SJIF Impact Factor (2026): 8.863| ISI I.F. Value: 1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 11 | Issue: 3 | March 2026 - Peer Reviewed Journal

DROUGHT-INDUCED MODULATION OF PLANT-FUNGAL INTERACTIONS AND SUSTAINABLE MANAGEMENT STRATEGIES IN ARID AGROECOSYSTEMS OF RAJASTHAN: A REVIEW

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Article DOI: https://doi.org/10.36713/epra26625
DOI No: 10.36713/epra26625

ABSTRACT

Drought is widely recognized as a major environmental constraint limiting agricultural productivity in arid regions such as Rajasthan. In addition to its direct influence on plant growth, drought conditions significantly alter plant-pathogen interactions, particularly those involving fungal diseases. The present study examines how water deficit conditions influence plant physiology and increase vulnerability to fungal pathogens, with special emphasis on Macrophomina phaseolina, Fusarium spp. and Alternaria spp.

Under drought stress, plants exhibit reduced photosynthetic efficiency, impaired metabolic processes, and increased accumulation of reactive oxygen species (ROS), which can damage cellular structures. Simultaneously, drought-induced hormonal changes especially elevated abscisic acid (ABA) interfere with defense signaling pathways, thereby weakening plant immunity.

In addition, drought disrupts the balance of rhizosphere microbial communities, reducing beneficial microorganisms while favoring pathogenic fungi. Sustainable approaches such as biological control using Trichoderma and Bacillus, arbuscular mycorrhizal fungi (AMF), and soil amendments like biochar have shown promising results in enhancing plant resilience and suppressing disease development.

Overall, the findings suggest that integrating eco-friendly and climate-resilient management strategies is essential for sustaining agricultural productivity in drought-prone environments.

KEYWORDS: *Drought Stress, Plant–Fungal Interaction, Arid Agriculture, Biocontrol, AMF, Sustainable Management*

1. INTRODUCTION

Agriculture in arid regions is increasingly challenged by environmental stress factors, among which drought remains the most critical (Shawaqfeh *et al.,* 2025). Rajasthan, being a predominantly dry region, frequently experiences water scarcity, high temperature fluctuations, and poor soil fertility. These factors collectively limit crop productivity and stability.

While the direct effects of drought such as reduced plant growth and yield are well documented, its indirect influence on plant health through disease development has gained attention in recent years. Under water-limited conditions, plants undergo physiological stress that weakens their natural defense mechanisms. As a result, they become more prone to infection by opportunistic pathogens (Kumar and Choudhary, 2024).

Fungal pathogens, in particular, play a major role in drought-affected agricultural systems. Species such as *Macrophomina phaseolina*, *Fusarium spp.*, and *Alternaria spp.* are commonly associated with dryland agriculture and can cause severe yield losses (Majeed *et al.,* 2025). These pathogens are well adapted to stressful conditions and often exploit weakened plants for successful colonization.
Understanding how drought influences plant–fungal interactions is essential for developing effective and sustainable management strategies.

2. MATERIALS AND METHODS

This study was carried out as a literature-based analytical investigation to explore how drought stress influences plant-fungal interactions and to identify suitable sustainable management strategies for arid agricultural systems (Abo *et al.,* 2020). Instead of relying on a single

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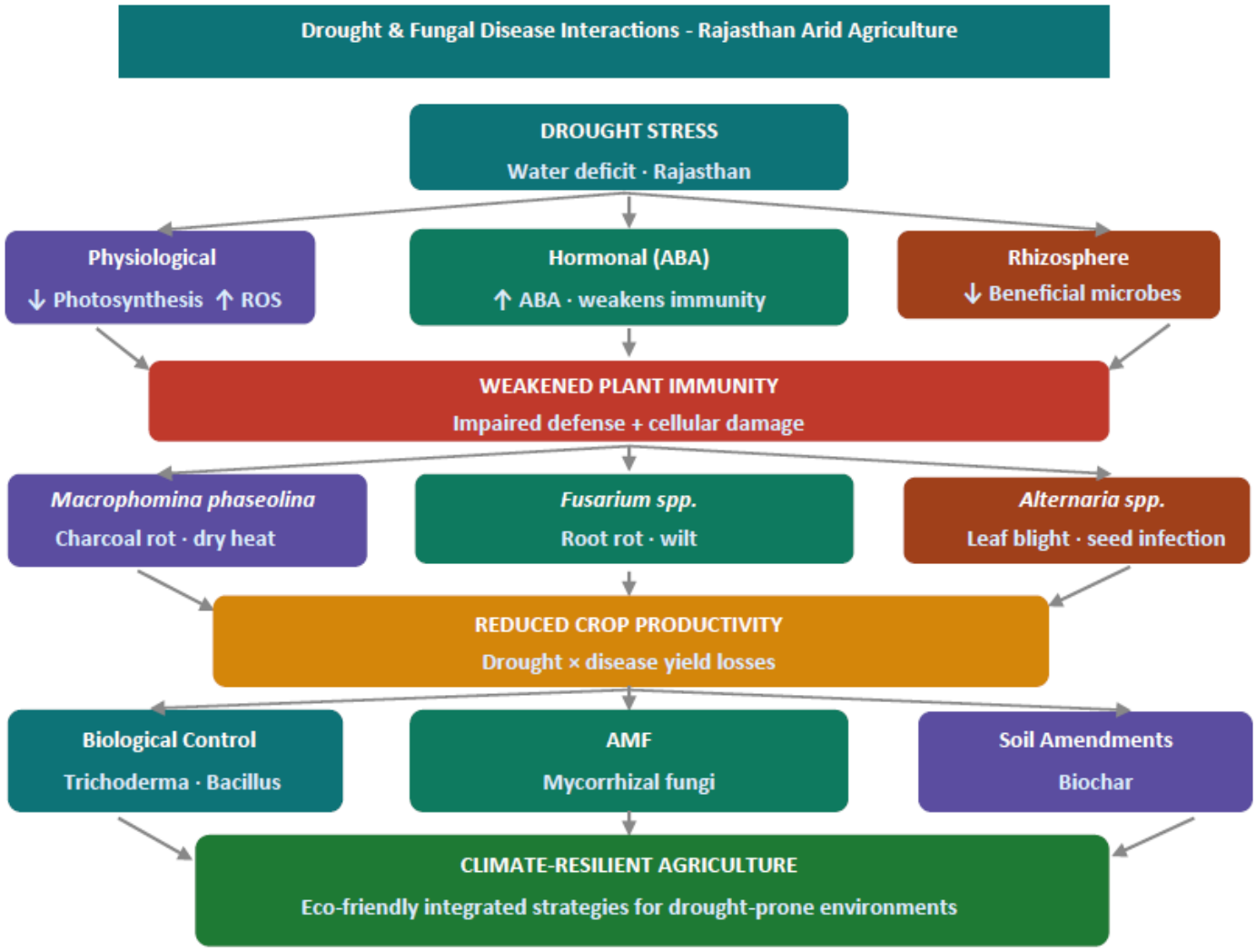
dataset, the study brings together findings from multiple scientific reports to develop a broader and more reliable understanding of the subject.

For this purpose, relevant research articles were carefully gathered from widely used academic databases such as Google Scholar, Scopus, Web of Science, and ScienceDirect. The search process was guided by specific keywords, including drought stress, fungal diseases, plant-pathogen interaction, and sustainable agriculture (Gimenez and Salinas, 2018). Preference was given to peer-reviewed articles to ensure the scientific reliability of the information considered in this study.

The selected studies were then examined with attention to three major aspects: plant responses under drought conditions, behavior and adaptation of fungal pathogens, and available management approaches. Particular focus was placed on changes in plant physiological processes, the ability of pathogens to survive and infect under stress conditions, and the role of eco-friendly methods such as biological control and soil improvement techniques (Ray *et al.,* 2024).

After collection, the information was organized into meaningful themes and reviewed in a stepwise manner to understand how drought conditions gradually influence plant health and disease development. A comparative approach was used to identify recurring patterns and consistent observations across different studies. This process helped in developing a clear understanding of the relationship between drought stress and fungal disease progression, as well as in evaluating the effectiveness of sustainable management strategies.



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3. RESULTS AND DISCUSSION

3.1 Effect of Drought on Plant Physiology

Drought stress leads to several physiological disturbances in plants. Reduced water availability results in stomatal closure, which limits carbon dioxide uptake and lowers photosynthetic efficiency (Lawson *et al.,* 2019). This ultimately affects plant growth and productivity. At the cellular level, drought induces osmotic imbalance and increases the formation of reactive oxygen species (ROS). These molecules can damage cellular components if not regulated properly (Sachdev and Ansari, 2021). Although plants activate antioxidant systems to counter this effect, prolonged stress often reduces their efficiency.

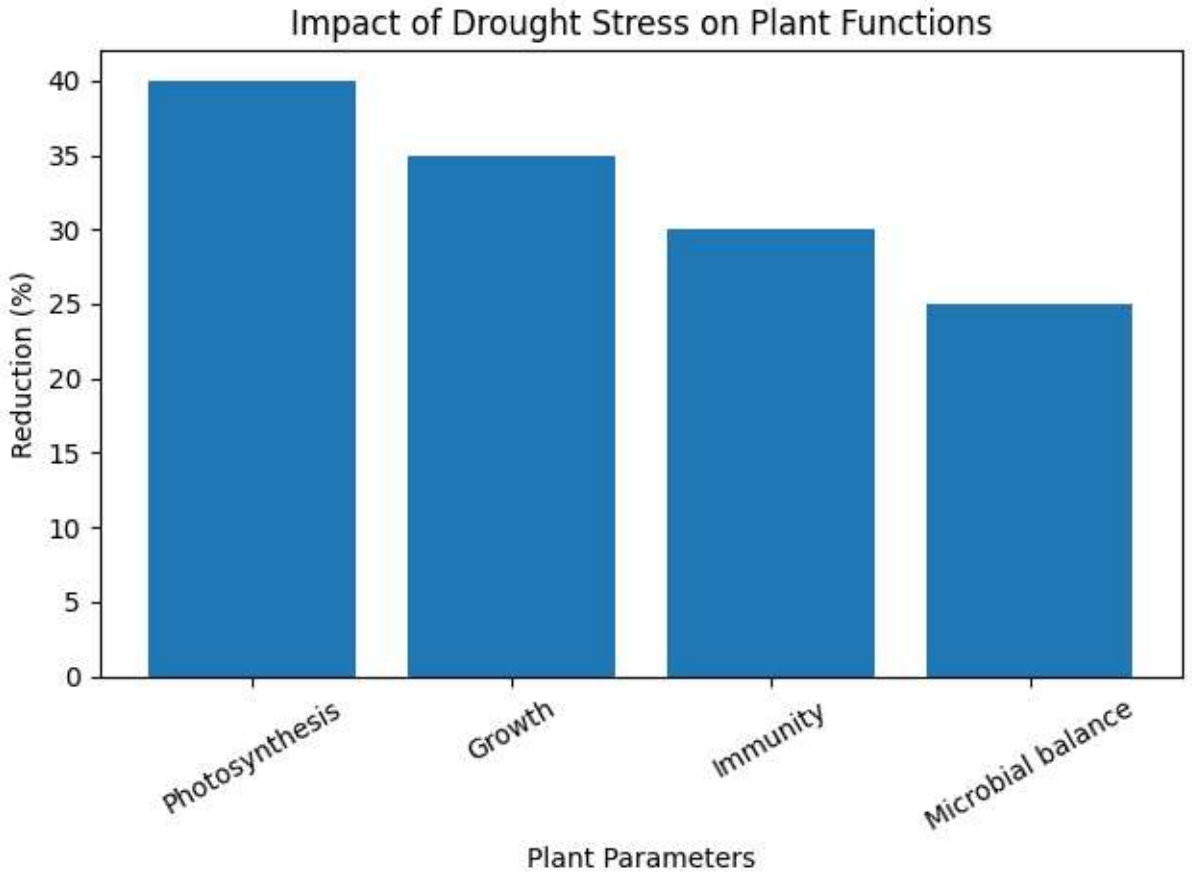

Figure 1: Impact of drought stress on major plant physiological parameters.

3.2 Influence on Plant–Fungal Interactions

Drought conditions create a favorable environment for fungal pathogens. The weakening of plant defense systems, combined with changes in hormone signaling, makes plants more susceptible to infection (Choudhary *et al.,* 2024).

Increased levels of abscisic acid (ABA) during drought interfere with defense-related pathways, reducing the plant's ability to respond effectively (Ali *et al.,* 2020). Meanwhile, pathogens such as *Macrophomina phaseolina* become more aggressive under dry conditions. As a result, disease severity increases significantly during drought periods.

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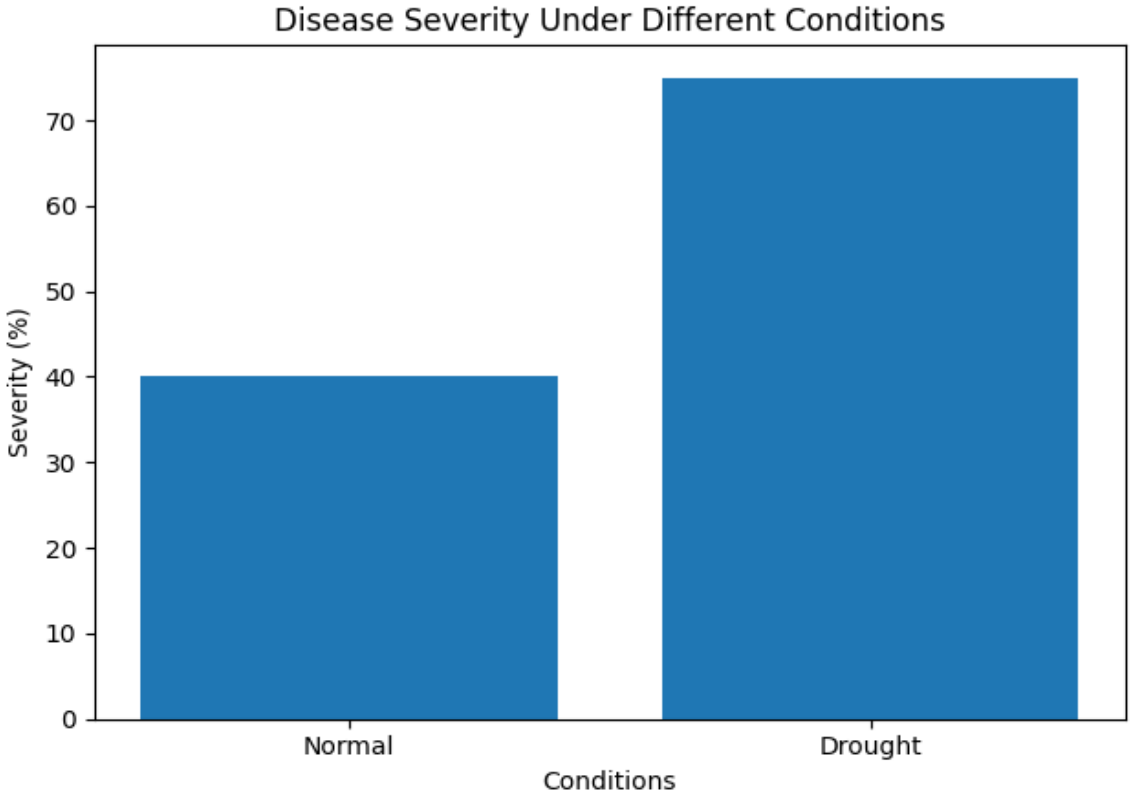

Figure 2: Comparison of disease severity under normal and drought conditions.

3.3 Changes in Rhizosphere Microbial Community

Drought also affects the soil environment, particularly the microbial population surrounding plant roots. Beneficial microorganisms that support plant growth and suppress pathogens tend to decline under dry conditions (Bogati *et al.,* 2022).

This imbalance allows pathogenic fungi to dominate, increasing the risk of infection. Thus, the rhizosphere plays a crucial role in determining plant health under drought stress (Vidal *et al.,* 2022).

3.4 Sustainable Management Strategies

Eco-friendly management approaches, particularly the use of beneficial microbes such as *Trichoderma* and *Bacillus*, play an important role in limiting fungal infections by competing with pathogens and stimulating plant defense responses (Ram and Keswani, 2018). In addition, practices like the application of arbuscular mycorrhizal fungi (AMF) and soil conditioners such as biochar help plants better withstand drought conditions, improve soil quality, and ultimately lower disease occurrence (Pu and Zhang, 2025).

Table 01: Sustainable Strategies for Managing Drought-Induced Fungal Diseases.

Strategy	Example	Mode of Action	Outcome
Biological Control	*Trichoderma*, *Bacillus*	Competition, induced resistance (Wang *et al.,* 2018)	Reduced pathogen load
Mycorrhizal Association	AMF	Enhanced nutrient and water uptake (Chandrasekaran *et al.,* 2022)	Improved stress tolerance
Soil Amendment	Biochar	Soil structure improvement (Amare *et al.,* 2023)	Lower disease incidence
Integrated Management	Crop rotation, resistant varieties	Combined approaches (Zou *et al.,* 2024)	Sustainable control

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Sustainable approaches focus on improving plant resilience while minimizing environmental impact.

Figure 3: Effectiveness of Different Sustainable Disease Management Strategies.

3.5 Integrated Approach for Disease Management

Combining multiple strategies provides better results than relying on a single method. Integrated disease management ensures long-term effectiveness and reduces dependency on chemical treatments (Barzman *et al.,* 2015).

4. FUTURE SCOPE

Future research should focus on developing climate-resilient crop varieties with enhanced tolerance to both drought stress and fungal infections. Advanced approaches such as microbiome engineering, molecular breeding, and nanotechnology-based interventions hold significant potential for improving plant health under stress conditions.

In addition, there is a need for more field-based studies to validate laboratory findings and to develop region-specific management strategies suitable for arid environments. Integration of sustainable practices with modern technologies can further strengthen disease management and support long-term agricultural sustainability.

5. CONCLUSION

Drought significantly influences plant-fungal interactions by weakening plant defenses and creating conditions favorable for pathogen development. The combined effects of physiological stress, microbial imbalance, and enhanced pathogen activity lead to increased disease severity.

Adopting sustainable and integrated management strategies can effectively reduce these impacts and improve crop resilience. Such approaches are essential for maintaining agricultural productivity in drought-prone regions like Rajasthan.

6. ACKNOWLEDGMENT

The author acknowledges the use of scientific literature and academic resources that contributed to the development of this review. The author also appreciates the continuous academic support and motivation that facilitated the completion of this work.

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