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SHEATH BLIGHT OF RICE: A REVIEW OF HOST PATHOGEN INTERACTION, MANAGEMENT STRATEGIES AND FUTURE PROSPECTS

[a]**Waqar Ali**, [b]**Aasma**, [b]**Asim Mehmood**, [c]**Aqsa Amin**, [b]**Saif Ullah**, [b]**Faisal Sohail Fateh**, [b]**Muhammad Fayyaz**
[a] *Department of Plant Pathology, College of Agriculture, University of Sargodha, Sargodha, 40100, Pakistan.*
[b] Crop Diseases Research Institute, National Agricultural Research Centre, Islamabad, Pakistan.
[c] *Department of Plant Pathology, Pir Mehr Ali Shah Arid Agriculture University Rawalpindi, Pakistan.*

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ABSTRACT

This review article delves into the impact, epidemiology, and management of sheath blight disease in rice, caused by *Rhizoctonia solani*, which is a pernicious pathogen causing severe quality and production losses globally. Rice is a staple crop for almost two-thirds of the world's population, and sheath blight disease significantly affects rice cultivation in many countries, causing substantial annual losses in grain yield. The article provides comprehensive insight into the biology of the pathogen, including its host range, symptoms, disease cycle, and factors influencing its severity. In particular, the pathogen's virulence factors and the underlying mechanisms of its pathogenesis are explored in detail. The review also highlights the significant economic implications of sheath blight disease in rice and the consequent impact on food security and the livelihoods of farmers. Various management strategies, including chemical, cultural, and biological control measures, are discussed in this manuscript. These strategies offer potential solutions to mitigate the devastating effects of sheath blight disease on rice crops. In particular, the review emphasizes the importance of integrated pest management strategies that combine multiple control measures, including the use of resistant cultivars, fungicides, and cultural practices, to achieve long-term sustainable management of the disease. The manuscript concludes with recommendations for farmers, researchers, and policymakers working in agriculture sector to combat the disease's threat and reduce crop losses. The findings of this review article can serve as a valuable resource for stakeholders in the rice production industry to enhance their understanding of sheath blight disease and develop effective management strategies to protect the rice crop's health and yield.

Corresponding Author: Asim Mehmood
Email: asimmehmood520@gmail.com

INTRODUCTION

Rice (*Oryza sativa* L.), which belongs to the family Poaceae, is an important staple food crop in Pakistan. It is cultivated on an area of 2.8 million hectares, and its grain production is 6.8 million tons with an average yield of 2387 kg/ha in Pakistan (Rashid et al., 2014). Rice is the second most extensively consumed cereal grain after wheat, providing a key source of nutrition for almost two-thirds of the world's population. More than 2 billion people in Asia alone get around 80% of their nutrition from rice. Rice grains comprise about 80% carbohydrates, 7-8% protein, 3% fat, and 3% fiber

(Juliano, 1985). Rice starch is found in ice cream, custard powder, gel, and puddings, whereas rice bran is found in baked products, snacks, and biscuits. In addition, rice bran oil is rich in crucial amino acids, including arginine, cysteine, histidine, methionine, and tryptophan, as well as a number of minerals like magnesium, calcium, phosphorus, manganese, and nine B vitamins (Chaudhari et al., 2018). Rice husk is utilized in the board and paper sectors, while rice straw is used in a variety of applications such as animal feed, fuel, mushroom beds, mulch for horticultural crops, compost, and paper manufacture (Chaudhari et al., 2018; Abbas et al., 2021).

Different types of B-complex vitamins found in natural brown rice, such as thiamin, riboflavin, and niacin, can boost energy levels and help with the regeneration of blood vessels and skin. Purple and red rice bran contains anthocyanins and tannins that have antioxidant and anti-inflammatory properties. Tannins have been studied for their antimicrobial properties and their ability to protect against cancer and heart disease (Chaudhari et al., 2018). Rice bran also contains antioxidants such as oryzanols, tocopherols, and tocotrienols, which are all members of the vitamin E family (Lloyd et al., 2000). Tocotrienols can prevent or treat blood clots and lesions that can lead to stroke or thrombosis (Frei and Becker, 2004), and tocopherols and tocotrienols have anti-cancer properties (Kline et al., 2004).

According to accounts from about 20 years ago, the Hemadu and Luojiajiao regions are believed to have been the first to cultivate rice (Crawford, 2006). The soil in Hemadu, which is waterlogged and retains organic content, is ideal for producing large rice grains (Fuller et al., 2007). Some experts believe that the Hemadu people had a thriving agricultural industry focused on rice cultivation (Mou, 1980). It is worth noting that the oldest known rice domestication in Southeast Asia is not as old as previously thought, compared to the original domestication of rice in China (Glover, 1996).

Rice is cultivated on more than 150 million hectares of land across 114 countries, representing nearly 10% of the world's agricultural land. Although India has an area of 114 million hectares devoted to rice cultivation, it is the world's second-largest producer of rice, with an average yield of 2.6 tons per hectare, which is lower than China's production of 6.0 tons per hectare and the global average yield of 4.0 tons per hectare (Nath et al., 2015). Shaheen et al. (2022) reported that more than 755 million tons of rice is produced globally on approximately 162 million hectares of land.

The current manuscript reviews sheath blight of rice, which causes yield losses in northern regions and other parts of the world, and poses a significant threat to rice crops. In this review, we have discussed the importance, etiology, epidemiology, disease cycle, management strategies, and future prospects of this disease. The findings and recommendations presented in this manuscript will be valuable for farmers, researchers, and policymakers working in agriculture sector.

Sheath blight of rice

Sheath blight is a devastating rice disease caused by *Rhizoctonia Solani*, which causes quality and production losses worldwide (Lee, 1983). The disease was first discovered in Japan (Miyake, 1910) and has spread to countries cultivating rice in temperate and tropical climates, including Bangladesh, Brazil, Burma, China, Taiwan, Thailand, Nigeria, India, Iran, the UK, the USA, and Vietnam (Sivalingam et al., 2006). Other plants that may be harmed by this fungus include tomato, barley, maize, lettuce, and sorghum (Zhang et al., 2009). In China alone, the disease destroys about 15 to 20 million hectares of rice, causing a yearly loss of 6 million tons of grains (Qingzhong et al., 2001). According to an American study, susceptible cultivars may have a 50% reduction in productivity (Xue-Wen et al., 2008). Fungal sclerotia may persist in the soil for up to two years before spreading, particularly during rice crop preparation and irrigation (Greer and Webster, 2001). According to Anees et al. (2010), the pathogen is a typical saprotrophic soil organism and is not host-dependent.

Monoculture, or the practice of producing a single crop species across a vast region, might raise the risk of disease development and dissemination. A huge population, dense canopy, and extensive nitrogen management are all factors that can lead to disease development in rice crops. Sheath blight is the second most destructive rice disease in Japan, Taiwan, and the United States, behind rice blast (Singh et al., 2004). The use of nitrogen fertilizers and the development of high-yielding cultivars (HYV) can both lead to an increase in disease incidence (Savary et al., 1995). Many plant species from around 32 taxonomic groupings are vulnerable to the soil-waterborne pathogen that causes sheath blight (Gangopadhyay and Chakrabarti, 1982). *R. Solani* has been divided into 14 anastomosis groups (AG), demonstrating its genetic diversity (Carling et al. 2002a, b).

Symptoms

During the tillering stage, the fungus might appear as oval to irregular, greenish-gray spots with brown margins on the leaf sheath. These patches can be 1-3 cm long and, when present in great numbers, can resemble snake skin. When conditions are suitable, the initial infection often begins at the leaf sheath and progresses to the top of the plant, resulting in poor grain filling. The disease can also induce panicle infection, which results in the formation of empty or partly full, colorless grains with brown-black to pale grey patches (Acharya and Basu, 2012). Lesions, plant lodging, and the appearance of empty grains are all visible symptoms of the disease. Large lesions on the diseased leaf sheath of the lower leaf might weaken the plant stem and induce stem lodging (Wu et al., 2012).

Disease cycle

The fungus produces sclerotia or dormant mycelia, which may spread for up to two years through irrigation and field preparation, allowing it to persist in harsh settings without spores (Sumner, 1996). Water-soaked abscesses on the leaf sheath, right below the water line, are one of the first warning signs of the disease. When hyphae penetrate healthy plant tissues and develop new lesions and sclerotia on the leaf sheath, this is known as a secondary infection. When tissues in the rice canopy come into contact often when it is blossoming, the inoculum can spread quickly and create the perfect environment for disease development (Brooks, 2007). The disease can affect seeds or fully established plants, causing small to large yield losses, depending on what portion of the plant is affected. Water, mineral, and carbohydrate transport via the xylem and phloem tissues can become significantly hampered when the disease reaches epidemic levels, affecting grain filling (Wu et al., 2012).

The stages of rice infection, environment, varietal resistance, seasonal and cultural practices, as well as the amount of disease inoculum contained in plant waste from prior harvests in the crop's field or topsoil, all have an influence on the spread and intensity of SB (Gangopadhyay and Chakrabarti, 1982). Over 250 plant species, including important crops, are susceptible to infection by *R. solani* (Singh, Sunder, and Dodan, 2012). Sheath blight may spread both horizontally and vertically; under typical conditions, it can move around 20 cm per day. Through buoyant mycelia, sclerotia, or pathogen-bearing seed material, the pathogen can move from plant to plant and from one field to another. Basidiospores can also be transported by wind to new infection sites. The disease can spread when infected plants come into contact with healthy ones (Savary et al., 1995).

Epidemiology

Increased air temperature, moisture, and leaf wetness are all factors that lead to disease growth in rice fields (Castilla et al., 1996; Biswas et al., 2011). Studies show that disease incidence increases by 9.03%, 23.03%, and 61.05% based on the highest, minimum, and evaporation rate in the field (Lenka et al., 2008). The optimal temperature range for epidemic disease spread is between 25 and 30°C, with relative humidity between 80 and 100% (Bhukal et al., 2015). The average daylight hours within the first five days, followed by the average relative humidity and temperature, are essential determinants of the disease's vertical progression (Kumar et al., 2016). Furthermore, the infection progressed rapidly after injecting the pathogen into leaf sheaths. Researchers have also discovered that sandy soil is conducive to the diseases (Sarkar and Gupta, 2002). The maximum disease incidence occurs in damp soils with 50-60% water holding capacities, and the lowest incidence occurs in submerged soils with 100% water holding capacities. Rice seedlings are substantially more sensitive to the disease at 20-30 days old than at 30-40 days old when artificially infected, according to pot culture experiments (Sharma and Thrimurty, 2006).

Host nutrition

According to reports, the usage of nitrogen fertilizers promotes *R. solani* development (Tang et al., 2007). Increased nitrogen and phosphorus consumption may decrease the incubation time and increase phenolic content, which can enhance disease severity. On the other hand, increased usage of K, S, Zn, and Fe may have the opposite effect (Prasad et al., 2010). Soil amendments such as fertilizers and animal waste (Daisy, 2010), as well as the spray application of *Ganoderma*, can successfully reduce the sickness (Sajeena et al., 2008).

Host pathogen interaction

When a pathogen attacks a plant host, the host responds by complexly changing signaling pathways. The three main signaling pathways utilized in this process are salicylic acid (SA), jasmonic acid (JA), and ethylene (ET) (Kunkel and Brooks, 2002; Glazebrook, 2005). While the pathogen is frequently referred to as a necrotrophic fungal disease, it is crucial to remember that the host may exhibit a combination of necrotrophic and hemibiotrophic responses (Gonzalez et al., 2006). Kouzai et al. (2018) speculate that the infection may be hemibiotrophic. Furthermore, signaling that is sensitive to SA mediates resistance to biotrophic infections, whereas signaling that is responsive to JA mediates resistance to necrotrophs (Glazebrook, 2005; Browse, 2009; Oka et al., 2013).

Numerous methods are used by fungi to infect their host plants, and host plants produce antimicrobial compounds and activate complex signaling pathways to ward against various pathogens. The fungus may infect and spread by releasing effectors that get past the plant's defenses (Lo Presti et al., 2015). The secretome of the pathogen causing sheath blight has also been extensively documented for inhibitor I9-containing proteins (Anderson et al., 2017). A recent RNA sequencing study revealed that *R. solani* was present in the host plant both throughout the infection and post-penetration stages (Ghosh et al., 2018). Chen et al. (2018) established that two polygalacturonase genes play a major role in the pathogenicity of *R. solani* by inducing rice sheath necrosis through carbohydrate release. The importance of a novel polygalacturanses gene (AG1IA 04727) in SB pathogenicity has also been demonstrated (Rao et al., 2019). It has been shown that sclerotia production, pathogenicity, and pathogen proliferation are all decreased by altering the *R. solani* gene RGa1, which codes for a G protein component (Charoensopharat et al., 2008).

Differentially expressed genes (DEGs) have been shown to have a role in acetaldehyde catabolism, aldehyde dehydrogenase activity, and to vary significantly from DEGs in interactions between *R. solani* in rice and *R. solani* in maize and soybean in the outer area. This finding might help to shed light on how *R. solani* infects such a wide range of cultivated crops (Xia et al., 2017). The user-friendly database RS1ADB for the *R. solani* AG1-1A genome and transcriptome has been developed (Chen et al., 2016).

JA, lipoxygenase, and the octadecanoid signal transduction pathway are thought to be involved in signal transmission (Taheri and Tarighi, 2010). The metabolic defense against SB has been connected to carbohydrate metabolism. For instance, in resistant varieties, the pentose phosphate and glycolytic pathways are heavily activated against the pathogen, but this is not the case in susceptible varieties (Danson et al., 2000). A polyphenol ester and intermediary in the formation of lignin, chlorogenic acid, is also produced in greater quantities by resistant cultivars (Suharti et al., 2016).

Furthermore, the virus has developed mechanisms to reduce or detoxify host phytoalexins, such as the cruciferous phytoalexin camaalexin (Pedras and Ahiahonu, 2005). Less virulent isolates do not produce the host-specific RS toxins, which consist of glucose, mannose, and N-acetylgalactosamine (Vidhyasekaran et al., 1997). The susceptibility of host plants to pathogen toxins has been linked to their susceptibility to disease (Brooks, 2007). Disease-resistant rice varieties have been found to have higher levels of the rice osmotin gene OSM1 in response to pathogen infection, suggesting that the production of osmotin protein may be an essential component of the rice plant's chemical defense against SB (Xue et al., 2016).

Management strategies

Despite extensive research into the origins of SB resistance in rice plants, effective vertical resistance has only been produced in a few rice varieties, breeds, or closely related wild species on rare occasions (Nadarajah et al., 2014; Lore et al., 2015). Cultural approaches, such as increased plant spacing, removal of agricultural residue, and the use of legume crops, can significantly reduce SB infection. Silica and soil amendments containing organic manures, such as neem cake, have also been shown to be effective against SB and to increase grain yield (Rodrigues et al., 2003; Kumar et al., 2006).

Several reports have indicated that *P. fluorescens* strains exhibit systemic resistance to SB (Karthiba et al., 2014). Biopesticides, such as SA, gamma-aminobutyric acid (GAB), and chitosan, can be used as seed treatments and foliar sprays to boost resistance and reduce the severity of SB (Dantre and Rathi, 2007; Liu et al., 2012). Treatment of seeds with Bavistin and Benlate, and foliar application with Topsin-M, have all been found to reduce seed-borne disease and SB infection, while boosting rice grain yield (Das and Mishra, 1990). Systemic fungicides, particularly azoxystrobin, have also been shown to be beneficial in disease prevention and yield increase (Slaton et al., 2003).

A combination of synthetic chemicals, antibiotics, and biopesticides has been shown to be effective in the treatment of SB in the context of integrated disease management (Mew et al., 2004; Mukhtar et al., 2023). In the field, spore suspension of *T. viride* with 0.1%

carbendazim 50 WP (Surulirajan and Kandhari, 2012) and *T. harzianum* with edifenphos @ 0.05% (Ali and Pathak, 1997) have been shown to be particularly effective against SB when used as foliar sprays. Similarly, using tricyclazole with *Pseudomonas* strain GRP 3 resulted in a significant reduction in disease resistance (Pathak et al., 2004). Cover cropping with *Brassica juncea* has shown to reduce the need for fungicides for SB management and has been recommended as a potential component of a long-term disease control strategy, together with host resistance and azoxystrobin (Handiseni et al., 2015).

Future prospects

A research study has been conducted to better understand various aspects of SB. However, further research is needed to fully comprehend the pathogen's polymorphism, including the identification of host genes and the processes and genetics of resistance. It is also essential to continue studying the biochemical and molecular aspects of disease resistance and pathogenesis. To effectively control SB, it is necessary to identify resistant donors who display high levels of resistance to different anastomosis groups in natural conditions and use them. Cultural practices are used to reduce the pathogen's population in rice fields. It is important to understand the role of seed-borne inoculum and identify seed-dressing fungicides and appropriate geographic locations for the production of disease-free seeds. Since commercially available cultivars often lack sufficient resistance to SB, disease management primarily relies on chemical control. Various strategies, such as disease-resistant cultivars, cultural techniques, effective bio control agents and bio-pesticides, prediction systems, and fungicides, can be used to control SB depending on the severity of the disease.

AUTHORS' CONTRIBUTION

WA and SU conceived the idea; AM, AA and A arranged the information and wrote the manuscript; FSF and MF provided important and valuable suggestions and proofread the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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