AWARDS AND HONOURS

K.C. Mehta and Manoranjan Mitra Award - 2016

Wheat blast - A new challenge to wheat production in South Asia

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Received: 14 May 2017/ Accepted: 24 May 2017 2017/ Published online: 25 May 2017
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Keywords: IPM, *Magnaporthe oryzae* pathotype *Triticum*, MoT, South Asia, Wheat blast, wheat

Wheat blast or Brosone is caused by *Magnaporthe oryzae* pathotype *Triticum* (MoT) B.C. Couch (Anamorph *Pyricularia oryzae Triticum*). It is a recent disease of wheat originated in 1985 in Brazil and later reported from other countries like Bolivia, Uruguay, Paraguay and Argentina in South America (Iragashi *et al.*, 1986; Prabhu *et al.*, 1992; Perelló *et al.*, 2015). During early 2016 this disease had been reported to occur in Bangladesh (South Asia) (Malaker *et al.*, 2016) in districts close to West Bengal borders of India. Wheat blast is not yet reported in India. The disease is categorized into most damaging diseases of wheat due to its multiple modes of survival (seed, secondary hosts, crop residue and airborne conidia), fast spread and damage to spikes thus causing losses ranging from 10-100%, development of resistance to fungicides, higher rate of mutation and lack of resistance in common wheat varieties. Goulart *et al.* (2007) reported an average loss of 3.87 q/ha (10.5%) in wheat yield, in the Embrapa Agropecuária Oeste experiment in Brazil while in Indápolis, the losses in grain yield were in the average 6.09 q/ha (13%). The losses in spike weight were higher (63.4%) in the case of an early infection than with late infection (46.0%). The grains below the infection point in the rachis were larger than the normal ones and may partially compensate for the losses due to empty spikelets.

The lack of knowledge on different aspects of the pathogen and its interaction with the host also a limitation in its effective management. Keeping in view, the cultivation of wheat in South Asia in warm and humid climate (>11 million ha) which is suitable for the development of wheat blast, larger numbers of resource deficit farmers, and climate change is further aggravating the situation thus causing greater concerns of food security in the region. The present review is prepared to bring the latest update of knowledge and strategies to contain the disease in the region with special emphasis

to India which shares the larger borders with Bangladesh. The present review will update the earlier published information on wheat blast (Singh, 2017).

Nomenclature

Pyricularia oryzae was described as a causal agent of rice blast in 1891. Sprague (1950) retained *P. oryzae* for the species attacking rice and *P. grisea* that attacks monocots other than rice. The teleomorphic states of *P. oryzae* and *P. grisea* have not been found in nature. *P. oryzae* was considered a synonym of *P. grisea* based on the morphological similarity of isolates of *P. oryzae* and *P. grisea* from rice and different grasses, respectively, as well as the interfertility among these isolates. The molecular genetic studies done later indicate the existence of genetically distinct clonal (asexually reproducing) populations in *P. grisea* (Rossman *et al.*, 1990). It may be the result due to strong selection to maintain host specificity and probably geographic isolation (Shull and Hamer, 1994). The multilocus phylogenetic analysis was performed by Couch and Kohn (2002) aiming to distinguish *M. oryzae* as a new species from *M. grisea* since these are morphologically indistinguishable. Pathogenically *M. oryzae* occurs on cultivated cereals and *M. grisea* on wild grasses including *Digitaria* spp. The isolates of *Magnaporthe* from rice (*O. sativa*) and other crops like wheat, barley, finger and foxtail millets and grasses were named as *M. oryzae* by Couch and Kohn (2002). *M. grisea* (anamorph *P. grisea*) was used only to the isolates from *Digitaria*. The detection of *M. oryzae* was done based on Polymerase chain reaction (PCR) (Couch and Kohn, 2002; Harmon *et al.*, 2003). Valent *et al.* (2016) divided *Magnaporthe oryzae* population into *M. oryzae Oryza* pathotype (MoO), the *M. oryzae Triticum* pathotype (MoT), and *M. oryzae Lolium* pathotype (MoL) causing blast disease of rice, wheat and grey leaf spot (GLS) disease in annual/

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perennial ryegrass (*Lolium perenne*) and tall fescue (*Festuca arundinacea*), respectively. Considering morphological, biological and molecular data, Luo and Zhang (2013) established a new genus, *Magnaporthiopsis*. *Pyricularia* was suggested for the rice blast fungus. *P. grisea* was considered co-generic with the anamorph *P. oryzae* (Couch and Kohn, 2002; Zhang *et al.*, 2013). Zhang *et al.* (2013) therefore it was proposed that scientific name could revert to the previously used name of *P. oryzae*, or *M. oryzae*. The current taxonomy can be in the Catalogue of Life, Fungal Databases and MycoBank (Farr and Rossman, 2005; Roskov *et al.*, 2015). It is phylum - Ascomycota, class - Sordariomycetes incertae sedis, Order-Magnaporthales, family - Magnaporthaceae of *Magnaporthe oryzae* pathotype *Triticum*.

The colonies of MoT appeared as white, light gray, or dark gray in color after 5 to 7 days. The V8 medium was found good for the growth of aerial hyphae, conidiophores and production of conidia. The conidiophores were single or clustered, simple, infrequently branched and exhibit sympodial growth. At the tip of the conidiophore, conidia form at points that ascend sympodially and in succession, narrowed toward the tip, pyriform to obclavate, rounded at the base, 2-septate, rarely 1- or 3-septate, hyaline to pale olive, primarily 19-23 × 7-9 µm with a distinct bulging basal hilum (USDA, 2015; Subramanian, 1968). *P. oryzae* culture may be stored at 4 to -20°C in desiccated form on a range of media without much loss of viability or pathogenicity for 20 years.

Diagnosis

The infected field has dry and bleached spikes while the leaves may be still green (Fig. 1a). The symptoms appear on seed, leaf, peduncle, and spike. On leaves, initial symptoms may be gray-green and water-soaked lesions with dark green borders which become light tan with necrotic borders, once they have completely expanded with typical eye shaped necrotic lesions with grey centres (Fig.1b, c). In the field, the symptoms on

leaves may, however, be difficult to identify due to mixed infection of spot blotch. The symptoms on spikes are most prominent and easily visible. The pathogen infects the rachis and develops dark brown discolouration at the point of infection with or without dark brown mycelial growth (Fig. 2a-b). The spikes may be completely or partially bleached. The spike portion above the infection point may dry quickly thus leaving the spikelets blank if the infection takes place before grain filling stage. In case of late infection on spike, few light weight, and thin grains with black discolouration are produced. The upper portion from point of infection is always dried out and mostly remains sterile (Igarashi, 1990; Islam *et al.*, 2016; Malaker *et al.*, 2016; Urashima, 2010).

The spike blight symptoms of the wheat blast are often confused with Fusarium head scab (Fig. 2c) and spike blight due to spot blotch (Fig. 2d) in the field under humid and warm climate. When the rachis is infected with Fusarium head blight (FHB), spikelets above and below the point of infection may also become bleached (Wise and Woloshuk, 2010), and the infected spikelets may contain pink to orange masses of spores (Valent *et al.*, 2016; Wise and Woloshuk, 2010) (Fig.2c). In case of spike blight due to *Bipolaris sorokiniana*, dark brown discolouration develops on the spike (Fig. 2d) and such spikes may possess healthy spikelets at both ends from point of infection (Singh, 2007).

The spikes if infected at grain filling stage yield only small, shrivelled, light weighted and discoloured grains. The lesions developed on spikes and leaves possess three-celled pyriform conidia on aerial conidiophores and these may be seen under microscope. The culture of MoT looked grayish. The infected plant parts are incubated on a 3-layered moist blotter at room temperature for 12 h light/darkness cycle for 5 days to induce production of pyriform conidia (Malakar *et al.*, 2016). Highly susceptible cultivars can be infected at the seedling stage. The resistant wheat cultivars show hypersensitive spots or small, round to elliptical shaped brown lesions. The older leaves of wheat are more susceptible to MoT than younger ones, in general.

Fig. 1. a. Wheat blast infected field, b. Water soaked lesions, c. Eye shaped necrotic spots on leaf (Source, Dr. T. Islam, <https://bmcbiol.biomedcentral.com/articles/10.1186/s1291501603097>)

Fig. 2. a-b. Spike blight due to MoT, c. Head scab, d. Head blight due to *B. sorokiniana*

An accurate and sensitive diagnostic assay is required to detect and distinguish MoT from other pathotypes infecting rice and grasses. Pieck *et al.* (2015) used whole genome sequencing and a custom bioinformatics pipeline for identification of 20 loci which were unique to *M. oryzae* (*Triticum* pathotype) genome of South American origin. Polymerase chain reaction (PCR) assays were standardized for MoT3 marker which was found in 109 of 110 South American *M. oryzae* (*Triticum* pathotype) isolates. A total of 169 numbers of isolates of the *M. oryzae* isolates out of 170 numbers collected from fourteen different host species of seven countries were tested negative for the MoT3 marker. Such tests will be of much use in quarantine to prevent spread of wheat blast through seed in different countries and continents.

Losses

The losses due to disease depend on weather conditions and level of resistance against wheat blast in a variety. The losses due to wheat blast were estimated in the range of 10 to 100% in recent years in South American countries (Duveiller *et al.*, 2016). The disease may leave the farmers to feel deceived since it affects the spike and grains badly and its spread on susceptible wheat cultivars is quite fast (2-3 weeks) thus leaving little time to farmers to prepare and cope up with the situation. Wheat blast if occurs with leaf rust and spot blotch may have devastating effect in wheat grown in warmer and humid climate of South Asia. The effect of the wheat blast was observed on the seed quality in Brazil. Wheat genotypes were inoculated with *P. oryzae* (0, 5, 10, 20 and 30% of inoculated plants). The inoculation was done at the stage of the complete emergence of spikes. The infected spikes had lower productivity and yielded seeds with reduced physiological quality as compared to uninoculated spikes. The seed-borne inoculum of *P. oryzae* pathotype *Triticum* infected the wheat seeds developed on the mother plant. The seeds harvested from

fields with blast incidence from 20% on spikes were therefore not recommended for seed purposes (Gomes *et al.*, 2017). The genotypes confining the low infection on the leaves with little infection on the spike are preferred.

Favourable climate

The disease may become an epidemic and devastate wheat crop within a week under most conducive temperature range of 8-30°C and at >80% RH during ear emergence or grain filling (CABI, 2017). The wet years; warm temperatures and high humidity were found associated with wheat blast epidemics (Kohli *et al.*, 2011). The rains for several days and average temperatures ranging from 18-25°C during flowering, followed by sunny, hot, humid days is favourable for the epidemic of the wheat blast. Since the disease is of relatively recent in origin, therefore, more precise information is needed on favourable conditions for its development and spread. The disease is reported as one of the major limiting factors in wheat cultivation in areas such as the Cerrados (tropical savanna ecoregion of Brazil) and Bolivian lowlands. The disease is seed-borne and able to survive on alternative hosts and in situations like changing the climate and lack of satisfactory genetic resistance against wheat blast, more research is needed to generate data to forecast epidemics and protect other regions and cropping systems from this menace (Ha *et al.*, 2017). Lowest blast intensity was reported at 15°C and the maximum between 25°C and 30°C with a wetting period of at least 10 h (Cardoso *et al.*, 2008). MoT requires tropical and subtropical temperatures to sporulate and survive. Kohli *et al.* (2011) reported increase in blast intensity (>85%) at 25°C with 40 h of wetting. Freezing temperature was not found favourable for survival of *M. oryzae* *Lolium* pathotype (Harmon and Latin, 2003) which is a close phylogenetic relative of the *M. oryzae* *Triticum* pathotype. Cruz (2013) concluded that *M. oryzae* *Triticum* pathotype populations could be limited over winter

survival of the U.S. Ferris *et al.* (1998 applied heat stress up to 40°C for 12 days (before and after anthesis) using a temperature gradient tunnel and reported 50% reduction in both grain yield and kernels. Harmon and Latin (2005) studied winter survival of conidia and reported that approximately 50,000 conidia per g dry weight of residue of *M. oryzae* were produced initially on ryegrass in North central Indiana which was reduced to fewer than 60 conidia per gram by spring.

Disease cycle

Wheat blast appears to follow the same disease cycle as the well-studied rice blast (Tufan *et al.*, 2009). Asexual reproduction takes place via mitotically produced spores/conidia (Couch *et al.*, 2005). Sexual stage does not occur in nature. One lesion can produce 2,000-6,000 conidia/day for about two weeks. Numerous infection and reproduction cycles occur during a single growing season (Couch *et al.*, 2005; Ou, 1985). The optimum temperature and wetting period for spore formation range from 25-30°C with spike wetness period from 25-40 h (Cardoso *et al.*, 2008). The dissemination of *M. oryzae* occurs primarily via airborne conidia (Ou, 1985; Urashima *et al.*, 2007). Extended dew periods and water droplets accumulated on infected leaves increase spore production and release (Ou, 1985; Suzuki, 1969). Ingold (1964) states that the conidium is likely violently discharged across a short distance when the minute stalk-cell attaching it to the conidiophore bursts. In the absence of wind, most spores are trapped near the ground (Ou, 1985). The dispersal studies in rice blast concluded that spores could travel at least 700 m to 1 km from an inoculated source and remain viable (Ishiguro *et al.*, 2002; Urashima *et al.*, 2007). Long dispersal of the pathogen is through infected seeds (Urashima *et al.*, 1999). Seed plays a limited role in epidemiology. The infection on spike takes place mainly from air-borne conidia from secondary host grasses. The pathogen is believed to survive between wheat crops on wild plants. However, the plant species which harbour MoT are not yet demonstrated conclusively. Several grasses and weeds occur commonly in wheat fields and may be the secondary hosts. However, information on their role in the epidemiology of wheat blast is scanty. The role of lower leaves in building inoculum for spike infection needs to be established (Cruz *et al.*, 2015a). The role of crop residue in the survival of MoT as mycelium may be investigated under conservation agriculture which is practiced in South Asia (CIMMYT, 2017).

Seed health testing and quarantine

Wheat blast is seed borne in nature besides airborne inoculum from crop residue and secondary hosts. Seed transmission is important for the spread of disease across continents. It also gives a caution to other countries importing wheat grains and emphasizes on strict quarantine norms for both seeds and grains of wheat to MoT while MoO remains as a non-invasive pest in the list of rice growing countries in general. Faivre-Rampant *et al.* (2013) demonstrated that *M. oryzae* was present in the seed coat of infected seeds and that spores were

produced shortly after germination. The seed health testing protocol developed in case of rice blast may be used for time being in the case of wheat blast. Further reliable ELISA and PCR-based detection methods are needed to prevent further spread of this pathogen through research or commercial consignments of wheat at global level.

Seed health testing protocol

The modified protocol of detection of wheat blast pathogen, MoT is prepared based on protocol of MoO (Source: <http://www.apsnet.org/edcenter/intropp/lessons/fungi/ascomycetes/Pages/RiceBlast.aspx>) and is as follows:

- Standard 'blotter' or 'agar' plate methods and washing test may be used.
- Under a stereo binocular microscope, infected seeds on a blotter exhibit a fine, grayish growth of erect conidiophores bearing conidia. *Cladosporium* may also appear similar, but it has bigger, dark brown to almost black conidiophores and smaller conidia. Colonies of *M. oryzae* on potato dextrose agar at 25°C measure approximately 4.1 cm in diameter after 5 days of incubation. Sporulating colonies look fleecy grayish on agar plate.
- Mycelia are thin, effuse, almost black in the centre with whitish margins and reverse blackish. Hyphae are hyaline and branched. Conidiophores are distinct from vegetative hyphae (macronematous), single or in groups, simple, and septate with distinct geniculations. Conidia are produced singly in sympodial fashion (at the apex of conidiophore), pyriform to obclavate, usually three celled, bi septate, rarely 1-3 septate, almost hyaline to pale olive-coloured, measuring 14-40 × 6-13 nm; with distinct protruding hilum.

Host range of *M. oryzae* pathotype *Triticum*

Besides wheat, wheat blast pathogen also infects barley, foxtail millet, knot root foxtail, black oat, and few grasses like sourgrass, large crabgrass, goose grass, southern cut grass, perennial ryegrass, fountain grass, and marmalade grass (CABI, 2017).

Pathogenic variability

Wheat blast pathogen is caused by a separate species, *M. oryzae* (Couch and Kohn, 2002) and it is divided into host-specific sub-groups or pathotypes specialized for infecting rice (*Oryza* pathotype), wheat (*Triticum* pathotype), foxtail millet (*Setaria* pathotype), ryegrass (*Lolium* pathotype), and other plant species. It has been proved based on host range, sexual fertility and DNA finger-printing that the isolates from wheat are distinct from other host specific subgroups. However, the origin of the wheat pathogen is still an issue of debate. The MoT population is still evolving and has the ability to mutate fast (CIMMYT, 2017; Maciel *et al.*, 2014; Tosa *et al.*, 2006; Urashima *et al.*, 2005). Maciel *et al.* (2014)

reported 27 wheat blast isolates and used these for the screening of wheat genotypes. Pieck *et al.* (2016) used a genomics-based approach to identify molecular markers unique to the *Triticum* pathotype of *M. oryzae*. A PCR-based diagnostic assay was done using MoT3. Conventional PCR primers were designed to amplify a 394 bp product and the protocol consistently amplified from as little as 0.1 ng of purified DNA. The specificity of the MoT3-based assay was also evaluated using *Fusarium* spp. DNA, from which no amplicons were detected. Keeping in view of the presence of wheat blast in South America and Bangladesh, it is important to develop a collection of pathotypes and monitor the virulence at the global level.

Host resistance

Host resistance is an effective mean for the management of diseases like leaf rust, spot blotch and wheat blast in warmer and humid climate of South Asia. It is important to develop a suitable protocol for creation of artificial disease epiphytotic of the wheat blast and simultaneous testing of segregating material, genotypes, and yield trial entries against other diseases like rusts and spot blotch.

Inoculum preparation and inoculations

Oat agar medium has been used to grow MoT. The incubation is done in a growth chamber maintained at 23 to 25°C for 12 days. To obtain the suspension of the inoculum, the conidia are removed from the plate with the aid of a brush and distilled water plus Tween 80 adhesive spreader. The suspension volume for young plant inoculation may be 500 ml and for adult plant 300 ml with spore suspension of 2×10^5 spores/ml of water. Leaf inoculation on young plants is performed at the four leaves stage and at the adult stage at beginning of the anthesis, corresponding respectively to stages 14 and 61 of the Zadoks *et al.* (1974).

Rating scales

The scoring of wheat blast incidence at seedling stage is done on the scale of 0 to 9 (IRRI, 1996). The 0 score referred to no lesions (highly resistant); 1 for small, brown, specks of pinhead size; 2 for small roundish to slightly elongated, necrotic gray spots, about 1-2 mm in diameter, with a distinct brown margin, 3 refers to small, roundish, elongated, necrotic gray spots (1-2 mm in diameter) 4 was given to typical susceptible blast lesions, 3 mm or more infecting less than 4% of leaf area. The score 5 was for typical blast lesions infecting <10% leaf area, 6 was for typical lesions of 3 mm or longer infecting 11-25% of the leaf area; 7 was for blighted area of leaf in the range of 26-50%; 8 referred to blast lesions of 3 mm or more with infected area from 51 to 75% of the leaf with few dead leaves and 9 was for >51% leaf area infected along with many dead leaves. The score 0-1 was for resistant reaction, 2-3 for moderately resistant, 4-5 for moderately susceptible, 6-7 for susceptible and 8-9 for the highly susceptible category.

At adult plant stage, diagrammatic scale recommended by the International Rice Research Institute (IRRI, 1996), with modifications, for wheat diseases is used where zero is – absence of symptoms; 1 (one) - 0.1 to 4%; 2 (two) - 5 to 10%; 3 (three) - 11 to 25%; 4 (four) - 26 to 50%; and 5 (five) - 51 to 100% of infected leaf area. A standard area diagram set (SADS) was developed and tested by Rios *et al.* (2013) to quantify the severity of wheat blast. It has ten levels of wheat blast severity from 0.1, 1, 5, 10, 22, 32, 42, 52, 62 and 72%.

The spike blight incidence is recorded in percent spikes infected. The scale proposed by Trindade *et al.* (2006) is used for deciding the severity. It is based according to the point at which the pathogen has penetrated the rachis and affected the length of the spike. The score 0 referred to nil visual symptoms, 1 for 25 % of the spike showing symptoms; 2 for 50%, for 75% and for 100% length of spike affected. Maciel *et al.* (2013) photographed the infected spikes. The blast severity was ascertained by using resources of the software ImageJ. A diagrammatic scale was prepared and the disease severity values were 3.7, 7.5, 21.4, 30.5, 43.8, 57.3, 68.1, 86.0, and 100.0%.

Since the spread of disease on spike from infection point varies in different genotypes, therefore, a more meaningful scale and the score is required to screen a large breeding population in the field.

Resistant genotypes

Current research, performed in Biosafety Level-3 in the U.S indicated a wild wheat chromosome segment, (2NS/2AS translocation of *Aegilops ventricosa*) used for rust resistance genes also confers wheat blast resistance in some genetic backgrounds, but it is not confirmed further. Wheat blast strains contain functional alleles of rice blast avirulence gene *AvrPiz-t*. Work in blast disease of wheat is underway to determine if *AvrPiz-t* gene from rice might be useful for controlling wheat blast (Valent *et al.*, 2016).

The durable blast resistance sources against wheat blast are still not found (Bockus *et al.*, 2013). Some wheat cultivars of Brazilian, Bolivian, and Paraguayan origin showed field resistance. However, it is not validated under artificial inoculation under multi-location testing in different countries. The cultivars, BR18, IPR85, and CD113 were found better against MoT. The cultivars and lines having 'Milan' (which is having 2NS/2AS) in their pedigrees have shown resistance in South America (Urashima *et al.*, 2004). Both qualitative and quantitative genetic resistance have been identified in wheat against wheat blast and former has been validated only at the seedling stage. The 2NS/2AS-based resistance now found breaking down when subjected to virulent pathotypes of MoT in USA (Cruz *et al.*, 2016).

Eight blast resistance genes from *Rmg1* to *Rmg8* have been identified in wheat. Out of these, only *Rmg2*, *Rmg3*, *Rmg7*, and *Rmg8* resulted in host-plant resistance against MoT (Anh *et al.*, 2015). Such genes are required

to express at seedling as well as heading stages. The corresponding avirulence genes may also be identified. It is postulated that *M. oryzae* fungal/cereal host interactions may be similar to those of the wheat rusts. Further studies on gene-for-gene reactions in rice blast systems and host resistance may provide better opportunities to combat MoT (CIMMYT, 2017).

Chemical control

Seed treatment: The pathogen (MoT) is seed transmissible (Goulart and Paiva, 1990) and remains viable for 22 months. Seed treatment with fungicides is, therefore, effective in reducing the seed-borne infection (Bockus *et al.*, 2014). The treatment of seeds in Bolivia with Benlate® and carbendazim plus thiram provided exceptional control of wheat blast when applied @ 200 ml per 100 kg of the seed (Valent *et al.*, 2016). Goulart and Paiva (1993) used iprodione @ 50 g ai/100 kg seed plus thiram @ 150 g ai/100 kg seed for control of seed-borne infection of MoT. Lasca *et al.* (2001) used seed treatment of carboxin @ 22.5g ai/100 kg, plus prochloraz @ 82.5 g ai/100 kg, triflumizole @ 45 g ai/100 kg plus thiophanate-methyl @ 135 g ai/100 kg, carbendazim @ 50 g ai/100 kg plus mancozeb (160 g ai/100 kg) and carbendazim (52.5 g ai/100 kg) plus iprodione (26.2 g ai/100 kg) of seed and got excellent control on wheat blast infection in seeds.

Foliar sprays: Fungicides typically provide only a partial defence if applied before the appearance of symptoms. Combining triazoles (tebuconazole and metconazole) with strobilurins has proven effective in wheat blast control during the heading stage on moderately resistant varieties (Kohli *et al.*, 2011; Valent *et al.*, 2016). However, these were not found proper in the case of susceptible varieties (Cruz, 2013; Kohli *et al.*, 2011; Urashima *et al.*, 2009). A mixture of triazoles (tebuconazole and metconazole) and strobilurins have been found effective in controlling MoT in moderately resistant wheat varieties (Kohli *et al.*, 2011; Rios *et al.*, 2016). MoT mutates fast. The use of fungicides with similar mode of action each year is therefore not recommended (Castroagudín *et al.*, 2015). Resistance in wheat blast pathogen to QoI fungicides, azoxystrobin and pyraclostrobin in Brazil have been reported by Oliveira *et al.* (2015). Application of trifloxystrobin + tebuconazole is more effective before rain or dew at flowering stage. Silicon (Si) applications significantly reduced disease (Cruz *et al.*, 2015b; Paula *et al.*, 2014). The use of synthetic fungicides gave an average blast severity control up to 55%.

The most effective strategy will be to create genetic resistance, coupled with fungicidal seed treatment and foliar sprays on crop with strobilurin (QoI) fungicides to reduce the severity of the disease. The alternative hosts in and around field act as source of inoculum and minimizing their presence will reduce wheat blast in the field. A coordinated survey and surveillance of wheat blast by involving state governments, NGOs, research institutes and private organizations is recommended. Strengthening plant quarantine measures governing

seed and grain movement, increasing knowledge and awareness about wheat blast amongst scientists, extension workers, decision makers and farmers are important issues to tackle the disease effectively. Regular monitoring and checking of the crop is recommended especially after continuous rains for few days with high temperatures (18-30°C) and followed by hot, sunny, and humid days (Cardoso *et al.*, 2008; Kohli *et al.*, 2011). The applications of fungicides at growth stages 45 and 65 of the scale of Zadoks were found better (Rocha *et al.*, 2014) under artificial inoculation done at stages 58-60. The foliar application of fungicides, epoxiconazole + pyraclostrobin and tebuconazole + trifloxystrobin resulted in lowest area under the disease progress curve (AUDPC) in VI 03061, VI 07505 and BRS 254 genotypes. The application of tebuconazole + trifloxystrobin gave highest grain yield and lowered the severity on spikes (SEVEsp). The blast disease severity on the spikes was higher than on flag leaves. The fungicides gave effective control of wheat blast for flag leaves but not for spikes.

Impact of wheat blast occurrence in Bangladesh on Indian wheat crop

The cropping system and climate in Bangladesh and India in adjoining districts near the borders are having similarities and exchange of grains may not be fully ruled out amongst farmers. Therefore, agencies are on high alert to prevent the entry of this disease in India and mechanisms are worked out to manage the threat effectively. After the occurrence of the wheat blast in Bangladesh during 2016 emphasis has been given on effective quarantine measures, regular survey, and surveillance close to border areas in Indian states which share their borders with Bangladesh. Integrated management practices are developed. Collaborative research is being carried out with CIMMYT in the evaluation of Indian wheat varieties and exchange of information and skills.

IPM of wheat blast (Islam, 2016)

- Use certified and a clean seed as the fungus is seed-borne. Even healthy looking seeds from infected crop may have inoculum of pathogen.
- Use seed treatment with fungicides.
- Replace susceptible varieties with resistant varieties.
- Adjust time of sowing so that heading occurs during dry weather.
- Regularly remove and destroy weeds, particularly grasses such as *Eleusineindica*, *Leersia*, *Echinochloa*, *Brachiaria*, *Digitaria*, *Lolium*, *Cenchrus*, and *Chloris* in and around the wheat field. The grassy weeds act as secondary hosts and spread the disease in wheat.
- Deep plough or burn crop residues as the fungus can survive on these and spread.

- Monitor the crop regularly for presence of symptoms of wheat blast on leaves and spike.
- Use foliar sprays of fungicides before rain or dew at flowering stage.

ACKNOWLEDGEMENTS

The author is thankful to Dr. G.P. Singh, Director, ICAR-IIWBR Karnal for facilitating the review and Hon. DG and DDG (CS) for supporting the wheat blast proactive research at ICAR-IIWBR Karnal and in AICWBIP. Thanks to Drs. T. Islam for providing photographs, A.K. Joshi, and Pawan K. Singh of CIMMYT for inputs on the disease. Appreciations to Dr. P.L. Kashyap for reviewing the manuscript internally.

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