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1 Acknowledgments

The work described in this report was undertaken with timely and prompt funding provided by ACIAR through which the International Maize and Wheat Improvement Center (CIMMYT) was able to convene research teams from Bangladesh including Bangladesh Agricultural Research Institute to develop strategies to mitigate the effects of wheat blast. Timely interventions by Government of Bangladesh and scientific and technical help received from Advance Research Institutes and National Agriculture Research System is greatly acknowledged.

2 Executive summary

Wheat blast is a devastating disease severely influencing wheat production in the Southern Cone region of South America and has the potential to cause yield reduction of up to 100% under conducive environments. In 2016, the disease outbreak for the first time in Bangladesh was observed, influencing about 15% of the wheat cultivation area in the country. This wheat blast outbreak in the heavily populated South Asia region represents a serious threat not only for Bangladesh wheat production but also for regional food security in South Asia, home to 300 million undernourished people and whose inhabitants consume over 100 million tons of wheat each year. This is the final report of a one year Small Research Activity (SRA) funded by ACIAR with the following aims: 1) identify the immediate research needs to contain the 2016 blast outbreak, 2) to identify research priorities in the period 2017-2021, and 3) to increase awareness on wheat blast of farmers, scientists and decision makers. Under the support of this project, an international consultation workshop on “Mitigating the Threat of Wheat Blast in Bangladesh and Beyond” was organized in Kathmandu, Nepal. Seven wheat blast workshops were held in different wheat growing regions of Bangladesh before the 2016-17 growing season to increase the awareness of the disease among farmers, breeders, extension agents, scientists, and other stakeholders. Nationwide seed health testing was carried out in Bangladesh to prevent the use of wheat blast infected grains as seeds. Fact-sheets were distributed across the country to make awareness about the disease and its control. A 3-day long hands-on training on wheat blast and its surveillance was organized by BARI-CIMMYT in early February 2017 at Wheat Research Centre, Dinajpur followed by field surveys of wheat blast were conducted in February-March, 2017 in major wheat growing areas of Bangladesh. A two-week wheat blast training was organized in USA and Bolivia in July 2017. Finally, a large research project proposal was developed and submitted to ACIAR, to guide the work from 2017 to 2021 in fighting the newly emerged disease. The large ACIAR project CIM-2016-219 was favourably reviewed and started in July 2017. A set of research outcomes from this SRA, including the resistant varieties development, effective fungicide ingredients identification, agronomic measures, and findings in epidemiology disease development will be helpful in subsequent research activities. This initial project has laid solid foundation for the subsequent large project to be carried out and its findings will show their impact in near future.

3 Background

Wheat blast (WB) or brusone caused by *Magnaporthe oryzae* (anamorph *Pyricularia oryzae* Sacc.) pathotype *Triticum*, has been a serious biotic limitation in increasing the acreage and production of wheat in the tropical parts of the Southern Cone Region of South America. In February 2016, WB outbreak was reported in Bangladesh, influencing about 15% of the total wheat area in the country (Malaker et al. 2016). This was the first blast outbreak outside South America, raising concerns in national, regional and international agriculture communities (Chowdhury et al. 2017). Genomic studies on the fungal isolates led to a conclusion that the causal agent was *Magnaporthe oryzae* pathotype *Triticum* (MoT), which was determined to be introduced from South America based on the extensive similarities across genome (Islam et al. 2016; Malaker et al. 2016).

The fear that WB can cause significant yield losses in Bangladesh is justified because: 1) MoT has very high evolution potential; 2) the strains introduced to Bangladesh are the most aggressive type and still have great potential to evolve; 3) the pathogen is both seed and air borne; 4) resistance source is very limited and their durability is questionable, and most commercial cultivars are susceptible; 5) the disease develops very rapidly, giving no time for remedial actions to be taken; 6) known fungicides are ineffective under high WB pressure and only partially effective under moderate to low disease, and fungicide resistance/ tolerance has been observed; and 7) there are many knowledge gaps to be filled and people generally have very limited knowledge on this devastating disease (Kohli et al. 2011; Maciel et al. 2014; Cruz and Valent 2017). The appearance of this disease on such a large scale represents a serious threat not only for Bangladesh wheat production but also for regional food security of South Asia, home to 300 million undernourished people and whose inhabitants consume over 100 million tons of wheat each year. In Bangladesh the committee headed by Prof. Dr. M.B. Meah on behalf of FAO estimates now that up to 40% yield was lost primarily to wheat blast in the districts of Jessore, Kushtia, Chuadanga, Meherpur, Jhenidah, Magura, Barisal and Bhola in 2016.

Inaction could lead to disaster, and the most important thing was to identify disease control strategies that are able to show immediate effects. In order to obtain this aim, Government of Bangladesh, CIMMYT and FAO took prompt reaction and led to the formation of an emergency task force led by Prof. Dr. M.B. Meah, BAU, to develop short-term recommendations for the Ministry of Agriculture to mitigate WB disease in Bangladesh. Considering that it was the first report of WB in Asia, BARI requested assistance to deal with this newly emerged devastating disease.

There is high risk of WB becoming regional, potentially affecting India, Pakistan and Nepal. Mitigating the effect of a new uncontrolled disease on productivity and livelihood aligns well with ACIAR priorities and protects the benefits of other Australian research investments in the South Asia region. The current SRA was aimed to identify the immediate research needs to contain the 2016 outbreak, and to reduce its impact as much as possible in the new planting season to prevent the disease from spreading and further losses to farmers. The SRA was also designed to support a regional consultation workshop organized by BARC/BARI/WRC and CIMMYT to discuss the recommendations from the emergency task force to be implemented in Bangladesh. Specific field activities were conducted in 2016-2017 by WRC with Department of Agricultural Extension in the area of seed health, surveillance and risk evaluation with local partners. Workshops were organized in different regions across Bangladesh and fact-sheets on WB were prepared and distributed to raise farmers' awareness and contribute to capacity building so that appropriate recommendations can reach farmers. A full project with WRC for 2017-2021 was co-designed by CIMMYT and WRC-BARI on mitigating the negative impact of WB in Bangladesh. The ultimate beneficiaries are primarily the wheat producers in Bangladesh but also include other intermediaries in the wheat value chain and consumers. Besides Bangladesh, this SRA can have led to large impact at regional level in terms of increasing awareness of wheat blast and taking preventive steps to avoid large production losses.

The WB management strategy required integrating knowledge from the Americas and Europe with local information from the fields and the local stakeholders, to guide future actions and decisions. It was clear that the magnitude of the new challenge required a partnership approach. In the SRA, CIMMYT was responsible to facilitate the knowledge sharing and integration of research outputs from different advanced research institutes (ARIs) and South America to propose a set of concrete and impact oriented activities, which include precision phenotyping, disease epidemiology, targeted breeding efforts, germplasm and data exchange, molecular tools and recent innovations resulting from better understanding of the pathogen.

4 Objectives

Three major objectives were as following:

1) Identifying immediate research needs to contain the 2016 outbreak;

2) Identifying research priorities for 2017-2021 and the most effective and efficient way to address them, including sustained breeding efforts for durable resistance to WB in heat stressed environments;

3) Limiting the effects of the 2016 outbreak and increasing farmers, scientists and decision makers' awareness.

The main potential impact of the SRA will be the containment of the WB outbreak in Asia with ACIAR and its partners taking the lead and showing the path. The benefit would be very large in terms of production loss avoided. The Eastern Gangetic Plains (EGP) produces about 100 M tons wheat per annum. Thus, the expected impacts is beyond Bangladesh and is for all South Asia.

Activities were focusing around four subjects:

1. A workshop with support of ACIAR and other donors (USAID) was planned to be held in July 26-27 2016 in Dhaka (which actually took place in Kathmandu, Nepal). The aims of the workshop included: 1) discussing the short-term recommendations by the committee to be implemented in Bangladesh to mitigate and control the disease before the start of next cropping season; 2) identifying specific research interventions to be addressed in Bangladesh in the areas of epidemiology, integrated disease management, agronomy and screening for resistance of elite wheat materials; 3) proposing a set of collective activities to be part of a long-term multi-partners and international breeding effort for durable resistance against MoT; and 4) building the capacity of farmers, scientists, extension specialists in Bangladesh and South Asia and organizing the disease surveillance to equip the stakeholders against the new threat to be addressed.

2. Conducting seed health, surveillance and risk evaluation by WRC and local partners such as Department of Agriculture Extension (DAE), Bangladesh Agriculture Development Corporation (BADC), etc. This included travelling seminars across the wheat belt in Bangladesh, seed treatments and foliar spray evaluation, screening wheat promising lines in a hot spot location at the epicentre of the 2016 outbreak (i.e. Regional Agricultural Research Station, Jessore) climatic data analysis, initiating investigation on the detection of conidia on residues and survival of pathogen on potential alternate hosts, and exploring ways for monitoring air-borne spores of the pathogen during the wheat season.

3. Piloting farmer awareness, participatory research and capacity building will be undertaken engaging all related stakeholders to ensure that both women and men farmers know how to react and handle the disease. This may require support from specialized NGOs or university partners (one or two partners to be identified by WRC).

4. Preparing a full four-year project proposal (2017-2021) to durably combat WB in Bangladesh and avert the threat in South Asia. This will be based on informed contributions and proposition by local, regional and international participants in the July 26-27 consultation workshop and shall be part of a larger multi-donor consortium based investment. Putting in place the human and physical infrastructure for breeding against WB is expected to be a major component of the project.

5 Methodology

The SRA was developed and co-designed by CIMMYT and WRC-BARI to make sure that the questions addressed are relevant to the needs of Bangladesh and results will guide future actions.

The choice of sites of work with Bangladesh Department of Agricultural Extension: Information generated at the hot spot location and communication with farmers will help to draw conclusions on the most effective approach to combat the disease. Researchers will start looking at the role of alternate hosts, understanding the disease cycle and agronomic interventions to mitigate epidemics.

The field based studies (e.g. surveillance and host resistance screening), the seminars on WB identification and control methods, and seed testing for the identification of blast pathogen took place in wheat producing regions in Bangladesh, especially hot spot region of the 2016 outbreak. Regarding host resistance screening, two locations in Bolivia, Quirusillas (highlands, wheat crop cycle from December to March) and Okinawa (lowlands, wheat cycle from May to September), were used for field screening with artificial and natural infections. Germplasm showing promising blast resistance in the aforementioned locations were confirmed in greenhouse tests at KSU, Manhattan and USDA-ARS, Fort Detrick, USA with artificial inoculation.

The core team members for this SRA were WRC-BARI and CIMMYT, with supports from local partners such as Department of Agriculture Extension (DAE), Bangladesh Agriculture Development Corporation (BADC), Jessore Regional Agricultural Research Station etc. and international partners including INIAF, Bolivia and USDA-ARS and KSU, USA etc.

6 Achievement against activities and outputs/milestones

6.1 International WB Consultation Workshop

An international consultation workshop entitled “Mitigating the Threat of Wheat Blast in Bangladesh and Beyond” was organized in Kathmandu, Nepal. It was well attended by researchers, extension workers, senior administrators, and policy makers from Bangladesh, India, Pakistan, Nepal, Bolivia, Brazil and Advanced Research Institutes (ARIs from USA, Germany). In-depth information was presented and discussed on various aspects of WB ranging from disease epidemiology to damage and control. Information on its hosts, sources of resistance, types and genetic basis of resistance, development of resistant cultivars, as well as studies on the pathogen’s population dynamics, enhancement of virulence and relationship of WB pathogen and its sister pathotypes, were also discussed.

An action plan for mitigating spread and damage caused by WB was recommended at the conclusion of the meeting. CIMMYT jointly with all concerned National Agriculture Research Systems (NARS) and ARIs have consequently embarked upon a strategy to combat WB through a large integrated multidisciplinary program involving the following broad objectives:

Objective 1: Awareness, surveillance and forecasting, and wheat blast epidemiology;

Objective 2: Development and establishment of phenotyping platform for wheat blast;

Objective 3: Genetics and breeding for wheat blast resistance;

Objective 4: Integrated wheat blast management and seed systems;

Objective 5: Human resources and capacity development to manage wheat blast.

Several projects funded by different donors (USAID through the Cereal Systems Initiative for South Asia (CSISA) and Climate Services for Resilient Development (CSRD) projects, CRP WHEAT, Bill and Melinda Gates Foundation though Durable Genetic Gains in Wheat (DGGW) project and NARS) are addressing different components of this large integrated and multidisciplinary effort. Resistant varieties have been identified by Bangladesh’s Ministry of Agriculture as a priority for combating WB, but so far, insufficient resources have been allocated for this effort. Hence, a large project designed by this SRA and funded by ACIAR support (CIM-2016-219) is mainly addressing WB management through genetics and breeding for resistant cultivars.

6.2 Seed Health Testing

About 620 wheat seed samples from 23 non-blast affected districts in Bangladesh were provided by BADC and DAE and analysed for association of seed-borne fungi at BAU, BRRI and BSMRAU laboratories prior to 2016-17 wheat growing season. The main purpose of this effort was to provide the farmers with good quality and *Pyricularia*-free wheat seed. None of the samples showed the association of

Pyricularia but the common seed-borne fungi like *Bipolaris sorokiniana*, *Alternaria alternata*, *Curvularia lunata*, *Fusarium* spp. were present. *Pyricularia* was also absent in the breeder seed of different varieties tested at WRC laboratory.

6.3 Awareness Workshop

Ahead of 2016-17 wheat growing season, seven regional workshops were organized by WRC-BARI in seven major wheat growing regions of Bangladesh with about 80 participants in each workshop from DAE, BADC, SCA, BARC, BARI, Universities, NGO and farmer representatives and other stakeholders to build up awareness about WB, its field diagnostics and to adopt timely and appropriate preventive measures to minimize the adverse effect of the disease on wheat production.

6.4 Development and Distribution of Fact-sheet on WB

A fact-sheet in Bangla describing the main features of WB and its management approaches was published by WRC-BARI in collaboration with CIMMYT, BARC, DAE, BADC, BRRI, BAU and other stakeholders and about 300,000 copies were distributed to the grass root-level service providers and farmers prior to 2016-17 wheat cycle so the farmers could follow the printed instructions to achieve success in WB management activities in the field.

6.5 Training on WB and its Surveillance

A 3-day long hands-on training on WB and its surveillance was organized by BARI-CIMMYT in early February 2017 at Wheat Research Centre, Dinajpur. Forty wheat pathologists, breeders and agronomists from Bangladesh, India and Nepal participated in this training. The training was imparted by the experts from CIMMYT, USA and Bangladesh. Following this training, the scientists actively participated in a ten-day surveillance and monitoring activities conducted in the major wheat growing areas of Bangladesh for field assessment of WB and collecting samples for pathogen isolation and PCR analysis in the laboratory.

6.6 Training on WB at USA and Bolivia

A two-week hands-on training on WB targeting disease screening was co-ordinated by CIMMYT in July 2017. Ten trainees from Bangladesh, India Nepal and Mexico participated in WB training at USDA-ARS, Fort Detrick, USA and INIAF, Santa Cruz, Bolivia.

6.7 Research Outcomes

6.7.1 Screening for resistance

A set of 100 elite wheat lines from CIMMYT, Bangladesh and India were screened in Bolivia under field condition and at USDA-ARS under greenhouse inoculation. A few of these lines had limited infection and some showed promising level of resistance with or without 2NS/2AS translocation as compared to 100% disease severity recorded in susceptible checks.

Wide variability in response to WB was observed in another set of 100 wheat lines screened at RARS, Jessore. Some of the lines were free from blast infection or had low disease severity, while the susceptible varieties showed 70-90% disease severity.

In a cohort of advanced wheat lines evaluated at RARS, Jessore, BAW 1260 was most promising showing good resistance to blast infection and a few lines showed very low levels (<10%) of disease severity, while 90-100% severity was observed in the susceptible varieties. The candidate variety BAW 1260 possesses 2NS segment and was found resistant under greenhouse inoculation at USDA. This line is also rich in zinc (55-60 ppm) and its yield level is 4.0-4.5 ton/ha. The Variety Evaluation Committee, of the National Seed Board of Bangladesh has evaluated the line in multi-location adaptive trial, and this line is likely to be released as a blast resistant variety.

6.7.2 Efficacy of foliar fungicides

Foliar spray with Nativo 75 WG (Tebuconazole 50% + Trifloxystrobin 25%), Amistar Top 325 SC (Azoxystrobin 20% + Difenoconazole 12.5%), Folicur 250 EC (Tebuconazole 25%) and Trooper 75 WP (Tricyclazole 75%) tested under field condition at RARS, Jessore was found effective in controlling WB infection with significant increase in yield and economic benefit. In laboratory bioassay conducted at WRC, Dinajpur, these fungicides were found effective in preventing the growth of the blast pathogen. These fungicides also control other foliar diseases of wheat.

6.7.3 Efficacy of seed treating fungicides

Seed treatment with Provax 200 WP (Carboxin 37.5% + Thiram 37.5%) and Vitaflo 200 FF (Carboxin 17.5% + Thiram 17.5%) provided complete control of seed infection by *Pyricularia oryzae* with significant improvement in germination. Rovral 50 WP (Iprodione 50%) was equally effective in controlling seed-borne *Pyricularia oryzae*. Seed treatment with these fungicides also kills other seed-borne fungi of wheat.

6.7.4 Sowing date and genotypes trial

Variability in disease severity was found among the genotypes and wheat planted in early to optimum times (Nov. 10, Nov. 20, Nov. 30), either escaped infection or had low disease severity (0-7%), while higher disease severity (11-60%) was recorded in later sowing dates (Dec. 10, Dec. 20, Dec. 30) depending on varieties.

The variety BARI Gom 30 showed the lowest disease severity followed by BARI Gom 28, while the highest disease severity was recorded in BARI Gom 26.

6.7.5 Seed to plant transmission

Seed to plant transmission studies with MoT was conducted in water-agar test tube, moist blotter and pot culture methods. In all these methods seed-borne MoT was found to cause seed rot and germination failure, infect coleoptiles and produce water soaked lesions on the growing seedlings confirming seed to plant transmission of the pathogen.

6.7.6 Investigation into alternative hosts

Pyricularia was isolated from typical blast lesions found on several grass species, such as wheat, rice, foxtail millet, goose grass (*Eleusine indica*), crab grass (*Digitaria* sp.), torpedo grass (*Panicum repens*) and basket grass (*Oplisma burmaniaii*), but MoT was confirmed in isolates from wheat only. Inoculation with MoT showed typical blast lesions on wheat and blast-like lesions on goose grass, but not on others. However, detail cross-inoculation studies need to be performed for conclusive information.

6.7.7 Surveillance of WB

Field surveys of WB were conducted in February-March, 2017 in major wheat growing areas of Bangladesh. Fields with visible symptoms of WB were found in 10 of the 24 sampled districts. Between 10 to 50% fields of the affected districts showed blast infection. Few additional districts not infected in 2016 exhibited WB symptoms in 2017 indicating potential spread of the disease in new areas. However, severity of infection was very low in 2017 due to minimum rainfall in February. Isolation of WB pathogen was made from more than 80 infected spike samples so far and MoT was confirmed in about 30 isolates from diverse locations through PCR analysis of DNA with MoT-specific marker.

6.7.8 Regional meeting on wheat blast (Dhaka, 13th of July 2017)

The meeting was organised jointly by BARI-CIMMYT and ACIAR. Part of expenditure was borne from this SRA funding.

7 Key results and discussion

WB is a destructive disease that can cause yield losses up to 100% according to the data from South America. It would be good if the disease can be eradicated from Bangladesh. Seed health testing showed some encouraging results, i.e. no *Pyricularia* contamination was found in non-epidemic region nor in breeders' seeds. But subsequent field surveys indicated the further spread of the disease to new areas, implying the wind borne nature of WB pathogen spores, **making eradication an unlikely option**. From the epidemiology point of view, WB outbreak is associated with spore concentration in field, thus any strategy that can efficiently reduce field spore concentration will be recommended. Seed treatment with fungicide is strongly recommended since it prevent the initial infection from seed contamination, and as can be seen from the results, Provax 200 WP and Vitaflo 200 FF were able to eliminate other seed borne pathogens in addition to *Pyricularia*, warranting seed health and avoiding the seed transmitted diseases. Weed control is another important management issue to reduce inoculum, since many grass species are suspected to serve as alternative host of *Pyricularia*. In this study, it was shown MoT was able to infect goose grass but not the other tested grass species. Repeated experiments are required to confirm this conclusion and more grass species need to be included to delineate the epidemiological cycle, and in this regard the survival of MoT on crop stubbles must not be neglected. Optimum planting (Nov. 15-30) is strongly recommended since it will help to escape from severe WB infection, and it contributes to escape from heat and spot blotch infection too. However most rice wheat farmers are constrained by the duration of the T. aman (wet season) rice crop, and the excessive residual moisture in the rice field at harvest, which makes it difficult to plant wheat by the end of November. Possible changes to farming systems, which would make it possible to adopt early wheat planting, include using short duration rice varieties; early establishment of the rice crop with direct seeding or unpuddled transplanting; establishment of the wheat crop using no-till or minimum tillage in standing rice straw. These changes may be beneficial for other reasons, but are not easy for farmers to adopt and further pilot and research activities may identify ways forward.

It was very encouraging to find varieties having promising resistance to WB under Bangladesh environments, represented by BAW 1260. As pointed out before, this line as well as many others carry the 2NS translocation, which is the most important known resistance source. Heavy reliance on this sole resistance source would lead to resistance breakdown, as is already being seen in South America, where some newly evolved isolates showed increased virulence to the 2NS carriers. Under this circumstance, the utilization of non-2NS sources of resistance is necessary. Crossing resistant lines with and without the 2NS translocation will lead to the accumulation of different resistance genes and result in improved WB resistance. Fungicide application is as important as host resistance, especially when high level of host resistance and durability has not been found. All the tested ingredients showed positive effects on controlling WB (under moderate to low disease pressure) and protecting yield, as well as controlling other foliar diseases. But it should be alerted that the utilization of a single ingredient for a long time will lead to fungicide resistance, as demonstrated in South America (Castroagudín et al. 2015). Timely shift of fungicide ingredients can avoid or at least slow down the emergence of fungicide resistant strains.

8 Impacts

8.1 Scientific impacts now and in 5 years

The findings in this SRA laid solid foundation for future research on WB in Bangladesh. The SRA contributed to one scientific publication: Chowdhury et al. (2017).

The slow progress in managing WB evidenced in the last three decades in South America is partly due to the sporadic nature of blast epidemics and the associated challenges for germplasm screening, which requires reliable, controlled disease pressure, whereas in practice the work has been largely relying on natural infection. Continuous fund support in this regard is critical. This pioneer SRA and its following four-year project will greatly contribute to the establishment of WB precision phenotyping platform providing high throughput screening capacity and generating phenotypic data with improved precision. This project contributed to improved and more rapid breeding efforts in South Asia, as well as opening new possibilities for South Asian scientific collaboration with international institutions. Major scientific impacts of this SRA include: confirmation of the 2NS translocation as a source of resistance in diverse sources of germplasm; an interesting research question about the relationship between high Zinc and tolerance to WB in elite breeding line BAW 1260; absence of the pathogen MoT in all alternative host species tested except goose grass. Further experiments will confirm the stability of the identified resistant or tolerant lines, as well as the performance of fungicides in large-scale fields. Controlling planting date is also a strategy that could be adopted by farmers, but would require significant changes to their farming system. With these strategies, WB can be contained to some level and severe yield reduction caused by WB may be avoided even under conducive environments.

These scientific impacts are paving the way for large project CIM-2016-219, in which sources of WB resistance identified and characterised, resistance to leaf and spike components of WB deciphered, and molecular markers for WB developed will count as significant scientific accomplishments in 5 years, in addition to facilitating WB resistance breeding. Breeders will be more confident in making crosses and selection based on the resistance genetics and the utilization of molecular markers which will result from CIM-2016-219.

8.2 Capacity impacts now and in 5 years

Hundreds of breeders, researchers, extension agents and farmers in Bangladesh have been trained on blast control through the seminars, workshops and training courses supported by this SRA, and they will convey the information to more people so that WB will not be an unfamiliar disease to them. Still more, gaining understanding on WB control strategies will help in enhancing their capacity to cope with other diseases. Equipment and facilities set up in this project (e.g., pathology laboratories, screening platforms) will be available for use for future wheat breeding, disease screening, research and training. With varietal and seed production demonstrations, extension workers and farmers can access project benefits.

8.3 Community impacts now and in 5 years

8.3.1 Economic impacts

Wheat is the second most important staple food in Bangladesh, which imports over 3/4 of the wheat grain the country consumes (5.6 million ton) at a current cost of nearly $ 850 million. The 2016 WB outbreaks severely influenced the wheat production in the country, with wheat cultivation dropping from 62,763 hectares in 2016 to just 14,238 hectares in 2017 in the areas affected by 2016 epidemic. A lack of effective control strategies against WB will discourage farmers' confidence on growing wheat. The current SRA proposed several control methods to reduce the influence of WB on wheat production, and the succeeded four-year project will further contribute to control WB in Bangladesh, leading to stable wheat production and reduced farmers' risks and improved food security. This in turn may also contribute to an increase of wheat production, as prioritized by the Government of Bangladesh.

The main economic impact of the project is the reduction of risk for wheat growers, and the maintenance of their confidence. In the absence of resistant varieties, wheat production costs would increase because of the need for fungicides. Wheat production would decrease because farmers would avoid the risk of growing wheat. This would threaten current attempts to diversify rotations, in the rice-rice systems. Although maize, oilseeds and pulses represent other options for the replacement of dry season rice, the Government of Bangladesh does not support reducing wheat production. Considering that the current wheat crop is worth about 280 M USD, it can be assumed that the cost of inaction could be in millions of USD. Indirectly, the investment of this project on capacity building will confer farmers and researchers in Bangladesh with an enhanced ability on learning new technologies and applying them in practice, which will in turn increase wheat production in the country.

8.3.2 Social impacts

Host resistance and fungicide control are two important components on WB management; but they have contrasting social impacts. While host resistance is being conveyed by seeds and no additional investment are needed, fungicide control requires farmers' investment in costly inputs. Resource-poor small-scale farmers may not be able to afford the inputs. In this regard, the development of blast resistant wheat cultivars will alleviate the reliance on fungicide and thus will reduce income gaps among farmers. Ultimately, wheat productivity will increase and farmers will benefit economically.

Through the training component of this project and the subsequent project, more women breeders/researchers, students, and farmers will be trained, enabling more women participating in crop improvement, elite variety promotion and production. This will specifically benefit woman-headed families and farms.

8.3.3 Environmental impacts

Chemical fungicides may pose hazardous effects on environment, human and animal health. For the time being, fungicides are indispensable in Bangladesh to control WB since cultivar resistance is very limited; but as mentioned before chemical fungicides have many drawbacks, including low effectiveness and vulnerability to fungicide resistance. Consequently, farmers usually apply much higher dose than recommended, as seen in South America, leading to environment pollution. Host plant resistance is the best option to free farmers from reliance on fungicides, increase the profitability of wheat farming, and safeguard the environment.

8.4 Communication and dissemination activities

WB is a new disease in Bangladesh thus most people in the country are not familiar with the symptoms. WB causes partially or completely bleached spikes that can be easily confused with Fusarium head blight while foliar symptoms can be confused to those of spot blotch. This requires proper identification and learning by researchers, extension workers and farmers to correctly identify WB. Considering this, it is very important for this SRA to disseminate information on WB through seminars, training courses, factsheets, so that the breeders, extension workers and farmers are aware of this disease and can report its occurrence timely and the corresponding remedial actions be taken. In the coming years, more extensive awareness campaign is needed so more farmers and the general public can realize the threat of this disease. To achieve these objectives, WB can be integrated in university curricula and taught in farmers' field schools. Radio, video, and other large-reach media communications regarding WB must be developed and used. Efforts on scientific communication and communication of research to extension and policy makers will be focused. Project achievements in research and deployment will be documented in stories (blogs) and published reports by communications specialists of Bangladesh, CIMMYT and the CRP WHEAT, with focus on benefits to farmers and other partners, and spread in conventional and social media.

9 Conclusions and recommendations

In response to the sudden WB outbreak in Bangladesh, the current SRA was set up. After one year's implementation of the project, public in Bangladesh are aware of this disease, researchers, breeders, extension agents and farmers in the country are familiar with the symptoms and management strategies of WB. Some promising wheat germplasm adapted to Bangladeshi environments as well as the promising fungicide ingredients have been identified however, confirmatory studies are in progress. Promoting early planting may contribute significantly in escaping the disease, which conforms well the avoidance of heat and spot blotch infection. Research on epidemiology of WB in Bangladesh is also progressing. So people are prepared for the future outbreak in the country and the region; but this is not yet enough and there is long way to go to have the disease under satisfactory control in severe epidemic years. From the lessons learnt in South America, it is clear that MoT has always rapidly evolving, with strong potentiality of overcoming host resistance as well as developing fungicide resistance. Thus, complacence is dangerous, researchers and breeders in the region have to keep hard working on development of new durably resistant varieties and effective fungicides. Considering the fact that majority of Bangladeshi farmers are of small-scale and the utilization of fungicides could be a severe financial burden for them, breeding of resistant and tolerant wheat cultivars should be given more emphasis. In this regard, international collaboration is critical. CIMMYT and other ARIs could provide newly developed breeding materials adapted to South Asian environments for the utilization by local breeders, and the information on resistance genes/QTL to WB and markers that could be used in breeding will accelerate the breeding progress.

It is widely acknowledged that knowledge gaps are present in every aspect of WB management. The succeeded four-year project CIM-2016-219 provides an opportunity to fill the gaps, further deepen the understanding on WB and develop new resistant varieties, continuing the road paved by the current SRA. The key of success relies on the strong partnership between BARI and CIMMYT and the inclusiveness of other stakeholders in Bangladesh (Universities, NGO's, private sector….) who can contribute to the ultimate goal to contain the disease and reduce its impact in Bangladesh and for the region. Participation of the seed sector, Dept. of Agricultural Extension and private sector needs to be encouraged.

10 References

Castroagudín VL, Ceresini PC, De Oliveira SC, Reges JTA, Maciel JLN, Bonato ALV, Dorigan AF, McDonald BA (2015) Resistance to QoI fungicides is widespread in Brazilian populations of the wheat blast pathogen *Magnaporthe oryzae*. Phytopathology 105:284-294

Chowdhury AK, Saharan MS, Aggrawal R, Malaker PK, Barma NCD, Tiwari TP, Duveiller E, Singh PK, Srivastava AK, Sonder K, Singh RP, Braun H, Joshi AK (2017) Occurrence of wheat blast in Bangladesh and its implications for South Asian wheat production. Indian Journal of Genetics 77: 1-9.

Cruz CD, Valent B (2017) Wheat blast disease: danger on the move. Tropical Plant Pathology 1-13

Islam T, Croll D, Gladieux P, Soanes D, Persoons A, Bhattacharjee P, Hossain S, Gupta D, Rahman MM, Mahboob MG, Cook N, Salam M, Bueno Sancho V, Nunes Maciel J, Nani A, Castroagudin V, Teodora de Assis Reges J, Ceresini P, Ravel S, Kellner R, Fournier E, Tharreau D, Lebrun m-h, McDonald B, Stitt T, Swan D, Talbot N, Saunders D, Win J, Kamoun S (2016) Emergence of wheat blast in Bangladesh was caused by a South American lineage of Magnaporthe oryzae. BMC Biology 14

Kohli MM, Mehta YR, Guzman E, De Viedma L, Cubilla LE (2011) *Pyricularia blast* - a threat to wheat cultivation. Czech J Genet Plant Breed 47:S130-S134

Maciel JLN, Ceresini PC, Castroagudin VL, Zala M, Kema GHJ, McDonald BA (2014) Population structure and pathotype diversity of the wheat blast pathogen *Magnaporthe oryzae* 25 years after its emergence in Brazil. Phytopathology 104:95-107

Malaker PK, Barma NC, Tiwari TP, Collis WJ, Duveiller E, Singh PK, Joshi AK, Singh RP, Braun H-J, Peterson GL, Pedley KF, Farman ML, Valent B (2016) First report of wheat blast caused by *Magnaporthe oryzae* pathotype *Triticum* in Bangladesh. Plant Dis 100:2330