Understanding and managing the threat of wheat blast in South Asia, South America, and beyond

Caused by *Magnaporthe oryzae* pathotype *Triticum* (*MoT*) and first discovered in Paraná State, Brazil (Igarashi et al. 1986), wheat blast has spread to Central and southern Brazil, the Santa Cruz region of Bolivia, South and southeastern Paraguay, and northeastern Argentina. *M.oryzae* comprises a range of morphologically identical but genetically distinct, host-specific pathotypes.

Wheat blast has become a serious constraint to wheat in warmer production areas of the Southern Cone of South America, reducing yields by 10 to 100%, depending on the year, genotype, planting date, rainfall, and disease severity. Strikingly, even with two fungicide applications, blast reduced the yields of two widely-grown cultivars by 14-32%, during the 2005 outbreak in Brazil.

The first outbreak of wheat blast outside the Americas was recorded in Bangladesh in February 2016, affecting a large area (15,000 hectares), establishing itself swiftly, and causing significant crop losses for small-scale farmers. Morphobiometrical analysis in Bangladesh followed by molecular analysis in US labs showed the causal pathogen to be *Magnaporthe oryzae* pathotype *Triticum* (*MoT*). Several research groups have reported that the pathotype found in Bangladesh is genetically similar to South American isolates and, more importantly, did not evolve from the rice blast pathotype or variants from other local hosts (www.wheatblast.org).

The sudden appearance of a highly virulent *MoT* variant presents a serious threat for food and income security in South Asia, home to 300 million undernourished people and whose inhabitants consume over 100 million tons of wheat each year. Inaction allowing the spread of the disease could severely harm wheat production in South Asia and push many smallholder wheat producers further into poverty. Immediate, concerted action should address the following issues:

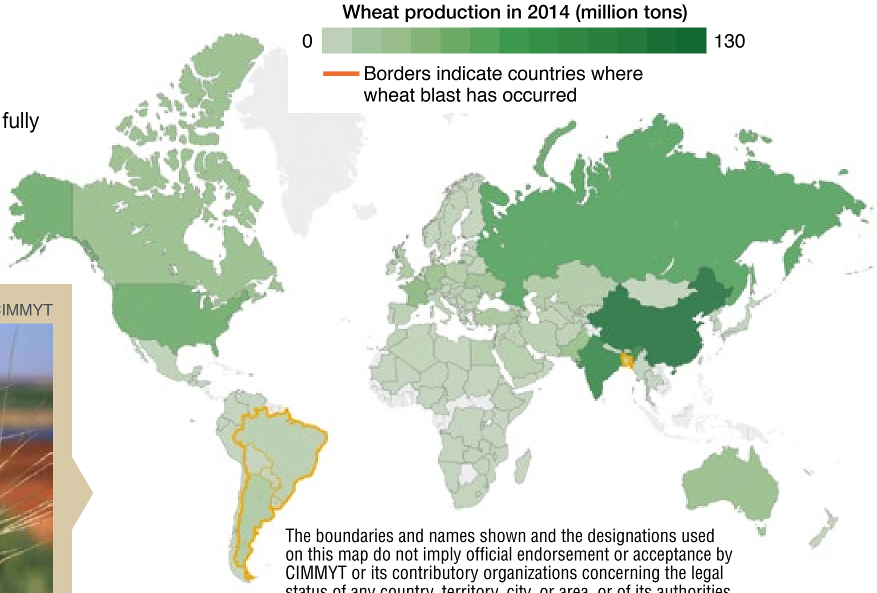
- Since its emergence 30 years ago in Latin America, *MoT* has fully adapted to its new host, wheat, and continues to spread and evolve genetically. Its appearance in Asia could trigger a new round of selection pressure and spread from Bangladesh.
- The new Bangladesh *MoT* strain is much more aggressive than earlier strains.
- Being seed-borne, wheat blast can spread easily via commercial grain shipments or farmer-to-farmer seed exchanges. Conidia can also be blown over long distances across farm areas and borders.

Photo: CIMMYT

The proposed work will help provide effective, economical, and environmentally safe means to control the effects and spread of wheat blast in South Asia and South America through:

- New resistance genes, diagnostic molecular markers, and resistant germplasm for breeding programs that target blast-prone wheat mega-environments.
- Integrated disease management strategies.
- An enhanced understanding of pathogen ecology and epidemiology.
- Strong partnerships with plant breeders and pathologists worldwide to share knowledge and develop resistant varieties and management strategies. This will include strengthening the global Wheat Blast Consortium established in 2011.
- Training for technical and scientific personnel in field screening for blast resistance in wheat.

Wheat-producing countries and the presence of wheat blast



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- The pathogen cycle and epidemiology of wheat blast are poorly understood, and prior experience with wheat diseases suggests that eradication will not be possible. Large-scale seed health measures, including seed treatment, can minimize the spread of inoculum but may not avoid outbreaks or the disease's eventual movement to new areas. A multi-pronged, multi-dimensional strategy is needed.
- Most wheat cultivars are susceptible to wheat blast. Tolerant cultivars have been identified in specific areas, but breeders have not developed ones with durable resistance. This, together with the large potential yield losses (up to 100%) and the speed and unpredictability of *MoT* outbreaks, will require innovative measures from farmers and researchers.
- The wheat blast fungus is very diverse, with a range of aggressiveness and pathotypes that could cross-infect and overcome genetic resistance in host plants. Together with their ability to evolve rapidly, this calls for durable resistance breeding strategies and a detailed understanding of host-pathogen interactions.
- Fungicides are ineffective under high disease pressure and partially effective under moderate-to-low pressure. The pathogen has been able rapidly to develop resistance to the commonly-used QoI (strobilurin) fungicides. The list of approved, locally-available fungicides is limited in South Asia, and active ingredients need to be tested for efficacy.
- Scientists, extension officers, decision makers, and farmers have little knowledge about wheat blast; extensive training is needed.
- Factors such as global warming, irregular rains, the increasing virulence of the pathogen, its fungicide resistance, and potential sexual recombinations could lead to more frequent outbreaks and the disease's spread to other major wheat-producing countries. Candidate regions would include parts of Africa, Asia, and North America with climate conditions similar to those of South America's wheat blast endemic areas.

Symptoms

Considered a spike disease, wheat blast can occur on all aerial plant parts. Foliar symptoms include gray-green and water-soaked leaf lesions with dark green borders; these become light tan with necrotic borders, once they have completely expanded. Partly or completely bleached spikes (often confused with symptoms of Fusarium head blight) and

Photo: EDuveiller/CIMMYT

Bangladesh wheat farmers' harvests quickly turned to shriveled grains and chaff, in many fields struck by blast.

blackened rachises are the most notable symptoms of wheat blast. Grains from blast-infected heads are usually small, wrinkled, deformed, and have low test-weight. The most severe yield losses occur when head infections start during flowering or early grain formation.

The pathogen

M. oryzae (anamorph *Pyricularia oryzae*) is divided into host-specific sub-groups or pathotypes specialized for infecting rice (*Oryza* pathotype), wheat (*Triticum* pathotype), ryegrass (*Lolium* pathotype), foxtail millet (*Setaria* pathotype), and many other plant species. These crop-specific isolates may occasionally infect plants from other genera.

Studies on the host range, sexual fertility, and fingerprinting with repetitive DNA elements have shown that isolates from wheat are distinct from other host-specific subgroups. The origin of the wheat pathogen is still debated. The *MoT* population has high evolutionary potential after 30 years and is still spreading and evolving. Wheat blast populations exhibit a mixed reproductive system in which sexual reproduction is followed by the local dispersion of clones. A thorough dissection of the fungal biology, including characterization of more isolates and mating types from Bangladesh, is critical to develop durable disease management approaches.

Epidemiology

Disease development conditions. Most severe wheat blast outbreaks have coincided with wet years; warm temperatures and high humidity favor disease development. Epidemic years are characterized by several days of continuous rains and average temperatures between 18–25°C during flowering, followed by sunny, hot, humid days. More precise information on blast-conducive conditions is crucial.

Pathogen life cycle. Though seed transmission of the wheat fungus has been demonstrated, seed infection may play a limited role in epidemiology, where spikes are infected mainly by air-borne conidia from secondary host grasses. The pathogen is believed to survive between wheat crops on wild plants at field borders and in open grasslands, but the plant species that harbor *MoT* have yet to be conclusively determined. Several grasses and weeds occur commonly in wheat fields and are secondary hosts, but their role in the epidemiology of wheat blast is not well understood and even less so in Bangladesh. The potential role of lower and older wheat leaves in inoculum build-up before ear emergence needs to be clarified. Likewise, the survival of *MoT* as mycelium in crop residues has to be investigated, particularly given that residue and stubble retention is being encouraged as part of conservation agriculture in South Asia, and those materials are seen as potential inoculum survival substrates in Latin America.

Surveillance and risk analysis

Surveillance and risk analysis based on historical climatic data in Bangladesh will help to determine the frequency of disease-favoring weather conditions during the 2016 Bangladesh outbreak. Investment is needed for a risk assessment in wheat-growing regions with climates that are similar to those in key blast-affected areas. Climate/dispersal/modelling should be considered. An epidemiological forecasting model, based on rainfall and temperature during the cropping season, would be helpful to guide fungicide applications.

Host-plant resistance

Despite intensive searches since the emergence of wheat blast in Brazil, no sources of durable resistance have been found. Several Brazilian, Bolivian, and Paraguayan cultivars show field resistance, but this has not been confirmed under artificial inoculation or multi-location (countries) studies. Cultivars such as BR18, IPR85, and CD113 have shown some resistance at many locations. Several cultivars and advanced lines derived from the CIMMYT line 'Milan' have shown a high level of resistance in South America. Both qualitative and quantitative genetic resistance to wheat blast have been identified in wheat, but the qualitative resistance has been validated only at the seedling stage and further studies are needed at the adult plant stage. In the USA, preliminary screening against *MoT* has identified a few entries with some tolerance to the disease. Using BSL-3 containment inoculations in the US and field tests in South America, the 2NS/2AS translocation from *Aegilops ventricosa* was observed to confer wheat blast resistance in some genetic backgrounds. Genotyping with the diagnostic markers indicated high frequencies of this translocation in most resistant varieties, including Milan. However, the 2NS/2AS-based resistance appears to be breaking down under field infections by more recently-isolated, virulent fungal populations, so additional resistance sources are urgently needed.

So far, eight blast resistance genes (*Rmg1* to *Rmg8*) have been identified in wheat, of which only *Rmg2, Rmg3, Rmg7*, and *Rmg8* provide host-plant resistance against *MoT*. To be effective in a breeding program, resistance genes must be expressed both at seedling and heading stages and be effective against prevailing *MoT* isolates. The identification of corresponding avirulence genes is also a prerequisite.

M. oryzae fungal/cereal host interactions bear similarities to those of the wheat rusts. Years of studies on gene-for-gene reactions in rice blast systems and host resistance provide opportunities to combat *MoT* more effectively. Novel approaches including genome editing could provide avenues for blast management.

Integrated control measures

Besides genetic resistance, optimum seeding and chemical control at heading can help reduce disease severity. Options in short duration wheat cropping seasons are limited and early sowing is required to avoid heat stress and other diseases like spot blotch. Rotation may not be a good control option, since the origin of inoculum is not known and many cereal crops (e.g. triticale, barley, maize, oat, foxtail millet) have been reported to be susceptible to *MoT*. As mentioned, the survival of the pathogen on crop stubble is an issue in Brazil, where conservation agriculture is widespread. Jute after wheat may reduce inoculum in Bangladesh.

Deep plowing and elimination of alternative hosts from the fields, thereby minimizing the presence of the fungus on the soil surface, were also recommended to reduce disease risk in the subsequent crop season, but this practice may not be cost effective nor in line with the widespread use of conservation agriculture.

Bleached wheat spikes in a blast-infected field. Photo: EDuveiller/CIMMYT

Wheat blast fungus can be transmitted efficiently on wheat seed and remain viable and infectious for up to 22 months. This underlines the need to use healthy seed and, possibly, fungicide treatments on seed, to restrict *MoT* establishment. Fungicides combining triazoles with strobilurins have proven effective at heading, especially in moderately resistant wheat varieties under low-to-moderate disease pressure. Fungicides have been ineffective when applied to susceptible varieties or under high disease pressure. Improper use of fungicides is costly, contaminates the environment, and may lead to fungicidal resistance in the pathogen. Increased resistance of wheat blast to strobilurin fungicides is being observed in endemic regions of South America.

Wheat blast in Bangladesh

The 2015-16 wheat blast outbreak occurred in southwestern Bangladesh near the border with India and Nepal, an area where some 10 million hectares of wheat are grown. Infected plants showed the typical wheat blast symptoms, with partly or completely bleached spikes and blackened rachises appearing quickly (in some fields the infection went from first appearance to devastating levels in a few days). Examination of diseased plants in pathology laboratories confirmed the production of pyriform conidia typical of *Pyricularia*, the genus to which *MoT* belongs. This first incidence of wheat blast was widespread, accounting for approximately 15% of the total wheat area in the region and thus indicating the presence of large amounts of inoculum.

Efforts have begun

Identifying resistant germplasm. A set of elite wheat germplasm is being evaluated in multi-location trials in Bolivia during May-August 2016 to identify promising lines with resistance to wheat blast. The lines will also be tested in greenhouses in the USA and Bolivia. Included are prominent cultivars and advanced lines from Bangladesh, early-maturing germplasm from CIMMYT adapted for South Asia, and South American varieties with promising levels of blast resistance.

Seed of these lines is being multiplied at CIMMYT's El Batán station in Mexico during the summer cycle (May to September 2016) and can be sent to Bangladesh in coming seasons for seed increase and evaluation.

Pathogen characterization. The wheat blast disease was identified based on visual symptoms on the plant and morphobiometrical characteristics of the pathogen in Bangladesh. Molecular characterization using pathotype-specific markers and comparative genome sequence analysis on a small number of Bangladesh *MoT* isolates in US labs indicates a narrow genetic diversity and sensitivity to strobilurin (QoI) fungicides. However an extensive collection and characterization of the Bangladesh *MoT* pathogen is needed.

Workshop. Key stakeholders in the wheat production chain, including researchers, extension workers, and policymakers from South Asia, CIMMYT, and advanced research institutes, along with donors, will meet in Bangladesh in July to develop and implement an action plan to elucidate, manage, and mitigate the threat of wheat blast in coming wheat crop cycles.

Following the model of the Durable Rust Resistance in Wheat (DRRW) project, whose precision phenotyping platform (PPP) at Njoro, Kenya, has helped control Ug99 stem rust, partners plan to establish a wheat blast PPP to characterize elite germplasm and wheat genetic resources in regions of high blast incidence and severity. This will allow breeders to confirm the disease reaction of known resistant germplasm, identify experimental wheat lines with durable resistance, and develop varieties with durable resistance. The PPP will also be used to screen germplasm from breeding programs around the globe, sharing data and capacities to speed development of high-yielding wheat varieties that carry genetically broad-based resistance and are adapted to areas where wheat blast is a potential threat.

Association mapping and genetic and allelic analysis of new sources of blast resistance will allow discovery and characterization of novel resistance genes that can immediately be crossed into superior wheat germplasm for use by partners and farmers. DNA markers associated with resistance genes will be used for marker-assisted selection and to develop resistant varieties for wheat production zones in blast's potential path of spread. Based on CIMMYT experience leading the "Ug99 Famine Seed Dissemination" project, a full proposal is planned for large-scale testing, multiplication, and dissemination of seed of blast tolerant cultivars.

Fungal biology and epidemiological studies will be conducted in association with the USDA/NIFA/AFRI project entitled "Novel Strategies for Managing Blast Diseases on Rice and Wheat," involving regional pathologists and molecular biologists in the Bangladesh Agricultural Research Institute (BARI), Bangladesh Agricultural Research Council (BARC), and BARI's Wheat Research Center (WRC). Routine disease surveys need to be strengthened, including PCR-based diagnostic tools developed by USDA/NIFA/AFRI for use by national partners to monitor and analyze *MoT* incidence and spread. Wheat blast forecasting models need to be developed so that farmers can take preventive or protective action. Optimal fungicidal use including seed treatments needs to be verified for different geographies.

Cultural practices have helped to mitigate the effects of wheat blast in South America. Integrated disease management practices need to be identified and applied in farmers' fields in South Asia.

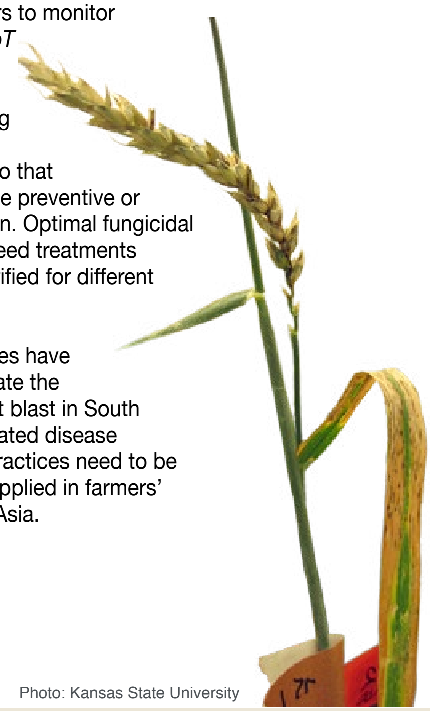

Photo: Kansas State University

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