Chapter 5
Integrated Management of Rice Blast Caused by *Magnaporthe oryzae*

Manish Kumar and Shabbir Ashraf

Abstract Rice (*Oryza sativa* L.) is the world's most important crop and is considered to be a primary source of food for over half of the world's population. In 2017, rice cultivation globally occupied an area of 166 m ha, with a production of 758.8 m t of paddy. More than 90% of the world's rice crop is consumed in Asian countries, which account for about 60% of the earth's population. Rice blast caused by the fungus *Magnaporthe oryzae* is one of the most severe diseases of rice. This pathogen is highly variable in nature. It attacks all developmental stages of rice, causing losses of around 10–30% annually in different rice-producing areas. The pathogen can infect several organs of the rice plant, such as the leaves, collars, necks, and panicles. Chemical agents have been used to combat several soil borne pathogens including *Magnaporthe oryzae*, but our environment is severely degraded by the use of chemicals that pollute the atmosphere and leave harmful effects. The excessive use of pesticides is responsible for the degradation of soil conditions, but this degradation can be limited by the use of targeted bioagents that are antagonistic to pathogens. The reduction of chemical pesticide use in agriculture is achieved by the integration of biocontrol agents, botanicals, and minimum doses of chemicals. Various management strategies, such as the controlled use of nitrogen fertilizers, the application of silica, and the flooding of fields have been used for a long time to control rice blast disease. Scientists are keen to develop durable resistant rice varieties through the pyramiding of quantitative trait loci and major genes. New strategies, such as the characterization of the *R* and *Avr* genes of rice, and biotechnological approaches that lead to the development of resistant cultivars should act against rice blast disease. However, the exploitation of durable host resistance remains a challenge for plant pathologists.

Keywords Rice · *Magnaporthe oryzae* · Management · Pathogens · Productivity

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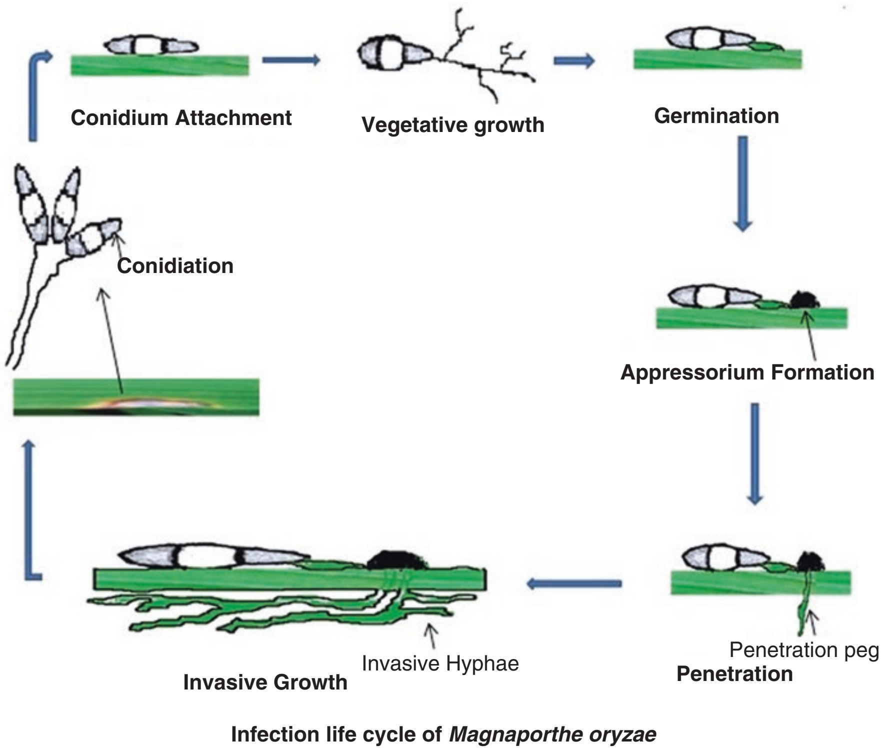
5.1 Introduction

Rice (*Oryza sativa* L.) is the world's most important crop and a primary source of food for more than half of the world's population. More than 90% of the world's rice crop is consumed in Asian countries, which account for about 60% of the earth's population (Kole 2006; Zeigler et al. 1994). In 2017 the Food and Agriculture Organization (FAO) reported that, globally, rice occupies an area of 166 m ha, with a production of 758.8 m t paddy crop. Many pests and diseases attack the rice crops. Rice blast caused by *Magnaporthe oryzae* has more significant economic importance than caused by other pathogenic fungi.

The *M. oryzae* pathogen can infect several parts of the rice plant, such as the leaves, collars, necks, and panicles (Ou 1987; Pinnschmidt et al. 1995). Rice blast caused by *M. oryzae* is an important disease in upland and rain-fed tropical and subtropical areas (Ou 1987; Zeigler et al. 1994). Rice blast is also known as rice fever; neck blast is particularly damaging, as infections damaging the panicle lead to significant yield reduction, of around 20–30% annually (Ou 1987). Rice blast was first reported in China by 1637, then in Japan in 1704, and in the United States and India in 1876 and 1913, respectively (Ou 1971). Blast is one of the major diseases of upland rice (Teng et al. 1990), including that grown in Indonesia (Suwarno et al. 2001). Traditional varieties are generally resistant to blast. However, these varieties generally have a large plant height, a long growth cycle, and a low attainable yield (Suwarno et al. 2001). Chemical fungicides are able to control plant diseases effectively, but the excessive use of chemicals leads to serious concerns for the environment and causes human health problems. Chemical residues in soil make it infertile, and disturb the proper growth and development of plants. Various integrated management strategies have been employed to manage blast diseases of rice, and these strategies involve good cultural as well as agronomic practices, the use of resistant varieties, the application of bioagents and botanicals, and less use of chemicals. Such approaches reduce the chemical load on the environment and enhance the activity of soil microbes, thus both directly and indirectly influencing the productivity, composition, and diversity of plant communities (Barea et al. 2002; Fitzsimons and Miller 2010; Ansari and Mahmood 2017; Lau and Lennon 2011; van der Heijden et al. 2006, 2008).

5.2 Biology of *Magnaporthe oryzae*

M. oryzae damages the aerial parts of the rice plant, and the most commonly affected parts are the leaves and panicles (Sesma and Osbourn 2004). Infection with this pathogen reduces the photosynthetic area of the plant, and panicle infection reduces the yield (Roumen 1992). The blast spores release a special adhesive which attaches them to the leaves, starting the infection (Hamer et al. 1988). The spore attaches to the leaf surface and the forms a specialized cell, the appressorium, that allows the fungus to penetrate the host tissues (Tucker and Talbot 2001; Talbot 2003; Xu et al. 2007). The appressoria of *M. oryzae* develop great cellular turgor due to the accumulation of glycerol as a compatible solute within these cells (de Jong et al. 1997). Owing to the presence of melanin in the appressorium, these cells are impermeable to glycerol efflux, but fully permeable to water. Rapid and continuous influx of water into the cell leads to the development of hydrostatic turgor pressure (Wilson and Talbot 2009; de Jong et al. 1997). The germ tube of the germinating fungal spore recognizes the hydrophobic hard surface of the rice leaf, differentiates in less than 3 h, and invades the underlying leaf tissue (Dean 1997; Hamer et al. 1988); owing to the extremely high turgor pressure (up to 8 MPa), this specialized infection cell ruptures the leaf cuticle. The penetration peg formed at the base of the appressorium (Dean et al. 2005), along with the action of cutinases, allows the appressorium to breach the host cuticle and cell wall, leading to infection of the host.



Life cycle of *M. oryzae* (modified/adopted from http://www.ibwf.de/index.php/fields-of-competence/plant-protection-research-development/molecular-basis-of-plant-microbe-interaction)

5.3 Rice Blast Management

Blast is present in most rice-growing areas; however, the *M. oryzae* pathogen is quite variable and the virulence factors present in one population may not be present in another geographically isolated one. The chemicals used to control blast disease of rice have a bad effect on soil health, and the chemical residues remain in the soil for a long time, affecting the soil microbiome. Such anthropogenic pollution affects human health both directly and indirectly. To reduce the chemical load on the environment, the integration of biocontrol agents (BCAs), which are able to combat pathogens, and botanicals, as well as the proper combination of appropriate nutrients and water, in addition to minimal doses of the required chemicals, should be used for the management of blast diseases of rice.

5.3.1 Water and Planting Time

Under upland conditions rice susceptibility to blast is increased with increasing drought stress (Kahn and Libby 1958). Hence, in upland rice, flooding of the fields would be effective to reduce the severity of blast. Planting time also affects the development of blast on rice crops. In tropical upland rice, early planting, rather than late sown crops, is recommended for preventing blast infection. In upland areas of Brazil, farmers are advised to sow early to escape the inoculum produced on neighboring farms (Prabhu and Morais 1986).

5.3.2 Nutrient Management

Nitrogen and silicon have been found to have a significant effect on the occurrence and development of rice blast disease. Hori (1898) reported that a high soil level of nitrogen led to a high incidence of rice blast. Prabhu and Morais (1986) conducted an experiment in upland rice fields in Brazil and suggested that a limit of 15 kg N/ha reduced blast disease of rice.

Plants with low silica content in the epidermal cells of leaves show low resistance to blast, while the nitrogen level is high (Miyake and Ikeda 1932). The correlation between silica content and disease incidence was studied in different cultivars of rice and it was observed that plants with a high silica content or a large number of silicated epidermal cells had slight damage from blast disease (Onodera 1917). The application of silica slag in the field increased the resistance of rice to blast (Kawashima 1927). Datnoff et al. (1997) reported that the application of silica (calcium silicate slag) reduced the occurrence of rice blast, in terms of the reduced use of a fungicide (benomyl). Now silicon fertilization has become a routine practice in Florida for better rice yields.

5.3.3 Botanical and Biological Management

5.3.3.1 Botanicals

Botanicals are used as alternatives to chemical pesticides, as an ecofriendly method to manage blast disease of rice. The effectiveness of neem (*Azadirachta indica*) oil and neem oil plus neem leaf extract against blast diseases on the Pusa Basmati 1121 rice variety were evaluated and it was found that these agents inhibited the pathogens by around 25% (Kumar et al. 2017). Other botanicals were also evaluated for their antifungal activity against *M. oryzae* and some of them were found to be very effective. The leaf extract of *Atalantia monophylla* was found to inhibit disease by up to 82.22%, while the leaf extract of *Plumbago rosea* inhibited disease by 70.57%. Biochemical studies showed that *A. monophylla* had a higher content of phenols (4.8 mg/g) and flavonoids (24.5 mg/g) than other botanical agents tested (Parimelazhagan 2001). The obnoxious weed eupatorium (*Chromolaena odorata* L.), which has spread extensively in the hill region of Karnataka, India, is known to have antifungal activity; extracts of this weed with different solvents were evaluated for the management of blast disease in rice (Manjappa 2013). Evaluation of the antifungal activity of the leaves of *Ocimum gratissimum*, *Chromolaena odorata*, and *Cymbopogon citratus* the seeds of *Eugenia aromatica* and *Piper guineense*; and the nuts of *Garcinia kola* at different concentrations revealed 70–90% inhibition of mycelial growth (Olufolaji et al. 2015).

5.3.3.2 Biocontrol Agents

Bio-management is an ecofriendly and economic method of managing *M. oryzae* that causes rice blast. Such management is an alternative to the use of chemical agents, and BCAs such as *Trichoderma viride*, *T. harzianum,* and *Pseudomonas fluorescens* have been found to be most effective against *M. oryzae* (Kumar et al. 2017). BCAs can antagonize soil-borne pathogens either directly or indirectly by eliciting a plant-mediated resistance response (Jamalizadeh et al. 2011; Pozo and Azcón-Aguilar 2007). *Trichoderma* spp. synthesize iron-chelating siderophores to cope with the problem of micronutrient scarcity arising from other pathogenic fungi (Benítez et al. 2004). Seeds of four rice varieties; namely, Swarna, IR–64, Samba Mahsuri, and Sahbhagi Dhan, grown under upland rice conditions at Almora and Hazaribagh in India, were treated with isolates of different *Trichoderma* spp. against leaf blast. Compared with control results, the seeds of Samba Mahsuri treated with *Trichoderma* spp. isolate Th–3 showed a maximum increase in plant height (57%), followed by Samba Mahsuri treated with the Tv–12 isolate (44%). Treatment with these isolates also increased root length (by 51–93%), total number of leaves (by 6–60%), number of tillers (by 3–41%), number of panicles (by 4–39%), flag leaf length (by 2–30%), and panicle length (by 5–32%) as compared with results in untreated controls (Aravindan et al. 2016). The biological agent *Chaetomium* *cochliodes* was also found to be effective in the control of *M. oryzae*. When rice seeds were coated with spore suspensions of *C. cochlioides*, early blast infection was controlled and the seedlings were healthy and taller than the controls. In India, studies of BCAs for the control of rice blast were conducted at the Center for Advanced Studies in Botany, University of Madras, and it was found that, among the 400 bacterial isolates collected from the rice fields of the International Rice Research Institute (IRRI), three strains of *Pseudomonas fluorescens*, five of *Bacillus* spp., and one of *Enterobacter* spp., were inhibitory under in vitro conditions (Gnanamanickam et al. 1989; Gnanamanickam and Mew 1992). Microbes have also been engineered to control rice blast. An epiphytic bacterium, *Erwinia ananas*, transformed by the chitinolytic enzyme gene (Chi A) from an antagonistic bacterium, *Serratia marcescens* strain B2, a tomato epiphytic bacterium, was found to be inhibitory against *M. oryzae* (Someya et al. 2004). Other studies on the biocontrol of rice blast showed that *Bacillus subtilis* strain B-332 (Mu et al. 2007) and strains 1Pe2, 2R37, and 1Re14 (Yang et al. 2008), as well as *Streptomyces sindenius* isolate 263, had good antagonistic activity against *M. oryzae*.

5.3.3.3 Chemical Management

The effectiveness of fungicides depends on several factors, e.g., the level of disease present, the compound used, the timing and method of its application, the efficiency of disease forecasting systems, and the rate of emergence of fungicide-resistant strains (Skamnioti and Gurr 2009). Fungicides are frequently used for the control of blast disease of rice. In Japan, a mixture of copper fungicides and phenyl mercuric acetate (PMA) was found to be more effective to control blast disease of rice than copper fungicides alone, while a mixture of slaked lime and PMA was found to be more effective than the mixture of copper fungicides and PMA (Ogawa 1953). However, PMA was eventually banned because of its toxic effects on mammals and because it caused serious environmental problems (Ou 1985). It was suggested that rotating the use of fungicides, or mixing them, rather than continuously relying on a single compound, greatly reduced the risk of developing highly resistant populations (Uesugi 1978). Copper fungicides were found to be effective for rice blast control in India as well, but it was seen that high-yielding varieties were copper-shy; hence, the emphasis shifted to another group of fungicides, viz., dithiocarbamate and edifenphos, but they had shorter residual activity. In 1975 the first-generation systemic fungicides benomyl, carbendazim, and others were evaluated and found to be effective against rice blast. These fungicides have different modes of action, and include anti-mitotic compounds, melanin inhibitors, and ergosterol biosynthesis inhibitors to control blast disease (Siddiq 1996). The fungicides tricyclazole and pyroquilon, as seed dressers, have been found to be effective for providing protection to rice seeds for up to 8 weeks after sowing. Trials of Bavistin (50% carbendazim; 1 g/L spray) at tillering plus Hinosan (edifenphos; 1 g/L) at heading and after flowering resulted in the best yield. In the most recent field evaluation of commercial fungicidal formulations, Rabicide (tetrachlorophthalide), Nativo (tebuconazole + trifloxystobin), and Score (difenoconazole) were found to be most effective (Usman et al. 2009). Fungicides such as azoxystrobin, carpropamid, dithiocarbamate, edifenphos, fenoxanil, tiadinil, tricyclazole, pyroquilon, probenazole, iprobenfos, isoprothiolane, metominostrobin, and propiconazole have been found to control blast disease of rice (Skamnioti and Gurr 2009; Pooja and Katoch 2014).

5.3.3.4 Antibiotics

The first antibiotic that was found to inhibit the growth of rice blast fungus on rice leaves was cephalothecin, produced by a species of *Cephalothecium* (Yoshii 1949), followed by antiblastin (Suzuki 1954), antimycin-A (Harada 1955), blastmycin (Watanabe et al. 1957), and blasticidin-A (Fukunaga et al. 1968), all of which were tested, but due to their chemical instability and toxicity to fish, none of them was put to practical use. In 1955 a new systemic antibiotic, blasticidin S, produced by *Streptomyces griseo chromogenes*, was developed by Fukunaga et al. (1968). It was found to control blast effectively but it was an inferior protectant and was highly toxic to plants and mammals (Ou 1985). A new antibiotic, kasugamycin, produced by the bacterium *Streptomyces kasugaensis*, was discovered and isolated. It showed excellent control of rice blast and had very low toxicity in mammals and rice plants (Okamoto 1972). In the 1970s, after antibiotics had been used extensively and exclusively for blast control, *M. oryzae* began to show resistance to antibiotic compounds (Uesugi 1978). Katagiri and Uesugi (1978) reported mutants of *M. oryzae* that were resistant to different chemicals; resistance was highest for kasugamycin, followed by IBP (Iprobenfos), edifenphos, and isoprothiolane, and was lowest for benomyl.

5.4 Forecasting

Plank (1963) quoted that "Chemical industries and plant breeders forge fine tactical weapons but only epidemiology sets the strategy". Knowledge of the epidemiology of a disease can help to better implement disease management strategies. For the most economical and most effective use of fungicides, forecasting is essential; the forecasting is based on information on the fungus, host plant, and environment (Ou 1971). Using 13-year data, Padmanabhan (1963) concluded that whenever a minimum temperature of 24 C or below was associated with RH (Relative Humodity) of 90% or above, the conditions were favorable for blast infection. Refaei (1977) found that the number of blast lesions was more closely correlated with the dew point than with the number of airborne spores. Today a number of computer simulation-based forecast models are available, such as:

1. LEAFBLAST (Choi et al. 1988).
2. EPIBLAST (Kim and Kim 1993).
3. EPIBLA (Manibhushanrao and Krishnan 1991).

5.5 Host Resistance

Miyake and Ikeda (1932) reported that the cultivar Bozu, which was resistant to rice blast, contained a greater amount of silicon than a susceptible cultivar. Ito and Sakamoto (1939) found that resistance to mechanical puncture of the leaf epidermis was positively related to resistance to blast. Resistance was reduced by the application of nitrogen fertilizer but increased as the plant became older. Hori et al. (1960) reported that the distribution of starch in the leaf sheath was related to blast resistance. A greater accumulation of starch in the leaves of rice indicates greater resistance to blast disease. Kawamura and Ono (1948) were able to isolate *M. oryzae* from lesions, and they reported that pyricularin and α-picolinic acid produced by *M. oryzae* were toxic to rice plants and caused stunting of seedlings and leaf spotting. Tamari and Kaji (1955) reported that, when combined with chlorogenic acid or ferulic acid, which are both present in the rice plant, pyricularin and α-picolinic acid become nontoxic to the plants. Resistance to *M. oryzae* in rice is usually dominant and is controlled by one or a few pairs of genes (Thurston 1998). Link and Ou (1969) proposed a system of standardization of race numbers of *M. oryzae*.

5.6 Biotechnological Approaches

Biotechnological approaches used in the studies of genome organization and molecular analysis of the rice blast fungus *M. oryzae* have become more frequent (Valent and Chumley 1991). The mechanism of host pathogen interaction at the molecular level involves the mitogen activated protein (MAP) kinase and cyclic adenosine monophosphate (cAMP) signaling pathways (Xu and Hamer 1996). Further research has explored the identification, isolation, cloning, and characterization of the *R* and *Avr* genes of rice. Biotechnological tools have also been exploited for gene pyramiding through marker-assisted selection and for the identification and mapping of quantitative trait loci for partial resistance to blast. Today, a total of 73 *R* genes conferring blast resistance in rice have been identified. Many of them have been mapped, but only 5, viz. *Pi-b*, *Pi-ta*, *Pi-25*, *Pi-5*, and *Pi-9*, have been isolated and characterized using molecular techniques (Tacconi et al. 2010). Several techniques that have found applications in plant pathogen diagnosis have been developed; these include the use of monoclonal antibodies, enzyme-linked immunosorbent assays, and DNA-based technologies.

Table 5.1 Blast resistance genes and their rice cultivars at different genetic locations

S. No.	Gene	Rice cultivar	Location	References
01	Pib2	Lemont	Philippines	Tabien et al. (1996)
02	*Pi44*	Moroberekan	United States	Chen et al. (1999)
03	*Pi42(t)*	DHR9	India	Kumar et al. (2010)
04	*Pikg*	GA20	Japan	Pan et al. (1996)
05	*PiGD1*	Sanhuangzhan 2	China	Liu et al. (2004)
06	*Pikh (Pi54)*	Tetep	India	Sharma et al. (2005)
07	*Pi28(t)*	IR64	France	Sallaud et al. (2003)
08	*Pigm(t)*	Gumei 4	China	Deng et al. (2006)
09	*Pi-tq5*	Tequing	United States	Tabien et al. (2000)
10	*Pi30(t)*	IR64	France	Sallaud et al. (2003)
11	*Pi36*	Q61	China	Liu et al. (2005)

5.6.1 Blast Resistance Genes

Two main rice genera are cultivated in the world: *Oryza sativa* and *Oryza glaberrima*. In Asian countries *Oryza sativa* (an ancient crop species) is cultivated, while *Oryza glaberrima* is confined to African countries. Rice has encountered many biotic and abiotic stressors and these stressors have influenced its growth and development, so that cultivated rice lines show more uniformity than the wild genotype. This uniformity makes rice lines narrow, which favors the better survival of plant pathogens. Meanwhile, a large genetic pool remains unexplored; e.g., the blast-resistant genes *Pi9* from *Oryza minuta* (Sitch et al. 1989; Amante-Bordeos et al. 1992), *Pi-40(t)* from *Oryza australiensis* (Jena et al. 1991), and *Pirf2–1(t)* from *Oryza rufipogon* (Dwinita et al. 2008). The resistant genes are responsible for the resistance to blast disease of rice. The introgression of broad-spectrum blast resistance gene(s) from *Oryza rufipogon* into an *indica* rice cultivar has also been reported (Ram et al. 2007). In plants, resistance to a particular pathogen is governed by incompatible interactions, which follow the gene-for-gene hypothesis (Flor 1955). Gene-for-gene resistance is resulted from the interactions between products of the pathogen avirulence (*Avr*) genes and their matching plant resistance (*R*) genes. *Avr* genes have been cloned from a variety of pathogens including fungi, bacteria, viruses, and oomycetes. (Jones and Dangl 2006). The first cloned *Avr* gene of *M. oryzae* was the *PWL* gene family, consisting of four genes, viz., *PWL1, PWL3, PWL4* (Kang et al. 1995), and *PWL2* (Sweigard et al. 1995) (Table 5.1).

5.7 Future of Rice Blast Management

Molecular and biotechnological tools have changed research on rice blast management. The availability of genome sequences for both the host rice (Dean et al. 2005) and the pathogen has opened many doors for further research. A combination of disease-resistant cultivars, more efficient use of nitrogen fertilizers, and minimal doses of fungicides will lead to better management of blast disease in rice. Nanotechnology in agriculture could prove to be beneficial in future research and management. Studies of the *R* and *Avr* genes and their gene products will add to our knowledge of host-pathogen interactions. For the management of resistance to blast treatments, strategies such as gene rotation, gene pyramiding, spatial and temporal gene deployment, and the use of varietal mixtures will be the best means to reduce blast epidemics. The development and use of transgenic rice could be the best form of rice blast management in the future. The development of genetically engineered bioagents will supplement the environmentally friendly management of rice blast. However, there is still a need for the further development of noble fungicides and fungistatic agents with longer residual effects; this development could be better assisted by biotechnology in future.

5.8 Conclusions

The chemicals used to control blast disease of rice have a bad impact on soil health. The residues of these chemicals remain in the soil for a long time and this affects the soil microbiome. Moreover, these residues inhibit the activity of BCAs that are able to act against pathogens. Anthropogenic pollution affects human health both directly and indirectly. For the management of blast diseases of rice, to reduce the chemical load on the environment, the integration of bioagents and botanicals, along with the proper combination of required nutrients and water, as well as the use of the minimal dose of the required chemical, should be used. The application of the required doses of nitrogen and the proper amounts of silica slag in the field have been shown to increase rice resistance to blast disease. Disease forecasting also plays a crucial role in the management of disease. Scientists should focus on the development of new forecasting systems for the management of blast disease. Biotechnological approaches will also help to manage pathogens, and the exploration of blast-resistant genes should make it easy to develop resistant rice varieties. The best option to manage blast diseases in rice is to develop resistant cultivars. However, owing to the highly variable nature of pathogens, continuous research is needed to develop durable resistant cultivars that will be fruitful for farming communities. Yet the exploitation of durable host resistance still remains a challenge for plant pathologists, although scientists are keen to develop durable resistant varieties through the pyramiding of quantitative trait loci and major genes.

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