Review Article

Rice Sheath Blight: A Review of Disease and Pathogen Management Approaches

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Abstract

Rice is an important food grain and is a staple food for majority of the world's population. To meet increasing global demand and consumption, rice productivity must be enhanced. However, biotic stresses such as diseases have impeded rice cultivation both in the tropics and subtropics. Of them, sheath blight is a major soil borne disease causing economic losses to rice cultivation. This article summarizes sheath blight (ShB) of rice, disease etiology and economics. Elaborative and updated accounts of various management options and their efficacy for ShB control are given. Specifically, the effects of popular cultural practices influencing ShB incidence, various chemical fungicides, and biological control individually and their combined effect on ShB are presented. The role of Plant Growth-Promoting Rhizobacteria (PGPR) and various genera of PGPR in ShB suppression are discussed. The present review also showed various aspects relating to ShB suppression by PGPR such as antagonism, competition for space and essential nutrients, and induction of systemic resistance. Integrated management of ShB involving all the compatible combinations is included in this review.

Keywords: Rice; Sheath blight; Fertilizers; Antagonism; Biological control

Importance of Rice Crop

The world's population is expected to surge from 6.1 billion in 2000 to 9.2 billion in 2050 [1]. A significant increase in predicted human population requires increasing crop yields to meet the requirements of the rising global demand for food. At current annual rate, the world population is expected to grow at 1.2% or approximately 77 million people per year [2]. Six countries, India, China, Pakistan, Bangladesh, Nigeria, and Indonesia, account for majority of the annual population growth. Of these, four countries, India, China, Pakistan, and Bangladesh, are major consumers of rice cereal. Regardless of major advances in agriculture science over the past 50 years, a significant number of the world's population suffer from hunger and undernourishment. Lack of balance between crop production and demographic food demand is due to existence of hunger and malnutrition [3,4]. With this population rise, it is expected that a corresponding food security problem will occur with the probability of losing agricultural land to industrialization and urbanization. Agriculture practices have incorporated greater part of world's available fertile farmland, which may limit further area expansion to low/non fertile land [5-7]. In addition to existing farmland problems, constrained farmland availability and identification of new plant diseases compound the challenges growers and scientists face globally to meet the nutritional requirements of the growing population.

Rice is a monocotyledonous annual grass, and belongs to the family *Gramineae* and the genus *Oryza*. *Oryza* includes 20 wild species and two cultivated species: *Oryza sativa* (grown throughout the world) and *Oryza glaberrima* (grown only in Africa) [8]. Globally, more than 3 billion people have rice as staple food, and it accounts for 50 to 80% of their daily calorie intake [9]. Over the next 20 years it is expected that demand for rice will grow by 2.5% per year [10]. Currently, China and India are ranked first and second in rice production according to Foreign Service Association of United States Department of Agriculture statistics [11]. Together they account for 51.4% of total world milled rice production.

Agriculture in the U.S. is diverse with the highest productivity when compared to other countries in terms of meeting its domestic food requirements and exporting a large amount of goods produced from a wide variety of crops [11]. Rice is no exception. Rice production in the U.S. is known to be diverse and includes all type of rice: short, medium, long grain and specialty rice [11]. Of the total estimate of world rice production of 450,200 thousand Metric tons (Mt), production in the U.S. accounts for up to 1.67% [11]. A significant part of the rice produced in the U.S. is exported in the international market, ranking the U.S. third among the leading global exporters of milled rice [11]. Each year in the U.S., 2.7 million acres of cultivation produce 19 billion pounds of rice, out of which approximately 50% is supplied to the domestic market (http://www.usarice.com/doclib/188/219/3674.PDF). Industrial and research advances have allowed the U.S. rice industry to flourish in a short time. In spite of successful adaptation of scientific developments and establishment of rice crop, pests and pathogens are inevitable and protective methods should be available to minimize the crop loss.

Sheath Blight of Rice

The world's huge rice agro-ecosystem, designed to feed the ever increasing human population, also provides a habitat for great number of pests and pathogens. Rice diseases can cause significant quality and yield losses and can be a threat to the U.S. rice export industry. Rice sheath blight (ShB), caused by *Rhizoctonia solani* Kuhn (Teleomorph: *Thanatephorus cucumeris* (Frank) Donk), is a destructive disease worldwide that causes significant yield loss and quality degradation [12,13]. Apart from rice, the pathogen also infects many other plant

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species, including barley, lettuce, tomato, sorghum, and maize [14]. A significant amount of achievable rice production is safeguarded from *R. solani* by using protection strategies. In their absence, rice ShB disease causes 10-30% yield loss [15] and may reach up to 50% during prevalent years [16]. In China only, about 15 to 20 million ha of rice growing area is affected, causing losses of 6 million tons of grains per year [15]. Planting ShB susceptible rice varieties in the U.S. resulted in yield losses of about 50% in trial plots [15,17]. In Arkansas, ShB was found present in 50-66% of rice fields, causing 5-15% yield losses in 2001 [18,19].

Rhizoctonia solani is a universal soil saprotrophic and facultative plant parasite [20,21]. The pathogen has limited movement due to lack of spores and survives in unfavorable conditions by forming sclerotia or dormant mycelia [21,22]. Sclerotia in soil can survive for 2 years, and are spread during field preparation and flooding the field for irrigation [23,24]. During permanent flooding the sclerotia may float and move within the field or to bordering fields through continuous flood irrigation. Sclerotia or hyphae attach to the plant, infecting and causing ShB disease, and the pathogen spreads under conditions favorable to disease development. Initial symptoms occur on leaf sheaths near the water line as water-soaked lesions. Secondary infections are caused by hyphae growing upward towards uninfected plant parts, producing additional lesions and sclerotia on leaf sheaths to complete the disease cycle [23,24].

The disease develop quickly during flowering when the rice canopy is most dense, forming a microclimate favorable to pathogen growth and spread [24]. *R. solani* can infect seed to fully mature plant, causing moderate to significant yield losses depending on the plant part affected. Visible plant disease symptoms include formation of lesions, plant lodging, and presence of empty grains. Large lesions formed on infected sheaths of lower rice leaves may lead to softness of the stem thereby initiating stem lodging [25]. Lodging alters the normal rice canopy design, affecting photosynthetic ability and total biomass production [25,26]. ShB presence during panicle initiation or flowering causes a reduction of total seed weight due to a lower percentage of filled spikelets and results in significant yield losses [13]. During rice sheath blight epidemics, severe lodging may occur, which obstructs the transportation of water, nutrients, and carbohydrate assimilates through the xylem and phloem channels, affecting grain filling [25]. Disease spread and intensity is dependent on the amount of infectious inoculum present in planting material and residues of previous crop remaining in the field or in the top soil where rice is grown. Other impact factors for ShB disease severity are rice development stage at infection, ecological surroundings, cultivar resistance, and cultural and seasonal crop practices [27,28].

The use of high rates of N fertilizer, double cropping, high plant densities, and early maturing, dwarf build, high tillering and susceptible varieties have been shown to enhance ShB severity in most of the world's rice growing areas [12,13]. In addition, plant morphological traits of rice cultivars are known to enhance ShB severity. Studies conducted on plant morphological characters and their relation with ShB development confirmed that plant height alters microclimate and light transmission inside the dense canopy, thereby facilitating disease development [29,30].

It is common for growers to apply rates of N higher than those recommended for rice. This results in lush green vegetative growth conducive to pathogen spread. Rice produces increased numbers of tillers when high N doses are applied, which increases its susceptibility to pathogens and insects. High N rates facilitate the ShB disease development and spread by increasing tiller density and moisture retention inside the rice canopy [30,31]. Therefore, N fertilizer management should be adopted for rice crop, which would increase nitrogen use efficiency during the growing season and diminish ShB disease concerns.

Sheath Blight Disease Management

Rice plants respond to various stresses in their surroundings by comprising attack by pests and pathogens like bacteria, fungi, virus, and nematodes. Plant defense responses correspond to the type of attacking external agent. The plant capacity to respond to an infection is determined by both the host and pathogen genetic traits [32]. To protect against pathogen infection plants have conferred various defense mechanisms such as, gene-for-gene interactions, and signal transduction networks that require jasmonic acid and ethylene [33,34]. However, a virulent pathogen overcomes a plant's defense mechanism by evading the effects of activated defenses, avoiding triggering plant defenses, or suppressing the plant's resistance reactions [35]. The virulent pathogen that escapes from the plant's natural defense will cause disease. A range of ShB disease control measures have been reported in the literature.

Cultural control

One approach to sustainable disease management without the use of chemicals is to develop disease-resistant cultivars. Benefits from disease-resistant cultivars include reduced disease incidence and increased grain and milling yields [36]. To date, resistance breeding efforts against ShB has been only moderately successful, mainly due to a lack of source for resistance in cultivated rice or in wild related species [24,37]. Nevertheless, rice cultivars ranging from susceptible to moderately resistant to ShB are available for cultivation. The development of new resistant cultivars was hampered through direct screening of germplasm because the fungal pathogen *R. solani* is plurivorous and semisaprobiotic [38]. Using molecular plant breeding programs, researchers manipulate the identified pathogen resistant genes to develop commercially resistant cultivar. So far, these attempts were ineffective and this may be attributed to the resistance being controlled by multiple genes or quantitative trait loci (QTLs) [39]. Although ShB resistance QTLs have been identified in 12 rice chromosomes, only few were mapped and most did not show any effect [40]. Current lack of effective resistant cultivars has led growers to rely increasingly on chemical fungicides.

Chemical control

Fungicides are widely used for combating rice ShB infection. Both systemic and non-systemic fungicides are available. Since systemic fungicide introduction in the 1960s, they generally provide better disease management than non-systemic products [32]. New products have been added to the market through fungicide research by agrichemical companies. Current fungicide research is mainly aimed at identification of suitable and novel target sites [32]. Several fungicides having novel modes and sites of action are available to growers for suppression o *R. solani*. At present, systemic fungicides belonging to the strobilurin group are used extensively to combat rice ShB pathogen.

Within the strobilurins group, azoxystrobin fungicide is widely used as it works effectively against ShB pathogen infestation [41]. The fungicide is a derivative of β-methoxyacrylate and was the first registered fungicide from this class of chemistry [42,43]. It is sold as Quadris 2.08 SC (Syngenta, Raleigh, NC). Azoxystrobin is considered one of the best fungicides in the U.S. for sheath blight control [43]. The mode of action of azoxystrobin is to inhibit electron transport and kill

the fungal pathogen [42,43]. Use of fungicide rate and composition is based on intensity of disease and the type of cultivars (susceptible/ medium susceptible/ moderately resistant) used. Benefits from fungicide control include lower disease incidence, likely reduction of inoculum, and improved grain and milling yields [44,45].

Research findings suggest the chance of a pathogen developing resistance to a particular chemical increases with regular use over a period of time [14,46]. The alternatives are to develop a new line of a chemical (fungicide) class that has no cross resistance to the chemical to which the pathogen developed resistance originally or to develop other preventative strategies free of chemicals. Manufacturing and releasing a new line of pesticide into the market are time consuming, expensive, and involve the risk of failure. Recently it was reported that only few chemicals have been introduced thereby creating shortage of pathogen control tools for most specialty crops [47]. One reason for this may be due to stringent pesticide regulations adopted by policy makers to prevent the use of chemicals considered too dangerous to human health and the environment.

Chemical control, though effective in managing disease, often has a significant impact on humans and the natural environment through the pollution of soils, above and below ground water resources, and the entire food supply chain. Human health and environmental protection regulations are strict. A major goal in developing a new fungicide is to ensure a good balance between potency and safety [48]. A fungicide that is effective against disease but fails to meet the area/topic regulations standardized by the representative group/organization may be banned completely from use. Furthermore, new pesticide should undergo constant reassessment, re-registration and changing guidelines of application techniques and residue levels [48].

A product that clears all regulations is patented and sold in the market. Patent time varies with the country of application. The success of the product is not guaranteed, as it may have competition from rival products, and it may develop pathogen resistance [32]. Each time a pathogen develops resistance to a pesticide in use, a replacement for the existing pesticide should be readily available. Due to the uncertainty of pathogen behavior to chemicals, it is necessary to develop non-chemical control methods.

Biological control using PGPR

Antagonism between organisms is common in the ecosystem and is most prevalent among soil microorganisms. Natural interference between beneficial soil microorganisms and plant pathogens results in zone of buffer, thereby inhibiting or reducing disease development [49]. Various microbial defense mechanisms may work independently or together, depending on the rhizosphere or phyllosphere characteristics. Managing soil-abundant beneficial microbes for the improvement of plant root and shoot growth and plant health is an exciting field. Microbial interactions in the rhizosphere influence plant health and soil fertility [50]. Advancements in biological control have led to identification and development of antagonistic bacteria with plant and root growth stimulating ability.

Rhizosphere-isolated, free living soil bacteria with proven plant beneficial properties are known as plant growth- promoting rhizobacteria (PGPR) [51]. Besides, PGPR role in increasing plant or root growth, they directly influence increased N uptake, phosphate solubilization, phytohormone synthesis, and production of iron chelating siderophores [25,52,53]. Some PGPR are used commercially to enhance plant growth and health. Seed treatment of rice with PGPR resulted in increased root and shoot length of seedlings [54].

PGPR are also known for biological control of various soil-inhabiting bacteria. PGPR are used in ecofriendly products. They are naturally available in the environment and provide resistance against a broad spectrum of pathogens [55]. The microbial populations in rhizosphere can be influenced by soil characteristics, agronomic practices, and plant type [55]. Inconsistent results of PGPR applications between the laboratory, greenhouse, and field studies can be due to changes in climate or soil [56]. An improved understanding of microbial population dynamics is needed before amending the farming practices to enhance plant growth and yield.

PGPR induce pathogen suppression by different modes of action such as antagonism, competition for space and essential nutrients, and initiation of systemic resistance (ISR) [25]. The concept of activating plants defense pathways to control pathogen infection is appealing, though difficult to implement effectively. Induced resistance occurs when a plant, once appropriately stimulated, exhibits an enhanced resistance upon challenge inoculation with the pathogen [57]. This type of resistance is mostly systemic in nature, spreading from point of infection to other distant plant parts [57]. PGPR might be more effective when combined with other ShB disease control methods through an integrated approach.

Moving forward with integrated disease management

In many countries rice is grown in the same field year after year, making it more susceptible to soilborne pathogens. Over time, pathogen inoculum accumulates in crop soil or surrounding fields and can cause epiphytotic disease. Over use or over dependence on chemical control or any other single control method is not sufficient to manage rice ShB. A systemic control approach uniting all ShB disease management options may produce better pathogen management. Integrated disease management (IDM) of rice ShB is broad-based, ecological plant pathogen control approach, combining all the available disease control methods with each method compensating the deficiencies of others [54]. IDM is recommended year round to monitor major crop programs. Regardless of any complete ShB resistance, growers may manage the disease using IDM. Forthcoming, educating farmers and disseminating information about effective and environmentally-sound IDM mitigate rice ShB pathogen damage while accomplishing sustainable farming. Although challenging, future research should also focus on identifying and developing cost effective complete resistance lines through conventional or molecular breeding.

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