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Strategy for Rice Disease Management in Bangladesh

M T Khatun[1*], B Nessa[1*], M U Salam[2] and M S Kabir[3]

ABSTRACT

Disease is one of the most limiting biotic factors that affects rice production worldwide. In Bangladesh, there are 10 rice diseases considered as major, which cause economic loss in farmers' fields. Therefore, the aim of this article is to explore all the feasible avenues of technology deployment on rice disease management to restrict the disease infection at minimum level and thus minimize economic loss. The article is generated using data and/or infromation from published and unpublished works and incorporating authors' experience. It is evident that periodically (odd year) a disease outbreak or epidemic occurred in Bangladesh such as blast. Under epidemic situation, research findings estimated a yield loss of up to 98% at the highest disease severity level of infection of blast. On the other hand, field survey indicated the highest of 65.4% yield loss from severly infected field with the disease. To overcome the epidemics in odd years and to keep the loss under economic threshold level, it is necessary to undertake preventive measures such as planting of resistant or tolerant varieties, use of disease-free seeds from healthy plants, use of balanced fertilizer where applicable, and following feasible crop rotations. Currently, it is urgent need for developing strong and precise weather-based disease-risk forecasting system at least one week's lead time based on real-time weather data. Subsequent quick management options such as disease-specific fungicidal treatment should be communicated to all stakeholders using fast-delivery media such as TV channels and SMS could be efficient and effective ways to address the disease outbreak under epidemic situation. To address annualized yield loss, it is suggested to execute interventions like effective training to the root level (both for farmers and extension personnel) and conducting demonstration in farmers fields, regular field monitoring, digitalization in disease management sector, revive indigenous technologies as appropriate, and improving rice production system. To continously improve rice disease management sector, this paper has proposed an innovative action for three decades through to 2050 under the banner 'Location, Variety and Disease Specific Smart Management' on research, development and extension.

Key words: Rice disease, effective training, monitoring, digitalization, epidemiology

INTRODUCTION

Global rice production is expected to face more challenges in the coming years, and Bangladesh is predicted to be exposed to more of those tricky situations. Those challenges include different bio-aggressors especially diseases of rice crop. Rice is anticipated to continue to be the major human staple food crop well into the 21st century (Zeigler *et al*., 1994). Therefore, we must think of the rice security for the generations of the next decades. And, to meet the demand, we must rethink about the efforts to reduce the risk of the losses caused by different diseases for sustainable rice production. It has been stated that the development and release of high input loving, high yielding cultivars are altering the micro-ecobalance, resulting in severe disease problems (Shahjahan, 1993). Quantified annual yield losses based on surveys due to a combination of rice diseases ranged from 1 to 10% in Asia (Rice diseases workshop, 2014). Unfortunately, there is no precise and updated yield loss data accounting for rice diseases for the whole nation. Our projected clean rice production for 2050 has been set as 40.40 million tons (Kabir *et al*., 2015). To achieve this estimated production and minimize the losses caused by diseases, it would be necessary to fully utilize existing resources, as indicated in Kabir *et al*. (2020). The farmers of Bangladesh

[1]Senior Scientific Officer, Plant Pathology Division, Bangladesh Rice Research Institute (BRRI), Gazipur-1701, Bangladesh; [2]Freelance International Consultant (Agricultural Systems), Bangladesh; [3]Director General, BRRI, Gazipur-1701, Bangladesh.
*Corresponding author's E-mail: tuhinabrri17@gmail.com (M T Khatun); runu.brri@yahoo.com (B Nessa)

are the catalyst to make the country self-sufficient in food production. Therefore, it is pertinent to transmit all of our knowledge, information, and technologies to the farmers to get maximum return from rice production.

With the above background, this article undertook three specific objectives in relation to rice diseases in Bangladesh: (i) presentation of their changing status, (ii) highlighting the scenarios of yield loss associated with the diseases, and (iii) development and mapping the action plan for three decades on reducing yield loss from the diseases.

METHODOLOGY

The study contains the information mostly conceptualized by the authors. Most data and some ideas were derived from secondary sources, which have been appropriately cited. A number of works (Shahjahan, 1993; Thurston, 1994; Shen and Lin, 1994; Teng, 1994; Islam and Catling, 2012; Arya, 2018) were used for reviewing purposes. The published and unpublished data on yield loss for four diseases - sheath rot, sheath blight, false smut, and blast - presented in graphs in this paper were collected either from farmers' fields or research fields are mostly from authors own research findings data. A simple diagram has been proposed on networking between farmers' field problems and researchers. The idea for this was burrowed from Rhoades and Booth (1982). The baseline data for yield loss were estimated by group discussion. The set of disease data were derived from farmers' demonstration those were conducted by plant pathologists of the Plant Pathology Division in Bangladesh Rice Research Institute (BRRI). Those data were sourced from presented and/or published in BRRI annual review research workshops.

RESULTS AND DISCUSSION

Status of rice diseases in Bangladesh

The disease that causes economic loss in rice yield is defined here as a 'major' disease, while the one does not cause significant economic loss as 'minor'; the definition is more as subjective than quantitative. The identified rice diseases in Bangladesh have increased from 24 (1987 report) to 32 (2016 and 2018 reports) (Table 1; Appendix 1). Out of 32 diseases, 22 are caused by the fungus, six by nematodes, three by bacteria, and one each by virus and mycoplazma (Appendix 1). Currently, 11 diseases are recognized as major; this number was 10 in 1987 (Table 1) and 1993 (Shahjahan, 1993). Eight diseases (alphabetically, bacterial leaf blight, bakanae, blast, brown spot, sheath blight, sheath rot, ufra and tungro) have remained as major during 1987-2016 period. Two diseases (alphabetically, leaf scald and stem rot) that were classed as major in 1987 have currently been downgraded to a minor. On the other hand, three diseases (alphabetically, bacterial leaf streak, false smut, and seedling blight) are presently graded as major that were considered as minor in 1987. A recent study on the potential impact of climate change on crop diseases in Bangladesh showed the continued risk of major rice diseases but a likely monthly- shift in their incidence under given future climate scenarios (Salam *et al*., 2019).

Yield loss scenarios due to rice diseases in Bangladesh

Shahjahan (1993) states, "There is little quantitative data available on crop losses due to diseases on a regional or country scale in Bangladesh. Available reports are based on estimates because of the apparent lack of proper crop loss assessment methods and monitoring of pest and disease incidence in the country". The same author further mentions that the loss assessment due to diseases is difficult because of the following reasons:

i) The yield or production in absence of the diseases is not known;

ii) Loss occurs only in a limited area, which must then be projected to estimate the loss over the whole crop;

iii) Loss may occur in one year or one season and needs to be averaged over several years; and,

iv) Loss may be on selected high infection, after artificial inoculation of selected crop timing.

Table 1. Rice diseases in Bangladesh during 1987 and 2016: the changes in number and status. The list (by common name) is in alphabetic order within bold-bordered boxes.

Rice disease		Status in	
Common name	Pathogen type	1987	2016
Bacterial leaf blight	Bacteria	Major	Major
Bakanae	Fungus	Major	Major
Blast	Fungus	Major	Major
Brown spot	Fungus	Major	Major
Sheath blight	Fungus	Major	Major
Sheath rot	Fungus	Major	Major
Ufra	Nematode	Major	Major
Tungro	Virus	Major	Major
Bacterial leaf streak	Bacteria	Minor	Major
False smut	Fungus	Minor	Major
Seedling blight	Fungus	Minor	Major
Leaf scald	Fungus	Major	Minor
Stem rot	Fungus	Major	Minor
Aggregated sheath spot	Fungus	Not reported	Minor
Bacterial foot rot	Bacteria	Minor	Minor
Crown sheath rot	Fungus	Not reported	Minor
Damping off	Fungus	Minor	Minor
Grain red blotch	Fungus	Not reported	Minor
Grain spot	Fungus	Minor	Minor
Kalo bij (Kernel spot)	Fungus	Minor	Minor
Kernel smut	Fungus	Not reported	Minor
Leaf smut	Fungus	Minor	Minor
Minute leaf spot	Fungus	Not reported	Minor
Narrow brown leaf spot	Fungus	Minor	Minor
Root knot	Nematode	Minor	Minor
Root lesion	Nematode	Not reported	Minor
Root rot	Nematode	Not reported	Minor
Sheath blotch	Fungus	Minor	Minor
Sheath spot	Fungus	Not reported	Minor
Stack burn	Fungus	Minor	Minor
White tip	Nematode	Minor	Minor
Yellow dwarf	Mycoplasma	Minor	Minor

Status class: Major (Gold dotted box); Minor (Green box); Not reported (White box)
Source: Miah and Shahjahan, 1987; BRRI, 2016; BRRI, 2018

Table 2 presents the national average yield loss scenarios due to rice diseases gathered from different sources. It is highly regarded by the expert, that national yield loss in rice ranges from 10 to 15%, which includes diseases and insects (Miah and Shahjahan, 1987). It was Khan (1991) stated that the average yield loss due to rice diseases is 9.9% in Bangladesh. However, average losses due to diseases over the decade 1989-90 to 1998-99 was estimated as 3% in Boro, 5.9% in Aus, and 6% in Aman with an average for three seasons is 4.9%, contributed to an annual loss of 1.52 million ton per year (Islam and Catling, 2012). The authors also mentioned that those figures still to be regarded as an over estimation since farmer's perceptions were from which the data were derived strongly influenced by their worst memories of yield. A recent quick phone survey from 15 northern districts of Bangladesh with high officials of the Department of Agricultural Extension (DAE) revealed a different scenario, which accounted for less than 1% of yield loss in farmer's fields. However, this is a general annualized figure. The yield loss could go up in individual years when disease epidemics would be high. Kabir *et al.* (2020) has found similar results.

Table 2. National yield loss scenarios from rice diseases in Bangladesh.

Loss (%)	Mode of estimation	Year of reporting	Reference	Comments
10-15	Highly regarded expert opinion	1987	Miah and Shahjahan, 1987	Including insects
9.9	Survey estimation	1991	Khan, 1991	-
4.9	Survey estimation	1999	Islam and Catling, 2012	-
<1.0	Phone survey	2019	Authors	-

Yield loss under varying epidemics

Blast, bacterial leaf blight, sheath blight, and more recently false smut are the heavy epidemic rice diseases in Bangladesh. Yield loss in severe infection conditions has been estimated as 65.4% and 56.9% for blast disease in the irrigated and rainfed ecosystem (Hossain *et al.*, 2017) respectively in the farmers' field (Table 3).

Table 3. Yield loss estimation from blast in the farmers' fields under various epidemics in Bangladesh.

Year of reporting	Loss (%)	Reference	Data environment
2017	65.4	Hossain *et al.*, 2017	Variety specific (Jhalak hybrid variety), highest yield reduction in irrigated ecosystem
2017	56.9	Hossain *et al.*, 2017	Variety specific (BRRI dhan34), highest yield reduction in rainfed ecosystem
2017	34.7	Hossain *et al.*, 2017	Location-specific, Among 30 agroecological zones (AEZs), highest yield loss in AEZ 9

The yield loss from sheath rot disease was estimated as 75% under the highest disease severity (DS) scale of 9 (equivalent to >80% of the panicles still enclosed by leaf sheath) (Ms Tuhina-Khatun, unpublished data, Plant Pathology Division, BRRI) (Fig. 1). While in the low disease severity scale (DS 1, equivalent to ≤ 20% of the panicles still enclosed by leaf sheath), the yield loss was recorded as 20%. In a broad scenario, Shahjahan *et al*. (1994) recorded a yield loss of 31% when the crop was attacked at a critical stage due to sheath rot disease. For false smut disease, yield loss up to 87% was estimated when 67 smut balls were present in a panicle considered to be a severe outbreak situation (Fig. 2) (Nessa *et al.*, 2015). For another important major disease, sheath blight caused 35% yield loss when the disease lesion reached about 80% of the plant height (B Nessa, unpublished data, Plant Pathology Division, BRRI) (Fig. 3).

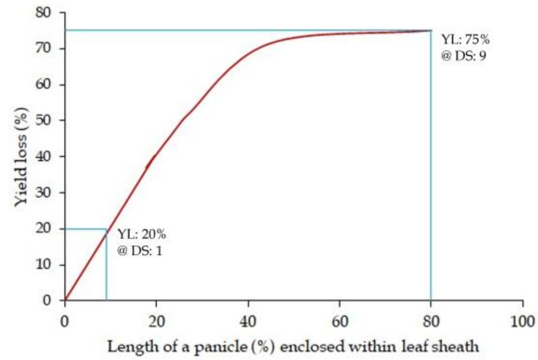

Fig. 1. Estimated yield loss from sheath rot in a severely naturally infected rice field (~ 100% incidence). DS: disease severity scale, YL: yield loss. DS 1: 0-20% of panicles still enclosed by leaf sheath; DS 3: 21-40% of panicles still enclosed by leaf sheath; DS 5: 41-60% of panicles still enclosed by leaf sheath; DS 7: 61-80% of panicles still enclosed by leaf sheath; DS 9: >80% of panicles still enclosed by leaf sheath. DS 1 represents a low disease severity scale, while DS 9 the highest disease severity scale. Unpublished data (M Tuhina-Khatun, Plant Pathology Division, BRRI).

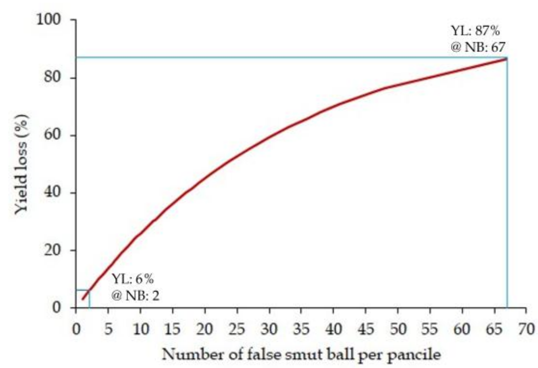

Fig. 2. Estimated yield loss from false smut infected rice fields. NB denotes the number of false smut infected balls per panicle, and YL for yield loss. Data from Nessa *et al*. (2015)

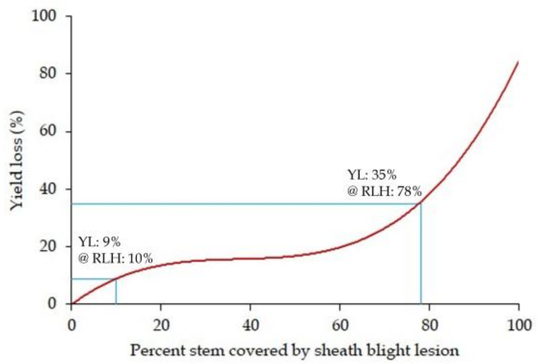

Fig. 3. Estimated yield loss from sheath blight infected rice fields. RLH denoted for relative lesion height of sheath blight disease as 0 to 100 percent. RLH 10 and RLH 78 indicate the disease symptom reached up to 10 and 78% of total plant height, respectively. YL is yield loss. Unpublished data (B Nessa, Plant Pathology Division, BRRI).

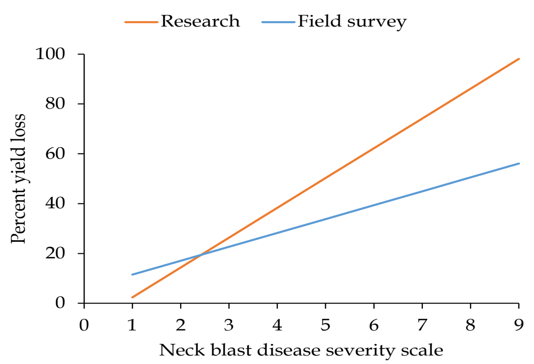

Fig. 4. Yield loss in rice due to blast disease under the whole range of disease severity scale based on research data and field survey data. The number on the x-axis, 1, indicates the lowest disease severity scale and 9 the highest disease severity scale. Odd year means the year when severe disease outbreak occurs. The research data represent the odd years when the yield loss in infected fields reached above 40%.

Yield loss under epidemic condition in odd year

It has been observed by rice scientists that a disease outbreak or epidemic generally occurred at several years intervals when favourable weather conditions prevail for a specific pathogen, and appropriate crop stages are available in the field for that organism. Currently, blast is such an epidemic disease that causes significant yield loss in farmers' fields. From research findings in farmer field under the devastating situation, blast caused the highest amount of yield loss up to 98% at disease severity scale of 9, when all the rice panicles in the field were severely affected by blast fungus (B Nessa, Plant Pathology Division, BRRI) (Fig. 4). From field survey, Hossain *et al.* (2017) recorded a yield loss of up to 56.1% due to this disease in farmers' fields from 10 agroecological zones of Bangladesh (Fig. 4).

Disease management under severe epidemics occur in odd year

The following are the potential ways to manage rice disease successfully under severe epidemics in the odd year.

A. Varietal interventions

The use of resistant or tolerant variety is the most economical and environmentally friendly method for the management of rice diseases especially for devastating diseases such as blast (Khan *et al.*, 2001; Haq *et al.*, 2002). However, the resistance is subject to break down due to the appearance of new or more virulent races of the pathogen (Ghazanfar *et al.*, 2009). Therefore, it is necessary to continually speed up the breeding program to develop resistant rice varieties for blast and other serious diseases. Plant Pathology Division of BRRI has developed some promising lines in the background of BRRI dhan28 and BRRI dhan29 to combat blast epidemics, which are in pipeline to release as varieties, which could be used in the future for cultivation in blast endemic areas.

B. Preventive measures

To control rice diseases in the farmers' field, it is economically feasible and sound to apply preventive measures rather than a curative ones. Following are some techniques which could be applied extensively to minimize disease outbreak in farmers field:

i. Use of disease free healthy seed
ii. Balanced application of phosphorus and potassium fertilizer
iii. Avoidance of excessive use of nitrogenous fertilizer
iv. Application of potash fertilizer in two splits. One split at the time of land preparation and the other at the time of last top-dress with urea fertilizer
v. Avoidance of seedbed preparation if the seedbed are disease infected in the previous year
vi. Destruction of stubbles and debris
vii. Destruction of alternate host
viii. Practice of wider spacing between two hills to avoid favourable condition for pathogen growth and development
ix. Avoid cultivation of susceptible variety
x. Following of crop rotation
xi. Seed treatment with chemicals

C. Strong forecasting system

Since disease epidemics or disease outbreaks mostly depend on weather parameters, therefore, it is urgent to develop a strong and precise weather-based disease risk forecasting system with at least one-week lead-time based on real-time weather data. The quick management option such as fungicidal treatment should also be broadcast along with weather forecasting. Digital platforms such as broadcast through TV channels, SMS to rice farmers, pronouncement through all mobile operators during phone call, and digital display of management packages at block level could be efficient and effective ways to address the disease outbreak under epidemics situation. For example: if the weather is conducive for blast disease at the booting stage, alert to be delivered to farmers through all channels recommending application of Tricyclazole/Strobin group of fungicides to rice fields in the afternoon on the susceptible varieties such as BRRI dhan28 and BRRI dhan29.

D. Effective training and advice to farmers and baseline extension agents for proper identification of rice diseases

"The farmers of rural Bangladesh, whether large or small, still depend largely on homegrown, indigenous methods-handed down from father to son to fight their unknown enemies that deplete their harvests each season" (Shahjahan, 1993). Since rice has been cultivated in Bangladesh for more than centuries and hopefully it will continue to cultivate for centuries-long then there is no alternative to provide every true farmer and Sub-Assistant Agricultural Officers (SAAOs) learning, training, knowledge, and every source of information to properly identify every type of rice disease and also manage and/or control those effectively. Initially, it will be costly and time-intense, however, in the long run, it will return enormous benefit to the country. In this context, BRRI regional stations can take a master plan to train all rice growers in their commanding areas on a long-term basis. Recently developed 'BRRI Rice Doctor' will be helpful for educated farmers to identify and manage rice diseases successfully.

E. Regularly monitoring of rice field

Monitoring and early detection would be very helpful for prevention of the rice diseases (Kim *et al.*, 2017). Monitoring of rice disease progress aims to forecast and decide the time for control action as well as assess the effect of management. Therefore, it is strongly recommended and advised to the farmers and SAAOs to regularly monitor their own fields and surveillance area. For example, early detection of rice leaf blast can be managed by irrigation in the field. Likely, the appearance of Kresek (bacterial foot rot) and bacterial leaf blight (BLB) can effectively control through drainage/removing of water for few days or following alternate wetting and drying technology. Brown spot disease, therefore, could successfully be managed by balanced urea fertilization. These are the simple management practices farmers can easily adapt to their rice field by early detection of the symptoms through regular supervision and control the diseases effectively. It is now realized in both developed and developing countries that there should be a permanent program at all national levels to monitor changes in diseases outbreaks by plant pathologists, resulting from a breakdown of the inherent resistance of certain varieties, the development of pesticide resistance in the pathogens, or a shift in disease incidence due to changes in cultural practices (Shahjahan, 1993).

F. Epidemiological study

Epidemiology is defined as the study of factors that affect the spread of disease in time and space (Madden *et al*., 2007). These factors include temperature, moisture, humidity, and precipitation, etc. that influence the pathogen either positively or negatively depending on the requirement of a pathogen (Arya, 2018) to develop a particular disease. Epidemiological studies are important for the management of rice diseases as the obtained data can be processed and transformed into technologies for the management of pathogens (Arya, 2018). Such studies can be used as strategies for managing plant disease epidemics, and we can organize our plant disease control tactics under: (a) reduction of the initial inoculum/pathogen, (b) reduction of the infection rate, and (c) reduction of the duration of the epidemic, following one or more of the strategies are stated below (adopted from Arya, 2018):

i. Avoidance: Reduce the level of disease by selecting a season or a site where the amount of pathogen/inoculum is low or where the environment is unfavorable for infection, eg., right time of planting of BRRI dhan49 escapes false smut.

ii. Exclusion: Reduce the amount of initial inoculum introduced from outside sources. The infection of BLB and bacterial leaf streak (BLS) is more concentrated in hybrid. Therefore, restriction/regulation in hybrid import will reduce BLB and BLS incidence in the rice field. BRRI has already developed six hybrids that are less susceptible to BLB and BLS infection. Farmers should be encouraged to cultivate BRRI released hybrids rather than foreign hybrids, later one is more susceptible to diseases in our environment.

iii. Eradication: Reduce the production of initial inoculum by destroying or inactivating the sources of an initial pathogen such as rouging, burning of straw, destruction of alternate host, etc. These are applicable for sheath blight, sheath rot, and stem rot diseases of rice.

iv. Protection: Reduce the level of initial infection by means of a toxicant or other barrier to infection such as spraying fungicides.

v. Resistance: Use cultivars/varieties that are resistant to infection, particularly the initial infection.

The epidemiological knowledge has to reach the resource-poor farmers through farmers' groups such as farmers' field school (FFS). The FFS uses discovery-based learning methods to improve the farmers' agro-ecological knowledge, and their capacity to make decisions (Van De Fliert *et al.,* 2002). The group of farmers gathers in a weekly meeting and shares their knowledge regarding the production constraints during the rice-growing season and by team discussions, they can make decisions for practical actions in the field.

G. Location-specific, variety specific and disease-specific smart disease management packages

There are some areas that tend to more vulnerable to a specific disease. For example, Habiganj district is prone to tungro disease, the Barishal region is favourable for ufra disease, and the incidence of the brown spot is higher in Satkhira district. To manage the specific disease in this specific location, we should suggest location-specific technology. For instance, to avoid tungro in Habiganj during Aus season, we can suggest farmers cultivate a variety like BR8 because it has the highest potential to recover from tungro disease after being affected by tungro virus (Khatun *et al.,* 2017). Similarly, BRRI dhan37 has the highest potential to give better yield against tungro during T. Aman season (Khatun *et al.,* 2017). Likely, if we advocate farmers to cultivate BRRI dhan49, then we should suggest farmers to planting BRRI dhan49 with the 'recommended-sowing-window' that means within 15 June to 14 July; if the variety is sown on or before 1 July, it would most likely escape the major risk of the false smut disease and the infection rate will be less than 1% (Nessa, 2017). If the farmers are planting BRRI dhan28 and BRRI dhan29, and the favourable weather (drizzling, prolong dew in the morning, night time cool but day time hot and cloudy weather) for blast disease development prevail during booting stage, then to strongly suggest applying fungicides from the groups Tricyclazole or Strobin to save their crop from significant or severe loss.

H. Instant delivery of disease risks together with remedies

We are making progress on circulating disease management packages to the farmers through diverse ways, namely leaflet, booklet, website, mobile apps like BRRI mobile apps (RKB), krishoker Janala, etc. Through these techniques, we have already reached a section of farmers but not all. The truth is most of our farmers are not compatible with website browsers or mobile apps. We must be more digitalized to deliver our latest management technology to all rice farmers by rapid but easier techniques. Such as by sending SMS through all mobile operators to all customers and/or farmers in Bangla, so that the less educated farmers can follow it. For example, when the rice crop is in the field, and a heavy rain-storm is predicted, we can send an SMS to all farmers with the message – "Don't apply urea fertilizer in your rice field, it will increase BLB incidence".

Table 6. Sustainability, external inputs needed, and labor requirements of selected plant disease management practices of traditional farmers (most, but not all, of these practices are sustainable in the long term).

Practice	Sustainable?	External inputs	Labor
Adjusting crop density	Yes	Low	Low
Adjusting planting depth	Yes	Low	Low
Adjusting planting time	Yes	Low	Low
Altering of plant and crop architecture	Yes	Low	High
Biological control (soilborne pathogen)	Yes	High	High
Burning	Yes[a]	Low	High
Fallowing	Yes	Low	Low
Flooding	Yes	Low	High
Manipulating	Yes	Low	Low
Mulching	Yes	High	High
Multistory cropping	Yes	Low	Low
Multiple cropping	Yes	Low	High
Planting diverse crops	Yes	Low	Low
Planting in raised beds	Yes	High	High
Rotation	Yes	Low	Low
Site selection	Yes	Low	Low
Tillage	No	Low	High
Using organic amendments	Yes	High	High
Weed control	No	Low	High

[a]Under high population pressure, the slash, and burn system is neither stable nor sustainable. Source: Thurston, 1992.

I. Farmers indigenous and traditional technologies

It is important to preserve and accumulate indigenous and traditional technologies which have been practicing by rural farmers for a long. The term traditional farming is usually associated with primitive agricultural systems or preindustrial peasant agriculture that has been practiced for many generations (Thurston, 1994) in the farmers' field.

Most practices for disease management used by indigenous farmers in developing countries are cultural practices, but little information is available in an easily accessible form. Table 6 presents many of the practices of the indigenous farmers (Thurston, 1994). Today there are serious concerns about "modern agriculture", which is extremely energy-intensive, the genetic base is narrow, and stress on increasingly high yields and efficiency leads to monoculture, and sometimes to serious erosion, pollution, and excessive pesticide residues (Thurston, 1994). A historical perspective on the practices and genetic materials used by traditional farmers through the centuries may help us to develop truly sustainable agriculture. To reduce reliance on pesticides, which our poor/marginal farmers are unable to afford, and to eliminate the risk of environmental pollution, attention should be given to non-chemical methods (genetic, mechanical, cultural, and biological) of control such as burning stubble/crop residues, water management, ash application, and spraying botanics (Shahjahan, 1993). These indigenous practices should be restored and practiced to provide safe food that is also one of our sustainable development goals.

J. Strengthening network between farmers and scientists

It is of utmost necessary to make bridge the gap between farmers and scientists. Here, we have proposed a simple model/diagram (the idea adopted from Rhoades and Booth, 1982) to identify the disease problem by plant pathologists from the farmers' field, to do basic research on diseases, and to do applied research on management practices (Fig. 6). Sometimes it may require interdisciplinary collaboration with an entomologist, soil scientists, and agronomist to identify genuine problems that arise from a farmer's field. After extensive researches, potential or possible solutions should go through evaluation and adaptation under researcher supervision and farmers' perception. Finally, farmers' accepted technology will go for dissemination. This is a continuous process between farmers, scientists, and extension personnel to generate sustainable technology arise directly from farmer's field on rice diseases. To achieve maximum benefit there should be a strong linkage between research, extension, and the technology users, i.e. the farmers (Shahjahan, 1994).

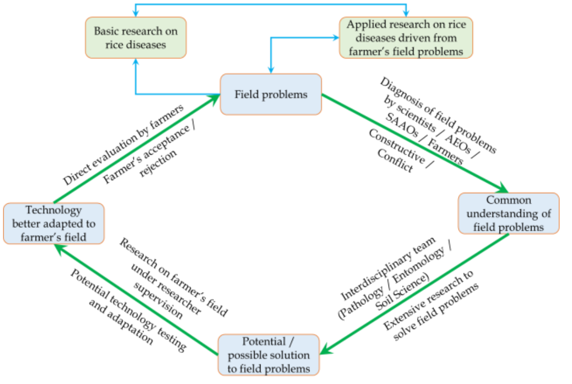

Fig. 6 Network between farmers and scientists to generate technology (Idea adapted from Rhoades and Booth, 1982).

K. Demonstrations to disseminate integrated disease management strategies to farmers field

To disseminate the latest technology, it is crucial to demonstrate it directly in the farmers' field. Whatever technologies are available or generated should reach the farmers through communication materials such as bulletins or folders; those to be written in local language and be distributed to extension agents (Shahjahan, 1993). Recent demonstrations of integrated disease management packages in farmer's field have recorded a reduction of blast disease incidence in BRRI recommendation practices over the farmers' practices by 43.57 to 70.88% (Tuhina-Khatun *et al.*, 2018). The yield increase with BRRI management practices was 0.82 to 1.18 t ha^{-1} (Table 7: partial data are shown). For sheath blight disease management in Aus rice, it was observed that the disease incidence in farmers' fields in Gopalganj was reduced by 68.89% and 73.95% with trichocompost and fungicides application, respectively (Jahan, 2017). There were also advantages of yield by 0.49 to 0.69 t ha^{-1} in BRRI managed plots (Jahan, 2017). The above findings in relation to the two major disease management delivers a clear message that effective control of devastating diseases is possible in farmers' fields, which will increase the yield.

Here, we have given simple mathematics, how could we minimize our yield loss, for example, in 2020 through our existing management techniques.

Lets consider, in 2020, we have a target of clean rice production of 37.0 million tons. If we expect the maximum 1% loss due to diseases, then it will be 0.37 million tons of clean rice production loss in the whole country. We have yield advantage in our disease management plots are 0.49, 0.69, 0.82, 1.18 t ha^{-1} in different locations in farmers fields. If we consider conservative figure, we will be able to increase yield at least 0.49 t ha^{-1} through our existing management packages. And, if we assume the rice land for T. Aman 2020 as 5.0 million hectares, then the production will be increased by at least 2.45 million tons. Practically, it is not possible to receive a yield advantage from 100% rice field. If we get yield advantage from 50% or even at least 25% field, then, we have a minimum of 1.23 or 0.61 million ton of rough rice production advantage, which will be, hopefully, enough to meet the loss of 0.37 million ton of clean rice production in 2020 (assuming we will have to disseminate our rice disease management technologies through our all possible channels to the farmers' field).

Table 7. Demonstrations on rice blast disease management executed in Gazipur district of Bangladesh in Boro season, 2017-18.

Variety	Disease incidence (%)		Disease reduction (%)	Yield (t ha^{-1})		Yield increase (t ha^{-1})	Yield increase (%)
	BRRI practice	Farmer practice		BRRI practice	Farmer practice		
BRRI dhan28 (L-1)	7.75	19.61	60.48	6.22	5.90	0.32	5.42
BRRI dhan29 (L-2)	0.00	30.19	100	8.75	7.46	1.29	17.29
BRRI dhan28 (L-3)	12.00	22.22	45.99	4.99	4.43	0.66	12.64
BRRI dhan28 (L-4)	3.85	16.77	77.04	5.92	4.93	0.99	20.08
Average	5.90	22.20	70.88	6.47	5.68	0.82	13.75

Note: L-1: Kapasia-Trial 1; L-2: Kapasia-Trial 2; L-3: Shreepur-Trial 1; L-4: Shreepur-Trial 2 (Source: Tuhina-Khatun *et al.*, 2018)

Action plan for three decades on reducing yield loss from rice diseases

"Location, Variety, and Disease Specific Smart Management (LVDSSM)" will be the banner of the action plan for plant pathology of BRRI in the next three decades 2021-30, 2031-40, and 2041-50. Table 8 shows the salient features of the LVDSSM.

Table 8. The salient features of the action plan on 'Location, Variety and Disease Specific Smart Management' (LVDSSM) for plant pathology of BRRI in the next three decades – 2021-30, 2031-40 and 2041-50.

Programme	Phase	Stage	Action
Research & Development	Primary	III	o Identification (symptom & the disease) o Isolation (for genetic ID & propagation behavior) o Inoculation (mass inoculation technique)
		YL-EST	o Yield loss estimation (by disease severity scale)
	Intermediate	Mtg-FWK	o Management framework (considering all possible options, based on current knowledge)
		EPI	o Epidemiology (based on local conditions, not just on information from literature. Finding the exact driver(s) of the disease epidemics
	Maturation	Cali-Valid	o Calibration and Validation (testing every component of the management framework by location & variety; applying all tools)
		SmMtg	o Smart management package developed to be acceptable to farm adoption
	Follow up	CO	o Continuous observations to keep on notice if changes happening on smart management package, e.g., variety tolerance; reaction to new varieties
Dissemination	Phase-1	Train	o Training (DAE officers and lead farmers)
	Phase-2	Demo	o Demonstration (in the location of disease risk)
	Phase-3	EW	o Early warning system-based disease alert communicated to farmers

The plan consists of two broad programmes – research and development (R and D), and dissemination. The R and D will progress through four phases – (i) primary, (ii) intermediate, (iii) maturation, and (iv) follow-up. The primary phase will be completed in two stages - (i) III (identification of symptoms of the diseases and the pathogens; isolation of the pathogens for genetic identification and propagation behaviour; inoculation for disease development with the associated pathogen, and (ii) YL-EST, which is the yield loss estimation for each major disease by disease severity scale. The intermediate phase will pass through two stages - Mtg-FWK (which is the development of management framework considering all possible options, based on past and current knowledge), and EPI (i.e., epidemiology based on local conditions, not just on information from literature in order to find the exact driver(s) of the disease epidemics). The maturation phase will be completed in two stages – Cali-Valid (which is calibration and validation to undertake to test, by applying all tools, of every component of the management framework, and SmMtg (which is the development of a smart management package to be acceptable to farm adoption). The single-stage follow-up (CO) phase will be the continuous observations to keep on notice if changes happen on the smart management package, such as variety tolerance, reaction to new varieties, etc.

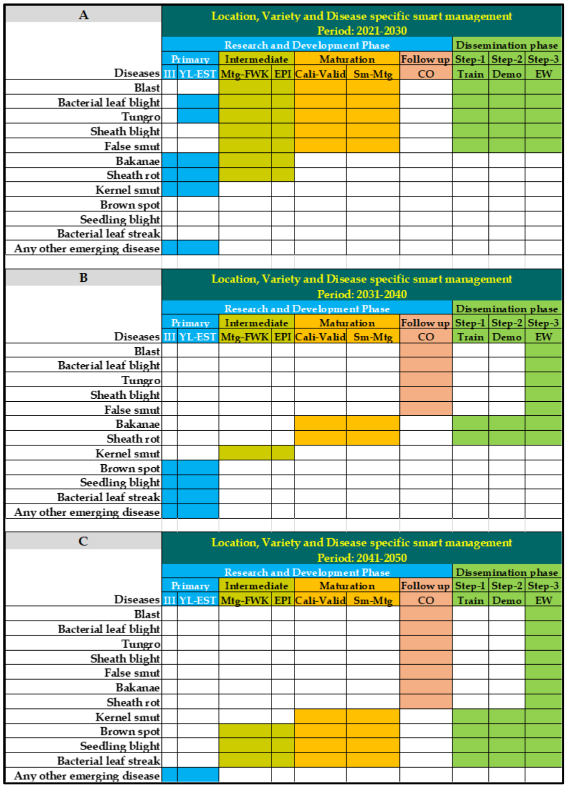

Fig. 7. The action plan on 'Location, Variety, and Disease Specific Smart Management' for plant pathology of the Bangladesh Rice Research Institute (BRRI) in the next three decades: 2021-30 (A), 2031-40 (B), and 2041-50 (C). III denotes for identification of symptom(s) and diseases, isolation for biology study and genetic identification, and inoculation for reproducing the disease; YL-EST for the yield loss estimation for major disease by disease severity scale; Mtg-FWK for development of management framework considering all possible options, based on past and current knowledge; EPI for

epidemiology based on local conditions, not just on information from literature in order to find the exact driver(s) of the disease epidemics; Cali-Valid for calibration and validation to undertake testing, by applying all tools, of every component of the management framework; SmMtg for development of smart management package to be acceptable to farm adoption; and CO for continuous observations to keep on notice if changes happen on smart management package, such as, variety tolerance, reaction to new varieties, etc.

The dissemination programme will be carried out in single-staged three phases, which includes training of officers of the Department of Agricultural Extension (DAE) and lead farmers (Trained), demonstration in the locations of specific disease risk (Demo), an early warning system-based disease alert communicated to farmers (EW).

Figure 7 shows the time dimension of the action plan for 10 major diseases in the next three decades, 2021-30, 2031-40, and 2041-50. If any diseases become a concern, they will be included in the plan. The plan has assigned varieties according to the importance and present R&D status.

CONCLUSION

The key drivers to meet food demand and sustain rice production in future are the farmers. Hence, emphasis has to be given to the farmers, and how they could reach to the existing technologies on rice disease management. However, acceptance of the technologies by the farmers depends on the authenticity of the technologies developed by the researchers. The proposed action plan accommodates both the requirements.

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AUTHORS' CONTRIBUTION

MTK, BN, MUS and MSK generated idea; BN and MUS coordinated the research; MTK and BN developed methodology; MTK, BN and MUS provided scientific insights; MTK and BN gathered data, carried out analysis and synthesis; MTK and MUS did the writings for all versions of the manuscript; MUS and MSK performed critical review and editing; All authors read and approved the final manuscript.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. List of identified rice diseases in Bangladesh (the list is in alphabetic order within the disease-causing organisms).

Disease	Causal organism
Fungal diseases	
1. Aggregated sheath spot	*Rhizoctonia oryzae sativae*
2. Bakanae	*Fusarium moniliforme*
3. Blast	*Pyricularia oryzae*
4. Brown spot	*Bipolaris oryzae*
5. Crown sheath rot	*Ophiobolus sp*
6. Damping off	*Achlya prolifera*
7. False smut	*Ustilaginoidea virens*
8. Grain red blotch	*Epicoccum purpurescens*
9. Grain spot	*Complex of fungi and bacteria*
10. Kernel smut	*Tilletia barclayana*
11. Leaf scald	*Microdochium oryzae*
12. Leaf smut	*Entyloma oryzae*
13. Leaf spot	*Curvularia lunata*
14. Minute leaf spot	*Nigrospora oryzae*
15. Narrow brown leaf spot	*Cercospora janseana*
16. Seedling blight	*Sclerotium rolfsii*
17. Sheath blight	*Rhizoctonia solani*
18. Sheath blotch	*Pyrenochaeta oryzae*
19. Sheath rot	*Sarocladium oryzae*
20. Sheath spot	*Rhizoctonia oryzae*
21. Stack burn	*Trichoconis padwickii*
22. Stem rot	*Sclerotium oryzae*
Bacterial disease	
1. Bacterial foot rot	*Erwinia chrysanthemi pv. chrysanthemi*
2. Bacterial leaf blight	*Xanthomonas oryzae pv. oryzae*
3. Bacterial leaf streak	*Xanthomonas oryzae pv. oryzicola*
Nematode disease	
1. Root knot	*Meloidogyne graminicola*
2. Root lesion	*Pratylenchus spp*
3. Root rot	*Hirschmaniella oryzae*
4. Ufra	*Ditylenchus angustus*
5. White tip	*Aphelenchoides besseyi*
Virus disease	
1. Tungro	*Vector: Nephotettix virescens*
Micoplasma disease	
1. Yellow dwarf	*Vector: Nephotettix virescens*

Source: BRRI, 2016