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Bio Diversity of Fungal Pathogens in Indian Arid Region: Impact of Climate Change

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Abstract

The arid zone of India encompasses approximately 12% of the country's geographical area, spanning 31.8 million hectares of land. It includes regions in western Rajasthan, Gujarat, Punjab, Haryana, Maharashtra, Karnataka, and Andhra Pradesh. These areas typically receive an annual rainfall ranging from 100 to 500mm. The region is characterized by low and unpredictable rainfall, wide temperature variations (ranging from 1 °C to 48 °C), high wind speeds, and sandy soils. Given such challenging conditions, one might assume that the region harbors a lower abundance of fungal species in the soil, plants, and other habitats. However, this assumption does not hold true. The fragile ecosystem of the arid zone actually hosts numerous mesophilic and thermophilic fungi in abundance. Additionally, many fungal species have developed adaptations over time, increasing their resistance to high temperatures in their dormant structures. Continuous cultivation of drought-resistant crops in the same area allows the survival and multiplication of various soil-borne plant pathogens. This problem is further compounded by the low moisture-holding capacity and microbial population of sandy soils.

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Plant Pathogens

Various fungal genera from different classes are responsible for causing diseases on both aerial plant parts and roots. Although diseases affecting aerial plant parts are less common due to the requirement of free water for the infection of fungal conidia and other infective structures, there have been notable changes in the cropping patterns over the past two decades. These changes, along with increased humidity and winter cultivation, have led to the emergence of many previously less prevalent fungal species as significant pathogens. Certain pathogens that were once considered of minor importance have now become a serious threat to the profitable cultivation of arid crops, largely due to climate change witnessed in the region in recent years. The warm weather experienced during the winter season and delays in rainfall during the rainy season have contributed to shifts in the crop disease scenario. As a result, the dynamics of crop diseases have been altered in the region, posing new challenges for sustainable cultivation.

Powdery Mildews

The region is known for the prevalence of several genera of powdery mildews, which cause diseases on various economically important plants such as wheat, cumin, mustard, mung bean, guar, chilli, sesame, and Indian jujube. The development and rapid spread of powdery mildews are favored by warm temperatures (28-35 °C), dry weather, and moisture stress, particularly during the months of February, March, and October. These fungal pathogens possess high water content in their conidia, allowing them to withstand warm growing conditions. Among the most significant genera are *Erysiphe polygoni*, *Oidiopsis taurica*, *Oidium erysiphoides f. ziziphi*, and *Macrosphaera alphitoides f. sp. zizyphi*. The powdery mildew of wheat, *E. polygoni*, was one of the earliest studied pathogens in the region, with at least five reported physiological races. [1] reported races 3 and 4 and a newly identified race from Jodhpur. Ascospores of this pathogen exhibit optimal germination at 16-20 °C, while high temperatures (30 °C) have a detrimental effect on the disease. Unlike most powdery mildew genera that favor dry weather, *E. polygoni* thrives equally well at low and high humidity levels. However, recent years have witnessed a considerable reduction in the occurrence of this disease due to climate change and the widespread cultivation of improved wheat varieties. *E. polygoni* also causes powdery mildew on cumin, a valuable cash crop. Under favorable weather conditions, it can result in losses of up to 50% [2]. The disease typically appears in early February to March in the arid region, with strains differing from those affecting wheat. Its spread is rapid under warm and moist conditions, and the fungus's mycelium remains superficial, with haustoria penetrating the epidermal cells. No perithecial stage has been reported, and the fungus overwinters as dormant mycelium in the seeds. However, the occurrence of this pathogen on cumin crops has reduced in recent years due to changing weather conditions. Two genera, *E. polygoni* and *Leveillula taurica*, cause powdery mildew on fenugreek, a primary crop in the region. *L. taurica* is also responsible for powdery mildew on chilli crops. On guar, another important crop, three genera, *L. taurica*, *E. polygoni*, and *Sphaerotheca fuliginea*, are known to cause powdery mildew. Additionally, *L. taurica* affects most other legumes, indicating its equal importance alongside *E. polygoni* in the region. The occurrence of the disease is favored by extended vegetative growth of legumes, primarily observed in the northern parts of the region.

Downy Mildews

Several genera belonging to the downy mildew group are abundant in the arid region, with the *Sclerospora* genus being the most significant. Pearl millet, the staple food crop of the Indian arid region, is cultivated in over 4 million hectares and is highly susceptible to downy mildew caused by different host-specific pathotypes within the *Sclerospora* genus. Certain male sterile lines have shown particularly high incidences of downy mildew. Investigations into the source of inoculum and pathogenic characterization of the isolate revealed that the commonly grown pearl millet landrace population known as Nokha local served as the primary inoculum source, and the identified isolate (Sg 139) exhibited the highest virulence among the characterized isolates. This isolate is currently maintained on Nokha local seedlings at ICRISAT, Patancheru. It should be noted that this pathotype differs from the one identified at Durgapura, Jaipur (Sg 212). The adoption of hybrids on a large scale by farmers has contributed to a reduction in downy mildew occurrence in recent years. Another important genus affecting Indian mustard is *Peronospora parasitica*, primarily causing foliar and other tissue infections. Infections by this pathogen are favored by temperatures between 10-15*°C* and high atmospheric humidity following rain or heavy dew. The frequency and development of the disease increase with prolonged leaf wetness, which commonly occurs in January, particularly in the northern parts of the arid region such as Sri Ganganagar and Hanumangarh districts. In these districts, mixed infections of *Peronospora parasitica* and white rust are observed. The prevalence of this pathogen is not seen in other districts where the winter period is shorter. Additionally, two other species within the Peronospora genus, *P. alta* and *P. plantaginis*, are significant pathogens of the winter crop Isabgol, along with the important genus *Pseudoperonospora plantaginis*. These pathogens thrive in temperatures around 15°C and humidity levels above 90%. One species within the Peronospora genus, *P. trigonellae*, causes downy mildew on fenugreek, an important spice crop in the region, during the winter season. The optimal conditions for maximum infection of this fungus on the host include a temperature of 18°C and 12 hours of leaf wetness. Based on the aforementioned information, it can be concluded that the most prevalent genus of downy mildew in the region is Peronospora, with most species occurring mainly during the winter season. Only *Sclerospora* and *P. cubensis* occur during the rainy season.

Leaf Spots

A wide range of genera and their species are widely distributed across various hosts in the region. Genera such as *Alternaria*, *Myrothecium*, *Curvularia*, *Cercospora*, *Cladosporium*, and *Isariopsis* are commonly observed on multiple crops throughout the year, depending on favorable weather conditions. The occurrence of *M. roridum* was first reported in Jodhpur on guar. Among the various species of *Alternaria, A*. alternata is particularly prevalent on many cultivated species during both cropping seasons. However, these fungal species are not economically significant as their occurrence is primarily favored by extended periods of rainfall and cloudy weather, which are not common features in the region. On the other hand, two species of Cercospora, namely *C. archidicola* and *C. personata*, cause severe early and late leaf spots on groundnut. Infection and disease development are favored by temperatures ranging from 25-30°C. Both species can survive in infected crop debris and are also present in the soil. In the case of date palm, severe leaf spot caused by *Graphiola phoenicis* is observed. This fungus is well adapted to the region to the extent that it can cause significant damage to date leaves even during the hot summer months. The emergence of blast disease, caused by *Pyricularia grisea*, has become a serious threat to pearl millet cultivation in recent years due to climate change. This pathogen induces leaf spots, reducing the photosynthetic area and resulting in decreased seed yield. Efforts are underway to manage this disease by incorporating resistance traits into existing germplasm.

Smuts

One of the prominent genera within this group is *Moesziomyces penicillariae* (formerly known as *Tolyposporium penicillariae*). This pathogen is particularly devastating on the upper edges of isolated fields, especially affecting the earliest flowering panicles of uniform single-cross hybrids, where there is limited availability of pollen. It can be transmitted through both seeds and soil. The incidence of smut infection is higher in conditions of high humidity and optimal temperatures (ranging from 25-35 °C) during the crop's flowering stage. Another notable fungus in this group is *Tilletia ehrenbergii*, which causes long smut on sorghum. This pathogen is typically more significant in regions with low rainfall. Additionally, the genus *Ustilago vilfae* is responsible for smut disease on *Lasiurus sindicus*, an important grass species in the region.

Ergot

A very important ascomycete, *Claviceps fusiformis* was posing serious threat to pearl millet cultivation in arid region. Gupta and his team reported daily optimum weather conditions for the disease development as 12mm rainfall, 75% relative humidity, 20 °C atmospheric temperature and sunshine for 6 hours from protogyny to early anthesis period.

Blast

Pearl millet is a significant cereal crop cultivated for its grain and fodder in the arid and semi-arid regions of India. The foliar blast disease caused by *Pyricularia grisea* (teleomorph: *Magnaporthe grisea*) poses a severe threat to pearl millet production, leading to decreased yields in both grain and fodder. Through the sequencing of the internal transcribed spacer region of ribosomal DNA, it has been revealed that the foliar blast disease in western arid Rajasthan, India, is specifically caused by *Pyricularia pennisetigena*. The alignment of multiple sequences confirmed that the reference sequence of *P. pennisetigena* from the USA closely matches our own sequence of *P. pennisetigena*. The phylogram clearly distinguishes *P. grisea* and *P. penniseticola* as separate species of Pyricularia from *P. pennisetigena*. Isolate CZPMP-17, identified through molecular methods as Colletotrichum sublioneola and isolated from P. glaucum, has been identified as a pathogen of pearl millet, causing foliar disease.

Root Rots

The arid region's specific agro-climatic conditions create a favorable environment for the survival and proliferation of soil-borne plant pathogens. Sandy soils with low organic matter and microbial population, coupled with poor moisture retention capacity, contribute to the development of root rots and wilts in rain-fed and sometimes irrigated crops (Figure 1). Among these pathogens, *Macrophomina phaseolina* is particularly notorious for causing dry root rot in numerous cultivated and wild plants, especially when subjected to simultaneous heat and moisture stress. The population of this pathogen tends to increase in the soil with each successive year of cultivating susceptible crops in the same field. Climate change-induced higher soil temperatures have made the sclerotia of *M. phaseolina* more thermally sensitive. Another pathogen gaining significance in recent years is *Aspergillus niger*, primarily due to the expanded cultivation of groundnut following the introduction of the Indira Gandhi Canal. Farmers typically sow groundnut in the third week of May, coinciding with high soil temperatures (50-55°C), which create favorable conditions for rapid multiplication of *A. niger* in the presence of susceptible hosts, leading to collar rot. Sclerotinia sclerotiorum is another pathogen that causes stem rot in Indian mustard. Sclerotia of this polyphagous fungus can survive in the soil for up to 10 years, even under adverse conditions. Based on the level of virulence, two pathotypes of *S. sclerotiorum* have been categorized.

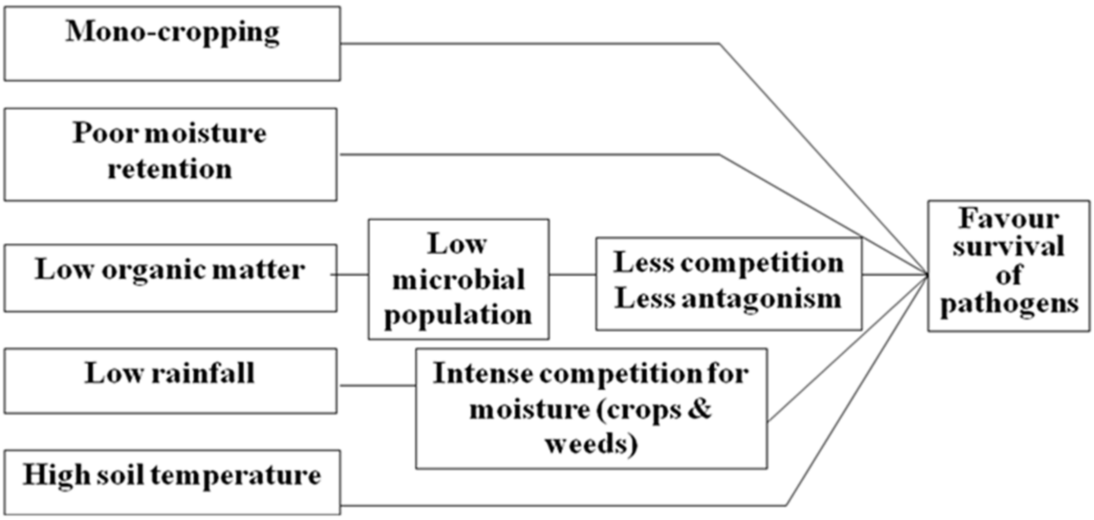

Figure 1: Factors Influencing Survival and Multiplication of Soil Borne Plant Pathogens in Indian arid region.

Wilts

In the arid region, several species of Fusarium are known to induce wilt disease in economically important crops. Among these, *F. oxysporum f. sp. cumini* (Foc) is of significant regional importance due to its impact on cumin cultivation. Extensive research has been conducted on this pathogen. Chlamydospores, a survival structure of Foc, can persist in the soil for more than 10 years, even in the absence of the crop. When the crop is present, the highest population density of Foc is typically found in the top 0-5cm soil depth, gradually decreasing with increasing distance from the soil surface. With climate change leading to increased soil temperatures, chlamydospores have shown the ability to survive up to 70°C in dry soil. Other species of Fusarium are also present in the region. *F. equiseti* causes wilt disease in *Ziziphus mauritiana*, commonly known as Indian jujube [3], while *F. oxysporum* and *F. solani* are the causative agents of wilt in chilli crops. These findings highlight that sandy soils and harsh climatic conditions favor the survival of Fusarium pathogens. Additionally, Neocosmospora vasinfectum has been reported to cause slow wilt disease in guar, another crop cultivated in the region.

Beneficial Fungi

The arid region is not only home to detrimental plant pathogens but also hosts a variety of beneficial fungi that play a crucial role in biological control of soil-borne pathogens, phosphorus solubilization, and decomposition of organic matter. One of the most significant genera among these biocontrol agents is *Trichoderma*. Certain species of *Trichoderma*, such as *T. harzianum*, *T. pseudokoninghi*, and, in specific areas, *T. virdi*, have been identified in sandy soils. These species contribute to maintaining the natural soil balance by parasitizing harmful plant pathogens and aiding in organic matter decomposition. However, their population tends to decline during hot summer months, limiting their widespread use. In recent years, *Aspergillus versicolor* has been isolated from the native soil and found to exhibit parasitic activity against *M. phaseolina* and various Fusarium species. Extensive research has been conducted on the biology and pathology of this species, highlighting its heat tolerance and adaptability to low soil moisture conditions, making it well-suited for sandy soils in the region [4]. Another biocontrol agent, *A. terreus*, has also been isolated from the native soil [5]. This fungus has shown high effectiveness in controlling *Ganoderma lucidum*, the causal agent of root rot in trees and shrubs. The population of this bioagent increases when onion residues are incorporated into the soil around the tree trunk. Further exploration of the potential of this fungus in sandy soils can help minimize root rot issues. Phosphate and phytase-producing fungi, including *Aspergillus niger*, *A. awamari*, *Emmericella nidulans*, *E. rugulosa*, *Penicillium simplicissimum*, and *P. ruburm*, have been isolated from arid soils [6]. These organisms can be utilized as seed inoculants to harness the native soil's organic phosphorus, thereby enhancing plant nutrition with higher phosphorus uptake. The region also exhibits a diverse array of Arbuscular Mycorrhizal Fungi (AMF). Glomus, with ten species, was the most frequently observed genus, followed by *Acaulospora* and *Scutellospora* with three species each. The dominant species among *Gigaspora* were *G. fasciculatum*, *G. intraradices*, *G. mosseae*, and *G. rubiforme* [7].

Other Fungi

A comprehensive compilation by Kaur [8] documented numerous fungi belonging to Pyranomycetes in the region. Among these, several fungi with potential roles in litter decomposition were reported, including *Penicillium pinophilum*, *P. purperogenm*, *P. oxalicum*, *P. rubrum*, *Chaetomium jodhpuriensis*, and others. Furthermore, four species of *Curvularia*, namely *C. lunata*, *C. pallescens*, *C. Siddiqui*, and *C. trifoli*, were isolated from various plant parts [9,10]. The important medicinal shrub of the arid region, Capparis decidua, was found to be infected by *Clathrosphaarina ellisii* [11]. Additionally, *Seimatosporium caudatum* was isolated from twigs of Rosa spp. [12]. These findings highlight the diverse fungal species present in the region and their associations with different plant species and parts [13-18].

Future thrust

The changing climate in recent years has had a significant impact on the occurrence and severity of crop diseases in the arid region. It is crucial to conduct research to assess the aggressiveness of each pathogen responsible for causing substantial economic losses in arid land crops. Several important genera require particular attention, including *Macrophomina*, *Fusarium*, *Pyricularia*, *Aspergillus*, *Ganoderma*, and *Erysiphe*. Among these, Ganoderma demands greater attention due to its detrimental effect on the *Prosopis cineraria*, which is considered a lifeline for desert dwellers. Constant efforts should be made to isolate native biocontrol agents that are well adapted to the harsh climate of the region. Additionally, research should focus on utilizing on-farm waste materials, as their incorporation into the soil can enhance the survival and proliferation of these beneficial bioagents [19-21]. A holistic approach can be developed to effectively tackle the challenges posed by crop diseases in the arid region.

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