WORLD JOURNAL OF PHARMACEUTICAL RESEARCH

SJIF Impact Factor 8.453

Volume 14, Issue 18, 580-594. Review Article ISSN 2277–7105

"WHEAT BLAST DISEASE: CURRENT UNDERSTANDING AND CHALLENGES IN GLOBAL CONTAINMENT"

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Article Received on 30 July 2025,

Revised on 21 August 2025,
Accepted on 09 Sept. 2025

DOI: 10.20959/wjpr202518-38332

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ABSTRACT

Wheat blast, caused by the pathotype Triticum of Magnaporthe oryzae (syn. Pyricularia oryzae), has become one of the most harmful diseases, posing a significant risk to worldwide wheat output and food safety. First identified in Brazil in 1985, the disease has quickly spread to South America, Bangladesh, and Africa, sparking concerns about its potential arrival in India. Wheat blast is well-known for inducing spike bleaching, shriveled kernels, and severe yield reductions that can hit 100% in optimal warm and humid conditions. In addition to its biological aggressiveness, shifting climate patterns and worldwide seed trade are hastening its proliferation. This review consolidates the existing knowledge of the disease cycle, epidemiology, and risk factors, while also emphasizing India's readiness via surveillance, risk modeling, and efforts in resistance breeding. It also highlights the critical necessity for comprehensive disease management approaches—blending cultural methods, resistant cultivars, chemical defenses, and biological interventions. Safeguarding wheat against this imminent risk will demand joint research efforts, farmer education, and robust regional networks to ensure both food security and livelihoods.

KEYWORDS: Wheat blast, *Magnaporthe oryzae Triticum*, *Pyricularia oryzae*, food security, epidemiology, integrated disease management, India.

INTRODUCTION

Wheat is a staple crop for the world and global food security (Bhatt et al., 2024); it provides 20% of the protein and calories in developing countries for the majority of the population (Saharan et al., 2016). According to the Food and Agriculture Organization's 2023 report, approximately 30 million hectares with an annual production of more than 100 million tonnes are occupied by wheat in India (FAO, 2023). The production of wheat is being affected by a fungal plant disease called "wheat blast." It is a harmful fungal disease caused by *Pyricularia oryzae Triticum (PoT)* (Islam et al., 2020; Ceresini et al., 2018). This has become a major problem worldwide (Islam et al., 2020). It can cause a high yield loss of 40-100% (Bhatt et al., 2024; Islam et al., 2020; Mottaleb et al., 2018). Wheat blast was detected for the first time in 1985 in Paraná, Brazil (Igarashi et al., 1986), the emergence of wheat from a host shift in grass species (Castroagudín et al., 2017; Inoue et al., 2017). It was restricted for a long time in South America, Brazil, Bolivia, Argentina, and most of the other countries (Igarashi, 1991; Goulart et al., 1990; Barea & Toledo, 1996).

The disease caused severe infection and attacked in Bangladesh in 2016 (Islam et al., 2016). It is supposed to be driven by the global trade of wheat, and it affected approximately 15% of Bangladesh's wheat region (Malaker et al., 2016).

The worldwide danger of pathogens made a sudden impact, and it escalated when wheat blast was observed not only in Zambia but also in Africa, and it was spreading too fast (Tembo et al., 2020). The disease causes spike bleaching, shriveled grains, and yield loss ranging from 20% to total crop failure under favourable conditions (Koga et al., 2022; Cruz et al., 2016) and climatic factors such as high temperature (25-30°C) combined with high humidity (>90%) during the heading and anthesis significantly increase the risk of infection (Kohli et al., 2011) because of the pathogen is not only seed-borne but also air-borne, and the wind currents and the global trade of wheat have facilitated its rapid geographic spread (Islam et al., 2016).

India has not yet reported a confirmed outbreak of wheat blast; however, simulation-based epidemiological risk analyses indicate that certain agro-climatic zones are highly vulnerable (Sadat et al., 2017; Mottaleb et al., 2018). eastern zones such as West Bengal, Bihar, and parts of Jharkhand, due to their proximity to Bangladesh (where the disease was first reported in Asia in 2016), are considered high-risk entry points (Islam et al., 2016)

ICAR-Indian Institute of Wheat and Barley Research (IIWBR), with the help of Agriculture University, Jobner, has conducted multi-location surveys since 2017 to detect potential of the pathogen, and these surveys revealed that current climatic conditions, like high temperature and low relative humidity during the anthesis, are generally unfavourable for the infection (Meena et al., 2022; Saharan et al, 2021)

Certain districts of Rajasthan located in eastern and southeastern parts of the state like as Kota, Baran, and Bundi, have relatively higher humidity and moderate temperatures in February-March, which could support the pathogen establishment if inoculum is introduced (Meena et al., 2022), and screening trials under the artificial inoculation at Jobner and Durgapura research farms identified partial resistance in several locally adapted cultivars, such as Raj 4238 and Raj 4079 (Meena et al., 2022)

INDICATORS, SYMPTOMS, AND DISEASE CYCLE

Wheat blast caused by the *Magnaporthe oryzae Triticum*, and it has highly characteristic indicators that make this one of the most destructive disease of wheat, not only in tropical but also in the subtropical regions. the most striking and diagnostically important symptom is the premature whitening of wheat spikes, and this also referred to as bleaching heads (Islam et al., 2020). this symptom directly impacts grain development; the whitening of spike begins soon after the little flowering and results from the pathogen colonizing spike tissues and it disrupts nutrients and water uptake and also the transport within the plant. because of this, spikes become completely white or light gray (Cruvinel et al., 2014). the lower portion of the plant, including the peduncle and flag leaves, remains green and healthy in appearance. the impact of this symptom is profound; the lack of nutrient supply leads to aborted, or completely missing kernels (Islam et al., 2020). the pathogen not only targets the spike but also targets additional parts of the plant; unique elliptical spots with greenish centers and dark edges are can be seen on foliage and these are similar to those found in rice blast (Urashima et al., 1993; Callaway, 2016). Nodes and stems may also form dark lesions, which occasionally result in lodging (Islam et al., 2020)

The disease cycle of wheat blast is not normal; it is so complex and highly efficient that it allows MoT to persist across seasons and spread across large geographic regions:

Mainly the primary agents of the infection are the conidia, which are the asexual spores produced in massive numbers in infected plant tissues, mainly on blighted spikes (Koga et al., 2022; Urashima et al., 2004). These tiny spores thrive in warm and humid conditions and are transported by the help of wind, which can carry them long distances, and as conidia are airborne, this complicates efforts for regional containment (Islam et al., 2016). The transboundary spread of the pathogen, as in Bangladesh in 2016, is believed to be facilitated by not only seed transmission but also by the help of wind-driven spore movement (Callaway et al., 2016).

Once conidia reach a susceptible host and find favourable weather conditions (25-30°C, high humidity and extended leaf or spike wetness), the conidia start to germinate rapidly and the formation of germ tube starts to occur, which develops a specialized infection appressorium, which generates enormous turgor pressure and this pressure enables the fungus to mechanically breach the cuticle and epidermal cell wall of plant and also bypass the external defensive barriers and than the pathogen colonizes host tissue and disrupts the vascular continuity (Koga et al., 2022; Cruz et al., 2016)

The newly blighted spikes become sites of the prolific sporulation, and the secondary infection cycle starts within the same growing season, and it enables an explosive outbreak of the disease under the favorable conditions, and it can remain dominant on plant debris left in the field, which offers a convenient source of inoculum for the subsequent planting (Cruz et al., 2016). MoT possesses various methods to endure between the growing seasons, as the fungus parasite infects the crop residue left in the field, which acts as a reservoir of inoculum for the next planting cycle and there is a wide range of wild grasses as alternative hosts and volunteer plants. studies from South America and Bangladesh show that genera such as *Echinochloa*, *Brachiaria*, *Digitaria*, and *Eleusine* serve as reservoir hosts, and sustaining the pathogen during the off-season (Castroagudin et al., 2017)

Indian scientists have emphasized the need to monitor volunteer wheat populations in border districts as part of a national surveillance strategy and Rajasthan's wheat-growing areas, such as Hanumangarh and Jaipur, often harbour wild grasses such as *Avena fatua* (wild oat), which are common weeds (Madhubala et al., 2018; IIWBR, 2021)

MoT has the capability to survive not only as airborne but also as seed-borne, and most of the farmers harvest the contaminated seed that carries fungal propagules, which can be transported across the regions or even continents and can spread the infection if conditions are favourable for the pathogen (Islam et al., 2016; Callaway et al., 2016)

EPIDEMIOLOGY AND ENVIRONMENTAL INFLUENCES

Wheat blast's epidemiology, based on the multiple factors also involves a complicated interaction of the host pathogen, a poor wheat plant, and the environment, including aspects such as the initial inoculum amount and the intensity and spread depend on initial inoculum load, stage of wheat growth, agronomic practices and climate conditions. these all factors act synergistically to determine epidemic potential (Cruz et al., 2016; GRDC, 2023)

The epidemics of wheat blast are most destructive during the heading and flowering stages when the exposition of floral organs is highly vulnerable to infection; the spikes get infected at this stage and exhibit bleaching and sterility, which results in near total loss of yield (Cruz & Valent., 2017; Islam et al., 2019). Different types of farming practices such as late sowing, dense crop stands, and rice-wheat rotations, significantly increase the power to enhance risk of blast as during the 2016 epidemic in Bangladesh the late-planted wheat in humid conditions was disproportionately affected (Malaker et al., 2016; Igarashi et al., 1986). In Rajasthan the arid climate generally limit the infection (Rathore et al., 2019)

The main key drivers of the epidemic are the weather conditions. an ideal temperature between 25-30°C is optimal range for MoT infection, and elevated humidity and extended leaf wetness (more than 10 hours from rain or dew) are the ideal conditions for the infection (Koga et al., 2022; Rajput et al., 2017). This highlights why significant ongoing rainfall during flowering can be disastrous (CABI.org; GRDC, 2023). A high range of humidity often promotes rapid conidial germination and penetration. in South Asia, the Bangladesh pandemic in 2016 was preceded by unusually wet and humid weather, which confirms the pivotal role rainfall (Islam et al., 2016)

Indian scientists are also involved in similar findings; even short periods of high humidity during flowering could cause significant spike infection (Rajput et al., 2017). Based on Rajasthan, researches also show that unseasonal winter showers combined with high night-time humidity can enable sporadic infection even in semi-arid regions (Singh et al., 2021)

The disease is becoming a worldwide issue because of its extensive spread; the dispersal of the pathogen is not based on a single type of factor; it uses multiple dispersal factors, as MoT has the capabilities to produce a large quantity of airborne conidia. These conidia are capable of being transferred by wind across the field areas and even continents (Urashima et al., 2004; GRDC, 2023), and MoT can also be carried by the seeds traveling on or within the seed with the help of trade (Islam et al., 2016; Callaway, 2016). This transportation method of wheat through global commerce has directly contributed to its rapid appearance in unfamiliar regions, as in the Bangladesh outbreak linked to South American lineages (Islam et al., 2016)

Climate change is making it harder to stop it and enlarging favorable environmental conditions for the pathogen and likely diminishing global wheat production considerably by

2050 (TUM, 2024; Embrapa, 2024). In India, many projections suggest that increasing vulnerability in the eastern Indo-Gangetic plains, when semi-arid states like Rajasthan may also experience outbreaks due to erratic rainfall and irrigation-induced humidity (Ceresini et al., 2018; Singh et al., 2021)

In India, scientists from ICAR-IIWBR (Karnal), Rajasthan Agriculture University (Bikaner), and SAUs across eastern states are focusing and monitoring, doing risk assessment, and identifying resistance cultivars. Rajasthan-specific studies point to the ecological risk posed by localized irrigation practices, wild grasses, and volunteer plants that could act as hidden inoculum reservoirs (Rathore et al., 2019).

DISEASE TRANSMISSION

The wheat blast is a highly damaging disease caused by the *Magnaporthe oryzae Triticum (MoT)* pathotype, and it is a specific lineage of the *Magnaporthe oryzae* fungus that is also known for causing blast disease, mainly in rice (ZHANG et al., 2022; Islam et al., 2020; Valent & Chumley, 1991).

The unique capabilities to infect wheat makes MoT set apart from other types of *Magnaporthe oryzae* variants (Inoue et al., 2017; Ceresini et al., 2018). and the life cycle of pathogen depends on the airborne spores (conidia) that flourish in humid and warm environments (25-30°C), and when a unique type of structure gets formed called an appressorium that penetrates the plant tissues (Koga et al., 2022; Cruz et al., 2016). The immediate entry of pathogen makes it difficult to prevent early whitening of the wheat spikes, which is the most common symptoms that leads to missing or shriveled grains when the fungus invades the spike's central shaft, the rachis, and makes water and essential nutrients insufficient (Islam et al., 2020; Cruvinel et al., 2014). The spike infection makes a significant yield loss, and it may also create lesions on the stem and leaves (Tufan et al., 2024). The dispersal of spores mostly happens by wind (Urashima et al., 2004), and transmission via seeds persists on crop residues (Cruz et al., 2016; Islam et al., 2016). These are the main elements in the shifting of wheat blast.

Wheat blast is not only aggressive in infection but also versatile in transmission:

1. Airborne Dissemination

The primary driver for the blast disease is wind; conidia of blast can travel across the fields and can cover a long distance and can rapidly establish new infection foci. studies from

Bangladesh and Brazil reveal that regional epidemics often coincide with windborne conidia dispersal during the heading stages (Urashima et al., 2004; Cruz et al., 2016)

2. Seed Transmission

MoT has vast capability and one of them is to infect seeds not only external (seed coat) but also internally (embryo/endosperm), which enables the vertical transmission to subsequent planting seasons (Islam et al., 2016). the contaminated seeds trade was the main cause for the initial introduction of MoT from south America into Bangladesh (Ceresini et al., 2018)

3. Soil and Crop Residues

If the infected crop residues are left on the soil surface, which serves as president source of inoculum, conidia and perithecia (sexual structures) can survive between seasons and initiate primary infection in the next cycle (Cruz et al., 2016; Raveloson et al., 2022)

4. Water-Mediated Dispersal

According to Ceresini et al., 2018, water irrigation and rain splash can aid short-distance dissemination of conidia, particularly in dense crop stands and waterlogged fields, and not only enhance spore survival but also stress plants, making them more vulnerable to infection.

5. Alternative hosts and cross-crop transmission

MoT has also been detected on non-wheat grasses and on barley genotypes, which suggests that it can exploit multiple poaceae hosts as green bridges (Cruz et al., 2016)

GLOBAL RISK AND INDIAN PREPAREDNESS

Warm, humid, and unpredictable climates are the main favorable factors for the wheat blast infection and new studies suggest that the temperature is rising and increasing humidity, especially during the heading stages, create conducive conditions for MoT infection (Ceresini et al., 2018; Igarashi et al., 1986). and in South Asia, parts of eastern India (West Bengal, Odisha, Jharkhand, and Bihar) possess environmental niches and are favorable to blast development with potential for up to many infection events during heading (Savary et al., 2019; Rios et al., 2020)

There has been no official outbreak reported in India, but Indian researchers have actively engaged in preemptive studies to mitigate the looming threat:

Breeding programs: The Indian Institute of Wheat and Barley Research (IIWBR) and ICAR centers have integrated 2NS-based resistance into elite Indian germplasm, though the reliance on a single gene poses durability risks (Joshi et al., 2020), and also a genome-wide association study (GWAS) on over 350 Indian wheat genotypes identified the 2NS translocation from Aegilops ventricosa (Cruz et al., 2016), which is the most effective resistance source, explaining ~32% of field resistance variation when tested in Bangladesh and Bolivia (Malaker et al., 2016; Singh et al., 2019).

Surveillance and Modeling: Indian scientists have collaborated with CIMMYT and global partners to model disease risk and implement early-warning systems based on weather patterns (Chakraborty et al., 2020).

ECONOMIC LOSSES AND THE NEED FOR IDM

The devastating impact of wheat blast is not limited to crop health alone; it has far-reaching economic, nutritional, and trade consequences, which underscore the urgency of adopting robust Integrated Disease Management (IDM) strategies (Cruz et al., 2016; Islam et al., 2020).

1. YIELD LOSS: Wheat blast directly impacts crop yields; because of this, it may cause significant economic loss, and it can also lead to catastrophic losses of up to 100% destruction in severe cases (Goulart and Paiva, 1990; Cruz and Valent, 2017). The 2016 outbreak in Bangladesh resulted in a yield loss as high as 51%, and a study estimated an average loss of 540 kg per hectare, which was around $2.1 million in production loss for the region (Islam et al., 2016; Mottaleb et al., 2023).

2. QUALITY REDUCTION: The quality of grains also reduces; grains are typically shriveled and low in weight, which makes them unsuitable for milling (Urashima et al., 2009). The disease also alters the grain's nutritional profile, decreasing essential components like zinc (Hoque et al., 2020). The pathogen can also contaminate seeds, lowering germination rates and serving as a source of new infection, which can lead to the rejection of entire seed lots (Cruz and Valent., 2017).

3. TRADE IMPLICATIONS: The spread of wheat blasts to new continents has been linked to the global market (Islam et al., 2016; Tembo et al., 2020). The trade of wheat is disrupting supply chains and negatively impacting the economies of both exporting and importing nations (USDA NIFA, 2016).

INTEGRATED DISEASE MANAGEMENT (IDM) STRATEGIES

A single defense solution against wheat blast is insufficient due to the highly adaptable and aggressive nature of Magnaporthe oryzae pathotype Triticum (MoT). The pathogen evolves rapidly, overcomes resistance genes, and thrives under favorable agro-climatic conditions, making wheat blast one of the most difficult diseases to manage. Thus, researchers and agronomists strongly emphasize the adoption of an Integrated Disease Management (IDM) strategy, which combines cultural, genetic, chemical, and biological tools in a complementary manner (Cruz et al., 2016; Islam et al., 2020).

1. CULTURAL TECHNIQUES

Burning the crop residues or burying them can be a good technique that can help decrease the original source of fungal spores (Cruz et al., 2016). Modifying the planting schedule can significantly reduce the infection risks (CIMMYT, 2019). Maintaining appropriate plant spacing can also make it less favorable for the disease (PlantwisePlus Knowledge Bank).

2. RESISTANCE TRAITS

Creating new wheat varieties that can pose natural resistance to blast would be our most sustainable and economically viable long-term approach (Tufan et al., 2024; L. Fan et al., 2024). The pathogen's impressive capability to adjust and defect current resistance genes is most difficult, and it also includes the commonly utilized 2NS/2AS (Ceresini et al., 2018; Inoue et al., 2017).

The ICAR–Indian Institute of Wheat and Barley Research (IIWBR) has released multiple resistant varieties under its "Karan" series, tailored to the North-Western Plains Zone (NWPZ), which includes large parts of Rajasthan. Among these:

DBW 370 (Karan Vaidehi), DBW 371 (Karan Vrindha), DBW 372 (Karan Varuna)—all released in 2023 (IIWBR, 2023)—and also some additional varieties include DBW 327 (Karan Shivani) and DBW 332 (Karan Aditya), released in 2021 (IIWBR, 2021).

These selections continue earlier releases like DBW 303 (Karan Vaishnavi), DBW 187 (Karan Vandana), and DBW 222 (Karan Narendra) (2020).

HI 1650 (Pusa Ojaswi), HI 1655 (Pusa Harsha), and HI 8830 (Pusa Kirti)—recommended for the Central Zone, including divisions of Rajasthan such as Kota and Udaipur Krishi Jagran.

3. CHEMICAL MANAGEMENT

Chemical interventions remain a critical short-term strategy in wheat blast management, particularly in epidemic-prone zones of South Asia and South America (CIMMYT, 2016). Conventional fungicides from the *triazole* (*e.g., tebuconazole, propiconazole, metconazole*) and *strobilurin* (*e.g., azoxystrobin, pyraclostrobin*) groups have been widely deployed at heading and flowering stages, when wheat spikes are most vulnerable (Ceresini et al., 2018; Ceresini et al., 2020).

Streptomycin and *Tetracycline* Derivatives: Though classically used against bacterial diseases, some studies reported synergistic effects when combined with fungicides in reducing initial fungal inoculum on wheat seeds. However, due to regulatory restrictions and risks of resistance transfer to bacteria, their use is tightly controlled (Singh et al., 2020).

Polyoxins and *Validamycin-A* (nucleoside-peptide antibiotics): These compounds inhibit chitin synthesis in fungal cell walls, and preliminary trials indicate potential in limiting wheat blast sporulation on leaves and spikes (Islam et al., 2020).

4. BIOLOGICAL CONTROL

Fungal Biocontrol Agents *Trichoderma spp*

● *Trichoderma harzianum* and *T. asperellum* colonize wheat roots and leaves, producing hydrolytic enzymes *(chitinases, glucanases, and proteases)* that degrade MoT cell walls (Mukherjee et al., 2013).

● Several Indian studies (ICAR-IIWBR, Karnal; IARI, New Delhi) have demonstrated reduction in blast sporulation when *Trichoderma*-based formulations were applied as seed treatments or foliar sprays.

Bacterial Biocontrol Agents Several bacterial genera are known for their antagonism against blast pathogens.

Bacillus subtilis and *B. amyloliquefaciens* produce lipopeptides (*iturin, fengycin, and surfactin*) that disrupt fungal membranes (Singh et al., 2020).

Pseudomonas fluorescens: Known for producing siderophores, hydrogen cyanide, and antibiotics, *pseudomonads* compete effectively in the rhizosphere and limit MoT establishment (Jogaiah et al., 2013).

Rajasthan-based ICAR centers have begun evaluating *Trichoderma* + *Pseudomonas consortia* as bio-formulations suitable for the North-Western Plains Zone (NWPZ), where blast risk is increasing due to climate variability.

ACKNOWLEDGEMENT

The authors acknowledge the principal of Raj Rishi College for the unwavering support and providing resources and guidance towards the study.

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