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BLAST DISEASE INTIMIDATION TOWARDS RICE CULTIVATION: A REVIEW OF PATHOGEN AND STRATEGIES TO CONTROL

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ABSTRACT

Rice blast is the most destructive disease to rice production globally. The objective of this review is to know the fundamentals of rice blast disease and to know the different methods for controlling blast disease. Rice blast disease has been recognised in more than 85 rice-producing countries worldwide. Currently, more than 100 R genes for blast resistance have been identified in rice. These resistance genes can be introgressed into a susceptible variety through marker-assisted backcrossing. Infested residues and seeds are the primary inoculum sources to spread the disease. Considering the importance of this disease, various management approaches have been practiced to control blast disease. The use of resistant varieties is an important measure to manage the disease. This review will provide use fulfacts about the pathogen and its epidemiology, assessment of resistance genes and effective control measure of rice blast disease through breeding and management. This update information will be helpful and guide to the research students and rice breeders to develop durable blast resistant rice varieties. So farmers will able to manage the blast disease in future.

Keywords: *Magnaporthe oryzae*, distribution, pathogen diversity, disease control, rice.

INTRODUCTION

Rice is considered as the most significant food crops for mankind because it feeds more than 50% of the world population (Zhang and Xie, 2014). Although rice production has increased significantly worldwide in the past decades, still it is inadequate to cope with the ever-increasing global demands. All countries are emerging their largely unexploited rice potential to boost local production. This is, however, difficult due to declined cultivable land every year, particularly in Asia where 90% of the world's rice are produced and consumed (Fischer *et al.,* 2005). Rice is grown globally under an extensive range of agro-climatic situations, and its productivity is affected by numerous abiotic and biotic stresses (Zhang and Xie, 2014). Among the biotic stresses, rice blast is the most harmful fungal disease, which can lead to losses in rice yield up to 70 to 80% (Miah *et al.,* 2013; Nasruddin and Amin, 2013). Rice blast disease is caused by *Magnaporthe oryzae*, which is also known as rice blast fungus, rice seedling blight, rice rotten neck, oval leaf spot of graminea, blast of rice, pitting disease, Johnson's spot and rye grass blast. Rice blast disease has been recognized in 85 rice-growing countries (Wang *et al.*, 2014). Rice blast disease is one of the most devastating rice diseases worldwide, causing large yield losses each year and is a threat to global rice security (Li *et al.*, 2011). Due to this disease, destroys abundant rice to feed more than 60 million people for one year and economic losses over $70 billion of a dollar (Scheuermann *et al.*, 2012). Rice blast is, therefore, a remarkable economic and humanitarian problem. However, climatic changes accompanying with the global warming could prompt its spread in to other parts around the world (Kohli *et al.*, 2011).

Knowledge about the geographic distribution and frequency of a virulence genes will contribute towards the development of rice varieties carrying different resistance genes. Management of rice blast is difficult because the pathogen is seed borne (Hubert *et al.*, 2015). A management strategy incorporating the use of resistant cultivar, suitable planting date, and fungicide need to be considered for the effective and sustainable control of the blast disease. The efficacy of a particular fungicide to control the blast disease could vary from season to season or place to place (Nasruddin and Amin, 2013). Continuously, mining novel resistance and avirulence genes for better understanding the interaction mechanisms, and using molecular markers to analyze the genetic structure of pathogen populations, the structure and function of genes need to be clear and may provide information for reasonably utilizing resistance genes (Hasan *et al.*, 2017; Miah *et al.*, 2015a; Tanweer *et al.*, 2015). The wide virulence diversity within the pathogen population makes breeding difficult for resistance (Marangoni *et al.*, 2013). Rice blast resistance is a complex process, and over 100 resistance genes have been identified (Costanzo and Jia, 2010). Use of resistant cultivars is an alternative way to control the disease. The main objectives of this review are as follows: (i) to know about the rice blast disease and pathogen; (ii) to know the genetic diversity of *M. oryzae*; and (iii) to know the various management approaches to control blast disease.

MATERIALS AND METHODS

This review article was prepared through the available published and own research findings. This paper provides a review of the existing and accessible literature from books, journal articles, conference proceedings and reports that deals with the blast disease in rice, causal agent and biology, disease development, epidemiology and the control measures of rice blast disease.

Pathogen biology: The synonym of *Magnaporthe oryzae* is *Magnaporthe grisea* or *Pyricularia grisea* (Couch and Konn, 2002). The *Magnaporthe* comprise of two divergent clades, one infecting Digitaria (crabgrass), is referred to as *M. grisea* isolates, and another one that is pathogenic on rice, millet and other grasses, denoted to as *M. oryzae*. *Magnaporthe oryzae* is the correct name for the isolates linked to the rice blast (Cuch and Kohn, 2002). *Magnaporthe oryzae* is filamentous ascomycetes that can reproduce both sexually and asexually. The conidia of the fungus size are 20-22 × 10-12 µm. The conidia are translucent, two-septate, and slightly darkened. They are obclavate and pointed at the apex (Devi and Sharma, 2010) (Figure 1).

Disease development: Several environmental factors can influence the infection rate and spread of the disease, including temperature, nitrogen levels, intermittent rain showers or drizzle airflow, high relative humidity and drought conditions. Blast susceptibility is inversely related to soil moisture. Plants grown under upland conditions are more susceptible, while plants grown under lowland condition are more resistant. The pathogen requires free moisture for spore penetration. High relative humidity (90-92%) is also reported to be essential for infection. Severe blast epidemics are usually associated with moist weather. Low solar radiation and cloudy skies are also good deeds to blast.

Fertilizer: Rice disease resistance is habitually affected through high nitrogen supply (Ballini *et al*., 2013). Many experiments have shown that a high nitrogen supply is likely to favour heavy blast infection compared to phosphorus or potassium supply. Reports suggest that application of required amount of quick-acting nitrogenous fertilizer like ammonium sulfate for an entire season was found to cause severe blast disease. Soil characteristics (alkaline pH, high concentration of salt, organic carbon, nitrogen and low concentration of potassium and phosphorus) also lead to rice blast disease (Maheshwari and Sharma, 2013).

Climatic conditions: Most severe blast disease occurs when more than a few days of continuous rains and average temperatures between 18–25°C during the flowering stage of the crop followed by sunny, hot and humid days (Kohli *et al*., 2011). Under controlled growth chamber conditions, the highest blast intensity was observed at 30°C which increased with a longer wet period, and low at 25°C with a wet period of less than 10h (Cardoso *et al*., 2008). However, at 25°C and 40h of wetting, blast intensity exceeded 85%.

Seed and secondary hosts as source of primary inoculum: Infested seeds are a source of primary inoculum. Dead infested grains could serve as primary inoculum when placed on the field during seedling development (Long *et al*., 2001). Transmission of *M. oryzae* from rice seeds to seedlings has already been recognized in different countries (Manandhar *et al*., 1998; Long *et al*., 2001). Seed contamination and panicle symptoms are interrelated using naturally infested seeds as primary inoculum in field conditions (Manandhar *et al*., 1998). They observed that sporulation of *M. oryzae* on infested seeds was favourably found at the embryonic end of germinating seeds. A seed lot with 21% contamination led to <4% seedlings with blast lesions. Tests employing different ways of covering seeds with soil and underwater seeding (no covering) pointed out that complete covering or seedings underwater induce a lower infection frequency (Manandhar *et al*., 1998). Guerber and TeBeest (2006) conveyed similar experiments in the USA, but no disease was observed when infested seeds were germinated under water. When infested seeds were sown in the field, the fungus was recovered from different seedling parts, including roots. These results clearly indicate that the fungus can survive on the grains used for seeding and could serve as primary inoculum.

The blast can attack most upper parts of the plant (Figure 2). The disease also attacks the leaf collar, the stem, and occasionally the internodes (Long *et al*., 1996). The fungus can infect plant roots and also grains. When no desire infected, all plants die and yield losses are severe. On the leaves, it causes elongated diamond-shaped white to grey lesions with dark green to brown borders surrounded by a yellowish halo. If the attack is at heading stage, the disease may result in the production of white panicle or breakage of the stem at the infected node. If infection arises early, the grains do not fill and the panicle remains erect. However, late infection results in partial filling of the grains and may cause weight loss.

Epidemiology: *Magnaporthe oryzae* is found worldwide and the diversity of pathogen population having more than 1,700 isolates from 40 countries (Divya *et al*., 2014). Many studies have been conducted using molecular markers and pathogenicity assessments on diverse rice varieties to identify the *M. oryzae* population structure all over the world. A total of 42 isolates were obtained from the infected USA commercial rice cultivars and confirmed the occurrence of eight lineages (Levy *et al*., 1991). Simple population structure was also observed in Europe and Africa, separated in to nine lineages (Takan *et al*., 2012). In the Philippines, 1156 isolates were obtained on 38 rice cultivars that were grouped into ten lineages (Chen *et al*., 1995).

The primary inoculum is initiated from crop residues, spores and infected seeds spread by the wind from neighbour farming zones. During germination, the spore produces specialized infectious structures called appressorium that infect aerial tissues. Spores that are formed from contaminated seeds, contaminate emerging seedling tissues and produce mycelium that colonizes the newly formed primary leaf and secondary roots. At the 2/4-leaf stage, *M. oryzae* exhibit distinct levels of resistance or susceptibility using different rice cultivars, and it was perceived that resistance or susceptibility of a considered genotype is recognized at the seedling stage. Infested seeds are produced when plants are inoculated either at the ripening stage, heading stage or even before heading. These seeds produce diseased seedlings that typically die and serve as an inoculum source for vigorous adjacent plants, which progressively develop disease symptoms on leaves (Faivre-Rampant *et al*., 2013). In the tropics, blast spores exist in the air throughout the year, thus supporting a constant development of the disease.

Strategies to control: There are several control strategies (chemical control, nutrition management, cultural practices and use of resistant varieties) that can be undertaken in the management of rice blast. Among the several strategies to control this disease, host-plant resistance is considered as the best possibility to hand gripth is problem.

Burning or composting of diseased tissues: Diseased straw and residual stubble need to be burned or composted; otherwise, they can develop inoculum sources for the next crop season.

Vigorous healthy seed: Disease-free healthy seeds can be collected from the field located under unfavourable conditions for the pathogen, and fungicide must be applied if necessary. Ammonium sulfate solution, $230g^{-1}$, or salt solution, $200g^{-1}$ can be used to separate sufficiently matured seeds, followed by chemical treatment for seed disinfection against a wide range of pathogens.

Cultural practices: This is an important control measure but will not provide complete eradication of the disease. Burning of crop residues reduces the over wintering inocula in the field, but this may not prevent the inoculums coming from other sources (Zeigler *et al*., 1994). Use of treated seed may reduce the inoculum load. Water seeding (planting on very wet soil) is recommended as this will reduce the transmission of disease from the seed to the seedling. Flooding is also recommended as a water management strategy to reduce rice blast compare to when under water stress (Manandhar *et al*., 1998). Draining of water allows the formation of nitrates resulting to drought stress. Rice is more susceptible to drought than other cereals due to its inability to regulate its transpirational water loss, a weakness that may accelerate rice blast attack (Kato *et al*., 2004).

The availability of water also affects the susceptibility of the host plant to *M. oryzae*. Rice grown under upland conditions is more susceptible than rice grown in flooded soil. Under upland conditions, susceptibility is increased further with increasing drought stress. Hence flooding the field in upland rice can decrease the severity of blast disease (Bonman, 1992).

Planting time has a marked effect on the development of blast within a rice crop. Early planting is recommended to control rice blast. In tropical upland rice, crops are sown early during the rainy season generally have a higher probability of escaping blast infection than late-sown crops. Early planting date can help susceptible cultivars escape from a severe infection of leaf blast but can be infected by the head blast at the onset of panicles. But, if susceptible cultivars are planted later in the season, the plants can be severely infected by both leaf and head blight. When epidemic starts early, in late sown plantings, plant growth and development are severely affected, leading to the death of many plants (Filippi and Prabu, 1997).

Phosphorus and nitrogen availability to the plants alter disease proneness. An excess amount of nitrogen fertilizer accelerates disease progress, while silica application decreases disease growth. Therefore, the type and amount of fertilizer must be cautiously pronounced according to the cultivar used, soil and climatic conditions, and disease risk.

Chemical control: Many fungicides, including tricyclazole, pyroquilon, iprobenfos, benomyl, isoprothiolane, diclocymet, edifenphos, felimzone, probenazole, carpropamid, fenoxanil and metominostrobin, and antibiotics such as blasticidin and kasugamycin are used against the blast disease. Di-potassium hydrogen phosphate (DHP) has also been used to reduce rice blast (Manandar *et al*., 1998). Systemic fungicides are extensively applied at seedling to protect against leaf blast and more than 20 days before heading to protect against panicle blast. The amount of fungicide, composition, application method and timing of fungicide applied depends on the disease forecast or disease severity.

The efficacy of various fungicides has been reported by researchers around the world. From the experiment of Magar *et al.* (2015) showed that maximum disease control and the highest grain yield were recorded from Tricyclazole 22% + Hexaconazole 3% SC thrice at weekly interval starting from the booting stage and hence, recommended this fungicide against rice leaf and neck blast disease to have effective control and higher grain yield under field condition.

Nutrition management: The understanding of effects of nutrition management on interactions between rice and diseases is a base to inspire high-yield production system (Luong *et al*., 2003). Nutrition management is one of the most significant practices for a high production system that affect the response of rice to diseases, as well as the developmental pattern of the disease populations due to the change of environments. The ability of a crop plant to resist diseases is tied to optimal physical, chemical and mainly biological properties of soils (Luong *et al*., 2003). Soils with high organic matter and high biological activity generally exhibit good soil fertility that prevents infection (Luong *et al*., 2003).

Nitrogen is essential for plant growth and development and is usually a limiting factor for high productivity. Long *et al*. (2000) found an increase in blast lesion when the level of nitrogen was applied above the recommended rate. On the contrary, Snoeijers *et al*. (2000) observed that low nitrogen also led to disease increase resulting from weak plants that lacked sufficient defences against disease.

Silicon (Si) is known as a “beneficial element” for plants. However, it is not an essential nutrient. The direct and indirect benefits of the element for crops, the especially grass is related to resistance to diseases, pests, and drought. Low Si uptake increase the susceptibility of rice to blast, and grain discoloration (Massey and Hartley, 2006). Similarly, Prabhu *et al*. (2001) found that rice cultivar that accumulated more silicon on the shoots showed fewer incidences of rice blast.

Integrated control measures: Multilines are mixtures of several near-isogenic lines (NILs) with uniform phenotypic agricultural traits but with different resistance genes to a crop disease. Multilines can be used to control rice blast and NILs with different complete resistance genes have been developed in Japan (Table1). Multilines increase blast resistance in rice cultivars thus contribute to the reduction of blasticide applications. The inter-cropping or mixture of rice varieties greatly reduces the occurrence and variation of rice blast disease, in particular, the variety of combinations, which makes the intercropping system more stable and consistent for disease suppression on a large scale of rice cultivation (Han *et al*., 2015).

Forecasting systems: Forecasting systems have been developed in some countries and being used effectively. In recent years, an emphasis was also given to the disease forecasting computer models. Through such models, it is possible to provide estimates of disease likelihood and forecast out breaks which in turn may improve the efficiency of fungicidal applications. Using 13-year data, Padmanabhan (1963) concluded that whenever the minimum temperature of 24°C or below was associated with RH of 90% or above, the conditions were favourable to blast infection. It attempts to correlate spore content and blast incidence in India. A new machine learning technique prediction approach based on support vector machines was introduced by Kaundal *et al.* (2006) for developing weather-based prediction models of rice blast disease.

Botanicals: Recently, some botanicals are used for their antifungal activity against *M. oryzae*. The leaf extracts of *Atalantia monophylla* can control disease upto 82.22% followed by *Plumbago rosea* 70.57%, because *A. monophylla* have a higher content of phenols (4.8mg/g) and flavonoids (24.5mg/g) compared to others (Parimelazhagan, 2001). Aqueous extracts of *Aloe vera, Allium sativum,Annona muricata, Azadirachta indica, Bidens pilosa,Camellia sinensis,Chrysanthemum coccineum*, processed *Coffee arabica,Datura stramonium, Nicotiana tabacum* and *Zingiber officinalis* were used by Hubert *et al*. (2015) for controlling rice blast disease (*Pyricularia grisea*) *in-vitro* and *in-vivo* (Table 2). The results indicated that processed *C. Arabica* at 10% and 25% (v/v) had the highest (81.12%) and (89.40%) inhibitory effect, respectively, against *P. grisea*. Aqueous extract from *N. tabacum* at 10% concentration ranked third (80.35%) ininhibiting *P. grisea*. These were followed by extracts from 25% *A. vera* (79.45%) and 25% *C. coccineum* flower (78.83%). The results also indicated that extracts of *A. indica, A. vera, A. sativum, C. arabica, D. stramonium, C. sinensis, Z. officinalis* and *N. tabacum* did not have any phytotoxic effect on seed germination, shoot height, root length, dry weight, seedling growth and seedling vigour index. These plant extracts can be used for rice seed treatment to manage rice blast disease (Hubert *et al*., 2015).

Biological control: The *Chaetomium cochliodes* is a biological agent that was found effective in the control of *M. oryzae*. When the rice seeds were coated with a spore suspension of *C. cochlioides* thee arly infection by the blast was controlled, and seedlings were healthy and taller than the control. It was found that rice blast incidence can be reduced by mass vaccination method with avirulent isolates of *M. oryzae*. Recent studies on biocontrol of rice blast showed that *Bacillus subtillis* strain B-332, 1Pe2, 2R37, 1Re14 and *Streptomyces sindenius* isolate 263 have good antagonistic activity against *M. oryzae* (Yang *et al*., 2008).

Cultivar resistance: Use of resistant varieties would offer a better management compared to other control strategies, as it is inexpensive. However, it may take a long time to develop a variety of the desired type that is resistant to rice blast (Zeigler *et al*., 1994). Marker-assisted backcrossing is the method of producing blast-resistant variety using resistant cultivar (Figure 3).

Several researchers (Miah *et al.,* 2017; Hasan *et al.,* 2016) developed blast resistant rice varieties using marker-assisted backcrossing. Inducing the resistance to rice plant is also an eco-friendly strategy for rice blast control. The host plant resistance is treated as the best tactic to grip the rice blast disease. Hence the arrangements of different blast resistance genes which interact with each other to impart resistance, are a combination of best alleles of the targeted genes in a host plant in the rice blast breeding programs (Ramkumar *et al*., 2010). Therefore, Identification of the novel and best resistance alleles of the blast resistance genes is an imperative task in the rice breeding program. Exploitation of resistance gene resources for rice breeding is one of the most significant strategies to control the disease. Several rice cultivars, such as IR36, IR64, Moroberekan, OrysicaL lanos5, CO39, Digu, Tetep, Suweon 365, Pongsu Seribu 1, sonarbangla1, and Pongsu Seribu 2, were found to be resistant to blast (Wang *et al*., 1994; Zeigler *et al*., 1994; Ahn *et al*., 2000; Chauhan *et al*., 2002; Sallaud *et al*., 2003; Chen *et al*., 2004; Sharma *et al*., 2005; Miah *et al*., 2015b; Latif *et al.,* 2011; Ashkani *et al*., 2011). It is essential to study the local and traditional varieties that have been known to be resistant to blast disease. Local varieties are generally used as sources for the introgression of new resistance genes into selected rice in breeding activities.

Future areas for research: Biotechnological approaches and molecular biology have changed the research on rice blast management. The availability of genome sequences of both, the host rice and the pathogen has opened many doors for further research. The introduction of new sciences like nanotechnology in agricultural research could be very effective to control rice blast using nano molecules. Cloning of R and Avr genes and study of their gene products will add to the knowledge of host-pathogen interaction. The development and use of transgenic rice would be the best way of rice blast management in the future. There is still a need for the further development of noble fungicides and fungistats with longer residual effect, which can be better assisted by biotechnology in the future. Different strategies like gene rotation, gene pyramiding, spatial and temporal gene deployment and use of varietal mixtures can be the best means to reduce the rice blast.

Table 1. Near-isogenic lines for rice blast control with multilines.

Sl. No.	Resistance genes in NILs	Recurrent parent (RP)	Genotype of RP
1.	*Pill, Pik-m, Piz, Piz-t, Pita, Pita-2, Pib, Pit*	Akitakomachi	*Pia, Pii*
2.	*Piz-t, Pib, Piz, Pita-2*	Kinuhikari	*Pii*
3.	*Pill, Pik-m, Piz, Piz-t, Pib, Pita, Pita-2*	Chubu64	*Pii*
4.	*Pill, Pik-m, Piz, Piz-t, Pib, Pita, Pita-2*	Mineasahi	*Pia, Pii*
5.	*Pii, Piz, Piz-t, Pita-2*	Etsunan157	*Pia*
6.	*Pill, Piz-t, Pita, Pita-2, Pib*	Hanaechizen	*Piz*
7.	*Pii, Pik-h, Pik-m, Piz, Pita, Pita-2, Piz-t, Pib*	Maihime	*Pia*
8.	*Pik-m, Pita, Pita-2*	Hinohikari	*Pia, Pii*
9.	*Pii, Pill, Pita, Pita-2, Piz-t*	Toyonishiki	*Pia*
10.	*Piz, Pib, Pita-2, Piz-t, Pi*	Hokkai241	-
11.	*Pii, Pill, Piz, Piz-t, Pita-2, Pib*	Nipponbare	*Piks/Pia*
12.	*Pill, Pik-m, Piz-t, Pib, Pita*	Manamusume	*Pii*
13.	*Pill, Pik-m, Piz, Piz-t, Pib, Pita, Pita-2*	Hitomebore	*Pii*
14.	*Pia, Pii, Pill, Pik-p, Pik-m, Piz, Piz-t, Pita, Pita-2, Pib*	Koshihikari	*Pik-s*
15.	*Pik-s, Pii, Pill, Pik-m, Piz, Piz-t, Pita, Pita-2, Pib*	Sasanishiki	*Pia*

Source: Koizumi *et al.* (2004)

Table 2. Scientific and common name of plants used as sources of antifungal extracts.

Scientific name	Common name
Aloe vera	Aloe
Allium sativum	Garlic
Annona muricata	Soursop
Azadirachta indica	Neem
Bidens pilosa	Blackjack
Camellia sinensis	Tea
Chrysanthemum coccineum	Pyrethrum
Coffee Arabica	Coffee
Datura stramonium	Thornapple
Nicotiana tabacum	Tobacco
Zingiber officinalis	Ginger

Figure 1. Shape and size of *M. oryzae* conidia.

Figure 2. Symptoms of blast disease on rice leaves (a), collar and neck (b), panicle (c) and grain (d).

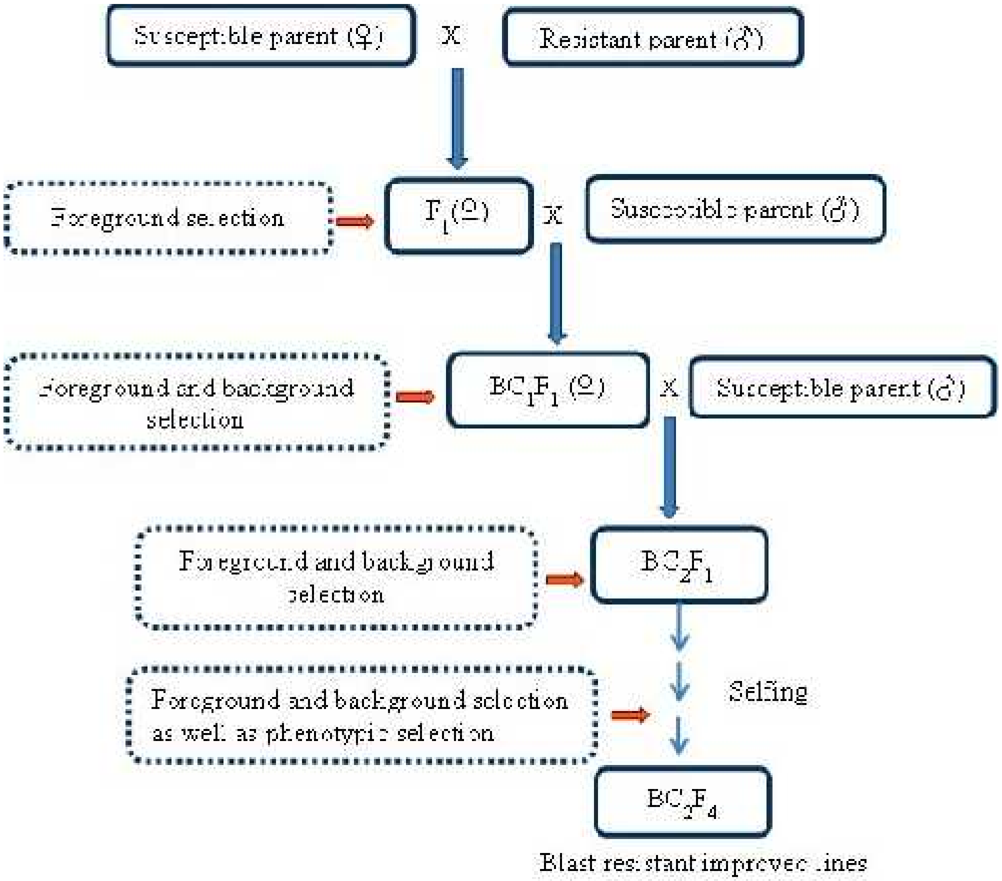

Figure 3. Marker-assisted backcrossing method for producing blast resistance rice variety using resistant cultivar.

Conclusions: Various management tools and practices are available to control the disease, but the effectiveness depends on their integrated use. Host-plant resistance is the durable resistance that is influenced by environmental factors. The breeding strategies such as pyramiding of genes, gene rotation, and multiline varieties are effective in resistance management. Using biotechnological tools as well as conventional means, breeders and pathologists need to work faster to develop resistant cultivars to control new virulent pathotypes of the fungus. Due to the highly variable nature of pathogen blast disease may pose to world rice production in the future and that is why continuous research efforts are deemed urgent and necessary on the development of durable resistant cultivars. The future direction will focus on the development of rice varieties with durable resistance to blast. In order to achieve this, we need to characterize blast fungus genetic diversity and identify different lineages and pathotypes. We need to look for new resistance genes in rice and related species through the diversity of studies and advice on pyramiding efficient genes. The availability of this information will allow for effective screening and development of donor varieties, inbred and hybrid lines, NILs, and differential varieties with durable blast resistance. Finally, the knowledge gained through research must be disseminated to the farmers so that they can practice. We hope that some of the ideas proposed in this article will encourage the rice scientific community to work together. We are optimistic that this article outlines will provide more information on the management of blast disease that can be used to accelerate sustainable rice yields to meet up the demand and food security in the coming years and decades globally.

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