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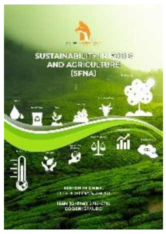

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REVIEW ARTICLE

BLAST DISEASE A MAJOR THREAT TO FOOD SECURITY: A REVIEW OF PATHOGEN AND STRATEGIES TO CONTROL

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ABSTRACT

Rice blast is caused by the fungi *Magnaporthe oryzae*, which belongs to the group *Ascomycota.* The disease cycle of rice blast begins with the infection of the plant tissue by the spores of the pathogen. The spores can be carried by wind, water, and insects, and can infect the plant at any growth stage, from seedling to the heading stage. Once the spore lands on the plant tissue, they germinate and penetrate the tissue through a specialized structure called appressoria. Inside the plant tissue, the fungus grows and produces lesions that appear as small grayish-white spots on the leaves, collar, neck, and panicle of the plant. Under favorable conditions, the lesions can enlarge rapidly, causing complete crop failure. The epidemiology of rice blasts is influenced by various factors, such as temperature, humidity, rainfall, wind, and varietal susceptibility. The pathogen can survive in the soil and plant debris for several months, providing a potential source of infection for the next crop. Several management strategies have been developed to control rice blasts, including cultural, botanical, nutrient management, biotechnological, and chemical methods. Chemical methods such as fungicides can be used to control the disease, but their use should be judicious to avoid the development of fungicide resistance and environmental pollution.

KEYWORDS

Magnaporthe oryzae, Disease control, Rice blast, Symptoms

1. Introduction

Rice (*Oryza Sativa*) is a vital crop that feeds over 50% of the world's population (Zhang, 2014). China is the largest rice-producing country with over 210 million metric tons followed by India, Indonesia, Bangladesh, Vietnam, etc (FAO, 2017). Rice production is hampered by numerous biotic and abiotic stresses, including pests, diseases, drought, acidity, salinity, and cold (Onyango, 2014). Despite globalization and development, climate change has been one of the major factors for the re-emergence of invasive pests that gradually leads to a decrease in the production of food crops (Saleh *et al.*, 2014). Rice blast disease caused by the fungus *Magnaporthe oryzae* (syn. *Pyricularia grisea*) has been a serious threat to rice plants as this pathogen leads to massive damage to up to 40% of rice plants. In Nepal, blast disease was first reported in Thimi, Bhaktapur in 1966 (Bhatt, 1966). Rice blast is the most destructive disease of rice and is hazardous as its yield loss potential is up to 100 % under favorable conditions (Kato *et al.*, 2004). Rice blast disease not only affects rice but also leads to diseases in other agriculturally significant crops such as wheat, barley, and finger millet. In Nepal, it is known locally as "Maruwa rog" (Acharya *et al.*, 2019), and different names are given to the disease such as leaf blast, collar rot, node blast, or panicle blast, depending on the portion of rice blast infected (Zeigler *et al.,* 1994). *Magnaporthe oryzae* belongs to the phylum Ascomycotina which has a vegetative stage as mycelium and a reproductive stage as conidia. Common symptoms of the blast are lesions or spots which are usually 1-1.5 cm long and 0.3-0.5 cm wide (NSW, 2012). Generally, this disease is favored by conditions such as long periods of leaf wetness, high relative humidity (>80%), and temperatures of about 15-20°C. The disease can cause significant economic losses for rice growers, making its control and management essential for maintaining food security.

2. Materials and Methods

This review article was based on the existing and accessible literature from journal articles, books, and reports. The information that was gathered was organized, and the conclusions are given in texts, tables, and figures with various headings.

3. Biology of Pathogen

Magnaporthe oryzae is also referred to as *Magnaporthe grisea* or *Pyricularia grisea* (Couch et al., 2002). The two pathogens infect different grasses, *Magnaporthe grisea* was found to infect crabgrass while *Magnaporthe oryzae* infect cereals like rice and millet. It is filamentous ascomycetes that can reproduce both sexually and asexually. Sexual reproduction occurs to form Perithecium which is a fruiting structure in which ascospores are formed (Dean et al., 2005). The asexual lifecycle begins when hyphae of fungus produce fruiting structures and sporulate to give conidia. The conidia of the fungus are of size 20-22×10-12 µm. Conidia are obclavate, translucent, two septate, slightly darkened and it is pointed at the apex (Devi et al., 2010)

4. Disease Cycle of Pathogen

The fungus infects the plant by spores germinating and forming an aspersorium (which is a thick fungal cell) on the plant's surface. Development of aspersorium when spores land on leaves and other aerial tissues of the susceptible plant. Pressure in the aspersorium increases

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resulting in the structure exploding forcing the penetration through the cell wall and into the cell (Dean et al., 2005). After the penetration of tissue, there occurs the development of invasive hyphae that get colonized quickly to living host cells, secretes effector molecules which leads to hinder the host immunity and spread the infection (Giraldo et al., 2013). The hyphae get changed into bulbous, branched infectious hyphae after they penetrate the plant. Initially, they fill the epidermal cells, and cylindrical hyphae infect adjacent tissue and leaf tissue which get colonized and affect the photosynthesis process of a plant (Sakulkoo et al., 2018). The fungus has the capability of replicating quickly by mitosis, and nuclear migration, and after the death of conidia, there occurs the production of appressoria which infects the aerial structure. Similarly, the hyphae produced are capable of infecting young seedlings and old rice plants. Here, the auto phagocytosis mechanism of death of conidia helps to control the cell cycle and to produce conidiophores which are dispersed to other plant tissue and plants with the help of wind and water. This will gradually reinitiate the infection cycle and again spores get attached and form appressorium (Agrios, 2005; Rosenzweig et al., 2005). A single lesion can be able to produce about 2000-6000 conidia per day for up to 14 days with multiple cycles during one growing season (Simkhada et al., 2022).

Mycelium and conidia survive through the infection of collateral hosts like *Eleusine coracana*, *E. indica, Panicum spp, Setaria spp,* etc which serve as primary sources of inoculums (MN Paudel, 2017). Primary infection is caused by the conidia produced on the collateral host which are disseminated by airwaves. When they arrived at to host leaf they get attached to the leaf surface and start infection and establish disease. Similarly, secondary infections occur from the conidia that are produced from the primary infection in the presence of water (dew drops) for germination. There may occur several secondary infection cycles:

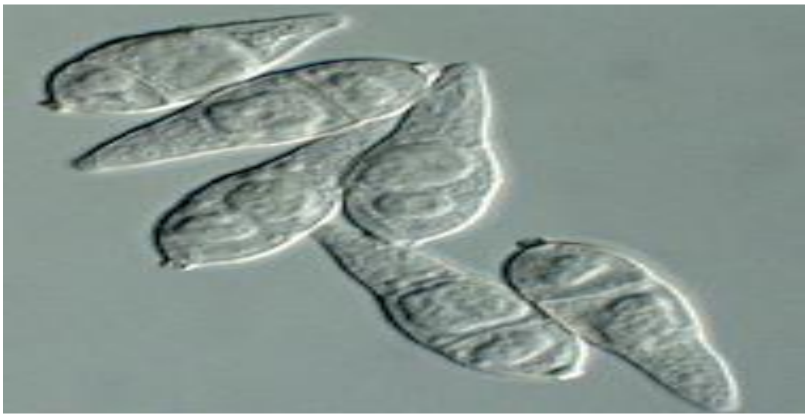

Figure 1: Shape and size of *Magnaporthe oryzae* conidia (Photo source:(Hubert et al., 2015))

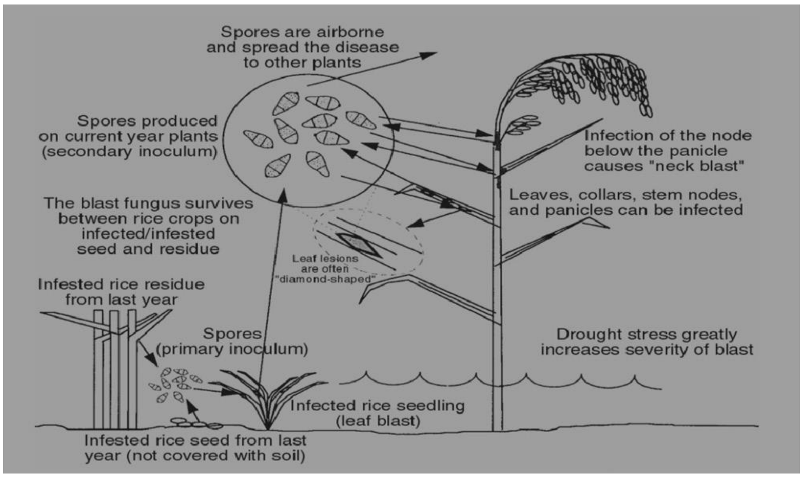

Figure 2: Disease cycle of *Magnaporthe oryzae* (Photo source: (Wamishe et al., 2013))

5. Symptoms

Being a crucial disease of the rice plant, blast fungus attack almost all the aboveground parts of the rice plant at all stage of growth. Blast fungus develops in nodes, leaves, collars, necks, panicles, seeds, and roots over the entire period of its growth. The major symptoms are briefly discussed below:

5.1 Leaf blast

A typical symptom of leaf blast is the appearance of a spindle or diamond shape lesion with a gray center and dark brown or reddish brown margin (Acharya et al., 2019). The lesion is 1 to 1.5 cm in length, 0.3 to 0.5 cm in width). The resistance variety of rice for this fungus develops the spot but is small in size and does not contain spores (Neupane et al., 2021). Lesions on the leaves coalesce and make leaves wither, mainly found at the seedling as well as tillering phase (Hajimok, 2001). This pathogen may cause loss of biomass up to 10% of infected leaf tips only in three days after the inoculation of fungus (Talbot et al., 1993).

5.2 Node/Culm Blast

The stem (culm) nodes are affected and they turn black or brown and a portion of the plant above the node soon dies. The infected node turns grey, shrivels, and breakdown as the xylem and phloem vessel of the plant is blocked which affects the nutrient and water supply to the portion above the infected point.

5.3 Collar Rot

Susceptible to blast fungus again begins when the rice plant reaches to reproductive stage. Collar rot can be seen massively during the reproductive stage. It is seen when the spores of fungus infect the base of the flag leaf near the leaf sheath (TeBeest et al., 2007). Later, these infection turns to grayish color lesion sometimes with brown border. After severe infection, these infected collar leaves eventually die and fall off (TeBeest et al., 2007).

5.4 Neck/Panicle Blast

Most damaging stage and it can occur without any significant damage to the leaves (Zhu et al., 2005). Infection on the neck causes triangular purplish lesions to elongate on both sides of the neck. The neck blast infects the panicle resulting in seed failure to fill or causing the whole panicle to fall over as it rots. The panicle will turn to white in contrast to the green of healthy grain when young necks are infected and later infection caused incomplete grain filling and low grain quality (Hajimok, 2001). Both neck and node blasts cause whiteheads which is similar to the infection done by a stem borer.

Figure 3: Symptoms of blast in rice plant leaves (Photo Source: IRRI Rice Knowledge Bank)

Figure 4: Symptoms of blast in nodes of rice plant (Photo Source: IRRI Rice Knowledge Bank)

Figure 5: Symptoms of blast in collar region of rice plant (Photo Source: IRRI Rice Knowledge Bank)

Figure 6&7: Symptoms of blast in neck and panicle region of rice plant (Photo Source: IRRI Rice Knowledge Bank)

6. Epidemiology

Magnaporthe oryzae is found in different parts of the world and the pathogen has more than 1,700 isolates from 40 countries (Divya et al., 2014). It is airborne conidia that exist all year round and is responsible for epidemics occurrence throughout the year (Guerber et al., 2006; Raveloson et al., 2018). The low night temperature (15-20 °C), high relative humidity (93-99%), and cloudy weather favor conidia germination, sporulation, and infection (Neupane et al., 2021). Blast development is favored by high nitrogen rates and thick stands which results in high moisture levels, but is most severe under drained or upland conditions. Research shows that the formation of appressorium was found to be 40% on a rainy day as compared to the rate of formation of appressorium on a normal day, i.e. 5%. This research concludes that the rainy season favors the growth of pathogens 8 times more than normal days (Suzuki, 1974). Host nutrition is also responsible for pathogen infection as susceptibility increases with the higher dose of nitrogen as more vegetative growth takes place during the early stage and increases the blast severity (Johnston T, 1970). Rice is also highly susceptible during a rapid tillering stage, seedling stage foliar infection, and ear or neck emergence stage for nodal and neck infection. Conidiophores produced from the autophagic cell are transmitted to nearby plants by wind, water splash, working tools, or plant contact starting a new infection cycle (Saunders et al., 2010; Veneault-Fourrey et al., 2006).

7. Management and Control

Management and control of pathogens greatly depend upon various factors which include the cropping area, ecosystem, climatic zones, cropping practices as well as the proper knowledge about the pathogen and its life cycle. Management of rice blasts can be conducted using various management strategies. These strategies include a wide range of cultural practices, biological control methods, host plant resistance methods, biotechnological, and chemical control methods, and many other IPM techniques.

7.1 Cultural Management

This is the oldest and most reliable control measure which involves all practices from sowing to after harvesting. Cultural practices will not provide complete eradication of the diseases but they provide control to some extent. Blast fungus is not easy to manage as it survives in unfavorable conditions so proper field sanitation by the destruction of weeds, summer plowing, use of wet seed bed, crop rotation, and removal of the collateral host is necessary (TeBeest et al., 2007). Timely burning of crop residues helps in managing inocula in the field, but this may not be enough to prevent inoculums coming from other sources (Zeigler et al., 1994). Application of the proper amount of Nitrogen fertilizer with the proper dose can also be helpful to prevent the disease incident. Studies show that the disease incident and severity of leaf blast were found to be significantly lower when the doses of Nitrogen were applied in three split doses as compared to high N- doses (Long et al., 2000). Planting time is seen to have a role in the development of blasts within a rice crop. So, early sowing of the seeds after the onset of monsoon is more advisable than late sown crops. Flooding of rice fields is done to control blasts as it creates an anaerobic condition which eliminates diseases as water makes the unfavorable condition for pathogens (Koutroubas et al., 2003). Broadcast sowing should be reduced as it can produce clusters of high plant densities due to non-uniform seed distribution, creating a favorable micro-climate for the development of rice blasts (Kato et al., 2004; Kingsolver et al., 1984). One of the effective methods to control the disease incidence is to use resistance variety which is sustainable and eco-friendly. Various genes resistant to rice blast have been used as resistance donors such as Piz, Piz-t, Pit, Pik, Pik-m, Pik-p, Pita, Pita-2, and Pib (CHEN et al., 2010). Similarly, various varieties using vertical and horizontal resistance are being developed against blast pathogens. Multiline varieties such as Nipponbare, Toyonishiki, Sasanishiki, etc have been identified and used (Horisue et al., 1984).

7.2 Chemical Control

Farmers depend highly on chemical fungicides because it is easily available and shows a quick response. Chemical spraying at three different stages of the plant i.e. tillering stage, boot leaf stage, and grain filling stage are important. Research carried out in Nepal found that Tricyclazole 22% and Hexaconazole 3% SC applied at intervals of 3 weeks from the booting stage have been effective to control blast and increment in the grain yield (Magar et al., 2015). Two systemic fungicides tricyclazole and benomyl are recorded to increase the grain yield over the control one by 42.17% and 18.14% respectively (Enyinnia, 1996). Spraying copper and organic mercury-based fungicides 5-6 times at 10-15 days intervals helps to control neck blast infection in various varieties (Padmanabhan et al., 1971). Chemicals such as Carbendazim, Isoprothiolane, Edifenphos, Iprobenfos, and Blasticidin (MN Paudel, 2017) are also used to control the blast fungus.

7.3 Biological Control

Biological control is inexpensive, long-lasting, and safe but it can be a slow process and require lots of time and effort to search for a suitable biocontrol agent (Law et al., 2017). Streptomyces bacteria, biocontrol agent *P. fluorescens* Pf7-14 produces antifungal chemical phenazine-1-carboxylic acid which can be very effective (Valasubramanian, 1994). Seed treatment by *Trichoderma virdi* @5 ml/ltr of water or *Pseudomonas fluorescens* @10 ml/ltr is effective against the leaf blast (Bhusal et al., 2018). Chemicals must not be used for a minimum of 15 days after treating the seed with a biocontrol agent as it stops the growth of Trichoderma or Pseudomonas. Research conducted in the Philippines shows that the bio fungicides formula produced by using indigenous antagonistic bacteria helps to improve the control of blast disease. Since these bacteria produce a mixture of antifungal compounds which can suppress the blast pathogen (Chen et al., 2010). It was also found that garlic extract at higher doses and neem extract at 4 ml/15 ml could suppress the mycelia growth of *Magnaporthe grisea* (Khanzada et al., 2012). Biocontrol agents which are to be used for control should be isolated from and applied to a location with similar environmental conditions (Suprapta, 2012).

7.4 Botanical Control

Chemical practices are highly effective but it has resulted in environmental hazards, so in this situation finding an alternative source is preferable (Ahamad et al., 2020). Garlic juice and Neem extracts are used to reduce the growth of *P. oryzae* in rice (Fry et al., 2005). Garlic contains an allicin compound that successfully inhibits blast fungus (Rajappan et al., 2001). According to (Hubert et al., 2015) various plant extracts are used in controlling rice blasts which are shown in the table below:

Table 1: Inhibitory Effects of Aqueous Extracts of Different Plants Against *P. oryzae* in %

Plant extract	Inhibitory effect (%)
Coffee arabica @10%	81.12
Coffee arabica @25%	89.4
Nicotiana tabacum @10%	80.35
Aloe vera @25%	79.45
Chrysanthemum coccineum @25%	78.83

Source:(Hubert et al., 2015)

7.5 Nutrient Management

Nitrogen(N) and Silicon (Si) elements majorly affect disease incidence and development. It is proven by the different experiments that heavy use of Nitrogen fertilizer creates a favorable condition for blast (Bonman et al., 1992; Kingsolver et al., 1984). The application of Nitrogen in split doses helps to reduce blast severity, by doing so it reduces excessive vegetative growth during the early season(TH et al., 1970). Silicon which is also known as a "beneficial element" for plant (Raij et al., 1973) when applied to soil act as a physical barrier against the blast (Ishiguro, 2001). Soil amendment with silica is responsible to reduce panicle blasts (Ahn et al., 1986). As an alternative source of silicon, locally available straws of rice genotypes could be used which have high silicon content (Marxen et al., 2016)

7.6 Biotechnological Method

Diseases forecasting computer model in many countries has been established to control disease incidents. These models predict or forecast the disease's incident according to the climatic condition, environmental factors, and weather-based scenes which have been effective in controlling the disease. Support Vector Model, Conventional REG approaches have been a boon for farmers against rice blast diseases. Biotechnological approaches such as Molecular diagnosis of the plant pathogen, analysis of molecular variability in plant pathogen, gene mapping using DNA markers, transgenic variety, and many other approaches have been developed to detect and control the pathogen (Taiga et al., 2009)

8. Conclusion

It is important to note that the use of chemical fungicides may have negative impacts on the environment and human health. Therefore, it is crucial to adopt sustainable and environmentally friendly methods for disease control. The use of biological control agents and host plant resistance varieties are two such methods that can be adopted. Biological control agents like *P. fluorescens* and *Chaetomium cochiliodes* are effective in inhibiting the growth of the rice blast fungus without harming the environment or human health. These biofungicides and biocontrol agents may take longer to show results compared to chemical fungicides, but they are safe and sustainable option. In addition to these methods, proper crop management practices like optimizing nitrogen inputs, water supply, and cultivar selection can also help reduce the severity of the rice blast disease.

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