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SUSTAINABLE APPROACH TO MITIGATE BIOTIC STRESS IN PULSES

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ABSTRACT

As the global population continues to grow, there is an urgent need for sustainable agricultural advancements to enhance food security while also addressing environmental concerns. Pulses, such as chickpeas, lentils, and cowpeas, play a crucial role in global nutrition and sustainable farming due to their rich protein content and ability to enhance soil fertility through nitrogen fixation. However, their cultivation faces significant threats from biotic stresses like pests, diseases, and parasitic weeds, which can lead to yield reductions of up to 30%. Biological control methods, including beneficial microorganisms such as Trichoderma species, plant growth-promoting rhizobacteria (PGPR), and arbuscular mycorrhizal fungi (AMF), have emerged as viable alternatives to synthetic pesticides. Integrated pest management (IPM), which combines cultural, biological, and eco-friendly chemical methods, provides a comprehensive solution for managing pests and diseases. Recent advancements in genomics and biotechnology, such as CRISPR/Cas-mediated gene editing and marker-assisted breeding, have enabled the development of pest-resistant pulse varieties. Furthermore, endophytes have shown significance in enhancing disease resistance and promoting plant health. Traditional agricultural practices that depend on chemicals and monoculture have proven insufficient, resulting in environmental harm and increased pest resistance, consequently, there is an urgent need to transition to sustainable strategies to alleviate biotic stresses in farming.

Keywords: Environment, Sustainable, Microorganism, Monoculture, Resistance

INTRODUCTION

The tremendously growing world population demands way more efforts and innovations for the resilient development of agricultural production, improvement in the global supply chain, decrease in food losses and waste, and regular checks on the availability of nutritious food to people suffering from malnutrition. Pulses, including legumes such as chickpeas, lentils, and cowpeas, play a crucial role in enhancing food security due to their high protein content and ability to improve soil health through nitrogen fixation (Selvaraj et al., 2019). However, the current scenario of food security is uncertain; despite pulses being vital for nutrition and sustainable agriculture, their production faces significant threats from biotic stresses such as pests and diseases. Recent studies indicate that approximately 87% of pulse cultivation occurs under rainfed conditions, making them particularly fragile to biotic stressors that can drastically reduce yields (Rana et al., 2016).

The importance of pulses in global agriculture cannot be overstated. They are integral to sustainable cropping systems, providing essential nutrients while requiring fewer external inputs compared to cereal crops. Despite their benefits, pulse production has stagnated in many regions due to various factors, including limited genetic diversity and outdated agricultural practices. Traditional methods often rely heavily on chemical inputs and monoculture systems, which not only exacerbate biotic stress but also contribute to environmental degradation. This highlights the urgent need for sustainable agricultural practices that prioritize resilience against biotic stress while maintaining productivity (Sivasankar, 2019; Ma et al., 2022).

Current estimates suggest that biotic stresses can lead to yield losses of up to 30% in pulses, significantly impacting food availability and farmer livelihoods (Sunani et al., 2024). The reliance on orthodox farming methods has proven detrimental; these practices often fail to address the complexities of modern agricultural challenges, including climate variability and pest resistance. Therefore, there is a pressing need for innovative approaches that integrate sustainability into pulse cultivation. This involves adopting practices such as crop rotation, intercropping with cereals, and utilizing biotechnological advancements to enhance biotic stress tolerance in pulse varieties (López et al., 2022).

Mitigating biotic stress in pulses through sustainable approaches is not only essential for improving food security but also for fostering resilient agricultural systems that can withstand the pressures of climate change. As we move forward, it is essential to explore and implement strategies that enhance the resilience of pulse crops while ensuring environmental sustainability.

OVERVIEW OF BIOTIC STRESSES IN PULSES AND THEIR IMPACT ON YIELD

Biotic stress in pulses refers to the adverse effects caused by living organisms such as pathogens, pests, and weeds, which significantly impact their growth, yield, and quality. Pulses are particularly susceptible to various diseases caused by fungi (e.g., rust, anthracnose), bacteria (e.g., bacterial blight), viruses (e.g., bean common mosaic virus), and nematodes (e.g., root-knot nematodes). Insect pests, such as aphids, pod borers, and bruchids, further exacerbate losses by damaging leaves, flowers, pods, and seeds, both in the field and during storage. Parasitic weeds like Striga and Cuscuta compete with pulses for nutrients and water, severely reducing productivity. Additionally, non-parasitic weeds compete for essential resources, diminishing crop Vigor. The combined effects of these biotic stresses result in reduced crop performance and economic losses. Effective management through integrated pest management (IPM), resistant cultivars, crop rotation, and biological control is essential to mitigate the impacts of biotic stress and ensure sustainable pulse production (Sunani et al., 2024).

The challenges posed by biotic stresses on pulses not only affect agricultural productivity but also have broader economic ramifications. These stresses are said to have possibly caused a 20% decrease in the yield of legumes as a result of increased pest activity and incidence of diseases in the latter decades of the twentieth century, mostly because of the influence of climate change (Sandhu et al., 2025). Overall, from 1990 to 2015, yield effects were quite profound on pulses in general. Yield effects accounted for almost 88.10% of the net growth of total pulses production during this period, while area effects contributed a mere 8.78% (Devegowda SR et al., 2019).

MITIGATION OF BIOTIC STRESSES IN PULSES

Pulse production is frequently challenged by biotic stresses, including pests, diseases, and parasites, which can lead to significant yield losses. And practicing conventional pest and disease management, which relies heavily on synthetic chemical pesticides, has raised concerns about environmental sustainability, human health, and the development of resistance in target organisms. Therefore, there is a growing need for sustainable approaches to mitigate biotic stress in pulses.

BIOLOGICAL CONTROL METHODS

This method has emerged as a promising alternative to synthetic chemical pesticides for managing biotic stresses in pulse crops. These methods utilize beneficial microorganisms, plant extracts, and other eco-friendly agents to combat pests and diseases. For instance, Trichoderma species have been identified as effective biocontrol agents for managing pulse pathogens, offering an environmentally friendly and economically viable solution (Mishra et al., 2020). Similarly, plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF) have been shown to enhance plant growth and yield while protecting against biotic stresses (Xavier et al,; Al-Khayri & Khan, 2024).

INTEGRATED PEST MANAGEMENT (IPM)

IPM is a holistic approach that combines multiple strategies to manage biotic stresses sustainably. IPM emphasizes the use of cultural, biological, and chemical controls in a coordinated manner to minimize pest and disease pressures while maintaining ecosystem balance (Singh et al., 2022). Various components of IPM include crop rotation and cultural practices which disrupt pest life cycles and reduce disease incidence by breaking the continuity of host availability, use of natural enemies, such as parasitoids and predators, to control pest populations, Plant extracts, microbial pesticides, and other eco-friendly products (Advances in Pest Management in Pulses-Based Cropping Systems Under Changing Climate, 2022).

BIOFERTILIZERS

Such as rhizobia, PGPR, and mycorrhizal fungi, play a crucial role in enhancing plant growth and mitigating biotic stress in pulses. These microorganisms improve nutrient acquisition by solubilizing phosphorus, fixing nitrogen, and enhancing nutrient availability, improving plant growth and yield, suppressing pathogens, and stimulating plant defense mechanisms by modulating phytohormone production and antioxidant activity, thereby contributing to sustainable pulse production (Xavier et al) (Bhowmik & Das, 2018).

SOIL MICROBIOME

The soil microbiome plays a pivotal role in plant health and stress tolerance. Beneficial microbes in the soil can enhance nutrient cycling, which includes decomposing organic matter, releasing nutrients, improving soil fertility, enhancing plant growth, suppressing pathogens, and modulating plant responses to biotic and abiotic stresses. Recent advancements in metagenomics and culturomics have provided deeper insights into the diversity and functional potential of soil microbiomes, enabling the development of microbiome-based solutions for sustainable agriculture (Clagnan et al., 2024; Ali et al., 2023).

HOST PLANT RESISTANCE

It is another sustainable approach to mitigating biotic stress in pulses. This method involves developing pulse varieties with genetic traits that make them resistant to insect pests and diseases. Host plant resistance is considered an eco-friendly alternative to synthetic pesticides, as it reduces the need for chemical inputs and minimizes environmental impact (Togola et al., 2024). Recent advances in host plant resistance are genomic tools that have facilitated the identification and introgression of resistance genes into pulse crops, accelerating the development of resistant varieties, transgenic technologies has enabled the introduction of pest-resistant genes, such as those from *Bacillus thuringiensis*, into pulse crops, enhancing their tolerance to insect pests, Breeding for multigenic resistance ensures durability against evolving pest populations, reducing the likelihood of resistance breakdown (Rathore et al., 2018).

GENETIC REGULATIONS TO MITIGATE BIOTIC STRESSES IN PULSES

Genetic regulations and the use of endophytes have emerged as promising strategies to enhance resistance and resilience in pulse crops. Research has identified several genes and pathways that play a critical role in biotic stress resistance in pulses. For instance, genes involved in pathogenesis-related (PR) proteins, such as chitinases and glucanases, are crucial for fungal resistance (Rubiales et al., 2023). Similarly, genes encoding for receptor-like kinases (RLKs) and nucleotide-binding site-leucine-rich repeat (NBS-LRR) proteins are central to bacterial and viral resistance (Singer et al., 2024; Gaur & Chaturvedi, 2003).

ROLE OF OMICS AND BREEDING TECHNIQUES

Advanced omics technologies, including genomics, transcriptomics, and proteomics, have accelerated the identification of stress-related genes and their regulatory networks. These tools have enabled the development of high-resolution genetic maps and DNA markers, facilitating the integration of resistance genes from diverse sources (Rubiales et al., 2023). Breeding programs have successfully utilized these resources to develop varieties resistant to specific stresses, such as fusarium wilt in chickpea and powdery mildew in pea (Gaur & Chaturvedi, 2004).

CRISPR/CAS-MEDIATED GENE EDITING

CRISPR/Cas technology has opened new avenues for precise gene editing to enhance biotic stress resistance. By targeting genes involved in plant immunity, such as those encoding susceptibility factors, researchers can engineer crops with durable resistance to pathogens (Singer et al., 2024). This approach has shown promise in other crops and holds potential for pulses.

ROLE OF ENDOPHYTES IN BIOTIC STRESS MITIGATION

Endophyte-Plant Interactions

Endophytes play a crucial role in mitigating biotic stress in plants, offering a sustainable solution to combat harmful microbes that hinder plant growth and crop productivity. These beneficial microorganisms, including bacteria and fungi, colonize plant tissues without causing damage and help plants cope with various biotic stressors such as pathogens, insects, and weeds (Chaudhary et al., 2022; Zhang et al., 2019).

Endophytes employ several mechanisms to mitigate biotic stress in plants. They produce antibiotic compounds, lytic enzymes, and secondary metabolites that inhibit pathogen growth and reduce disease severity (Chaudhary et al., 2022; Mei & Flinn, 2010). Endophytes offer a promising alternative to conventional farming practices, reducing the need for synthetic fertilizers and pesticides (Watts et al., 2023). Their ability to enhance nutrient uptake, stress tolerance, and disease resistance in host plants makes them valuable tools for sustainable agriculture and environmental management (Kaur et al., 2023; Mei & Flinn, 2010). As research in this field continues to advance, the development of endophyte-based products for commercial use holds great potential for improving crop productivity and plant health while promoting environmentally friendly agricultural practices (Anand et al., 2023; Kaur et al., 2023).

CONCLUSION

Mitigation of biotic stress in pulse crops is crucial to maintaining global food security and encouraging resilient agricultural systems. Different biotic stress agents, such as pests, pathogens, and parasitic weeds, are responsible for high yield losses, harming pulse production. Conventional overreliance on chemical pesticides and monoculture has been unsustainable, calling for a change towards environmentally friendly options. Sustainable management practices, like biological control, integrated pest management (IPM), and biofertilizers, provide strong tools to strengthen pulse resilience. Useful microbes like Trichoderma species and plant growth-promoting rhizobacteria reinforce the defence apparatus of the plants with a reduced reliance on man-made inputs. Improvements in genomics, transcriptomics, and CRISPR-based gene editing have enhanced stress-resistant pulses' variety development towards sustained agriculture for a longer period.

Moreover, the plant protection function of endophytes also points towards the efficacy of microbiome-based interventions in countering biotic stress. Genetic resistance, microbiome research, and advanced breeding methods have to be combined effectively in ensuring sustainable pulse production in the face of changing climatic conditions. Optimizing these strategies with the least environmental cost should be the focus of future research. Through embracing sustainable and innovative approaches in farming, pulse production can be protected, both enhancing farmer livelihoods and global food security while doing so in an environmentally sustainable way.

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