for the foreseeable future.

The Relevance of Genome Editing in Rice

1. **Speed and precision:** Unlike conventional breeding, which typically requires up to 10 years to produce the desired outcomes, genome editing could contribute to two to three years. This substantially speeds up variety development.
2. **Non-GMO categorisation:** Because genome-edited products like DRR Dhan 100 and Pusa DST Rice 1 lack the inclusion of foreign DNA, they are not classified as GMOs under India's extant regulatory framework, thus rendering them less objectionable to the farmers and consumers.
3. **Environmental Benefits:** Disease and drought-resistant rice reduces the demand for pesticides and irrigation, promoting environmentally friendly farming practices.
4. **Economic Profits:** Due to their higher crop yields and lower input costs, these varieties of rice offer an opportunity to enhance the livelihoods of farmers while ensuring food security.

The Impact of Socioeconomic Elements on Rural Development

The potential socioeconomic benefits of rice with a genome are tremendous. Consistent revenues correlate to steadier profits. When minimal chemical intervention is required, farmers and the environment both benefit. Economic viability is greatly increased by lower production expenses, which promotes new agricultural endeavors by subsequent generations. Their access to international markets is facilitated by the non-GMO variety. As a result, Indian rice could grow more competitive in international trade, and its export opportunities could expand.

Conclusion

An important turning point in Indian agriculture was marked by the introduction of the country's first genome-edited rice cultivars, DRR Dhan 100 and Pusa DST Rice 1. With their enhanced nutritional profiles, early maturation, and climate resistance, these advancements signify a paradigm shift towards precision breeding. By utilizing genome-editing technologies such as CRISPR, India has ushered in a new era of sustainable and farmer-friendly agricultural growth. This development not only boosts agricultural productivity and food security but also enhances India's image in the international biotechnology community. Such technologies can drastically transform crop production and rural livelihoods once they reach the farmlands.

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Bacillus: The Plant Probiotic Bacteria

Introduction:

Agriculture is the backbone of human civilization and it remains as an important sector for economic growth, food security, and sustainable development. It also involves crop cultivation, livestock rearing, and related activities that provides essential resources such as food, fiber, and raw materials for various industries. Since 50 years, global demand of food nearly tripled due to exponential rise in population. Also, agricultural productivity faces significant challenges from both biotic and abiotic stresses, leading to substantial crop losses worldwide. Biotic factors like pests, diseases, and weeds account for over 70% of agricultural losses, while abiotic stresses such as drought, salinity, and extreme temperatures contribute to more than 50% of losses **(Junaid & Gokce, 2024)**. To mitigate biotic stress agrochemicals are engaged while abiotic stress are managed through agricultural practices, specialized seeds and biotechnological strategies. Biotic and abiotic stress and simultaneously exerted on crop leading to crop loss. Farmers also encounter difficulties in managing and mitigating such circumstances. Biocontrol agents with multiple modes of action are solutions for climate smart agriculture. Plant growth-promoting microorganisms (PGPMs) like *Pseudomonas*, *Agrobacterium*, *Alcaligenes*, *Rhizobium*, *Stenotrophomonas*, *Streptomyces*, *Xanthomonas Bacillus*, *Alternaria*, *Penicillum* and *Trichoderma* have also been reported to manage various insects and pests of crop. Mechanisms include competitive exclusion of the pathogen and colonization of infected places as well as antagonistic activity resulting from the release of highly active antimicrobial agents such antibiotics or cell wall lytic enzymes and generation of plant resistance. One among the most often used beneficial bacteria as biopesticides are *Bacillus* that has received world wide acceptance and are also commercialized for management of various pathogens and diseases in agriculture.

Bacillus: The Revolutionary Bacterial Genera

Bacillus is derived from the latin word 'stick' representing the phylum 'Bacillota'. The genus *Bacillus* has a rich history in microbiology. *Bacillus* species can be either obligate aerobes which are dependent on oxygen, or facultative anaerobes which can survive in the absence of oxygen. *Bacillus anthracis*, the anthrax bacillus, was first observed microscopically by Pollender in 1849. *Bacillus thuringiensis* was isolated in 1915 by Berliner, though it had been previously described by Ishiwata in 1902. *Bacillus* species are gram positive, aerobic, sporulating, rod-shaped bacteria that are ubiquitous in nature.

Bacillus species are used in many medical, pharmaceutical, agricultural, and industrial processes that take advantage of their wide range of physiologic characteristics and their ability to produce a host of enzymes, antibiotics, and other metabolites. Bacitracin and polymyxin are two well-known antibiotics obtained from *Bacillus* species. Several species are used as standards in medical and pharmaceutical assays.

The term "plant probiotic bacteria" was first coined by Haas and Keel for bacteria that possess three key characteristics that contribute to better plant protection: (i) the ability to initiate induced systemic resistance (ISR) in their hosts, (ii) effectiveness and competitiveness in niche colonization, and (iii) the presence of direct antagonistic traits on pathogens. The capacity to generate a broad variety of metabolites that increase crop output by providing plants with different micronutrients, volatile chemicals, and antimicrobials that target diseases, *Bacillus* species have been a remarkable biological agent. The most amazing feature of *Bacillus spp.* is their capacity to generate a wide range of bioactive chemicals useful for agricultural use, including surface-active, antibacterial, and linked in the development of plant defensive responses. By either generating pores in the cell membrane or by interfering with the production of the cell wall, bacteriocins and bacteriocin-like molecules are ribosomally produced, peptides that act against target cells. Amylolysin, Amylocyclicin, Amysin, Subtilin, Subtilosin A, Subtilosin B, Thuricin are among the numerous bacteriocins produced by *Bacillus spp*. with antibacterial action. A few of them have participated in plant pathogen biocontrol like thuricin Bn1 from *B. thuringiensis* subsp. kurstaki has activity against *Pseudomonas savastanoi* and *Pseudomonas syringae*, and BacGM17 generated by *B. clausii* GM17 has activity against *Agrobacterium tumefaciens*.

Important role of *Bacillus* sp. in agriculture:

- *Bacillus* species play multifaceted roles in agriculture, serving as biocontrol agents against pests and diseases while promoting plant growth by elicitating systematic resistance against pathogens or by producing growth hormones like cytokinins, IAA, gibberellin, and spermidines.
- These bacteria enhance crop productivity through mechanisms such as phosphate solubilization, ACC-deaminase activity, and synthesis of phytohormones and siderophores.
- *Bacillus* strains produce various metabolites, including antibiotics, chitinase, and lipopeptides, which target pathogens and elicit systemic resistance in plants.
- They also confer tolerance to environmental stressors like heavy metals, drought, and salinity.
- The use of *Bacillus*-based formulations in agriculture is increasing due to their eco-friendly nature and potential for sustainable production.
- Molecular biology tools are employed to study genes involved in plant growth modulation by *Bacillus*, and optimal concentrations for bioproducts are established at 1 x 10^8 CFU/mL.

Role of *Bacillus* sp. in abiotic stress:

Bacillus species play a crucial role in enhancing plant tolerance to abiotic stresses, such as drought, salinity, and heavy metal toxicity. By colonizing the rhizosphere and phyllosphere, these bacteria control plant metabolic processes and produce biochemicals that reduce abiotic stress.

Table 1: Various products of *Bacillus* spp commercialized for agriculture benefits:

Sl no	Name of species	Product	Function
1.	*Bacillus subtilis*	FZB24	Enhancing plant vitality
2.	*Bacillus subtilis*	Kodiak	Suppression of soil-borne plant pathogens of cotton.
3.	*Bacillus velezensis*	Rhizovital	Bio stimulating microbial fertilizer
4.	*B. amyloliquefaciens*	Quantum - 400	Solubilize the P and fix the N in soil and increase their transport to roots
5.	*Bacillus subtilis*	Dipel, Javelin, Thuricin, Worm attack, Caterpillar killer, Bactospeine	Management of lepidopteran pests
6.	*Bacillus subtilis*		Bio floc technology

Bacillus-induced physiological changes in plants include the production of exopolysaccharides, siderophores, and phytohormones, which help regulate water transport, nutrient uptake, and antioxidant defense systems. These adaptations enable plants to better withstand adverse environmental conditions and maintain productivity. Plants colonized by *Bacillus* spp. take up more water, which is an important mechanism for plant protection against drought-induced damage. A microbial inoculation that includes *Bacillus* spp. can enhance plant growth during salt stress by phosphate solubilization, ammonia, IAA and siderophore production.

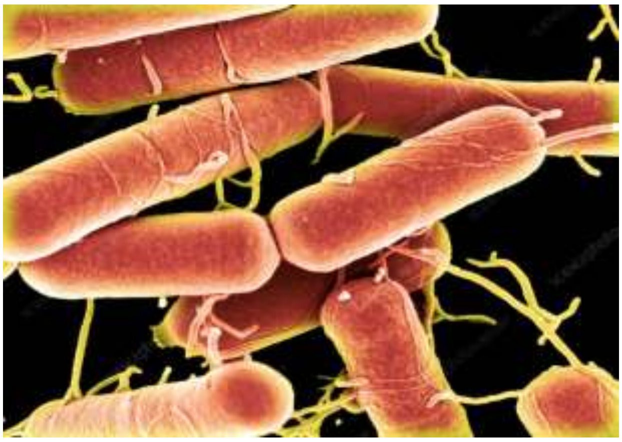

Fig 1: Image of *Bacillus* spp under SEM (Source: Library)

Fig 2: Commercial product of BT against lepidopteran pests

Conclusion and Future prospectives:

The global *Bacillus* market was estimated at $18 billion in 2020, with increasing patent submissions, indicating the growing importance of these bacteria in sustainable industrial applications. Biological methods provide a new ray of hope to enhance plant productivity and simultaneously curtailing the role of chemical fertilizer and pesticide. As the usage of chemical molecules are taking severe hit due to deleterious environmental outputs so there is a silent search for alternatives that advocate sustainability. Biocontrol agents including *Bacillus* spp. can be options that can be exercised for sustainable and organic management of pathogens and diseases. Bacillus bacteria have beneficial characteristics for plant growth, stress resistance, and bioremediation, with potential for future agricultural applications. The bacteria have diverse applications in biotechnology, agriculture, and environmental cleanup, with future prospects for sustainable solutions. So, *Bacillus* spp. promises to be a potential plant probiotic to improve crop productivity and immunity in adverse climatic conditions and soil deteorating conditions in current scenario that should be further worked upon.

Table 2: Various *Bacillus* spp isolated in India and abroad and its agriculture benefits:

me of *Bacillus* spp.	Place of Identification	ole in agriculture
cillus luciferensis	ganic farming soils, Sikkim, India	nt growth-promoting rhizobacteria (PGPR); solubilizes phosphate; controls pathogens.
cillus amyloliquefaciens	ganic farming soils, Sikkim, India	duces phytohormones; fixes nitrogen; enhances crop resistance and productivity.
cillus subtilis	ganic farming soils, Sikkim, India	ts as a biocontrol agent; antagonistic against phytopathogens l insect pests.
cillus thuringiensis	)1 – Japan (silkworms), 1911 – Thuringia, Germany	ological pesticide: produces Cry proteins toxic to insect larvae. Used in organic farming and Bt. crops.
cillus amyloliquefaciens	lated from soil in Japan by Juichiro Fukumoto in 1943	ocontrol agent; root colonizer; inhibits root pathogens; promotes plant health.
cillus firmus	rine sediment, South China Sea (2014)	matode control (e.g., *Meloidogyne* spp.); produces nematicidal proteins and induces systemic plant resistance.
cillus velezensis	First isolated from the river Velez in Maaga, southern Spain	ppresses plant pathogens; produces secondary metabolites; promotes growth in crops like cotton, tomato, and strawberry.

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BARRIERS FACED IN ACHIEVING ZERO HUNGER

Abstract

Hunger Remains the most pressing global challenge affecting over 735 million people worldwide. The United Nations Sustainable Development Goal 2 aims to eliminate hunger, ensure food security, improve nutrition and promote sustainable agriculture by 2030. But there are many barriers to progress such as climate change, food distribution, economics, disparities, and political allocation. This paper describes the major barriers to zero hunger such as environmental degradation, food waste, social inequalities, and proposes solutions such as agroecology, biotechnology, climate-smart and policy smart agriculture policy interventions. It emphasizes the need for collective action, improved food management and environmentally friendly agricultural methods, policies aimed at the fundamentals of hunger, and sustained global efforts. Every person having access to food is a major Goal in sustainable development because meeting this goal gafficates hunger, hunger, combatting poverty, and ensuring social equity while building a just sustainable world for people in the present and future. This in effect means addressing the issue of hunger—one of the harrowing realities facing millions. The main target of these goals however remains eluded due hurdles such as climate change, political challenges, and poverty. Effective approaches do exist but the level of unprecedented international collaboration, constant innovation, and irrefutable commitment is direly needed.

While solutions exist,true progress requires global cooperation, innovations and commitment to ensuring no one stays hungry.

Keywords: Zero Hunger, Food Security, Malnutrition, Agroecology, Biotechnology in Agriculture, Sustainable farming practices

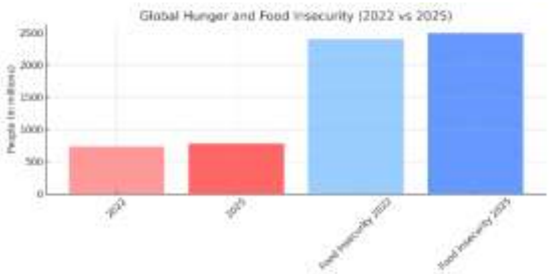
Introduction

Hunger remains one of the most pressing challenges of our time, affecting millions of people worldwide. As part of the global effort to tackle this issue, the United Nations introduced Zero Hunger as the second Sustainable Development Goal (SDG-2), with the ambitious target of ending hunger by 2030. This goal is not just about providing food—it's about ensuring that everyone has access to safe, nutritious, and sufficient food for a healthy life. However, despite global efforts, hunger and food insecurity have been on the rise since 2015. Various challenges, including the COVID-19 pandemic, ongoing conflicts, climate change, and widening social and economic inequalities, have only made the situation worse.

Achieving Zero Hunger requires urgent and collective action to address these root causes and create a future where no one has to go to bed hungry.

By 2022, an estimated 735 million people—about 9.2% of the global population—were living with chronic hunger, a sharp and troubling increase from 2019. This growing crisis highlights the urgent need for action. On top of this, around 2.4 billion people experienced moderate to severe food insecurity in 2022,

Hunger and food insecurity continue to escalate due to a complex mix of factors, including conflict, climate change, economic instability, and global inequalities. Without urgent intervention, these numbers will only worsen. Hunger isn't just about missing meals—it's a cycle that traps people in poverty. Malnutrition weakens the body, making individuals more susceptible to illness, reducing productivity, and limiting opportunities to improve their lives. Addressing this crisis isn't just about providing food; it's about breaking this vicious cycle and creating a path toward sustainable development for all.



In 2015, 192 countries came together to adopt the United Nations 2030 Agenda for Sustainable Development, setting 17 ambitious goals to tackle global challenges. Among them, SDG 2: Zero Hunger aims to eradicate hunger and malnutrition worldwide. While progress has been made, the fight is far from over—by 2019, 8.9% of the global population is still undernourished, 1.5 billion people lack essential nutrients, and adult obesity has surpassed 13%.

The COVID-19 pandemic further worsened food insecurity, as lockdowns and economic disruptions made access to food even more difficult for many. At the same time, agriculture and human activities have been driving large-scale environmental changes, pushing our planet beyond safe limits. Recognizing this, the 2030 Agenda integrates environmental sustainability into global development efforts. To navigate these complex challenges, experts are working to model the global food system, identifying ways to balance food security, sustainability, and economic growth for a better future.

The COVID-19 pandemic caused major new obstacles to the attainment of zero hunger while compounding existing ones, with effects that still resonate through global food systems years after the first outbreak.

Barriers to Reaching Zero Hunger: International Challenges and Complications

Zero hunger in 2030, as incorporated into Sustainable Development Goal 2, is highly challenged notwithstanding international pledges. Existing projections show that the world is not headed towards ending hunger in the desired time, as it unfolds with alarming trends pointing to deteriorating circumstances. If current trends persist, hunger will impact over 840 million individuals by the year 2030-roughly 10% of the world's population. This in-depth study looks at the complexities of barriers to reaching zero hunger, considering how interconnected issues make it difficult to break cycles of food insecurity globally.

The Current State of Zero Hunger in 2025: A Growing Crisis Amidst Global Challenges

Hunger remains one of the most pressing challenges in 2025, affecting millions of people around the world who struggle every day to find enough nutritious food. Despite years of effort under the United

Nations' Zero Hunger goal, the dream of a world without hunger is slipping further out of reach. Instead of progress, food insecurity is rising, fueled by economic hardships, climate disasters, conflicts, and deep-rooted inequalities. For countless families, putting a meal on the table is becoming harder than ever, turning what should be a basic human right into a daily battle for survival.

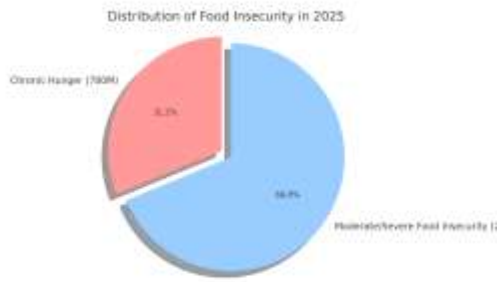
Rising Food Insecurity and Malnutrition

In 2025, hunger is a daily reality for an estimated 780 million people, a heartbreaking rise from previous years. Beyond that, over 2.5 billion people struggle with some level of food insecurity, unsure where their next meal will come from. The crisis is most severe in war-torn regions, drought-stricken areas, and communities grappling with economic hardship. Malnutrition is becoming more widespread, not just in the form of hunger but also in rising obesity rates, creating a serious global health challenge. Children are the hardest hit—nearly 45 million kids under five are suffering from wasting, a life-threatening condition that leaves them dangerously undernourished and weak. For these children, every meal can mean the difference between survival and tragedy.

Key Challenges Feuling Hunger Crisis

In 2025, feeding the world has become an even greater challenge. For millions, hunger is a daily reality, made worse by climate change, conflict, and economic instability. At the same time, the way we produce food is reshaping the planet—deforestation, soil degradation, and water shortages are pushing ecosystems beyond safe limits.

Recognizing these urgent threats, the global community has made sustainability a core part of its fight against hunger. As part of the 2030 Agenda for Sustainable Development, experts are working to rethink the global food system—seeking solutions that not only provide enough food for everyone but also protect the environment and support economic growth. With the right policies and innovations, a better future is possible—one where no one goes hungry, and the way we feed the world doesn't come at the cost of our planet's health.



The Way Forward: Action Needed

With just five years left to meet the goal of Zero Hunger, the world is at a critical crossroads. If we want to end hunger, we need urgent and united action from governments, humanitarian groups, and the private sector to create lasting change:

1. Build Climate-Resilient Agriculture: Farmers need better tools, technology, and support to grow food even as climate change brings more droughts, floods, and unpredictable weather.

2. Make Food More Accessible and

Affordable: Strengthening food supply chains can help people especially in vulnerable communities and can find and afford nutritious food.

3. Tackle Conflict and Economic Inequality: Wars, political instability, and widening wealth gaps are pushing more families into hunger. We need policies that protect people's ability to earn a living and feed their families.

4. Improve Nutrition for the Most Vulnerable: Millions of children, pregnant women, and the elderly suffer from malnutrition. Investing in nutrition programs can save lives and help future generations thrive.

the IoT devices' limitations, which include low power consumption and limited processing capacity (Lone et al., 2023).

Literature Review: Barriers to Achieving Zero Hunger (SDG 2)

1. Introduction to Zero Hunger (SDG 2)

The United Nations' Sustainable Development Goal 2 (SDG 2): Zero Hunger was introduced with a bold vision—to end hunger, ensure food security, improve nutrition, and promote sustainable agriculture by 2030. However, despite global efforts, hunger remains a pressing issue, with over 735 million people suffering from undernourishment as of 2022 (FAO, 2023).

Organizations like the Food and Agriculture Organization (FAO) and the World Food Programme (WFP) highlight the complex web of challenges that continue to hinder progress. Economic instability, climate change, ongoing conflicts, and technological limitations all contribute to food insecurity, making it difficult for millions to access the nutrition they need (FAO, 2023; WFP, 2022).

This literature review takes a deeper look at these barriers—examining the economic, political, environmental, technological, and social factors that are preventing the world from achieving Zero Hunger. Understanding these challenges is crucial in shaping effective solutions and ensuring that no one is left behind in the fight against hunger.

2. Economic Barriers to Zero Hunger

Economic constraints are one of the primary barriers to achieving food security. Several studies have highlighted the relationship between poverty, food affordability, and hunger.

2.1 Poverty and Income Inequality

Poverty remains one of the most significant drivers of food insecurity, particularly in low-income countries, where families often spend more than 60% of their income just to afford food (Smith et al., 2021). When so much of a household's budget is consumed by food expenses, little remains for healthcare, education, and other essentials, perpetuating the cycle of poverty.

According to the Food and Agriculture Organization (FAO, 2022), extreme poverty not only limits access to nutritious food but also restricts opportunities for farmers to invest in agricultural resources, making it difficult to improve food production and distribution. Additionally, social welfare programs that could provide relief are often insufficient or inaccessible to those in the most vulnerable communities.

Regions with high levels of income inequality, such as Sub-Saharan Africa and South Asia, experience some of the worst hunger crises in the world (World Bank, 2022). The gap between the wealthy and the poor in these regions means that while some have more than enough resources, millions struggle daily to access even the most basic nutrition. Addressing poverty and inequality is crucial to breaking this cycle and ensuring food security for all.

Real-life Example: Venezuela has experienced a deep economic and political crisis since around 2013, with hyperinflation, currency collapse, and massive unemployment. According to the World

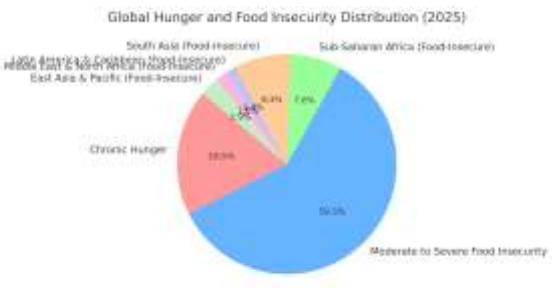
Bank and the World Food Programme (WFP), **over 90% of Venezuelans were living in poverty** by 2021, and millions suffered from food insecurity.

2.2 Food Price Volatility & Inflation

For low-income households, rising food prices can mean the difference between having a meal or going hungry. Studies by Tadesse et al. (2021) reveal that fluctuations in food prices, driven by supply chain disruptions, trade restrictions, and climate change, disproportionately affect vulnerable populations.

A striking example of this occurred during the 2007–2008 global food crisis, when wheat and rice prices surged by over 200%, pushing millions into hunger (Headey & Fan, 2010). More recently, the Russia-Ukraine war has led to wheat shortages, further escalating food prices worldwide (FAO, 2023). As essential staples become more expensive, struggling families find it even harder to access sufficient and nutritious food, worsening the global hunger crisis.

Addressing these challenges requires urgent action—reducing poverty, stabilizing food prices, and ensuring equal



access to resources are key steps toward achieving a world free from hunger.

Real-life Example: Venezuela has experienced a deep economic and political crisis since around 2013, with hyperinflation, currency collapse, and massive unemployment. According to the World Bank and the World Food Programme (WFP), over 90% of Venezuelans were living in poverty by 2021, and millions suffered from food insecurity.

2.3 Growing Economic Inequalities

Economic inequality remains one of the core barriers to achieving zero hunger. Despite global food production being sufficient to feed the population, millions remain hungry due to lack of access and purchasing power, especially in rural or impoverished areas. Poorer households often spend a large portion of their income on food, making them more vulnerable to price shocks and inflation. As a result, hunger is not always about food scarcity but about economic exclusion from food systems.

Real-life Example: During the 2010 food price crisis, global food prices surged dramatically, leading to riots and social unrest in over 30 countries including Haiti, Egypt, and Bangladesh. In Haiti, where over 50% of the population lives in poverty, the price of staple foods like rice became unaffordable for many, causing widespread hunger despite availability.

2.4 Financing Challenges in Low- and Middle-Income Countries

A significant number of low- and middle-income countries lack sufficient **financial resources to implement robust food security programs**. Budget constraints, debt burdens, and reliance on external aid often mean that hunger reduction programs are underfunded or poorly implemented. These countries struggle to invest in sustainable agriculture, infrastructure, or social protection systems, leaving the most food-insecure populations without reliable support.

Real-life Example: In **South Sudan**, ongoing food insecurity has been intensified by

inadequate funding for humanitarian efforts. Despite urgent needs, many UN food assistance operations in the region have been **cut or delayed** due to funding gaps, leaving millions at risk of starvation in a country already plagued by conflict and economic instability.

3. Political Barriers to Zero Hunger
3.1 Poor Governance & Corruption

Weak governance structures and widespread corruption severely hinder efforts to achieve food security, particularly in vulnerable and conflict-affected regions. As noted by Anderson & Johnson (2020), mismanagement and corrupt agricultural policies often lead to the diversion of critical funds intended for food production and distribution. This not only stalls agricultural development but also undermines the reach and efficiency of food aid programs.

According to Transparency International (2022), corruption within food assistance initiatives—such as embezzlement, favoritism, and manipulation of beneficiary lists—frequently results in unequal and inefficient distribution of aid, especially in regions experiencing political instability. These practices disproportionately harm impoverished and marginalized populations who rely on such support for survival.

Furthermore, poor regulatory oversight and lack of transparency in government procurement and subsidy systems can inflate food prices, exclude small-scale farmers from markets, and enable monopolies that restrict fair food access.

Real-Life Example: Somalia provides a stark illustration of how governance failure and corruption exacerbate hunger.

In 2011, during a devastating famine that killed over 250,000 people, investigations revealed that a significant portion of international food aid was diverted by corrupt officials and local militias.

According to the United Nations Monitoring Group on Somalia, up to 80% of food aid in Mogadishu was misappropriated, often sold on the black market instead of being delivered to those in desperate need.

3.2 Conflict & War

Armed conflicts disrupt agricultural production, food supply chains, and humanitarian aid efforts. A study by Brinkman & Hendrix (2021) shows that 70% of people facing food insecurity live in conflict-affected areas such as Syria, Yemen, and South Sudan. The United Nations Security Council (UNSC, 2022) reported that wars in these regions led to severe food shortages as farmland was destroyed and markets became inaccessible. Additionally, the forced displacement of farmers and rural populations creates significant labor shortages in already fragile agricultural areas. Transportation routes and marketplaces are frequently blocked or destroyed, cutting off food supply chains and making it nearly impossible for essential goods to reach civilians. Moreover, conflict often results in the collapse of local economies, leaving millions without income or purchasing power to afford basic food items. Humanitarian efforts are further hindered by the obstruction or even targeting of aid convoys, which prevents critical food relief from reaching the most vulnerable. Together, these consequences deepen the hunger crisis and make sustainable food security nearly unattainable in conflict zones.

Real-Life Example: South Sudan's Civil Conflict

South Sudan's civil war, which began in 2013, led to widespread hunger:

Armed groups have looted food warehouses, burned crops, and displaced entire farming communities.

Floods and insecurity have exacerbated the situation, making food production and aid delivery nearly impossible.

As of 2022, over 60% of South Sudan's population faced severe food insecurity (FAO & WFP, 2022).

4. Environmental Barriers to Zero Hunger

4.1 Climate Change & Extreme Weather Events

Climate change and extreme weather events are increasingly threatening global food security by disrupting agricultural systems and reducing crop productivity. The Intergovernmental Panel on Climate Change (IPCC, 2021) reports that global warming has already led to a 20% decline in staple crop yields such as wheat, maize, and rice—essential sources of food for billions. Shifting rainfall patterns, prolonged droughts, and more frequent floods have made farming unpredictable and less productive. For instance, the Sahel region in Africa has experienced recurring droughts, devastating harvests and pushing millions into hunger. Similarly, in India, severe droughts in states like Maharashtra and Tamil Nadu have resulted in massive crop failures, forcing farmers into debt and increasing rural food insecurity. These environmental stressors make it increasingly difficult for vulnerable populations to access adequate nutrition and threaten long-term progress toward achieving Zero Hunger.

Real-Life Example: The 2015–2016 drought in Ethiopia, part of the broader Horn of Africa drought crisis, was triggered by one of the strongest El Niño events in recorded history and marked the country's worst drought in over 30 years. This climate-induced disaster severely impacted both of Ethiopia's primary growing seasons, leading to the failure of crops and the death of millions of livestock. As a result, over 10 million people were left in urgent need of emergency food assistance, with farming communities bearing the brunt of the crisis. The root cause lay in the irregular rainfall patterns and extreme heat brought on by climate change and El Niño, which disrupted planting cycles and dried up water sources. In response, the Ethiopian government, supported by international humanitarian agencies, scaled up efforts in food distribution and agricultural recovery. Despite these measures, the long-term effects were significant—food prices soared, child malnutrition rose, and the economic stability of rural households suffered greatly, highlighting the deep link between climate change and food insecurity.

4.2 Soil Degradation & Water Scarcity

Soil degradation and water scarcity are critical environmental challenges that directly threaten global food security. Degraded soil—caused by overuse, deforestation, chemical fertilizers, and erosion—loses its essential nutrients, reducing agricultural productivity and crop yields. At the same time, increasing water scarcity, driven by climate change, over-irrigation, and poor water management, limits the availability of water for farming. Together, these factors make it difficult to grow enough food to meet the needs of growing populations, especially in already vulnerable regions. Countries like India, Ethiopia, and parts of Sub-Saharan Africa have faced severe impacts, where barren land and dried-up water sources have led to crop failures, food shortages, and rising hunger levels. To achieve Zero Hunger, it is vital to promote sustainable farming practices, soil conservation, and efficient water use.

Real-Life Example: Between 2016 and 2019, Maharashtra, a major agricultural state in India, experienced severe droughts and soil degradation that deeply affected food production. Years of over-irrigation, deforestation, and poor land management led to the depletion of groundwater and the loss of fertile topsoil. Farmers in districts like Marathwada and Vidarbha saw repeated crop failures—particularly of water-intensive crops like sugarcane and cotton.

Impact: Over 80% of rural households in affected regions faced food insecurity. Thousands of farmers were forced to migrate to cities in search of work. Reports of farmer suicides increased dramatically due to debt and crop losses. Local food markets experienced shortages and rising prices for basic staples.

The Impact of the COVID-19 Pandemic:

The COVID-19 pandemic, which began in late 2019, quickly evolved into a global health crisis, but its impact extended far beyond hospitals and healthcare systems. It triggered one of the most severe disruptions to global food systems in modern history. The pandemic magnified existing barriers to achieving Sustainable Development Goal 2: Zero Hunger, while introducing new challenges that continue to affect food security years later.

1. Collapse of Food Supply Chains

One of the earliest and most visible impacts of COVID-19 was the breakdown of food supply chains. Lockdowns, curfews, and movement restrictions across countries led to the **inability of farmers to access markets**, and **perishable produce** such as fruits, vegetables, and dairy products were left to rot in fields.

Real-Life Example: In **India**, the national lockdown in March 2020 prevented farmers from selling their crops. Truck drivers were unable to transport vegetables from farms to urban markets due to roadblocks and police restrictions. The result was a paradox: **food surplus in rural areas and scarcity in cities**, causing prices to rise in cities while farmers suffered losses.

2. Rising Unemployment and Loss of Income

The pandemic caused mass layoffs and wage cuts, especially in the informal sector—which accounts for a large portion of employment in developing countries. With no income, families struggled to purchase food, especially in urban slums and rural settlements.

According to the **World Bank (2021)**, the pandemic pushed nearly **97 million people into extreme poverty**, many of whom could no longer afford basic food items. Food banks saw unprecedented demand.

Real-Life Example: In **South Africa**, over 2 million jobs were lost in the first three months of lockdown. The poorest households, particularly in townships, reported missing multiple meals per week. Social unrest and food riots broke out in areas like **Soweto**, where communities protested food shortages and delays in government aid.

3. Disruption of School Meal Programs

School closures in more than 190 countries affected **over 1.5 billion students**, cutting off a key source of daily nutrition for children in low-income households. In many regions, school meals were the only guaranteed meal a child received.

Real-Life Example: In **Kenya**, over 1.5 million children lost access to school-based meals. Many families, already facing job loss, could not compensate for this loss at home. As a result, **malnutrition rates surged**, particularly in urban informal settlements like Kibera in Nairobi.

4. Increased Food Prices

COVID-19 caused disruptions in food production and distribution, which led to rising prices globally. Panic buying, export restrictions, and hoarding worsened the situation.

The **Food and Agriculture Organization (FAO)** reported that global food prices rose by over **28% between 2020 and 2021**—the largest increase in a decade.

Real-Life Example: In **Lebanon**, already facing economic turmoil, the price of basic staples like bread and cooking oil doubled during the pandemic. The World Food Programme reported that **more than 50% of Lebanese households were food insecure** by 2021.

5. Obstructed Humanitarian Aid

The pandemic severely affected humanitarian operations. Border closures and lockdowns slowed or halted the delivery of emergency food aid, especially in conflict-affected regions.

Real-Life Example: In **Yemen**, a war-torn country already dependent on food aid, COVID-19 restricted UN and NGO operations. As a result, **nearly 16 million people were pushed into acute food insecurity**. The **World Food Programme** was forced to cut rations in some areas due to both supply issues and funding constraints.

Research Problem

1. Socioeconomic Barriers to Accessing Nutritious Food

Despite the availability of food in many regions, a significant portion of the population remains undernourished or malnourished. This paradox often arises not from food scarcity, but from social and economic limitations that prevent equitable access. This research investigates how three key socioeconomic indicators—income level, education, and employment status—collectively and independently influence an individual's or a household's ability to access sufficient, safe, and nutritious food, with a focus on low-income and marginalized communities.

Objectives of the Study:

- To analyze the relationship between household income levels and the quality/quantity of food consumed.
- To assess how educational attainment influences food choices and nutritional awareness.
- To evaluate how employment status (formal/informal/unemployed) affects food purchasing power and stability of food access.
- To identify and document the primary socio-economic obstacles preventing access to a balanced diet.
- To suggest policy-level and technology-driven interventions that can bridge these socioeconomic gaps in food access.

Key Concepts to Explore in Detail:

1. **Income Inequality:**
   - Direct link between purchasing power and dietary diversity.

- Hidden hunger due to consumption of cheap but nutrient-poor food.

- Food inflation and its disproportionate effect on the poor.

Education and Nutrition Awareness:

- Educated individuals make more informed food choices.
- Lack of nutritional literacy leads to poor food planning, even if income is modestly sufficient.
- Intergenerational impact: parents' education levels affect children's nutrition outcomes.

Employment and Food Security:

- Informal sector jobs often offer low wages and no job security, affecting food affordability.
- Unemployment leads to erratic food access and increased dependence on public distribution or charities.
- Migration and seasonal labor patterns also contribute to unstable food access.

2. Technological Barriers in Small-Scale Farming

Smallholder farmers are the backbone of food production in many developing countries, contributing over 70% of the total food output. However, their productivity remains significantly low due to limited access to and adoption of modern agricultural technologies. These technologies—which include precision farming tools, improved seed varieties, mechanized equipment, irrigation systems, and digital platforms—have the potential to drastically improve yields, reduce labor, minimize post-harvest losses, and ensure food security. Despite their proven benefits, small-scale farmers often encounter a range of technological, financial, social, and infrastructural barriers that prevent adoption. This research aims to explore these challenges in detail and understand how they affect productivity and sustainability in small-scale farming.

Objectives of the Study:

- To identify the modern agricultural technologies that are beneficial for small-scale farming.
- To investigate the key challenges (economic, educational, infrastructural, and social) faced by smallholder farmers in adopting these technologies.
- To analyze how the lack of access to technology contributes to low productivity and food insecurity.
- To evaluate the role of government and private sector initiatives in addressing technological gaps.
- To recommend strategic interventions that can improve the technological adoption rate among smallholder farmers.

Key Challenges Faced by Smallholder Farmers:

1. **Financial Constraints:**
   - High cost of equipment and advanced inputs.
   - Limited access to agricultural loans and micro-financing.
   - Poor insurance coverage and risk mitigation support.

2. **Lack of Technical Knowledge and Training:**
   - Low awareness of available technologies.
   - Limited extension services or training programs.
   - Language and literacy barriers in using digital tools or manuals.

3. **Inadequate Infrastructure:**

- Poor road connectivity affecting delivery of tech products.
- Unreliable electricity and internet access for smart tech usage.
- Lack of cold storage and transport leading to post-harvest losses.

4. **Social and Cultural Factors:**

- Resistance to change and preference for traditional methods.
- Gender disparities in access to technology and resources.
- Lack of trust in external interventions or government schemes.

5. **Policy and Institutional Gaps:**

- Inconsistent or insufficient government support and subsidies.
- Weak linkage between research institutions and local farmers.
- Bureaucratic hurdles in accessing state-sponsored schemes.

3. Impact of Climate Change on Local Food Security

Climate change is one of the most significant threats to global food security in the 21st century. In many vulnerable regions, particularly those in low- and middle-income countries, agriculture remains heavily dependent on predictable weather conditions. Increasingly erratic rainfall patterns, rising temperatures, prolonged droughts, unseasonal storms, and frequent flooding caused by climate change have directly affected agricultural productivity and disrupted food systems. This research aims to explore the extent to which climate variability impacts crop yields and food availability in vulnerable regions, with an emphasis on understanding local coping mechanisms and proposing sustainable solutions to mitigate the effects of climate-induced food insecurity.

Objectives of the Study:

- To examine how changing climate patterns (rainfall, temperature, extreme events) influence crop yields in vulnerable regions.
- To assess the impact of these changes on local food availability and accessibility.
- To identify geographic regions and communities most affected by climate-induced food insecurity.
- To evaluate the adaptive capacity of farmers and food systems in response to climate shocks.
- To suggest policy recommendations and sustainable agricultural practices that can mitigate the negative effects of climate change on food security.

Key Factors and Challenges:

1. **Erratic Rainfall and Drought:**

- Crops depend on predictable rainfall patterns; changes disrupt sowing and harvesting cycles.
- Drought leads to lower yields and higher food prices, disproportionately affecting poor households.

2. **Rising Temperatures:**

- Excessive heat reduces soil moisture and leads to heat stress in crops.
- Affects crop growing seasons, particularly for temperature-sensitive crops like wheat and maize.

3. **Floods and Storms:**

- Sudden heavy rains cause soil erosion, destroy standing crops, and damage storage facilities.
- Livelihood loss for smallholder farmers and disruption in local food markets.

4. Decline in Soil Fertility:

- Temperature and rainfall changes degrade soil health, affecting long-term productivity.

5. Pest and Disease Outbreaks:

- Warmer climates create favorable conditions for pests and diseases that threaten crops.

6. Livelihood Disruption:

- Agriculture-dependent communities face food insecurity due to yield instability and income loss.
- Women and marginalized groups are particularly vulnerable.

Methodology

I am conducting my research by using a **qualitative approach**. This means I am not collecting new data through surveys or experiments. Instead, I am analyzing **existing information** from reliable sources such as reports, articles, and case studies published by organizations like the **United Nations (UN)**, **FAO**, **World Food Programme (WFP)**, and **academic journals**.

The research involves carefully reading and examining these documents to identify common barriers to achieving Zero Hunger. I am organizing the information into key themes (like poverty, food waste, and climate change) and then explaining possible solutions based on what experts and global programs have already suggested.

This research is **qualitative** in nature. It focuses on understanding and interpreting the **barriers to achieving Zero Hunger** by analyzing **existing reports, case studies, and academic literature**. Rather than using numbers or statistical data, qualitative research emphasizes **themes, patterns, and expert insights** drawn from trusted sources such as the **United Nations**, **FAO**, **WFP**, and peer-reviewed journals. This approach allows for a deeper exploration of complex issues like food insecurity, poverty, and policy challenges, and helps in suggesting practical and theoretical solutions.

Qualitative Research Approach: Understanding Barriers to Zero Hunger

a. Rationale for Qualitative Approach

Qualitative research is particularly well-suited for examining complex social issues like hunger, as it:

- Emphasizes Depth Over Breadth: By analyzing narratives, expert opinions, and thematic patterns, qualitative research provides a nuanced understanding of the underlying causes and consequences of hunger.
- Explores Contextual Factors: It allows for the examination of how cultural, political, and economic contexts shape the effectiveness of interventions and policies.
- Highlights Human Experience: This approach brings forward the voices and experiences of affected communities, policymakers, and practitioners, offering insights that numbers alone cannot capture.

b. Data Sources

To ensure reliability and depth, this research draws from trusted and authoritative sources, including:

- United Nations (UN) reports
- Food and Agriculture Organization (FAO) publications
- World Food Programme (WFP) case studies
- Peer-reviewed academic journals

c. Analytical Focus

The analysis centers on identifying themes, patterns, and expert insights related to:

- Structural and systemic barriers (e.g., conflict, climate change, economic inequality)
- Policy and governance challenges
- Social and cultural factors influencing food security
- Practical and theoretical solutions proposed in the literature.

d. Contribution

By leveraging qualitative methods, this research aims to:

- Illuminate the complexity of achieving Zero Hunger
- Inform policymakers and practitioners about the nuanced barriers and potential pathways forward
- Suggest actionable recommendations grounded in real-world experiences and expert consensus

Conclusion

Hunger continues to be one of the most urgent and complex global challenges of our time. Despite numerous international efforts and strategic goals like SDG 2, the journey toward achieving Zero Hunger by 2030 remains deeply obstructed by a range of socioeconomic, environmental, political, and technological barriers. This research has shown that food insecurity is not merely a matter of insufficient supply but is rooted in structural issues such as poverty, inequality, weak governance, conflict, and the growing impacts of climate change.

The analysis also highlighted how smallholder farmers—who form the backbone of food production in many developing nations—struggle with limited access to modern technologies, financial resources, and institutional support. Climate change, with its unpredictable weather patterns and extreme events, has only worsened the situation by disrupting agricultural cycles and damaging food systems. Additionally, the COVID-19 pandemic has had long-lasting effects on food supply chains, employment, and nutrition, reversing years of progress.

While the barriers are significant, this research also points to pathways for hope. Technological innovations, climate-resilient agriculture, improved governance, and targeted policies can make a substantial difference. However, these solutions require coordinated global cooperation, inclusive policy-making, and sustained investment. Achieving Zero Hunger is not just a goal—it is a moral obligation to ensure that every individual, regardless of their background or geography, has the right to safe, sufficient, and nutritious food.

The way forward must involve integrating knowledge, resources, and compassion. Only through collective action—by governments, global organizations, private sectors, and local communities—can we transform hunger from a crisis into a solvable challenge and move closer to a more just, equitable, and food-secure world.

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CLEAN AND SAFE: EFFECTIVE HOUSEHOLD METHODS TO REDUCE PESTICIDE RESIDUES IN FRESH PRODUCE

Introduction

Agricultural pesticide applications have become fundamental for crop protection because they preserve secure food supplies. The improper and overuse of chemical pesticides creates multiple health threats to humans and environmental damage. More than 500 - 600 different pesticides are currently utilized in India for insecticides, fungicides, herbicides acaricides *etc*., The chemicals used for spraying produce residues that linger on fruits and vegetables if producers fail to observe the recommended waiting times. Pesticides at any concentration show links to health problems that include endocrine disruption, neurotoxicity, carcinogenicity, immune suppression and many others. The remaining pesticide residues on the surface of the produce have the potential to enter the human body through consumption which results in progressive health problems. The elimination of these residues must be done before food consumption since it builds the foundation of safe food handling. The following study examines different basic methods which demonstrate scientific validity and operational affordability that consumers and farmers can use to minimize pesticide residue on their produce effectively.

Pesticide Residues and their Persistence

Pesticide Use in India

India stands as one of the leading countries in pesticide consumption throughout Asia. Organophosphates together with carbamates, pyrethroids and neonicotinoids represent the primary pesticide groups that farmers use. Food crops build up toxic substances because of wrong pesticide application methods, excessive use and failure to follow Good Agricultural Practices (GAPs).

Persistence and Waiting Period

The Pre-Harvest Interval (PHI) determines the waiting period until the residue levels reach safe levels before harvest. Many farmers fail to observe the waiting period because market demands or insufficient knowledge cause them to ignore it.

Health Implications

The WHO together with the FAO has established that enduring exposure to pesticide residues generates different health problems.

- Developmental and behavioural disorders in children
- Reproductive toxicity
- DNA damage and increased cancer risk
- Hormonal imbalance

Post-harvest decontamination practices at consumer level need to become essential because of these identified risks.

Methods for Removing Pesticide Residues

Different physical and chemical methods exist to evaluate their effectiveness in removing pesticide residues from fruits and vegetables. The various removal methods differ in terms of their cost efficiency and accessibility together with their effectiveness levels.

1. Tap Water Washing

Running tap water washing produces pesticide residue removal rates between 30 - 50% which depends on both produce type and pesticide type. Light surface friction improves the washing process.

2. Salt Water Wash

A salt water solution (2%) made from 20g salt dissolved in 1 litre of water proves highly successful as a pesticide remover. The soaking of produce for 30 seconds to 1 minute period removes approximately 90% of surface residues especially in contact pesticides.

3. Baking Soda Solution

Baking soda (sodium bicarbonate) shows weak alkalinity that helps break down specific pesticides. A mixture of baking soda at 1 tablespoon dissolved in 1 litre of water produces an effective alkaline solution for residue hydrolysis.

4. Vinegar Wash

A mixture of vinegar diluted with water in a ratio of 1:3 effectively denatures pesticide residues. The solution shows effectiveness in fungicide removal and serves as a natural disinfectant.

5. Lemon Juice and Baking Soda

When lemon juice (citric acid) mixes with baking soda (alkali) it creates a fizzing reaction which breaks down residues and suitable for human consumption.

6. Turmeric Water Wash

The antimicrobial and detoxifying abilities exist in turmeric. Addition of small amount of turmeric to water and washing the vegetables and fruits effectively removes pesticide residues.

7. Peeling

The outer vegetable layers contain high concentrations of residues so peeling these sections effectively removes them.

8. Blanching

Vegetables need to soak in hot water at 80 - 90°C for 30 - 60 seconds and then require quick cooling in cold water through blanching. This procedure works well for leafy greens.

Limitations

- The methods primarily work to eliminate surface-based residues.
- Systemic pesticides that penetrate tissue structures remain difficult to eliminate from produce.
- Combined approaches, e.g., washing + peeling may offer better results.

Conclusion and Recommendations

Public health is threatened by pesticide residues that remain on fruits and vegetables because developing nations lack strong pesticide residue monitoring systems. The long-term objective involves both pesticide reduction and organic farming promotion yet short-term solutions can be obtained through basic cleaning techniques.

Key Recommendations

For farmers

- Use pesticides judiciously and only when needed.
- The recommended harvest waiting periods must be observed exactly as stated.
- Seek training in Integrated Pest Management (IPM).

For consumers

- Consumers should wash their produce either with water mixed with salt solution or baking soda solution.
- Peel when possible and blanch leafy greens.

Final Thoughts

The foundation of safe food consumption starts from raising awareness about proper practices while farmers and consumers implement them at their respective stages. Rural communities require educational programs together with village awareness campaigns to develop their empowerment and achieve pesticide-free food.

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DUS Characterization in Legume Crops: A Tool for Variety Protection and Improvement

1. Introduction

Legume crops, including chickpea, pigeon pea, lentil, mung bean, urd bean, soybean, and others, are essential components of global agriculture due to their high protein content, ability to fix atmospheric nitrogen, and adaptability to diverse environments. The improvement of legume varieties is essential for enhancing yield, stress tolerance, and nutritional quality. In this context, DUS characterization serves as a standardized tool to ensure the distinctiveness, uniformity, and stability of new and existing legume varieties.

DUS testing is a legal and scientific requirement for the protection of new plant varieties under the International Union for the Protection of New Varieties of Plants (UPOV) and national laws such as the Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act in India. It ensures that a variety proposed for registration is novel, identifiable, and reproducible, thus supporting plant breeders' rights and agricultural innovation.

2. Concept of DUS Testing

DUS testing involves the assessment of three fundamental criteria:

- **Distinctness**: The variety must be clearly distinguishable from any other known variety.
- **Uniformity**: The individuals of the variety must show a consistent phenotype with limited variation.
- **Stability**: The variety must retain its distinct characteristics across successive generations or environments.

These criteria are evaluated using morphological, physiological, and sometimes molecular descriptors under prescribed testing protocols.

3. Legal Framework and Importance

3.1 UPOV Convention

The UPOV Convention provides an international framework for plant variety protection, and DUS testing is a cornerstone of this system. Member countries adopt standardized testing protocols for different crops, ensuring international harmonization.

3.2 PPV&FR Act, 2001 (India)

India's PPV&FR Act is a pioneering legislation that balances breeders' rights with farmers' rights. DUS testing is mandatory for the registration of varieties, whether they are new, extant, or farmers' varieties. The Act ensures, Legal protection for new varieties, Recognition of traditional knowledge, Facilitation of benefit-sharing.

3.3 Role in Variety Registration and Certification

DUS characterization forms the basis for:

- Grant of plant breeders' rights
- Entry into national and international germplasm databases
- Eligibility for seed certification
- Quality assurance in seed production

4. Methodology of DUS Testing in Legumes

DUS testing is conducted under field or controlled conditions following established guidelines for each crop. The PPV&FR Authority and UPOV have published crop-specific descriptors for legumes.

4.1 Selection of Descriptors

Descriptors are morphological, physiological, or biochemical traits used to evaluate the DUS characteristics. Examples for legumes include:

- Plant height
- Growth habit
- Leaf shape and size
- Flower color
- Pod length and color
- Seed shape, size, and color

4.2 Experimental Design

Typically, trials are conducted for at least two growing seasons, Randomized complete block design (RCBD) with two to three replications is commonly used, Comparative varieties are grown alongside the candidate variety.

4.3 Data Collection and Analysis

- Data are recorded at specific growth stages.
- Quantitative traits are analyzed using statistical tools like ANOVA.
- Qualitative traits are visually assessed.

5. Role of Molecular Markers in DUS Testing

Although DUS testing traditionally relies on morphological traits, molecular markers are increasingly being integrated to enhance precision and efficiency.

5.1 Advantages of Molecular Tools

- Discriminate between phenotypically similar varieties
- Detect genetic uniformity and stability
- Complement morphological data

5.2 Techniques Used

- SSR (Simple Sequence Repeat)
- RAPD (Random Amplified Polymorphic DNA)
- SNP (Single Nucleotide Polymorphism)

These techniques are particularly useful in legumes with narrow morphological diversity or where environmental influence is significant.

6. Applications of DUS Characterization in Legumes

6.1 Plant Variety Protection

DUS testing is essential for obtaining legal protection under national and international laws. It empowers breeders to commercialize their varieties while safeguarding their intellectual property.

6.2 Germplasm Management

DUS descriptors help in cataloging and conserving germplasm. It aids in the identification of duplicate accessions and enhances the utility of genetic resources.

6.3 Breeding and Selection

Characterization data guide breeders in parent selection, hybridization programs, and selection of stable lines. It ensures the development of distinct and superior varieties.

6.4 Quality Assurance in Seed Production

Uniformity and stability ensure consistent seed quality. DUS testing supports the maintenance of genetic purity in certified seed programs.

7. Challenges in DUS Testing of Legumes

Despite its utility, DUS testing in legumes faces several challenges:

7.1 Environmental Influence

Morphological traits are often influenced by the environment, complicating the assessment of distinctness and stability.

7.2 Limited Descriptors

For some minor legumes, comprehensive descriptor lists are lacking, limiting the scope of DUS evaluation.

7.3 Cost and Time

DUS testing is resource-intensive, requiring multiple seasons and locations. This can be a barrier for small-scale breeders and institutions.

7.4 Integration with Molecular Data

Although molecular tools are promising, their standardization and legal recognition remain in development stages.

8. Case Studies in DUS Characterization of Legumes

8.1 Chickpea (*Cicer arietinum* L.)

Chickpea DUS testing includes traits such as plant growth habit, flower color, pod beak shape, and seed coat texture. Studies have shown significant variability, aiding variety identification and protection.

8.2 Pigeon Pea (*Cajanus cajan*)

Key descriptors include plant branching pattern, flowering duration, pod shape, and seed color. DUS data have helped in breeding programs aimed at early maturity and disease resistance.

8.3 Soybean (*Glycine max*)

Soybean testing includes leaf shape, hilum color, pubescence, and seed size. Molecular markers have been used to support DUS characterization in elite varieties.

9. Future Prospects

The future of DUS characterization in legumes lies in:

- **Digital phenotyping**: Use of imaging and AI to assess morphological traits with precision.
- **Genomic-assisted DUS testing**: Integration of whole-genome data for high-resolution variety identification.
- **Policy support**: Development of farmer-friendly and cost-effective DUS protocols.
- **Public-private collaboration**: Encouraging partnerships for broader dissemination and protection of legume varieties.

10. Conclusion

DUS characterization in legume crops is a cornerstone of variety protection and agricultural innovation. It supports legal frameworks, enhances genetic resource utilization, and promotes the development of improved cultivars. As legumes continue to play a critical role in global food systems, strengthening DUS protocols through technological advancement and policy support will be essential. Ensuring accessibility, affordability, and accuracy in DUS testing will empower breeders, safeguard biodiversity, and enhance food and nutritional security.

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EFFECTS OF TERMINAL HEAT STRESS IN WHEAT AND IT'S MITIGATION

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SUMMARY

Global climate change continuously lead to decrease in food productivity of major crops. Wheat is one of those affected crops in which high terminal heat stress reduce the grain formation and grain filling period significantly and ultimately lead to poor grain yield. There are several ways to deal with this abiotic stress including agronomic managements and genetic managements. Choosing the varieties which are heat tolerant must be a priority of farmers to deal with it. Breeding for several traits like stay green traits, identification of QTL's etc. lead a significant reduction in losses due to heat stress.

INTRODUCTION

Wheat is the most important cereal crop grown globally and feeds a major portion of world's population with an area of 224.05 million hectares and production of 793.37 million tonnes globally. During 2024-25 period, China holds the leading position in wheat production followed by European Union and India. Nowadays, wheat production exposed to several challenges, mainly due to climate variability. Heat stress is one of the major abiotic stress affecting the wheat productivity worldwide. Because of global climate changes, wheat production will decline by 4.1%-6.4% for every 1℃ rise in average temperature (Liu *et al.*, 2016). Supraoptimal temperatures and unpredictable fluctuations in global climate severely affect growth and development of plant resulting in high threat to wheat production.

EFFECT OF CLIMATE CHANGE ON TEMPERATURE

Due to climate change, there is occurrence of heat stress which is the result of increased air temperature, increased soil temperature, loss of soil moisture, adverse soil physical properties and altered canopy properties. Plant will response to these phenomenon as follows: a) poor plant establishment (b) plant tissue dehydration (c) decreased photosynthesis (d) leaf senescence (e) pollen sterility and (f) reduced grain growth. In major wheat growing areas of India including Punjab, Haryana, U.P., Rajasthan and Uttrakhand, the main reason for reduction in wheat yields in past few years is the sudden rise of 2.1-6.6℃ in the minimum temperature and 2.6-6℃ in the maximum temperature in the month of March, make unfavourable conditions for the crop (Singh *et al.*, 2023).

TERMINAL HEAT STRESS

The optimum temperature requirements for wheat at anthesis is 23±1.75℃ and at grain filling duration is 26±1.53℃. The term "terminal heat stress" generally refers to a rise in temperature (>30℃) after anthesis and during grain development which impairs the process of grain filling in wheat. There is reduction in various traits of wheat under heat stress *viz.*, days to heading, days to anthesis, days to maturity, grain filing duration, grain weight per spike, grain yield etc.

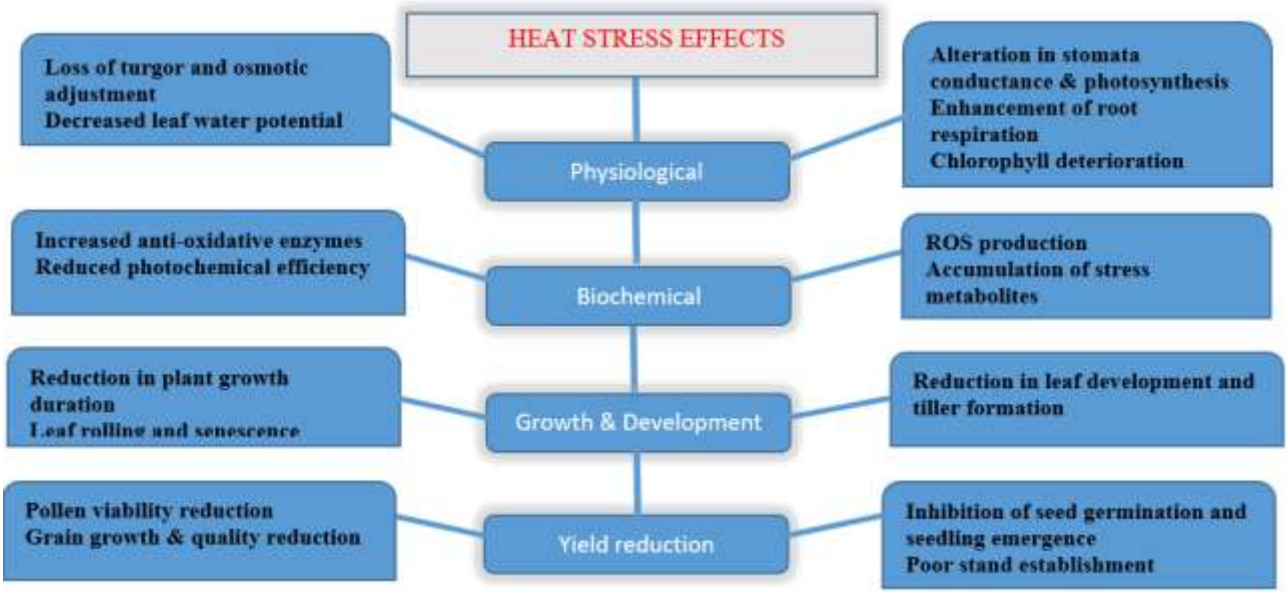
EFFECTS OF HEAT STRESS

1. **Effect on flower development and fertilization:** It includes pollen abortion during development of pollen grains, delays flower initiation, damage the reproductive development, desiccates the stigma resulting in adhesion of few pollen grains to the stigma, formation of abnormal pistil & stamens leading to poor fertilization and reduced grain size.
2. **Effects on grain development:** Heat stress inhibits the synthesis of starch and protein in grains by inhibiting the enzymatic processes. Starch synthesis is more susceptible to heat stress as compared to protein synthesis due to the high sensitivity of soluble starch synthase in developing wheat kernels. It also affects the rate and duration of grain filling as well as decreases the stem reserves.
3. **Reproductive failure:** Pollen development is more susceptible to high temperature stress as compared to female gametophyte and vegetative tissues. Increased temperature affects the viability of pollen grains in wheat.
4. **Carbohydrates availability and grain abortion:** High temperature impairs the activity of beta-amylase, increases ethylene concentration and influences the metabolic pathway of carbohydrate assimilation. Increased ethylene concentrations will result in grain abortion and ultimately in reducing yields.
5. **Grain filling and maturation:** Heat stress accelerates grain maturity and reduces the grain-filling duration, it will result in formation of shriveled grains with low weight.

STRATEGIES FOR ITS MITIGATION:

A. AGRONOMIC MANAGEMNET:

- **Irrigation management:** As heat stress is associated with greater loss of water, there is a need to manage the water requirements of crop properly during these days. Irrigate the timely sown crop upto the March end, depending upon the rainfall patterns. It helps the crop to cope-up with increasing temperatures during grain formation/grain filling stage.
- **Sowing date:** Late sown varieties of wheat generally faces more high temperature stress as they include short durations of heading and maturity comparatively, which will result in lower grain yields. To deal with terminal heat stress, sowing of wheat should be done in between 25 October to 15 November.
- **Osmoprotectants spray:** These are non-toxic and highly soluble compatible solutes. They stimulates the photosynthesis machinery and improves the grain yield and quality of crop. Some of common examples

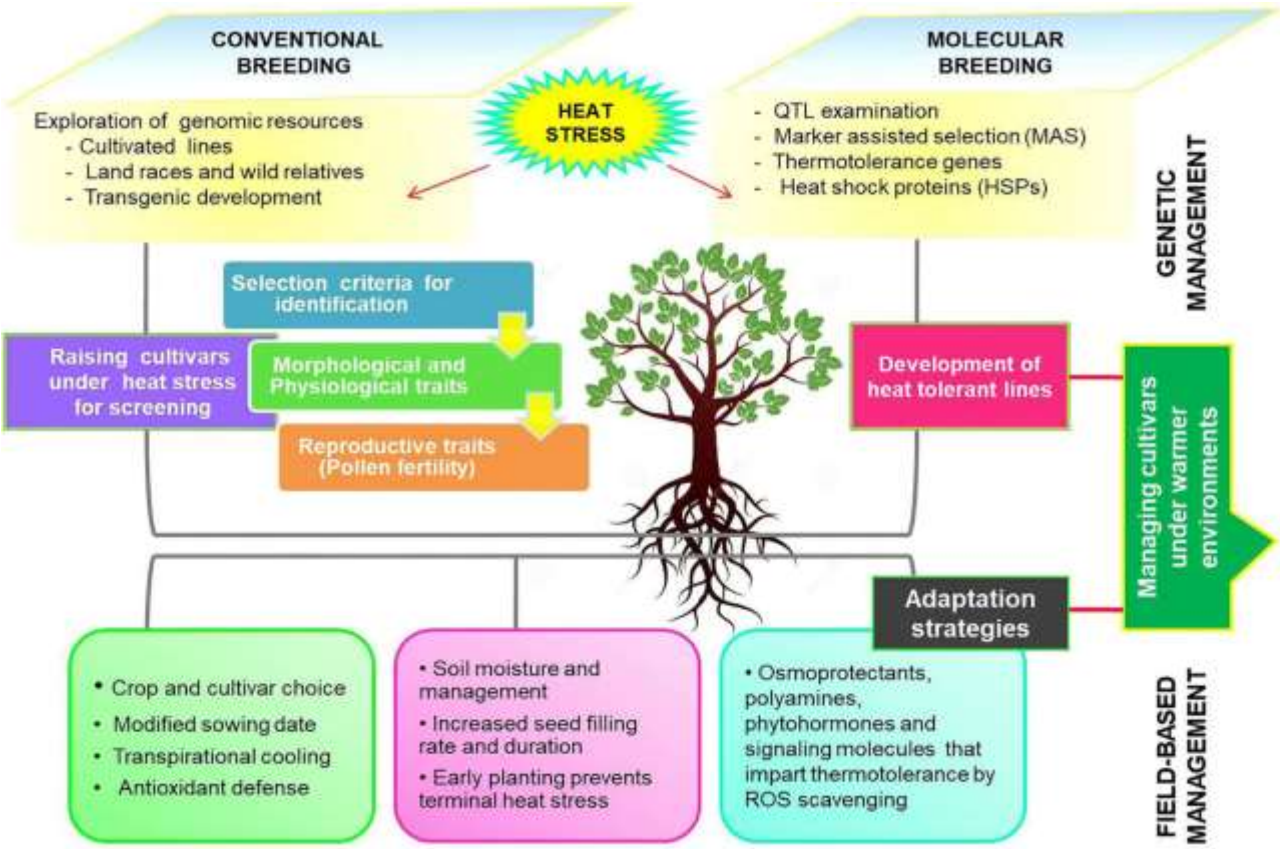


of osmoprotectants are: sodium nitroprusside 400 ug/ml, 2% KNO_3 and thiourea 20mM, apply two spray of these after anthesis.

- **Crop and cultivar choice:** Sowing of varieties which are heat tolerant would be a better idea. Example: WH 730, WH 1218, HD 298, NW 1014, WH 1021, WH 1142, WH 1249 etc.

B. GENETIC MANAGEMENTS:

- **Breeding and selection:** Landraces are an important source of genetic variation as they are well-adapted to harsh environmental conditions. Breeding for thermotolerance utilizing the landraces and wild relatives *viz.*, *Aegilops speltoides*, *Aegilops tauschii*, *Triticum turgidum* etc. have the ability to maintain chlorophyll content, canopy temperature depression, membrane stability and photosynthesis under stress conditions.
- **Characters to be used for thermotolerance breeding:** Photosynthesis rate, leaf chlorophyll content, chlorophyll fluorescence, canopy temperature depression, membrane thermostability, days to heading, days to maturity, antioxidant activity, stay-green duration, number of tillers per plant, grain filling rate and grain filling duration are the main traits to focus for breeding.
- **Genetic engineering:** Genetic engineering that increases osmolyte levels, increases expression of heat-shock proteins/chaperons, alters membrane fluidity or changes various cell detoxification enzymes could impart heat tolerance in crop plants and be successfully adopted to improve terminal heat tolerance. The transgenic wheat cultivar PC27 and PC51, which contained the *ZmPEPC* gene from maize enhance antioxidant enzyme activity, delay degradation of chlorophyll, change contents of proline and other metabolites. Similarly, expression of a rice gene *OsSS-I* with increased heat stability lead to a



significant, 21-34%, yield increase in transgenic wheat under heat stress conditions.

- **Molecular breeding:** Heat tolerance is quantitative and irregular, so the efficient selection of terminal heat tolerance traits is challenging for breeders. Marker assisted selection (MAS) refers to the use of DNA markers that are tightly linked to target loci as a substitute for or to assist phenotypic screening. The identification of QTL, using marker-assisted selection, related to heat stress tolerance in wheat can produce the genotypes with improved terminal heat stress tolerance. Improved heat tolerance of HD2733 by introgression of QTLs associated with early anthesis and high kernel weight through marker-assisted backcross breeding (MABB) from a tolerant donor, WH730.

CONCLUSION:

Terminal heat stress affects wheat phenology and all yield-related parameters in all major wheat-growing regions. The substantial effects of heat stress on grain setting duration and rate ultimately leads to reduction in grain yield. Conventional breeding along modern biotechnological and molecular tools are an important area for future research. These technologies allow for the rapid and efficient evaluation of large numbers of wheat varieties, making it possible to identify those with the highest levels of heat tolerance. Heat-tolerance-related genes can be introgressed for the development of new heat-tolerant wheat varieties either by marker-assisted breeding or various genetic engineering approaches.

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EMERGING PESTS IN AGRICULTURE: CLIMATE CHANGE AND EVOLVING THREATS

Abstract

The rapid emergence and spread of insect pests pose significant threats to crop yields, biodiversity, global trade, and migration. In India, pest infestations contribute to an 18–20% reduction in agricultural productivity. A review of recent literature highlights that several species, including *Helicoverpa armigera* (American bollworm), *Nilaparvata lugens* (brown planthopper), *Plutella xylostella* (diamondback moth), *Sesamia inferens* (pink stem borer), *Bemisia tabaci* (whitefly), *Macrosiphum miscanthi* (wheat aphid) and *Spodoptera frugiperda* (fall armyworm) have emerged as major pests across diverse cropping systems. Several anthropogenic factors, including excessive fertilizer use, indiscriminate pesticide application, widespread adoption of high-yielding and hybrid cultivars and shifting cropping patterns have altered pest dynamics, leading to resistance, resurgence, and secondary outbreaks. Despite that, One of the main reasons, that has usually been overlooked by us, for the changing status and scenario of insect pest species is climate change. Addressing these challenges requires ecologically sustainable Integrated Pest Management (IPM) strategies that are climate-resilient and research-driven. Strengthening such approaches is essential to safeguarding agricultural productivity and ensuring long-term food security.

Keywords: Insect pests, agricultural productivity loss, pest resistance, climate change impact, Integrated Pest Management (IPM), anthropogenic factors

Introduction

Climate change is causing global shifts in temperature patterns, precipitation dynamics, and the frequency of extreme weather events. It is well known that climate change has a significant impact on crop yields in the global agricultural sector (**Lobell and Field, 2007**), and this trend is likely to continue in the future also (**Beddington *et al*., 2012**). Beyond direct effects on crop yields, climate change is also influencing the distribution, severity and emergence of crop pests, i.e. 'any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products' (**FAO, 2013**) on a global scale (**Juroszek and von Tiedemann, 2011**). Moreover, shifting climatic conditions are facilitating the emergence of invasive species in new regions, further threatening global food security and ecosystem stability. According to FAO estimates, pests cause up to 40% of global crop losses annually. Additionally, plant diseases impose an economic burden exceeding $220 billion per year, while invasive insect species contribute to losses of at least $70 billion annually (**FAO, 2021**).

In the absence of effective monitoring and management strategies, minor pests may become major agricultural threats (**Hellmann *et al.*, 2008**). The rising severity of these biotic stresses highlights the need for integrated pest management and climate-resilient agricultural strategies.

Climate change and the emergence of new pest threats in India

Changing climatic conditions have significantly influenced insect dynamics within crop ecosystems, leading to the increase of certain species to the status of major or key pests. Insect species that are likely to move to newer areas as invasive pests, will also become an important threat to crop production, and food security as they will likely find better climatic niches in the new areas. In the absence of natural enemies in the new habitats, invasive species are likely to cause more damage than they would under normal circumstances. The insect pests that have emerged as or are likely to emerge as key or serious pests due to climate change are tabulated in Table 1.

Table 1. Insect pests that have emerged and are likely to emerge as key or serious insect pests (Sharma, 2016)

Insect pest	Scientific name	Crop
Diamond back moth	*Plutella xylostella*	Cauliflower, Cabbage
Wheat aphid	*Macrosiphum miscanthi*	Wheat, Barley, Oats
American bollworm	*Helicoverpa armigera*	Cotton, Chick pea, Tomato etc.
Beet armyworm	*Spodoptera exigua*	Chick pea in Southern India
Pink stem borer	*Sesamia inferens*	Maize, Sorghum, Wheat
Fall armyworm	*Spodoptera frugiperda*	Maize
Whitefly	*Bemisia tabaci*	Cotton, Tobacco
Pod sucking bugs	*Clavigralla spp.*	Pigeon pea
Spotted pod borer	*Maruca vitrala*	Pigeon pea, Cow pea
Brown plant hopper	*Nilaparvata lugens*	Rice
Green leaf hopper	*Nephotettix spp.*	Rice
Gall midge	*Orseolia oryzae*	Rice
Sugarcane aphid	*Ceratovacuna lanigera*	Sugarcane
Mealy bugs	*Paracoccus marginatus*	Several field & horticultural crops

How is climate change impacting plant pests?

Insects are highly susceptible to climate change due to their strong dependence on environmental conditions for development, reproduction and survival including both pest species and their natural enemies (**Bale *et al.*, 2002**). Their relatively short generation times and high fecundity enable rapid adaptation to changing climatic conditions, making them more responsive to environmental shifts compared to plants and vertebrates.

1. **Impact of climate change on insect pest distribution and population dynamics**

Rising temperatures may enhance insect overwintering, facilitating their expansion into higher latitudes (**Hill & Dymock, 1989**). Climate-driven shifts in crop cultivation will further influence pest distribution (**Parry & Carter, 1989**). Notable examples include the projected northward migration of *Heliothis zea* in North America, increasing maize infestations (**EPA, 1989**), and the potential invasion of *Helicoverpa armigera* and *Maruca vitrata* into northern Europe. *H. armigera* has already established in Brazil and may spread to North America (**Czepak *et al*., 2013**). Higher temperatures accelerate insect development, reducing time to reproductive maturity and driving rapid population growth.

2. **Impact of climate change on expression of resistance to insect pests**

Host plant resistance is a vital component of sustainable pest management; however, climate change may modify insect-plant interactions, potentially compromising resistance mechanisms (**Sharma, 2012**). For example, resistance to sorghum midge, observed in India, deteriorates under the high humidity and moderate temperatures in Kenya (**Sharma *et al*., 1999**). Climate change is expected to exacerbate the impact of insect pests, particularly those that exploit weakened host plants experiencing stress due to suboptimal climatic conditions and a lack of adaptive mechanisms. Additionally, shifts in climate may facilitate the emergence of new pest problems by promoting the cultivation of susceptible crops or cultivars that lack resistance to prevailing pest pressures. The development and deployment of climate-resilient cultivars have been proposed as an adaptive strategy to mitigate these challenges (**Parry & Carter, 1989**).

3. **Risk of introducing invasive alien species**

Biological invasions are driven by environmental changes, including climate shifts and altered biotic and abiotic factors (**Dukes & Mooney, 1999**). Globalization, trade, and rapid transportation further increase the risk of exotic species introductions, threatening biodiversity and ecosystem stability. The Convention on Biological Diversity (CBD) identifies invasive alien species as a major driver of biodiversity loss, imposing economic burdens on agriculture, forestry, and aquatic ecosystems (**Mooney & Hobbs, 2000**). Global warming may intensify pest invasions by disrupting phenological events, making temperate plants more vulnerable, while climate-induced shifts could promote insect-susceptible crops, increasing pest risks (**Fitter & Fitter, 2002; Gregory et al., 2009**).

4. **Impact of climate change on pest outbreaks**

Climate variability has escalated the frequency and severity of insect pest outbreaks, causing substantial crop losses. The outbreak of the sugarcane woolly aphid (*Ceratovacuna lanigera*) in Karnataka and Maharashtra during 2002–03 caused yield reductions of up to 30% as given in table 2. These recurring infestations have increased plant protection costs, further burdening farmers by diminishing profit margins (**Joshi and Viraktamath, 2004**).

Table 2. Recent insect pest outbreaks in India

Insect-pest	**Host**	**Region**	**Probable reason**	**Impact of pest outbreak**	**Reference**
sugarcane woolly aphid (*Ceratovacuna lanigera*) Zehntner	Sugar cane	Sugarcane belt of Karnataka and Maharashtra	Abnormal weather patterns and Insecticide misuse	30% yield losses	Joshi, and Viraktamath, 2004
Papaya	Papay	Tamil	-do-	Signifi	Tanwar

mealybug (*Paracoccus marginatus*)	a	Nadu, Karnataka, Maharashtra		cant yield losses	*et al.*, 2010
Mealybug (*Phenacoccus Solenopsis*) Tinsley	Cotton	Cotton growing belt of the country	Recent abnormal weather patterns, Insecticide misuse and Changed cropping environment (introduction of Bt cotton)	30-40 % yield losses	Dhawan *et al.*, 2007
Plant hoppers (*Nilparvata lugens*)	Rice	North India	Abnormal weather patterns and Insecticide misuse	Crop failure (more than 33000 ha area)	IARI News, 2008; IRRI News, 2009

5. Increased incidence of insect vectored plant diseases

Climate change is expected to increase the incidence of insect-transmitted plant diseases by expanding vector ranges and accelerating their reproduction (**Sharma *et al*., 2005**). Rising early-season temperatures have been associated with increased potato viral diseases due to the early arrival of virus-bearing aphids, the primary vectors in Northern Europe (**Robert *et al*., 2000**).

6. Reduced effectiveness of biological control agents

Biological control is a key component of integrated pest management, maintaining ecological balance. Natural enemies of insect pests, including predators, parasitoids, and pathogens, are highly sensitive to climatic extremes such as temperature fluctuations, wind, and precipitation. Changes in rainfall patterns can influence pest-natural enemy interactions, creating complex dynamics. While prolonged humidity may favour entomopathogenic fungi, drier conditions can reduce their efficacy (**Newton *et al.*, 2011**). Additionally, climate change may disrupt host-parasitoid relationships, as higher temperatures can shorten host vulnerability periods, limiting parasitoid survival and reproduction (**Gutierrez, 2008**).

How to overcome these issues?

1. Breeding Climate-Resilient Varieties
2. Rescheduling of Crop Calendars such as crop rotation and planting time
3. GIS Based Risk Mapping of Crop Pests
4. Screening of Pesticides with Novel Mode of Actions

Conclusion

Climate change is a key driver in the emergence and proliferation of agricultural pests, altering their distribution, population dynamics, and interactions with host plants. Rising temperatures, shifting precipitation patterns, and extreme weather events are facilitating the expansion of insect pests into new regions, reducing the effectiveness of natural enemies, and increasing the incidence of insect-vectored plant diseases. Additionally, climate-induced changes in crop cultivation and the introduction of susceptible cultivars further exacerbate pest-related challenges. To mitigate these evolving threats, an integrated approach incorporating climate-resilient crop varieties, enhanced biological control strategies, and adaptive pest management practices is essential. Proactive monitoring and research will be critical in developing sustainable solutions to safeguard global agricultural productivity and food security in the face of a changing climate.

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Exploring the Spectrum of Phytoplasma Diseases in Palms

1. Introduction

Phytoplasmas are wall-less, non-helical, obligate bacteria of the class Mollicutes, with cell sizes between 200 and 1000 nm. Obligate in nature, phytoplasmas colonize phloem sieve elements and are mainly transmitted by sap-sucking insect vectors. Phytoplasmas have a low GC content, with genome sizes between 530 and 1350 kb (Marcone *et al.*, 1999), which lack crucial genes associated with oxidative phosphorylation, the tricarboxylic acid cycle, and fatty acid and amino acid metabolism, indicating reductive evolution and reliance on hosts for essential pathway products. The presence of Potential Mobile Units (multicopy repeat sequences) is a hallmark of the phytoplasma genome and are essential for its interaction with the environment (Huang *et al*., 2022).

Phytoplasmas ('*Candidatus* Phytoplasma') are classified based on the 16S rRNA sequence using restriction fragment length polymorphism (RFLP). Lee *et al*. (1998) categorized 34 phytoplasma strains into 14 primary groups (known as 16Sr groups) and 32 subgroups, based on similarity coefficients derived from RFLP analyses of the phytoplasma 16S rRNA gene. In addition to the 16S rRNA gene, other genetic markers, such as ribosomal protein genes, 16S/23S rRNA intergenic spacer sequences, 23S rRNA, tuf, secA, secY, rpoB, GroEL, and amp genes, have been proposed as useful tools for detecting and differentiating phytoplasma (Martini *et al*., 2019). Based on the 16Sr RNA gene, lethal yellowing (LY) and root wilt disease (RWD) phytoplasmas belong to the 16SrIV and 16SrXI group respectively (Ortiz-García *et al*., 2024; Manimekalai *et al*., 2010). LY phytoplasma is further categorized into distinct subgroups, with subgroups 16SrIV-A, Subgroup16SrIV-B, Subgroup16SrIV-D, Subgroup 16SrIV-E and Subgroup16SrIV-F affecting palms in multiple countries (Ramos Hernández *et al*., 2020).

2. Lethal yellowing (LY)

LY phytoplasma symptoms vary depending on the plant growth stage, including fruit abortion, inflorescence necrosis, leaf yellowing, stem tissue rot, and palm crown collapse, leading to death (Bertaccini *et al*., 2014; Dollet *et al*., 2009; Harrison *et al*., 2014). In Florida, *Haplaxius crudus* has been identified as an insect vector (Dzido *et al*., 2020) with failed efforts to reproduce transmission studies outside Florida. Various plant hoppers and leafhoppers have been confirmed to correlate with LY worldwide using molecular screening, but their vector status remains unproven without successful transmission trials (Bila *et al*., 2017).

1. **Root wilt disease (RWD)**

RWD affects palms from seedling to maturity and elicits diagnostic symptoms such as flaccidity, yellowing, and marginal necrosis of leaflets, as well as yield loss and quality drop of oil, kernels, and husks due to disease-induced physiological and biochemical alterations. As the disease progresses, rotting of roots, dropping of immature nuts and necrosis of spikelets become more evident, resulting in significant economic loss to coconut growers. They are transmitted by phloem-feeding insects, lace bugs (*Stephanitis typica*), and plant hoppers (*Proutista moesta*) (Ramjegathesh *et al*., 2012) and reside endo-cellularly in the insects and phloem tissues of coconut palms. Phytoplasma has been detected in lace bug salivary glands 18-23 days post-feeding on infected palms (Mathen *et al*., 1987) and in plant hoppers after over 30 days of feeding on diseased palms (Rajan *et al*., 2011). Phytoplasmas can also be transmitted via dodder. Manimekalai *et al*. (2014) explored its seed transmission potential and found root (wilt) phytoplasma DNA in 16.67% of embryos from nuts of diseased palms but no phytoplasma DNA in the resulting seedlings.

2. **Weligama coconut leaf wilt disease (WCLWD)**

The first case of WCLWD was reported in 2006 in the Weligama region in Sri Lanka. A common symptom is characterized by the initial softening of leaves, which is followed by deep yellowing of the lower portions of the fronds and the subsequent downwards bending of the unopened spear leaves. As the disease progresses, there is a reduction in the number of female flowers, resulting in the low productivity of fruits and nuts. Phytoplasma can be grouped under 16SrXI and '*Candidatus* Phytoplasma oryzae' related strains based on sequence analysis (16S rRNA gene). Conversely, a multilocus sequence typing (MLST) study revealed that the secA gene of WCLWD was associated with the Bermuda Grass White Leaf Disease (BGWLD) phytoplasma of the 16SrXIV group (*Candidatus* Phytoplasma cynodontis) (Abeysinghe *et al*., 2016).

3. **Tatipaka Disease (TD)**

Tatipaka is a non-lethal, debilitating disease caused by phytoplasmas in coconut trees in India, mainly affecting palms between the ages of 20 and 60 years. Disease-affected palms produce an abundance of nuts for 2 to 3 years before exhibiting visible symptoms, such as a decrease in the number and size of leaves, the presence of chlorotic, water-soaked spots, and twisted fronds. In the advanced phases, leaflets are narrow, crowns shrink, and palms resemble date palms. Small spathes with sparse rachillae and bunches of normal and atrophied nuts were observed. Atrophied nuts are barren with a thin, spongy mesocarp. Undersized nuts exhibit longitudinal cracks and occasional gumming. Stems are eventually tapered, resulting in smaller spathes and fruitless inflorescences. Underground symptoms include decreased root growth and root rot (Solomon and Geetha, 2004).

4. **Spear rot disease (SRD)**

Endemic to Kerala and with sporadic incidence in Sullia district of Karnataka, SRD is an important phytoplasma disease of the oil palm. Molecular characterization based on the 16S rRNA gene revealed the association of the 16SrXI group phytoplasmas with the disease. The affected palms show characteristic symptoms of chlorosis of the youngest whorl of the fronds, rotting of spears and reduction in frond size (Sumi *et al*., 2017).

5. **Yellow leaf disease of areca palm (YLD)**

YLD posed a serious threat to areca palm plantations in the world and was first observed in India (1914), destroying large-scale areca plantations. Typical symptoms of YLD include yellowing along the vascular tissues, while the midrib retains a green color, forming distinct yellow-green borders between the diseased and healthy parts. In advanced stages, a 'bunchy top' symptom appears, along with root rot, nut shrinkage, and break at the top. Jin *et al*. (1995) classify YLD into 'bunchy top' and 'yellowing' types, which may be different stages of the same disease. However, it is unclear whether these symptoms are caused by different pathogens. Phytoplasma was found in infected areca palm leaves but was absent in healthy leaves (Gopinath *et al*., 2016). Based on the 16S rRNA gene, Indian YLD phytoplasma showed 99% similarity to sugarcane white leaf and Napier grass stunt phytoplasma, which clustered with 16SrXI. Chinese YLD phytoplasma are classified as 16SrI-G and 16SrI-B, which differs from that of India (Che *et al*., 2010). In Sri Lanka, YLD co-occurs with WCLWD, which has 100% secA sequence identity with WCLWD phytoplasma and is categorized as 16SrXIV (Kanatiwela-de Silva *et al*., 2015). Abeysinghe *et al*. (2016) employed leuS and secA genes to improve the categorization and group phytoplasmas from southern India and Sri Lanka in 16SrXI.

6. **Coconut Yellow Decline (CYD)**

CYD is a debilitating disease affecting coconut trees in Malaysia, characterized by symptoms, such as yellowing of leaves in the outer whorl, which gradually turned light brown. This disease also causes the developing spear leaves to become chlorotic, and the affected palms exhibit inflorescence necrosis and early nut fall. As the disease progresses, the fronds gradually collapse, and the growth points of the immature palms decay. CYD is caused by two distinct groups of phytoplasma: 16SrXIV, *Candidatus* Phytoplasma cynodontis group, and 16Sr XXXII-B, *Candidatus* Phytoplasma malaysianum group (Nejat *et al*., 2009 a, b).

7. **Kalimantan Wilt (KW)**

KW significantly threatens coconut plantations in Indonesia. The first noticeable symptom is wilting and drying of older fronds, which later break near the base. Another key symptom is the blackening and rotting of young developing inflorescences, whereas older inflorescences remain normal or only partially rotten. In newly opened inflorescences, rotting or blackening occurs in the middle, but not at the tip, unlike in LY-affected palms. The infected palm dies within four months of symptom onset (Warokka 1998). Based on the 16S rRNA sequences, KW belongs to the 16Sr XI and 16Sr XIII groups.

8. **Lethal Bronzing Disease (LB)**

Lethal bronzing disease (LB) or Texas Phoenix Palm Decline (TPPD) is a palm disease attributed to the 16SrIV-D phytoplasma, which has a wide host range, including *Sabal palmetto* (cabbage palm), *Phoenix roebelenii* (pygmy date palm), *Phoenix canariensis* (Canary Island date palm), *Phoenix dactylifera* (edible date palm), and *Phoenix sylvestris* (wild date palm) (Bahder *et al.*, 2020). First identified in Texas (1978) and the United States, the disease causes premature fruit drop, inflorescence necrosis, discoloration of older and younger foliage, spear leaf collapse, and eventually tree death.

9. **Crown choking of areca palm**

Crown choking, caused by 16SrII phytoplasma (500- 2000 nm) on areca palm plantations induces symptoms such as stunting and dark green leaves with a wavy leaf lamina and failure of leaflets to unfold, resulting in a bunchy top or witches' broom appearance. The internodes became shorter with inflorescences desiccated, and stem tapered at the tip. Affected plants cease growing new leaves, loose their existing leaves, and soon perish, leaving just a naked stem. Approximately 80-100% of the plants in afflicted areas die (Naik *et al*., 2022).

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FROM SPIKY TO SMOOTH: THE SURPRISING DIVERSITY OF CUCUMBERS

Cucumbers (*Cucumis sativus*) are among the oldest cultivated vegetables, with domestication dating back over 3,000 years to South Asia. Since their origin, cucumbers have spread across continents, undergoing extensive adaptation to diverse climates, cultural practices, and culinary preferences. This process has resulted in a remarkable breadth of agro-biodiversity.

Diversity Within Cucumbers

Modern supermarket cucumbers represent only a fraction of the species' variability. Globally, cucumber cultivars exhibit a wide range of morphologies, including differences in fruit size, shape, color, texture, and taste. Varieties range from large, pale-yellow fruits cultivated for cooking in India, to thin-skinned, sweet snacking cucumbers favored in Europe and the Middle East, to spiny, drought-tolerant types in arid regions of Africa.

This morphological diversity often corresponds to valuable agronomic traits such as pest and disease resistance, heat and drought tolerance, and variation in nutritional content.

Fig. 1-The diverse cucumber germplasm

The Importance of Agro-Biodiversity

Agro-biodiversity, the genetic variability within and among crop species, is critical for resilient agricultural systems. Maintaining a wide gene pool allows breeders to develop new cucumber varieties that can meet future challenges, including emerging diseases, changing climatic conditions, and shifting market demands.

However, modern agricultural practices increasingly favor a narrow range of commercial cucumber cultivars. This trend risks genetic erosion — the irreversible loss of unique genotypes that may hold key adaptations for future food security.

Conservation Efforts

Recognizing these threats, conservation programs worldwide are prioritizing the preservation of cucumber genetic diversity. Seed banks such as the Svalbard Global Seed Vault and national germplasm repositories maintain extensive cucumber collections. Meanwhile, in-situ conservation through traditional farming and home gardening practices remains vital for sustaining landraces and wild relatives.

Promoting the cultivation and consumption of diverse cucumber types, alongside continued scientific research, is essential to safeguard the species' rich genetic heritage.

Conclusion

The agro-biodiversity of cucumbers is not merely a botanical curiosity but a strategic resource for global food security. Preserving this diversity ensures that future generations will benefit from the full genetic potential of one of humanity's oldest — and most surprisingly diverse — crops.

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Methods To Minimise Herbicide Carry-Over Effects In Agricultural Systems

The weed control approaches must be carefully planned in order to prevent pesticide carryover in the agricultural systems. For instant, a weed management program should be planned based on the problem of weeds, crop rotation, soil properties, weather, and herbicide alternatives, including formulation and persistence. It is certain that, this plan will impact cropping alternatives for the upcoming year or years to follow. In addition, always leave an untreated check area in the field for future comparison. This will help in maintaining accurate records which is crucial to preventing crop losses brought on by herbicide carryover.

To reduce or completely eradicate herbicide carry-over, a weed control strategy should integrate different steps or techniques. Following are some of the major facts or management practices to be kept in mind for the controlling the herbicide carryover effect in the agricultural systems.

Adoption of integrated weed management - Utilise a variety of management strategies, such as crop selection, fertiliser location, and sowing date, to encourage a competitive, robust crop that outperforms weeds and reduces carryover the following year.
Practice herbicide rotation along with crop rotation - This is crucial because it lessens the need to use herbicides that can linger in the soil for years to come. Applying Sundance or Everest, for instance, to soil that was treated with Odyssey the year before is not advised.
Selection of herbicides with minimum carry-over potential - Future crop harm issues can be avoided by selecting herbicide that has little to no carry-over given the soil and weather conditions in agricultural area.
Recommended or minimum rates of application of herbicides - According to theory, the rate at which herbicide is administered should never exceed that which is necessary to attain a satisfactory degree of weed control, however this may differ depending on the kind of soil and the level of moisture. This procedure will lessen the possibility of carryover. For instance, sandy soils with low organic matter need far less trifluralin than clay soils with greater organic matter.
Right time of application of herbicide- According to research, crop productivity is increased and competition is decreased when weeds are removed early, when they are still young. Additionally, early-season spraying helps lower the possibility of carryover to subsequent crops. The likelihood of carry-over decreases with the length of time the herbicide is exposed to breakdown elements including temperature and moisture.
Right method of application - To lessen the possibility of carry-over, herbicide application must be precise and careful. Make sure the sprayer is calibrated correctly and applies evenly across the boom width, combine the right amount of active ingredient, read the label before usage, and take all necessary precautions. The application rate is doubled if you overlap on the spray run. Additionally, avoid making abrupt bends while the sprayer is running because the inside boom's application rate multiplies several times.
Tank-mixture opportunities - Carry-over potential can be decreased by mixing a non-residual herbicide with the tank mixture's lowest recommended rate of residual herbicide. Only registered tank-mixes should be used, and the application guidelines on product labels should be followed.

Grow a tolerant crop- A tolerant crop ought to be cultivated whenever pesticide residue is found or suspected. The residue can be stored or broken down into non-toxic chemicals by a tolerant crop. For instance, crops like flax and canola (non-Clearfield) should be avoided when carry-over pursuit is suspected.

Use of soil additives - Activated charcoal and other adsorbent materials can be added to boost the adsorption of herbicide residue. Large-scale activated charcoal utilisation is not cost-effective. However, its application may be financially justifiable in small areas where high-value crops are grown or as a spot remedy for chemical spills.

Application of fertilizer- Herbicide uptake from the soil is increased when tolerant plants grow more readily as a result of fertiliser input. Additionally, it encourages the development of microflora, which increases the soil's biological breakdown of herbicides. For instance, the microbial degradation of the phenoxy herbicides 2,4-D and MCPA is improved by the addition of phosphate.

To summerise, it is highly important to reduce or completely irradiate the herbicide carry-over effect in the agricultural systems. Therefore, all the management practices carried out in the field should only result in reduced or no herbicide residual effects to the next season/seasons' crops. Adoption of integrated weed management along with herbicide rotation and crop rotation and use of herbicides with minimum carry-over potential are very much essential. Moreover, growing of tolerant crop along with right amount, quantity and method of application need to be followed. Moreover, make use the tank-mixture opportunities, soil additives and right quantity application of fertilizer.

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INSECT PREDATORS: GUARDIANS OF ECOSYSTEMS AND PILLARS OF SUSTAINABLE AGRICULTURE

INTRODUCTION

In ecological terms, a predator is an organism that actively hunts, captures and consumes other organisms, known as prey, to sustain itself. This behavior, termed predation, is a fundamental ecological interaction that influences population dynamics and community structure. In Indian agriculture, insect predators such as ladybird beetles, green lacewings, spiders, dragonflies and parasitic wasps play a crucial role in maintaining ecological balance by naturally controlling pest populations. For instance, ladybird beetles consume large numbers of aphids, whiteflies and mealybugs, while green lacewing larvae target pests like thrips and mites. Spiders and parasitic wasps further contribute by preying on various crop-damaging insects. These predators reduce the need for chemical pesticides, promoting healthier ecosystems and reducing environmental pollution. Additionally, they enhance soil health by decomposing organic matter, improving soil structure and increasing nutrient availability for crops. Traditional Indian agricultural practices, such as crop rotation and intercropping, support the conservation of these beneficial insects, aligning with sustainable farming principles. Recognizing and preserving the role of insect predators is vital for ensuring long-term agricultural productivity and ecological sustainability in India.

Benefits in Sustainable Agriculture

Natural Pest Control: By preying on harmful insects, predators reduce the need for chemical pesticides, promoting healthier crops and ecosystems.

Cost-Effectiveness: Utilizing natural predators can lower pest management costs, as they reduce the reliance on expensive chemical treatments.

Enhanced Crop Yields and Quality: Crops protected by natural predators often exhibit higher yields and better quality, appealing to eco-conscious consumers.

Biodiversity Support: A diverse range of predators contributes to a resilient agricultural system, capable of withstanding pests and diseases.

Indicator of Ecological Health: The presence and abundance of insect predators can signal the overall health of an agricultural ecosystem

Integrating Predators into Agricultural Practices

Indian farmers have long recognized the value of insect predators. Traditional practices, such as maintaining diverse cropping systems and avoiding indiscriminate pesticide use, have supported the natural control of pests, demonstrating the synergy between indigenous knowledge and ecological pest management. Adopting practices that support insect predators involves:

Conservation Tillage: Reducing tillage can increase populations of beneficial insects like beetles and spiders.

Habitat Enhancement: Planting hedgerows and flower strips provides shelter and food sources for predators.

Reduced Pesticide Use: Limiting chemical pesticide applications helps protect beneficial insect populations. By fostering environments conducive to insect predators, farmers can enhance the sustainability and productivity of their agricultural systems.

CONCLUSION

The current pest management system in agriculture predominantly relies on chemical pesticides to control pest populations. While effective in the short term, this approach has significant drawbacks. Indiscriminate pesticide uses not only harms target pests but also destroys natural predators such as ladybird beetles, spiders and parasitic wasps, which play a crucial role in regulating pest populations. The elimination of these beneficial insects leads to pest resurgence, where pest populations rebound to higher levels than before pesticide application. Additionally, the loss of natural enemies can result in secondary pest outbreaks, where previously minor pests become major problems. This cycle, known as the "pesticide treadmill," increases farmers dependency on chemical controls, escalating costs and environmental harm. The need of the hour is to adopt Integrated Pest Management (IPM) strategies that combine biological control, cultural practices and need based use of chemical methods or pesticides to manage pests sustainably. By conserving and promoting natural predators, IPM can reduce pesticide use, lower costs and enhance ecological balance, ensuring long-term agricultural productivity.

INSECT PREDATORS


Green lace wing


Lady bird beetle


Dragonfly


Spider


Preying mantid


Stink bug

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Melia dubia as a potential agro-forestry species: A review

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Abstract

Agroforestry presents a sustainable and comprehensive land management approach, offering substantial benefits for agriculture and farmers. Planting trees on agricultural lands can help address numerous challenges in agricultural systems, including diminishing soil fertility and income uncertainty. Over the past two decades, *Melia dubia* has prominently emerged as a highly compatible agroforestry tree species due to its morphological, physiological and functional traits. The species reportedly demonstrates negligible allelopathic effects on various understorey food crops. This review synthesizes findings from 20 years of national and international research to highlight the capacity of *M. dubia* as an agroforestry species, focusing on its key characteristics, ecological advantages, soil interactions, allelopathic properties, and effective agroforestry models. The paper analyzes the species' significant potential to enhance farmers' livelihoods through diversified income streams and improved ecosystem health, thereby positioning *M. dubia* as a compatible species for sustainable agroforestry systems.

Keyword: *M. dubia*, agroforestry.

Introduction

Agrarian rural communities are facing numerous challenges in economic, social, cultural, and technological fields, together with climate change and its consequences. In this context, agroforestry emerges as a crucial sustainable land-use practice, integrating woody perennials with agricultural or pasture crops in specific temporal and spatial arrangements (Bhatia *et al*., 2024). Agricultural systems with trees facilitate nutrient recycling, positively influencing soil properties (Muchane *et al*., 2018; Shin *et al*., 2020). Among promising indigenous agroforestry species, *M. dubia* is regarded as a successful option. *M. dubia* (also called *M. composita*) is a multipurpose, fast-growing, large deciduous tree belonging to the family Meliaceae. It is commonly known as Malabar neem, Malabar dek or dreak (Swaminathan *et al*., 2012). The tree is native to the Indian subcontinent and is distributed in India, Sri Lanka, Myanmar, Malaysia, Java, China, and Australia. In India, it occurs in the Himalayas, North Bengal and upper Assam, Khasi hills, Western Ghats, Deccan, and Hills of Odisha. It is a relatively fast-growing alternative pulpwood species adaptable to a wide range of agro-climatic conditions.

The industrial and ecological importance of *M. dubia* has encouraged farmers to undertake large-scale plantations, either in block formations or within agroforestry systems (Chauhan and Ritu, 2005; Parthiban *et al*., 2009; Nuthan *et al*., 2009; Thakur *et al*., 2018). The species has established itself as one of the most adaptable agroforestry tree species, allowing for the cultivation of a variety of understorey crops (Parmar *et al*., 2019). It has been reported that *M. dubia*-based agroforestry systems are more profitable than monocropping systems (Mohanty *et al*., 2017).

Material and methods

This article is primarily based on a systematic review of *M. dubia* as an agroforestry species, focusing on its various components and the cumulative impacts over the years. The review synthesizes and analyzes information from national and international research publications to provide a comprehensive understanding, incorporating both qualitative and quantitative perspectives in the field of agroforestry. Research studies from the past 20 years were reviewed, and key findings were systematically compiled and organized to facilitate clear and accessible insights into agroforestry practices and their impacts.

Morphological characteristics

As the species has a cylindrical and straight bole, there's a vast scope for vertical increase by introducing intercrops in the *M. dubia* plantations. The species is renowned for its rapid growth with a young tree reaching up to the height of 4-5 meters within a year under optimal climate conditions. At 10-12 years old, *M. dubia* attains a height of 20–25m with a wide spreading crown and a cylindrical, straight bole of 9m length and 1.2 to 1.5m girth (Nuthan *et al*., 2009). It has a thin to moderate crown that allows enough light to pass through to understory crops. Furthermore, the roots of *M. dubia* are reported to interfere less with crops in agroforestry systems; they're mostly concentrated below the crop root zone with minimal lateral expansion. Being a deciduous tree species, *M. dubia* sheds leaves in winter (December-January), with new flushing occurring in February-March along with flowers. This short leafless period provides ample light, nutrients, and moisture for winter crops to flourish. The litterfall from *Melia* also adds organic matter to the soil, enhancing its fertility and productivity. It grows on a variety of soils, though it shows optimum growth in deep, fertile sandy loam soils.

Allelopathic effects

In a study examining the allelochemicals in the leaf litter of *M. dubia*, Parmar *et al*. (2018) found that the phytotoxic compounds present in the species exhibit an ephemeral allelopathic effect. These compounds are transient in nature, and their phytotoxicity diminishes over time. The authors suggested that *M. dubia* meets the criteria for agroforestry ideotypes—specifically, that the species does not exert allelopathic antagonism on understorey crops. Similarly, Ruwali and Negi (2021) reported that while *M. dubia* leaf extracts inhibited early growth traits of chilli and and eggplant under laboratory conditions, they had no significant impact on later growth or fruit yield in pot experiments. Their findings also support the conclusion that *M. dubia*'s allelochemicals have a transient effect, affirming its agroforestry suitability. Therefore, intercropping under *M. dubia* is ecologically viable, as its leaf litter allelochemicals does not have lasting deleterious effects on understorey crops. In fact, mature leaves of *M. dubia* are a rich source of mineral elements, crude protein, crude lipid, and vitamins, making them excellent fodder for ruminants.

Effect on soil moisture content

Kumar *et al*. (2024) through their experiments showed that soil moisture content was consistently higher under the *M. dubia* trees compared to open conditions, especially at greater soil depths (15-30 cm) and further away from the tree line. This enhanced moisture retention is linked to the deciduous nature of *M. dubia*, which provides a mulch layer from litterfall, reducing evaporation. Additionally, during the Rabi season, the trees are dormant, minimizing water loss through transpiration. Nanda *et al*. (2021) observed that under the *M. dubia* plantation in agri-silvicultural system the moisture content decreased at all the investigated depths (0-15 cm, 15-30 cm, 30-45 cm). Similarly, Sumit *et al*. (2024) reported that there was more soil moisture under *M. dubia*-based agroforestry system. Narendra *et al*. (2021) too reported increased soil moisture under *Melia*-wheat system.

Effect on soil fertility

Studies have revealed that *M. dubia*-based land-use system has the potential to improve soil fertility, i.e., stabilizing soil physico-chemical properties and increasing nutrient contents by recycling available natural resources. *M. dubia* has shown a positive impact on soil characteristics in semi-arid regions by improving soil fertility, organic carbon, and nutrient levels across various stand densities (Ramesh *et al*., 2022). Nanda *et al*. (2021) observed that under a *M. dubia*-based agri-silvicultural system compared to a control (field without trees), soil pH and electrical conductivity (EC) decreased more significantly. Conversely, soil organic carbon and available soil N, P, and K increased substantially in both 0-15 cm and 15-30 cm soil depths. The nutrient content in the post-harvest soil was found to increase compared to the initial stage in all the stand densities. Principal component analysis revealed a positive correlation between stand density and soil parameters like EC, SOC, nutrient contents, and exchangeable cations. Narendra *et al*. (2021) reported that intercropping *M. dubia* with wheat significantly enhanced soil organic carbon to 0.46% and increased available nitrogen, phosphorus, and potassium to 131.38, 16.00, and 301.10 kg/ha, respectively.

Agroforestry Models

M. dubia-based agroforestry systems are reportedly more profitable than monocropping systems. Various agricultural crops such as brinjal, groundnut, chilli, turmeric, blackgram, papaya, banana, melon, sugarcane, are being successfully cultivated as intercrops with the species. Ashalatha *et al*. (2023) reported that intercropping *M. dubia* with brinjal yielded the highest benefit-cost ratio with minimal yield loss. Hemalatha *et al*. (2025) through their study reported that cluster beans can be successfully cultivated under *M. dubia* plantations during the early stages of tree growth to achieve optimal yields. Srivastav *et al*. (2024) reported that the growth performance of trees was inferior without intercrop as compared to intercropped with paddy rice and wheat. In silvi-medicinal systems, *M. dubia* planted at 3×3 m spacing with *Cymbopogon citratus* showed the best performance in terms of height (6.71 m), DBH (6.75 cm), volume (27.36 m^3/ha), and biomass (11.53 Mg/ha). Similarly, the 3×3 m spacing with *Cymbopogon martini* recorded favorable growth (height: 6.59 m; DBH: 6.51 cm) (Thakur *et al*., 2019). Similarly, Thakur *et al*. (2020) demonstrated that silvi-medicinal systems involving *M. dubia* and *Cymbopogon flexuosus* exceeded sole cropping in growth, physiological parameters, herbage yield, and essential oil production. Mesharam *et al*. (2024) reported that adoption of *M. dubia* based suitable medicinal intercrops agroforestry system is a better option for the farmers to achieve sustainable production and doubling farmer's income in future.

Economic feasibility

Planting *M. dubia* is highly beneficial for farmers as it's a market-valued tree with guaranteed repurchase and minimal maintenance needs. Its economic viability in agroforestry is confirmed by its successful biophysical compatibility with diverse intercrops like pulse, vegetable, medicinal, and aromatic plants (Mohanty *et al*., 2019). Pratap *et al*. (2020) assessed the economic viability of a Melia composita-radish (8m × 5m) agrisilviculture system, reporting net returns of ₹2,92,364 per hectare and a benefit-cost ratio of 3.60, outperforming sole radish cropping. Shrivastava *et al.* (2023) further reported that a *M. dubia* tree typically yields four quintals of wood after five years, with a market value of Rs. 0.03-0.04 lakh per tree. This translates to an average gain of Rs. 14.0 lakh per hectare after 5-6 years from 400 trees planted at a 5m x 5m spacing. Additionally, Ashalatha *et al.* (2023) showed that the maximum gross income (Rs. 87,000 ha^{-1}) and net return (Rs.67,000 ha^{-1}) were recorded in a brinjal + *M. dubia* combination. Where as in Silvi-medicinal system, *M. dubia* + *Clerodendrum phlomidis* agroforestry system showed the maximum total gross returns (Rs. 516190 ha–1), net returns (Rs. 378490 ha-1) (Mesharam *et al*. 2024)

Conclusion and Discussion

Any species is regarded ideal for agro-forestry if it does not compete with crops for water or nutrients, supports soil fertility through deep rooting and nutrient cycling, and adapts well to various environments (Kumar *et al.*, 2022). It should have a light branching pattern, withstand pruning, and be fast-growing with a short rotation. High survival and multiple uses like fodder add to its desirability. The results of researches show that *M. dubia*, with all the above characteristics, is ideal for plantation in agro-forestry. Further, including the species on agricultural lands can help address various agricultural issues such as sustainable biological production and monetary returns, deforestation and declining soil fertility.

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Powdery Mildew in Wheat: Unseen Perils and Solutions for Farmers

Introduction

Wheat (*Triticum spp.*) is a staple crop that plays a crucial role in food security worldwide. It belongs to the Poaceae family and originated in Southwest Asia. Wheat is grown in a variety of climates, and different varieties of this crop are cultivated across the globe. In India, three main species of wheat are grown: Triticum aestivum, Triticum durum, and Triticum dicoccum, with Triticum aestivum covering the largest area. The ideal region for wheat cultivation is between the latitudes of 30°N and 60°N. As the world's population grows, there is an increasing need for higher wheat production to meet the demand. However, wheat cultivation faces several challenges, one of the most significant being Powdery Mildew, which has a negative impact on both crop yield and quality.

Symptoms of Powdery Mildew: The primary symptom of Powdery Mildew is the formation of a powdery white or greyish coating on the leaves. This coating is mainly made up of fungal spores and mycelium. Infected plants show stunted growth, with fewer tillers and shorter plant height. As the disease progresses, the leaves may curl, become distorted, or show necrotic (dead) spots. This results in a reduction in grain yield, which can lead to significant economic losses for farmers.


Causes of Powdery Mildew: The cause of this disease is the fungus *Blumeria graminis* f.sp. *tritici*, which specifically infects wheat plants. It is an obligate, host-specific pathogen, meaning it can only infect wheat. This disease is considered the fourth most destructive after the three major rust diseases. The life cycle of Powdery Mildew is complex and depends on specific environmental conditions for its spread.

Life Cycle of the Fungus: The life cycle of Powdery Mildew begins in the winter when the fungus survives as mycelium in volunteer and autumn-sown crops. During humid conditions, the fungus releases sexual spores (ascospores) from cleistothecia, which can initiate infections in the autumn. As the weather warms up in the spring, dormant mycelium becomes active, producing new conidia (asexual spores) that spread the disease. These spores germinate at a temperature range of 5-30°C, with 15°C being the optimum temperature for spore germination, especially when relative humidity is above 95%. In dry conditions, new spores can form within seven days.

Impact of Powdery Mildew: Powdery Mildew can severely affect wheat yield and quality. Late-sown winter wheat crops are particularly susceptible to this disease, as they grow rapidly during the spring. High nitrogen fertilizer levels and dense planting conditions can further exacerbate the spread of this disease. However, if detected early, the yield loss can be minimized (up to 20%). It is essential to take prompt action for disease management, as late attacks on the flag leaf and ear (after flowering) generally cause less significant damage.

Favourable Conditions for Powdery Mildew: Certain environmental conditions promote the growth of Powdery Mildew:

Moderate Temperatures: The fungus thrives in temperatures between 15°C and 25°C.

High Humidity: Although some humidity is unfavourable, high relative humidity enhances the spread of Powdery Mildew. Unlike other fungal diseases, it does not require free water on the plant surface for infection.

Crowded Planting: Dense wheat planting creates a favourable environment for the disease to spread, as it thrives in moist, shaded areas.

Management and Control: Effective management of Powdery Mildew in wheat involves a combination of cultural, chemical, and genetic strategies:

Resistant Varieties: Planting wheat varieties that are genetically resistant to Powdery Mildew is the most effective preventive measure. Use of resistant varieties like: PBW343, HD2967 and many more.

Crop Rotation: Implementing crop rotation practices can help break the disease cycle, as the fungus cannot survive on alternate host plants.

Adequate Spacing: Avoiding overcrowding in wheat fields is important, as it reduces humidity between plants, which can help prevent the spread of the disease.

Fungicide Application: In severe cases, fungicides can be used to control Powdery Mildew. However, their application should be judicious, taking into account environmental and economic factors.

Monitoring and Surveillance: Regular monitoring of wheat fields is crucial for early detection of the disease, so that control measures can be initiated promptly.

Conclusion: Powdery Mildew in wheat is a widespread fungal disease that can significantly affect both the yield and quality of wheat crops. For farmers wishing to protect their wheat crops, understanding the symptoms, favourable conditions, and effective management strategies is essential. By combining the use of resistant wheat varieties, crop rotation, proper planting practices, and chemical treatments, when necessary, growers can reduce the losses caused by this persistent and economically damaging disease. This approach will contribute to the sustainable production of this vital global food staple.

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Probiotics Roles in Plant-Based Fish Feed

Abstract

Aquaculture has rapidly emerged as a key food production sector, vital for global nutritional security. The sector's growth relies heavily on artificial feed, which is dependent on traditional ingredients like fishmeal and fish oil. However, these ingredients present challenges such as high costs, limited availability, and environmental and ethical issues. These factors drive the aquafeed industry to seek plant-based alternatives due to their availability and cost-effectiveness. While plant ingredients present challenges like nutrient imbalance, anti-nutritional factors, and high fiber content that reduces digestibility and performance. Feed additives such as probiotics are incorporated to overcome these issues by enhancing nutrient bioavailability, fish health, growth, and feed efficiency. The strategic incorporation of probiotics paves the way for a more cost-effective and nutritionally balanced inclusion of plant ingredients in aquaculture feed production.

Introduction

Aquaculture is one of the fastest-growing food production sectors globally, providing a significant source of protein to millions of people while addressing challenges posed by overfishing. Artificial feed has played a pivotal role in the industry's growth, becoming a cornerstone of modern aquaculture practices and one of the major input expenses. Global aquaculture heavily relies on feed-based systems, with fed aquaculture contributing approximately 73% of total production in 2022 (FAO, 2024). However, the industry faces several challenges, including unsustainable reliance on traditional feed ingredients like fishmeal and fish oil, their high costs, availability, and ethical concerns, beside disease outbreaks, and environmental sustainability issues. In response, the aquafeed industry has turned to plant-based ingredients as an alternative to fishmeal. and grain by-products are widely used in feeds for aquaculture species. Aquaculture feed ingredients tend to be mostly plant protein products, cereal grains and by-products of processing or milling industries. Beside the conventional ingredients like soybean meal, bran etc, non-conventional source such as legumes, and oilseed meals are also being explored for their availability and cost-effectiveness. However, the inclusion of plant ingredient in the feed formulation is not without challenges. Plant-based feeds often lack the essential nutrients, contain anti-nutritional factors and are high in fiber content that reduces nutrient digestibility and availability.

To address these challenges, feed additives such as enzymes, probiotics, and other bioactive compounds are incorporated to enhance nutrient bioavailability and feed efficiency. Probiotics, beneficial microorganisms, have been widely utilized in animal feed to promote health, digestibility, and growth. The different probiotic strains produce enzymes that enhance the digestion of feed by breaking down complex nutrients into more bioavailable forms. This enzymatic activity significantly improves nutrient absorption, addressing the nutritional limitations of plant-based diets. By incorporating probiotics, the aquaculture industry can mitigate the challenges of plant-based feeds, offering a sustainable and cost-effective solution that ensures optimal fish health, growth, and production efficiency. Probiotics also improve gut health by balancing microbiota, enhance immune responses, and support better nutrient utilization, making them essential for sustainable aquaculture.

The Need for Plant-Based Fish Feed

The need for plant ingredients in fish feed is essential due to pressing challenges in sustainability, resource availability, and economic efficiency. Fishmeal the primary nutrient sources in fish feed, primarily derived from wild-caught fish and bycatch, contributes to overfishing and the depletion of marine resources and the production process for fishmeal and fish oil also has a considerable environmental footprint, characterized by high energy use, greenhouse gas emissions, and water pollution. The rising demand for fishmeal, coupled with its limited availability, has led to escalating costs, straining aquaculture production budgets. Plant ingredients are generally cheaper and more readily available compared to ingredients of animal origin. Agri-processing by-products such as bran, oilcake, meal etc, transform agricultural waste into valuable feed components, supporting circular economy principles and enhancing resource efficiency. Properly processed plant products and by-products generally have high protein digestibility. This makes them an economically viable option for fish feed formulation. Public concern over the use of marine species in aquaculture diet environmental cost of fishmeal production is driving demand for sustainable and ethical feed solutions. While plant-based ingredients may lack essential amino acids or omega-3 fatty acids, modern feed formulations leverage fortification with supplements, enzymes, and probiotics to enhance their nutritional profile and digestibility. Techniques such as fermentation and enzyme treatment help mitigate anti-nutritional factors (ANFs) like phytates and tannins, further improving the efficacy of plant-based feeds.

Probiotics Application in Fish Nutrition

Probiotics, which are beneficial microorganisms, play a vital role in enhancing fish health, digestion, and growth. Their incorporation into fish diets has gained significant attention in modern aquaculture due to their multifaceted benefits. Below are the key roles of probiotics in fish nutrition:

1. **Enhancement of Gut Microbiota:** Probiotics are generally incorporated into fish diet to help balance and modulate the gut microbiota, promoting a diverse and stable microbial community. A healthy gut microbiota supports better digestion and nutrient absorption, as well as improved immune responses.
2. **Improvement in Digestion and Nutrient Absorption:** Probiotic strains like *Bacillus*, *Lactobacillus*, and *Pediococcus* secrete digestive enzymes produce such as amylase, protease, and lipase in the fish and shrimp gut,

which aid in breaking down complex nutrients in feed. This enzymatic activity enhances nutrient bioavailability, allowing for more efficient nutrient absorption and utilization.

3. **Immune System Stimulation:** Probiotics boost the immune system of fish, enhancing resistance to bacterial, viral, and parasitic infections. They modulate the production of immuno-regulatory compounds such as cytokines, macrophages, and natural killer (NK) cells strengthening the fish's defense system.
4. **Disease Prevention and Health Management:** By preventing the colonization of pathogenic bacteria in the gut, probiotics act as a biological barrier against infections. Probiotic strains produce bacteriocins, hydrogen peroxide, and organic acids, which inhibit pathogenic bacteria such as *Aeromonas* and *Vibrio* species. Their presence reduces the risk of diseases, contributing to healthier fish populations and reducing the need for antibiotics.
5. **Growth Promotion and Feed Efficiency:** Probiotics increase feed efficiency, enabling fish to convert feed into body mass more effectively and contribute to higher growth rates through enhancement of digestibility and nutrient absorption and reducing feed wastage. This results in faster growth rates, better weight gain, and overall cost efficiency in production.
6. **Stress Mitigation:** Probiotics help maintain gut homeostasis, even under stressful conditions such as handling, temperature fluctuations, or poor water quality. Probiotics improve stress tolerance in fish, especially during handling, transportation, temperature and salinity fluctuations or exposure to poor water quality. Some probiotic strains regulate the production of cortisol, a stress-related hormone, helping fish maintain homeostasis. A balanced gut microbiota can alleviate stress-induced immune suppression, supporting fish health and welfare. Probiotics reduce oxidative stress in fish by promoting the production of antioxidant enzymes such as superoxide dismutase (SOD) and glutathione peroxidase. This effect helps maintain a healthy gut lining and reduces disease susceptibility.

Plant ingredients used in fish feed

Plant ingredients used in fish and shrimp feed can be broadly categorized into whole grains, by-products, processed products, and unconventional ingredients.

Whole grains: Maize, wheat, rice, barley, oats, millet, and sorghum.

By-products: De-oiled soybean meal, canola meal, mustard/rapeseed meal, corn gluten meal, groundnut meal, sunflower meal, sesame cake, rice bran, wheat bran, broken rice.

Processed product: soy protein concentrate, wheat gluten, corn starch, wheat flour, rice flour, tapioca flour.

Unconventional ingredients: Moringa leaves, sesbania leaves, alfalfa leaves, sweet potato leaves, taro leaves, cassava leaf, azolla, seaweed, lupin meal, cottonseed meal, coconut meal, leucaena meal, palm kernel meal, distiller's dried grains, cane molasses,

Challenges with plant ingredient inclusion

While plant-based feeds are more sustainable and cost-effective, they often contain anti-nutritional factors (ANFs) and lack certain essential nutrients such as certain amino acids like methionine and lysine and omega-3 fatty acids, which are abundant in fishmeal. Additionally, they contain anti-nutritional factors like phytates, tannins, and protease inhibitors that reduces nutrient digestibility and availability. Many plant-based ingredients have high fiber content, such as non-starch polysaccharides (NSPs) like cellulose and hemicellulose, which are indigestible for most fish species and hinder the digestion process and nutrient release. Some plant ingredients, like oilseeds, legumes, and grains, contain bitter or astringent compounds, such as tannins and phenolic compounds, that reduce feed palatability. Reduced palatability leads to lower feed intake, ultimately affecting growth performance. Consequently, fish fed entirely on plant-based diets may suffer from slower growth rates, weakened immune systems, and reduced feed conversion efficiency.

Application of probiotics in plant-based diet

The application of probiotics in plant-based fish diets may addresses many of the limitations posed by plant-derived feed ingredients. Probiotics offer a viable solution to these challenges by enhancing the nutritional quality, digestibility, and overall performance of plant-based diets. Key roles played by probiotics in improving the effectiveness of plant-based fish diets are

1. **Breakdown of Carbohydrates and Fibers:** Plant-based ingredients contain complex polysaccharides, like cellulose, hemicellulose, and non-starch polysaccharides (NSPs), which are indigestible for fish. Probiotic strains like Bacillus spp., Lactobacillus spp., and Enterococcus spp. produce enzymes such as cellulase, xylanase, and β-glucanase, which break down these polysaccharides, enhancing nutrient availability.
2. **Enhanced Protein Hydrolysis**: Plant-based protein sources like soybean meal have lower protein digestibility compared to fishmeal due to the presence of protease inhibitors. Probiotics like Bacillus spp., Lactobacillus spp., etc secrete protease enzymes that hydrolyze plant proteins, making amino acids more bioavailable. This is crucial for plant ingredients which are rich in protein but contain ANFs that block digestive enzymes.
3. **Nutrient Bioavailability**: Phytic acid, a common ANF in plant ingredients, binds essential minerals like phosphorus, calcium, and zinc, making them unavailable for fish absorption. Certain Bacillus strains produce phytase, which breaks down phytic acid, releasing bound phosphorus and other minerals. The release of phosphorus enhances the bioavailability, reduces the need for mineral supplements, and decreases phosphorus excretion into the environment, which mitigates water pollution.
4. **Short-Chain Fatty Acids Production:** Plant-based diets are rich in dietary fiber and NSPs, probiotics help convert these indigestible fibers into bioactive compounds. Probiotics, especially *Lactobacillus* and *Bifidobacterium* species, ferment non-starch polysaccharides (NSPs) and dietary fibers. This fermentation process produces short-chain fatty acids such as acetate, propionate, and butyrate, which serve as an energy source for intestinal epithelial cells.
5. **Mitigation of Anti-Nutritional Factors:** Plant-based ingredients contain various ANFs, such as tannins, saponins, protease inhibitors, and lectins, which interfere with nutrient digestibility, absorption, and gut health. Microbial fermentation of plant ingredients with probiotics can reduce or eliminate these anti-nutritional factors. Probiotics like *Bacillus* and *Lactobacillus* degrade tannins and saponins, which are present in soy, legumes, and some oilseed meals through the production of tannase and related enzymes. Probiotics produce proteases

that counteract protease inhibitors, which block the activity of digestive enzymes like trypsin and chymotrypsin, restoring protein digestion. The reduction of ANFs improves digestibility, gut health, and immune response, enabling the efficient use of plant-based feed ingredients.

6. **Anti-Inflammatory Properties**: ANFs in plant ingredients can cause gut inflammation in fish. Dietary inclusion of soybean meal induced enteritis especially in many fish species due to anti-nutritional factors like saponins. Probiotics produce short-chain fatty acids like butyrate, which have anti-inflammatory effects. They also support the production of cytokines and anti-inflammatory markers. Reduced gut inflammation promotes better nutrient absorption, healthier gut morphology, and overall fish well-being. This is crucial in mitigating conditions like soybean meal-induced enteritis.
7. **Maintenance of Gut Health**: Plant-based feeds alter the gut microbiota due to their high fiber content. Probiotics help restore the balance of gut microbiota by increasing beneficial microbial populations (*Lactobacillus*, *Bifidobacterium*, etc.) while suppressing pathogenic bacteria (*Vibrio*, *Aeromonas*) through competitive exclusion, bacteriocin production, and modulation of the gut environment. A balanced gut microbiota ensures better digestion, immune protection, gut health and reduces the risk of dysbiosis (microbial imbalance) and pathogenic infections.
8. **Boosting Immunity:** Plant-based diets sometimes compromise immune response due to a lack of fishmeal-derived immunostimulants. Probiotics stimulate the immune system by increasing the production of cytokines, immunoglobulins, and antimicrobial peptides. This reduces the need for antibiotics, supporting sustainable aquaculture.
9. **Sustainable Use of Local Resources**: The reliance on imported fishmeal increases production costs and limits sustainability. Probiotics support the efficient use of local, low-cost, and widely available plant-based feed ingredients, non-conventional feed ingredients, thereby supporting sustainable aquaculture practices.

Conclusion

With the aquafeed industry's shift toward more economical and readily available ingredients to support the sustainable growth of aquaculture, the incorporation of plant-based ingredients into feed formulations becomes essential. Considering cost, availability, and nutritional value, these plant-based alternatives address several challenges posed by traditional feed ingredients. There is also a need for plant ingredients to be more nutritive and palatable, enhancing nutrient digestibility and bioavailability. The incorporation of probiotics in plant-based fish diets presents a transformative approach to sustainable aquaculture. Probiotics not only address the nutritional gaps and ANFs present in plant feed but also enhance fish health, feed efficiency, and growth. Their role in reducing environmental pollution and promoting the use of local agricultural by-products makes them an essential component of modern aquafeed formulations. Probiotic-aided plant-based feeds have the potential to reduce dependency on fishmeal while ensuring optimal fish performance and sustainability.

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ARTICLE ID: 15

THE MODE OF ACTION, MAJOR EFFECTS AND USE OF PLANT GROWTH RETARDANTS IN PLANTS

What are plant growth retardants?

Plant growth retardants are compounds which are used to reduce plant growth without changing developmental patterns or being phytotoxic. The largest group of plant growth retardants consists of chemicals antagonistic to gibberellins (GA), the hormone that is responsible for plant growth. Therefore, the PGRs can be majorly classified as gibberellin biosynthesis inhibitors and growth retardant compound not inhibiting gibberellin biosynthesis.

I. Gibberellin biosynthesis inhibitors

Includes:- Onium compounds, Pyrimidines, Triazoles compounds.
Other chemicals are Tetcyclacis, Prohexadione calcium, Inabenfide etc.

I a. Onium compounds

Eg: Chlormequate chloride, Cycocel, Mepiquat chloride, Phosphon D, Piperium bromide.
However, the most commonly used onium compounds are Cycocel and Mepiquate Chloride.

- **Mode of action:** Inhibition of cyclization of geranylgeranyl pyrophosphate to copallyl pyrophosphate leading to inhibition of gibberellin formation.

- **Major effects on plants:** shortened inter nodes and thickened greener leaves compared to untreated controls.

- **Other effects are:** Enhanced net photosynthesis
  Better drought tolerance, which can be due to reduction in leaf area and reduced transpiration surface.
  Better tolerance to abiotic stresses such as salt and temperature stress, and biotic stresses such as insects, diseases and nematodes.

I b. Pyrimidines:

Eg: Ancymidol and Flurprimidol

- **Mode of action:** Inhibits cytochrome P-450, which controls the oxidation of kaurene to kaurenoic acid, thereby inhibiting the biosynthesis of gibberellin.

Also interferes with (inhibits) sterol and abscisic acid biosynthesis.

- **Major effects on plants:** Other than retarding the growth, either have no effect or slight reduction in photosynthesis. Moreover, they cause reduction in water use.

I c. Triazoles:

Eg: Paclobutrazol, Uniconazole, Triapenthenol, BAS 111 etc.

- **Mode of action:** Inhibits microsomal oxidation of kaurene, kaurenol, and kaurenal, which is catalysed by kaurene oxidase, a cytochrome P-450 oxidase.

It also inhibits sterol biosynthesis, reduce abscisic acid, ethylene and IAA content, and increases cytokinin content.

- **Major effects on plants:** Increase chlorophyll content.

Protects plants against abiotic stresses due to water and sulfur dioxide. Also reduces insect population densities.

I d. Other gibberellin biosynthesis inhibitors

Tetcyclacis:- It blocks microsomal oxidation of kaurene to kaurenoic acid. It also inhibits sterol biosynthesis.

Prohexadione calcium:- It inhibits 3 beta hydroxylation of GA_{20} to GA_1 and 2 beta hydroxylation of GA_1 to GA_8.

Inabenfide:-It inhibits gibberellin biosynthesis by blocking the oxidation of conversion of kaurene to kaurenoic acid.

II. Growth retardant compound not inhibiting gibberellin biosynthesis

II a. Morphactins

They have the ability to affect plant morphogenesis. As a general rule, morphactins inhibits plant growth while gibberellins have a promotive effect.

Eg: Fluorene, fluorene-9-caboxylic acid, Chlorflurenol

II b. Dikegulac sodium

It retards the apical dominance leading to lateral bud break.

It reduces Gibberellin like substances while stimulate ABA like substances and ethylene.

II c. Ethylene-releasing compound ethephon

It is also a growth retardant as ethylene causes shorter thicker stems.

The primary use of ethephon as a growth retardant is controlling lodging of cereals and grain crops.

II d. Malic hydrazide

It blocks cell division by interfering with the production of uracil.

II e. Acetamide derivatives

Eg: Mefluidide and Amidochlor

Both inhibits turf grass growth.

II f. Daminozide

Control height of bedding plants

II h. Cimetacarb

It is a turf growth retardant

Use of plant growth retardants

- ✓ In floricultural crops it is important to reduce plant size to increase saleability. Plant growth retardants have been used for many years to manipulate the size, shape and overall quality of floricultural crops.
- ✓ At present time, CCC, daminozide, ancymidol, and paclobutrazol are the primary compounds used for poinsettias and chrysanthemums, although uniconazole and tetcyclacis have been shown to have potential.
- ✓ In case of bedding plants such as zinnia and geranium, the treatments of growth retardants promote compactness, maintain quality prior to sale, and also promote longer-shelf life.
- ✓ Earlier, daminozide was the primary growth retardant used to control the height of the bedding plants for many years.
- ✓ Paclobutrazol has been shown to be very effective in reducing the height of a variety of bedding plants.
- ✓ CCC and ethephon used to control lodging in cereals.
- ✓ Maleic hydrazide has been used as a sprout inhibitor in onions and potatoes.
- ✓ Paclobutrazol and uniconazole facilitate tomato transplant production.
- ✓ Daminozide (banned in USA in 1989) is effective in reducing vegetative growth and also stimulated floral bud induction, resulting

in increased bloom the following year in apple, pear and cherry trees.

- ✓ Paclobutrazol retards plant growth in deciduous fruit trees. It controls the vegetative growth in apple and pear trees by foliar application (presently registered in seven countries).
- ✓ Paclobutrazol also controls mites.
- ✓ It is also an effective vegetative growth inhibitor in both table and wine grapes without affecting yield, berry quality or cold- hardness of dormant buds.
- ✓ It is also shown to reduce vegetative growth in tangelo seedlings, sour orange seedlings and lemon trees.

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THE ROLE OF EDIBLE COATINGS AND FILMS IN MODERN FOOD SYSTEMS

Food is fundamental for human survival, and as time progresses, consumers are increasingly focused on the quality of their food. This growing concern has highlighted the importance of innovative packaging solutions, particularly edible coatings and films (ECFs), which are gaining prominence in biobased packaging. ECFs play a crucial role in enhancing the sensory attributes of food products and minimizing the proliferation of microorganisms, contributing to a safer and healthier environment. These sustainable materials are essential for addressing the challenges of food preservation and environmental impact. Edible films are thin sheets applied directly to food products, while edible coatings are formed on the food surface through various techniques. Both are crafted from eco-friendly and safe materials, often including proteins, polysaccharides, lipids, plasticizers, emulsifiers, and active substances such as antimicrobials and antioxidants. The use of edible coatings and films is not a novel concept but has been employed since prehistoric times, such as waxing fruits and using cellulose coatings in meat casings.

In response to increasing consumer demand for food preservation methods derived from biological sources, modified techniques utilizing ingestible biopolymers have emerged. ECFs offer a promising alternative to conventional petroleum-based plastic packaging, which are non-degradable and environmentally unfriendly. By utilizing renewable resources, edible coatings and films contribute to more sustainable food systems and can potentially reduce food waste by maintaining the freshness and safety of perishable goods. The technology for edible coating production involves several key aspects, including the preparation of the coating material and the methods used to apply it to food products.

Edible Coating Materials

Edible coatings and films are manufactured using solutions with a mixture of different natural components. These components can include proteins, polysaccharides, and lipids, as well as other ingredients like plasticizers, emulsifiers, and active substances such as antioxidants and antimicrobials.

The selection of these materials depends on the desired properties of the coating, such as mechanical strength, barrier properties (to moisture, oxygen, CO2), and adhesion to the food surface.

•Novel film-forming ingredients from sources like root plants (cassava, potato, sweet potato) and other plants (achira flour, amylum, yam, ulluco, water chestnut) are being explored.

•The physical properties of the biopolymers used are influenced by factors like their characteristics, biochemical conformation, compatibility, relative humidity, temperature, water resistance, and application procedures.

•In some cases, nanocomposite films are being developed, which involve support networks of biological polymers.

- Tannic acid can be used as a cross-linking agent to improve the strength and mechanical properties of edible coatings and films due to covalent bonds and cross-linking with coating materials.
- Plasticizers are often added to the coating solution to increase mechanical properties. Common plasticizers include glycerol, fatty acids, sorbitol, propylene glycol, sucrose polyethylene glycol, and monoglycerides.

Methods of Applying Edible Coatings:

The technique and way of coating application are very important to ensure thorough coverage of the product and prolong shelf life. Several strategies are utilized for applying edible coatings to food products:

• Dipping (Immersion Technique): This is a widely used method where the food item is plunged into the ECF solution. It is particularly applicable for products with uneven surfaces and can result in dense coatings. The food is typically submerged for 5 to 30 seconds and then dried naturally. While simple, this method can sometimes lead to hindrance in reparation due to thick coating or solution and may weaken the food surface's outer covering.

• Spraying: This is another fundamental strategy for food covering, allowing for the creation of consistent and uniform layers.

• Brushing: Edible coatings can be applied using a brush, which is reported to give good results, particularly for beans and highly perishable fruits and vegetables like strawberries and berries.

• Extrusion: This method depends on the thermoplastic properties of the edible coating and is considered a best technique for applying edible coatings for industrial purposes compared to other methods.

• Solvent Casting: This is another method used in the food industry for applying coatings.

• Other strategies mentioned include brushing, individual wrapping, spreading, and fluidized-bed handling.

The choice of application method depends on the type of food product, the desired thickness and uniformity of the coating, and the scale of production. Regardless of the method, the applied ECF should be consistent and free of faults. Achieving suitable adhesion properties during the implementation of ECFs can be challenging. Furthermore, it is important to note that edible films can also be produced separately using methods like film casting in the lab and then potentially used to wrap food items, though the primary focus of the sources is on coatings applied directly in liquid form.

The ongoing exploration of novel materials and advancements in formulation techniques are expected to shape the future of edible films and coatings. Research efforts are likely to focus on improving mechanical qualities, barrier capabilities, and stability to broaden their applicability across diverse food applications. Furthermore, the development of ECFs with enhanced antibacterial properties and the application of nanotechnology in their production represent promising areas for future study.

The edible films and coatings are not merely a trend but a significant evolution in food packaging technology. Their capacity to preserve food quality, extend shelf life, reduce environmental impact, and potentially enhance nutritional value positions them as a crucial element in creating more sustainable and efficient food systems for the future. Continued innovation and wider adoption of ECFs hold the key to addressing global financial issues and environmental concerns associated with food production and consumption.

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Unlocking the Secrets of Jeevamrutha: A Path to Sustainable Agriculture

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Abstract

Jeevamrutha is a cornerstone of Zero Budget Natural Farming (ZBNF), an eco-friendly agricultural approach that eliminates the use of synthetic inputs. Comprising cow dung, cow urine, jaggery, gram flour, and water, Jeevamrutha is a fermented microbial solution that boosts soil fertility and plant growth through enhanced microbial activity. This preparation, made from locally available, cost-effective materials, is applied as a foliar spray or soil amendment. Its use fosters microbial diversity, suppresses plant diseases, improves nutrient availability, and promotes sustainable, low-cost farming. Jeevamrutha exemplifies an accessible, biologically-driven method for revitalizing soil health and achieving productive, natural farming systems.

Keywords: *Jeevamrutha, Zero Budget Natural Farming, ZBNF, sustainable agriculture, microbial culture, soil fertility, organic farming, cost-effective farming, foliar spray, plant growth enhancer*

Jeevamrutha is a key component of Zero Budget Natural Farming (ZBNF), a sustainable agricultural method that promotes organic farming practices without relying on synthetic inputs. Jeevamrutha is an organic microbial culture that farmers use to enhance soil fertility, improve microbial activity, and promote plant growth. The term "Jeevamrutha" can be translated to mean 'nectar for the soil organisms,' reflecting its role in fostering a healthy and thriving soil ecosystem.

Making Jeevamrutha:

The preparation of Jeevamrutha involves using locally available materials and follows a simple and cost-effective method. Here is a step-by-step guide on how to make Jeevamrutha:

Ingredients:

1. Cow dung: Collect fresh cow dung from indigenous cows. Cow dung serves as a source of beneficial microorganisms.

2. Cow urine: Collect fresh urine from cows. Cow urine is rich in nutrients and helps in activating the microbial activity.

3. Jaggery (or molasses): Use jaggery or molasses as a source of sugar to feed the microorganisms and stimulate their growth.

4. Gram flour (optional): Gram flour can be added to provide additional nutrients for microbial growth.

5. Water: Use chlorine-free water, preferably well water or rainwater.

Method:

1. Collect the Ingredients:

Gather the required quantities of cow dung, cow urine, jaggery, gram flour, and water. Ensure that the cow dung and urine come from healthy, disease-free cows.

2. Mixing the Ingredients:

In a large container or pit, mix the following ingredients:

- 10 kg of fresh cow dung
- 10 liters of cow urine
- 1 kg of jaggery (or molasses)
- 1 kg of gram flour (optional)
- Approximately 200 liters of water

3. **Stirring and Fermentation:**

Thoroughly mix the ingredients to form a solution. Stirring helps in incorporating oxygen, which is essential for the growth of aerobic microorganisms. Cover the container with a lid or plastic sheet to protect it from rain. Allow the mixture to ferment for 3 to 4 days.

Flow chart showing the making method

Collect Cow Dung & Urine
↓
Mix in a Large Container
↓
Add Jaggery or Molasses)
↓
Add Gram Flour (Optional)
↓
Add Water (Non- Chlorinated)
↓
Thoroughly stir the Mixture
↓
Cover the Container for Fermentation
↓
Allow to Ferment for (3-4 days)
↓
Check for Sweet- Sour Smell & Color Change
↓
Dilute Jeevamrutha in the ratio of (1:10 Ratio)
↓
Apply to Fields as Foliar Spray or Soil Application

4. **Checking Fermentation:**

During the fermentation period, the mixture will undergo a transformation. It will develop a sweet-sour smell, indicating the growth of beneficial microorganisms. The color may change to a brownish hue.

5. Application:

Once the fermentation is complete, dilute the Jeevamrutha before applying it to the fields. Typically, one part of Jeevamrutha is mixed with ten parts of water. This diluted solution can be applied to crops as a foliar spray or directly to the soil around the plant's root zone.

Benefits of Jeevamrutha:

1. Microbial Diversity:

Jeevamrutha promotes the growth and diversity of beneficial microorganisms, including bacteria, fungi, and actinomycetes, in the soil.

2. Improved Soil Fertility:

The microorganisms in Jeevamrutha help break down organic matter in the soil, making essential nutrients more available to plants. This enhances soil fertility over time.

3. Disease Suppression:

The presence of beneficial microorganisms can suppress the growth of harmful pathogens, reducing the risk of diseases in plants.

4. Enhanced Plant Growth:

The application of Jeevamrutha contributes to better plant growth, increased yields, and improved overall crop health.

5. Cost-Effective:

Jeevamrutha is made from locally available materials, making it a cost-effective alternative to synthetic fertilizers.

In summary, Jeevamrutha is a valuable input in Zero Budget Natural Farming, contributing to sustainable and organic agriculture by harnessing the power of beneficial microorganisms for soil health and plant nutrition.

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Use of 'Plant Growth Regulators' in Horticultural Crops

PGR's

Introduction: Plant growth regulator are the Chemicals substances which govern all the factors of development and growth within plants.

Some other names used to refer to as 'Phytoharmones' and 'Plant growth Regulatore'

Phytoharmones are organic compounds which are either synthesized in laboratories or produced naturally in the plants. They profoundly control and modify the physiological process like the growth, development, and movement of plants.

Defination:- "Plant growth regulators may be refers to as those chemical substance which are regulate the growth of plant either promote or limit."

Plant growth regulators are broadly classified into two majar groups, on the basis of their actions.

(i) Plant growth promoters.

(ii) Plant growth inhibitars/retardants.

Aluxins, Gibberellin, and Cytokinins are grouped into plant growth promoters, while Abscisic acid and Ethylene are grouped into plant growth inhibitors.

- Ethylene can be grouped either into promoters or into inhibitors.

Let's some talk about the plant growth and development before taking a look of hormenes or plant growth regulators.

Types of plant growth

1. **Primary and Secondary Growth.**

The meristematic cells present at the root and shoot apices divide mitotically and increase the lenth of the plant body. This is known as primary growth.

Secondary growth is reffered to as the increase in the diameter of the plant body by the division of the secondary meristem.

Unlimited growth:- When the plant constantly grows from the germination stage to death, it is called unlimited growth.

Limited growth:- In this stage, the plant parts stop growing after attaining a certain size.

Vegetative growth:- It involves the production of stem, leaves, and branches, except the flowers.

Reproductive growth:- Flowring occurs at this type of growth stage.

Factors affecting plant growth:- There are four major factors that affect the growth of the plants.

- **Light:-** Plant are autotrophs, they require light for preparation their food, limited light as the absence of it greatly affects the growth of the plant. The intensity of light, quality of light, and light duration influence the movement of stomata, Chlorophyll synthesis, photosynthesis and various other physiological factors. Light also encourages flowring and fruiting During winters when the days are short, the growth of the plants is retarded.
- **Water:-** Plants can not survive without water, araund 90% of the plant body comprises water plants become stressed in the absence of water and die. Water present in the soil is absorbed by the plant which absobs and transports the nutrients along with it water keeps the plant hydrated.
- **Temprature :-** Plant growth is greatly influnced by temprature. High tempratures speed up transpiration, photosynthesis, and germination process. however low temperatures slow dawn the growth of the plants.
- **Nutrients :-**Just like human beings, plants require proper norishment for their growth and development. Soil nutrients are divided into macronutrients and micronutrients. Nitrogen, Potasium, Calcium, Magnisium, sulfer and Phaspharus are the macronutrients required to the plants.

  The micronutrients include iron, copper, etc. Deficiency of these nutrients in plants makes them prone to several discare. Even if a single nutrient is lack, it results stunted growth of the plant.

Discovery of plant growth regulatars:- It was Though sarendipity, initial steps of the discovery of major plant growth regulators begain with Charles Darwin and his Son Francis Darwin. They observed the growth of coleoptiles of canary grass towards the light source Phototropism. Followed by a series of expriments, they concluded the presence of a transmittable substance that influnces the light. That transmittable Substance was what we know as Auxin which was isolated later by F.w. Went later, many scientists discovered and isolated different plant growth regulators. Gibabrallins & Gibberellic acid was formarly found in uninfected rice seedlings and was reported by E. kurosawa. F. skong and Miller discovered another growth -promoting substance named kinetin, which is haw khawn as Cytokinins

Charcterstics of plant growth regulators :-

As the plants require oxygen, water, Sunlight, and nutrition to developmet and grow, they do require Certain chemical substances to manage their growth and development, these chemicals substances are Known as plant growth regulators and are naturally produced by the plants itself.

These are simple organic molecules having several chemical compositions. They are also described as phytoharmones, plant growth substances, or plant growth harmones..

They can accelerate as well as retard the rate of growth in plants.

Plants growth harmones ar plant growth regulators exhibit the following charcterstics:-

a) Differentiation and alongation of calls.
b) Formation of leaves, flowers, and stems.
c) wilting of leaves
d) Ripening of fruit
e) Seed dormancy etc.

Generally, there are five types of plant harmones namely, Auxın, Gibberellins (GAS) Cytokinins, Abscisic acid(ABA) and Ethylene in addition to these, three are more derivative Compounds, both natural and synthetic, which also act as plant growth regulators.

Types of plant growth regulators.

Plant growth harmones & regulators are of the following types.

(a) Plant growth Promoters
(b) Plant growth Inhibitars

Plant growth Promoters

(A) Auxing: The first phytohormone to be discovered is the Auxins and it Jay the biologist Charles Darwin. was discovered.

Auxing are with one of the most important plant harmones. The Chief naturally occuring auxın is indole-3 acetic and -IAA and other related compounds The Haim Auxin is derived from the Gureete language meaning to grow.

These plant growth regulotars and generally produced at the points of stems and monts from where they are transported to other parts of the plants. These plant harmones include both naturally and synthetic sources. Indole-3- acetic awd and indole by butyric acid are obtained from natural plant sources, where as Napthalene acetic acid and 2, 4- dichlorophenoxy actic acid are obtained from synthetic sources.

Functions of Auxins:-

(a) Facilitate flawring in plants.
(b) used in the process of plant propagation.
(c) Used by gardeners to keep lawns free from weeds.
(d) Involved in the initiation of roots in stem cuttings.
(e) Brevention of dropping of leaves and fruits at carly stages.
(f) Regulate xylem differentitation and assits in cell division.
(g) Auxing are widely used weeds, as herbicides to kill dicot
(h) Used to produce fruit without proceding fertilization.
(i) Promote natural detachment of alder leaves and yourts.
(j) Spiral dominance may occur in which the growth f lateral beides is inhibited Jay the growth of shoot caps may be removed.
(k) They are produced by the apex of rest and shoot.

(B) **Gibberellins:-** Gibberelling are an extensive chemical family based on the ent-gibberellane structure. The first gibberallin to be discovered by Gibberellic acid. Now there are more than 100 types of gibberellins and are mainly gathered from a variety of organisms from fungi to higher plants. They are acidic acid and denoted as follows – GA_1, GA_2, GA_3 etc.

Functions of Gibberellins

(a) Delay senescence in fruits.
(b) Involved in leaf expansion.
(c) Break bau and seed dormancy.
(d) Promote bolting in cabbages and beet.
(e) Facilitate elongation of fruits such as apples and enhance their shape.
(f) Used by the brewing industry to accelerate the malting process.
(g) Used as the spraying agent to increase the yield of sugarcane by elongation of the stem.
(h) In young conifers, utilized to fasten the maturity period and faciliate early seed production.
(i) Helps in enhancing the crop yield by enhancing the hieght in plants such as sugarcane and increase the axis length in plants such as grape stalks.

(C) **Cytokinins:-** These are produced in the regions where call division occurs, mostly in the roots and shoots. They help in the production of new leaves, lateral shoot growth, choloroplasts in leaves etc. They help in overcoming apical dominance and delay ageing of leaves.

Functions of Cytokinins

(a) Break bud and seed dormanay.
(b) Promotes the growth of the lateral bud.
(c) Promotes cell division and apical dominance.
(d) They are used to keep flowers fresh for a longer time..
(e) Used in tissue culture to induce cell division in mature tissues.
(f) Facilitate adventitious shoot formation and lateral shoot growth.
(g) Promotes nutrients mobilization that in turn assits delaying leaf senescence.
(h) Helps in delaying the process of ageing in fresh leaf crops like cabbage and lettuce.
(i)Involved in the formation of new leaves and choloroplast organelles within the plant cell.
(j) used to induce the development of shoot and roots along with auxin depending on the ratio.

Plant growth Inhibitors

(A) **Abscisic acid:** It is a growth inhibitor, which was discovered in the 19608. It wah initially called dormant. Latar, another compound adscisin-II was discovered and are Commonly called as abscisic acid. This growth, inhibitor is synthesized within the stem, leaves, fruits and seeds of the plant. Mostly, abscisic acid serves as an antagonist to gibberalic acid. It is also kmown as the stress hormone as it helps by increasing the plant-tolrance to Various types of stress.

Function of Abscisic acid

(a) Stimulates closing of stomata in the epidermis.
(b) Helps in the maturation and development of seeds.
(c) Inhibits plant metabolism and seed germination.
(d) It is involved in regulating abscission and dormancy.
(e)It is widely used as a spraying agent on trees to regulate dropping of fruits.
(f) Include seed- dormancy and aids in with standing desiccation and Various undesired growth factors.

(B) Ethylene

Ethylene is a simple, gaseous plant growth reguaoters, synthesized by most of the plant organs includes ripening fruits and ageing tissues. It is an unsaturated hydrocarbon having double covalent bonds between and adjacent to carbon atoms.

Ethylene is used as both plant growth promoters and plant growth inhibitors.

Ethylene is synthesized by the ripening fruits and ageing tissues.

Function of Ethylene

Ethylene is the most widely used plant growth regulatar as it helps in regulating many physiological process.

(a) Induce flowring in the Mango tree.
(b) Promotes sprouting of Potato tubers.
(c) Breaks the dormancy of seeds and buds.
(d) Enhances respiration rate during ripening of fruits.
(e) Applied to rubber trees to stimulation the flow of latex.
(f) Facilitates sencenece and abscission of both flowers and leaves.
(g) Used to stimulate the ripening of fruits for example, tomatoes and citrus.
(i) Affects horizontal growth of seedling and swelling of the axis in dicot seedlings.
(j) Increases root hair formation and growth, thus aids plant to expand their surface area for absorption.

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Nanophytovirology: An emerging arsenal in plant viral disease management

Introduction

Plant diseases significantly threaten agricultural crops worldwide, leading to substantial economic losses each year. Several plant pathogens are responsible for causing the losses, with viral diseases contributing to 47% (Frank *et al* 2022). As the global population is projected to reach 9 billion by 2050, ensuring food security becomes increasingly critical (Jones 2021). To meet this growing demand, it is essential to effectively manage and mitigate plant diseases that compromise crop productivity and sustainability. Nanotechnology is an emerging tool in the pursuit of sustainable agriculture, offering promising applications in plant disease management. While its effectiveness has been well demonstrated against fungal and bacterial pathogens, its use in managing viral diseases is still in the early stages but holds significant potential.

In contrast to conventional management of plant viruses, nanophytovirology combines both nanotechnology and plant virology to study the etiology, diagnosis, drug transport, biostimulation and induction of plant defenses. Engineered nanoparticles (ENPs), typically ranging in size from 1 to 100 nanometers, encompass a diverse group of materials. These include nanometals, metal oxides, carbon-based nanomaterials, metalloids, and advanced structures such as functionalized liposomes, dendrimers, and quantum dots (Farooq *et al* 2021). Due to their high surface area-to-volume ratio, nanoparticles exhibit greater reactivity compared to larger particles or conventional chemical treatments, enhancing their effectiveness in various applications. Apart from enhancing target specificity, minimizing adverse effects on non-target organisms, NPs can improve plant health and strengthen resistance to diseases. Thus, the integration of nanotechnology holds a great promise for advancing precision in both virus detection and management shortly.

Types of nanoparticles used for control of plant virus

Various nanoparticles have been employed against plant viruses and have proven effective in reducing both infection levels and viral symptoms. In addition to their antiviral activity, some nanoparticles have also demonstrated the ability to enhance plant health and immunity. Below is an overview of various nanoparticles and their reported effects on different plant viruses:

1. Silver Nanoparticles (AgNPs):
AgNPs have been shown to inhibit local lesions, reduce *Tomato spotted wilt virus* (TSWV) infection, and induce resistance in potatoes against *Potato virus Y* (PVY).

2. Graphene Oxide-Silver Nanocomposites (GO-AgNPs):
In the case of *Tomato bushy stunt virus* (TBSV), GO-AgNPs significantly reduced disease severity, viral concentration, and infection rate.

3. Nickel Oxide Nanoparticles (NiO NPs):
Treatment of *Cucumber mosaic virus* (CMV) with NiO NPs led to a marked reduction in disease severity and virus concentration in cucumber.

4. Titanium Dioxide Nanoparticles (TiO_2 NPs):
TiO_2-based nanomaterials have demonstrated a 15–60% reduction in disease severity caused by *Turnip mosaic virus* (TuMV), along with increased shoot biomass and enhanced phytohormone levels. TiO_2 NPs have also been effective in reducing symptoms of *Broad bean stain virus* (BBSV).

5. Silicon Dioxide Nanoparticles (SiO_2 NPs):
These nanoparticles have been reported to decrease disease severity associated with *Tomato yellow leaf curl virus* (TYLCV).

6. Zinc Oxide and Iron Oxide Nanoparticles (ZnO and Fe_2O_3 NPs):
These have shown in vitro inhibitory activity against *Tobacco mosaic virus* (TMV), suggesting their potential for antiviral applications.

7. Cerium Oxide Nanoparticles (CeO_2 NPs):
CeO_2 NPs have demonstrated the ability to suppress TMV symptoms, highlighting their role in viral inhibition.

8. Schiff Base-Functionalized Silver Nanoparticles:
These modified AgNPs have shown potential in reducing TMV infection, likely through enhanced interaction with viral particles.

9. Gold Nanoparticles (AuNPs):
AuNPs have been found to dissociate *Barley yellow mosaic virus* (BaYMV) particles in vitro, indicating a direct antiviral mechanism.

10. Carbon Nanotubes (CNTs):
CNTs interfere with TMV movement and replication, and they may also contribute to the induction of plant resistance.

Mode of action of nanoparticles against viral pathogens

The concept of the use of nanoparticles to manage plant viruses is still very new, and hence its underlying mechanisms are not completely understood yet. Metallic nanoparticles such as zinc oxide (ZnO), silicon dioxide (SiO_2), and silver (Ag) possess antiviral properties by disrupting viral replication, making them effective agents for managing plant viral infections. In plants, nanoparticles typically act through two primary mechanisms to combat viral diseases, direct and indirect methods (Vargas-Hernandez *et al* 2020). In the direct method, the nanoparticles interact with the virus. The following events take place here (Yasamineh *et al* 2022):

- Interfere with viral genome replication
- Inhibit viral protein synthesis, especially coat protein production
- Disrupt viral genome packaging and degrade capsid proteins
- Disturb the electron transport system in infected plant cells
- Strengthen cellular barriers (e.g., cell wall thickening, lignin deposition).
- Block viral entry into host cells
- Inhibit viral DNA replication

Whereas, in the indirect mode of action, nanoparticles (NPs) do not target or inactivate the virus directly. Instead, they enhance the plant's innate immune system, enabling it to better defend itself against viral infections. Upon exposure to NPs, infected plants often exhibit increased activity of key antioxidant and defense-related enzymes, such as peroxidase (POD), polyphenol oxidase (PPO), phenylalanine ammonia-lyase (PAL), and superoxide dismutase (SOD (Vargas-Hernandez *et al* 2020). Nanoparticle (NP) treatment in virus-infected plants leads to increased salicylic acid (SA) accumulation, which triggers the production of phytoanticipins and phytoalexins. These compounds help in combating viral infection. SA also activates systemic acquired resistance (SAR) and upregulates defense-related proteins via signaling pathways. Additionally, NP-induced lignin deposition reinforces cell walls, acting as a physical barrier against virus spread. Elevated reactive oxygen species (ROS) further enhances antiviral defense (Nandhini *et al* 2019).

Delivery of nanoparticles to combat viral pathogens

Nanoparticles (NPs) can enter plants primarily through natural openings such as stomata and are subsequently transported into cells via the plasma membrane. Once inside, they are readily absorbed and translocated within plant tissues, where they can activate defense responses and reduce disease severity. Their small size and high reactivity enable them to interact efficiently with plant cells, making them valuable tools in plant disease management (Warghane *et al* 2024).

There are several effective methods for applying nanoparticles to crops, depending on the desired outcome:

- **Foliar Application**: NPs can be directly sprayed onto the leaves or stems, allowing for quick absorption and localized action.
- **As Carriers for Agrochemicals**: NPs can be used to deliver herbicides or pesticides more precisely, improving efficacy and reducing environmental impact.
- **Genetic Delivery Systems**: NPs can also serve as carriers for double-stranded DNA or RNA molecules, facilitating CRISPR/Cas-mediated gene editing or silencing to enhance plant resistance against viral infections.

Potential hazards of nanoparticles in agriculture

Nanoparticles have long existed in the environment without causing significant harm to agriculture or ecological systems. However, growing research is focused on understanding their interactions with plants, particularly potential adverse effects. Notably, nanoparticles used in fertilizers can influence the plant microbiome, often leading to biotransformation of plant components. For instance, mesquite plants treated with $Ni(OH)_2$ nanoparticles accumulated these metals in the roots but showed the presence of NiNPs in shoots and leaves, illustrating in-plant biotransformation.

Nanoparticle accumulation is a growing concern due to its adverse effects on plants. Caesium oxide (CeO_2) NPs disrupt nitrogen fixation in soybean, while multi-walled carbon nanotubes (MWCNTs) inhibit growth, increase ROS production, and cause necrosis in red spinach (Pullaguarla *et al* 2018). Caesium oxide NPs damage cell membranes and trigger oxidative stress in rice. Zinc NPs have been linked to reduced seed germination and root elongation, likely due to both plant-induced toxicity and zinc ion release. Zinc oxide nanoparticles (ZnO NPs) have also been shown to cause DNA damage in earthworms, highlighting their toxicity (Hu *et al* 2010).

More broadly, agricultural soils are being impacted, and through the Trojan effect, nanoparticles spread via water, entering the food chain and posing widespread ecological risks. Nanopesticides from industrial and agricultural wastewater contaminate water sources, threatening both ecological balance and human health. Due to their high diffusibility, bioaccumulation, and biomimetic properties, nanoparticles pose toxic risks across ecosystems, especially to mammals. In humans, exposure can lead to acute and chronic conditions, including respiratory, cardiovascular, neurological disorders, and cancers (Chaud *et al* 2021).

Conclusion

Nanophytovirology is a rapidly emerging field combining nanotechnology and plant virology. It holds immense promise as a sustainable and innovative approach to managing viral diseases in plants. Its unique advantages, such as target specificity, non-invasiveness, and additional biostimulant effects, make it an attractive alternative to conventional chemical-based strategies that often have off-target impacts and environmental consequences. Despite these advantages, the current application of nanotechnology in plant virology remains largely limited to in vitro studies, with minimal dissemination into in vivo or field-level research. This limitation has created a significant knowledge gap in understanding how nanoparticles function within complex plant-pathogen-environment systems. Hence, there is an urgent need for comprehensive studies focusing on the mechanism of nanoparticle-mediated defense responses, including how they modulate host immunity and interfere with viral replication or movement within plant tissues.

Moreover, the impact of nanoparticles on satellite viruses, which often influence the virulence of helper viruses, remains largely unexplored. Studying these interactions could reveal novel roles of nanoparticles in modulating virus virulence, symptom expression, or host range, thereby broadening our understanding of virus ecology and evolution. Equally important is investigating the influence of nanoparticles on virus–vector relationships. Further research should also prioritize evaluating nanoparticle efficacy across a broad range of plant species and crop types to determine any species-specific responses or potential phytotoxicity.

In conclusion, nanophytovirology represents a frontier in plant health management, not only for its potential in precise and eco-friendly disease control, but also as a powerful tool in virus detection and diagnostics. With interdisciplinary research and field validation, this approach could redefine how we understand, monitor, and manage plant viral diseases in the future, contributing to more resilient and sustainable agricultural systems.

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CAMOUFLAGE IN THE INSECT WORLD

Introduction

In the vast and competitive ecosystems of our planet, survival often hinges on the ability to avoid detection. Among the most fascinating strategies evolved by animals is **camouflage**—a technique of blending into one's environment to evade predators or sneak up on prey. Insects, being among the most diverse and adaptable creatures on Earth, showcase some of the most ingenious forms of camouflage. From stick insects that look like twigs to moths with bark-like wings, the insect world is a masterclass in natural disguise.

What is Camouflage?

Camouflage is a biological adaptation that allows organisms to conceal their appearance, either by blending into the background, mimicking other objects or species, or altering their body shape or behaviour. In insects, camouflage has evolved over millions of years as a primary defense mechanism. It helps insects remain unnoticed by both predators and prey, increasing their chances of survival and reproduction.


The Evolutionary Journey of Camouflage

Camouflage in insects is a result of natural selection, where traits that improve an insect's ability to survive and reproduce become more common over generations. Early insects likely relied on basic color matching, but as ecosystems diversified and predator pressure increased, more complex forms of camouflage began to emerge.

Key Evolutionary Milestones:

Color Matching (Basic Crypsis): One of the earliest adaptations—blending with soil, bark, or leaves.

Mimicry Development: Evolution of body shapes and textures that resemble twigs, leaves, or other organisms.

- **Adaptive Camouflage**: Some insects, like chameleons in other groups, began showing signs of dynamic color shifts based on environment or season.
- **Industrial Melanism**: A modern example—**peppered moths** in England changed color to match soot-darkened trees during the Industrial Revolution.

These shifts reflect the coevolution between insects and their predators—each adaptation in prey triggers new strategies in predators, and vice versa.

White and black form of peppered moths

Driving Forces of Camouflage Evolution

Predator Pressure – Birds, reptiles, and other insectivores drove the need for better concealment.

1. **Habitat Complexity** – Diverse environments (forests, deserts, grasslands) demanded specialized camouflage forms.
2. **Climate Change & Seasonal Shifts** – Insects had to adapt to changing foliage colors and temperatures.
3. **Urbanization** – Modern environments have introduced artificial colors and textures, influencing camouflage patterns.

Types of Camouflage in Insects

There are several types of camouflage observed in the insect world:

1. **Cryptic Coloration**: This is the most common form, where insects match the color of their surroundings. Examples include leaf insects and grasshoppers that blend into foliage.
2. **Mimicry**: Insects may resemble objects in their environment, such as sticks, leaves, or even other animals. The stick insect is a perfect example, appearing indistinguishable from a twig.

Stick insect

3. **Disruptive Coloration**: This involves bold patterns and colors that break up the outline of the insect's body, making it harder for predators to detect them. Many moths use this method when resting on bark.

Butterfly matches with bark of tree

4. **Seasonal Camouflage**: Some insects change their appearance with the seasons. For instance, certain caterpillars or butterflies change their coloration to match dry or green foliage.
5. **Behavioural Camouflage**: This includes movement or posture that helps an insect stay hidden, like remaining motionless during the day or swaying with the wind to mimic leaves.

Advantages of Camouflage

- **Predator Avoidance**: Camouflaged insects can hide in plain sight, reducing the risk of being eaten.
- **Increased Hunting Success**: Some predatory insects use camouflage to sneak up on prey unnoticed.
- **Reproductive Success**: Survival through camouflage often leads to more opportunities to reproduce, passing on these traits to the next generation.
- **Habitat Versatility**: Camouflage allows insects to exploit a variety of ecological niches.

Disadvantages of Camouflage

- **Limited to Specific Environments**: An insect perfectly camouflaged in one habitat may become highly visible in another.
- **Vulnerability During Movement**: Camouflage is most effective when the insect remains still; movement can give them away.
- **Dependence on Background**: Changes in the environment, such as deforestation or urbanization, can disrupt camouflage effectiveness.

How Camouflage Helps in Survival

Camouflage enhances insect survival by reducing the likelihood of detection, allowing insects to:

- Escape predation by birds, reptiles, and other insects.
- Ambush prey effectively, especially in predatory species like mantises.
- Reproduce successfully in areas with high predation pressure.
- Conserve energy by avoiding frequent flights or escapes due to lower predator encounters.

Examples of Camouflage in Insects

- **Leaf Insects (Phylliidae)**: These insects resemble leaves so accurately that even their veins and bite marks mimic real foliage.
- **Stick Insects (Phasmatodea)**: With elongated bodies and muted colors, they look almost identical to twigs or branches.
- **Peppered Moth (Biston betularia)**: Famous for its role in studies on natural selection, this moth's coloration changed during the Industrial Revolution to match soot-covered trees.
- **Moss Mimic Katydids**: These katydids have lichen-like structures on their body that allow them to blend seamlessly with mossy trees.

- **Orchid Mantis (Hymenopus coronatus)**: This predator mimics flower petals, attracting pollinating insects which it then preys upon.

Future Prospects of Camouflage in Insects As ecosystems undergo rapid change due to climate change, habitat loss, and urbanization, the evolution of insect camouflage is also entering a new phase.

What the Future Might Look Like:

- **Urban Camouflage**: Insects adapting to man-made surfaces like concrete, plastics, and metals.
- **Faster Evolutionary Changes**: Due to high selection pressure in rapidly changing climates.
- **Loss of Camouflage Efficacy**: In species unable to adapt quickly, leading to population decline or extinction.
- **Genetic Engineering & Conservation**: Possibilities of enhancing camouflage traits in endangered insects through bioengineering.
- **Applications in Biomimicry**: Future military, clothing, and tech industries may develop advanced materials inspired by insect camouflage.

Conclusion

Camouflage in insects is not a static trait—it's a dynamic adaptation shaped by millions of years of evolution. From blending into leaves to mimicking twigs or even adapting to industrial landscapes, insects continue to evolve new strategies for survival. Looking ahead, the pressures of climate change, habitat alteration, and human encroachment may push camouflage in new and unpredictable directions. Studying this evolution not only deepens our appreciation of nature's creativity but also offers potential insights for innovation in design, defense, and sustainability.