



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(7): 1578-1583
Received: 24-05-2026
Accepted: 28-06-2026

Prajwal Chaudhary
Research Scholar, Haridwar
University, Roorkee, Uttarakhand,
India

Vipin Kumar Saini
Professor, Haridwar University,
Roorkee, Uttarakhand, India

Rohit Gangwar
Assistant Professor, Haridwar
University, Roorkee, Uttarakhand,
India

Deepak Kumar
Assistant Professor, Ganna
Utpadak Mahavidyalaya, Baheri,
Bareilly, Uttarakhand, India

Corresponding Author:
Prajwal Chaudhary
Research Scholar, Haridwar
University, Roorkee, Uttarakhand,
India

Role of resistant genotypes, fungicides and biological control agents in the management of brown leaf spot of rice

Prajwal Chaudhary, Vipin Kumar Saini, Rohit Gangwar and Deepak Kumar

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i7t.6164>

Abstract

Brown leaf spot of rice caused by *Helminthosporium oryzae* (*Bipolaris oryzae*) is among the most common fungal pathogens that attack *Oryza sativa* L. globally. Brown leaf spot of rice reduces grain yield and quality in environments of nutrient deficiency, drought and high humidity. Disease management requires an integrated approach which includes use of resistant hosts, careful use of fungicides and use of biological control agents that are not harmful to the environment. Use of resistant rice varieties provides the best economical and sustainable disease control method through reducing infection and decreasing use of chemicals. Fungicides such as triazoles and strobilurins remain important in disease control for the purpose of quick action and control during epidemic situations but excessive use of fungicides leads to development of resistance, contamination of environment and increases in production costs. Biological control agents include *Trichoderma harzianum*, *Pseudomonas fluorescens* and *Bacillus subtilis*.

Keywords: *Helminthosporium oryzae*, *Bipolaris oryzae*, resistant genotypes, fungicides, biological control agents, *Trichoderma harzianum*, *Pseudomonas fluorescens*, integrated disease management, sustainable agriculture, rice (*Oryza sativa* L.), brown leaf spot

Introduction

The plant *Oryza sativa* L., commonly known as rice, is an essential cereal crop and provides food to about half of the total population of the world. It not only contributes to food security and nutrition but also provides sustenance for millions of farmers especially in the Asian countries. Rice is the second-largest producer of the country India, and it forms a major part of the cultivated land and plays an important role in the economy of the nation. Rice production gets affected by various biotic and abiotic stresses, among them fungal diseases are major constraints. *Helminthosporium oryzae*, now known as *Bipolaris oryzae*, is a fungus responsible for causing brown leaf spot. It is the one of the oldest and most common fungal disease of the plant *Oryza*. This disease was earlier associated with the Bengal famine of 1943 and continues to affect yield and quality of rice grown in different parts of the world. The fungus affects rice at all stages of its growth cycle and produces small lesions of brown color on leaves, developing into circular or oval spots with gray or light brown center and dark brown margin. When there is a severe infection, the lesions merge to cause early drying of leaves, low photosynthesis, poor grain filling, bad seeds, and yield loss. Usually, the losses in yields amount to 10-30%. However, they can exceed 50% when favorable environmental conditions are present and where the host plant is highly susceptible. The occurrence and severity of brown leaf spot disease are greatly affected by environmental factors including high humidity, presence of continuous moisture in the leaves, temperature of 25 to 30 °C, poor soil fertility, and deficiency of critical elements such as nitrogen, potassium, silicon, and micronutrients. Repeated planting of rice, infection of the crop residue, infested seeds, and susceptible host plants increase the incidence of disease. Changes in climate have increased its incidence in many rice-growing regions. Fungicide treatment for the control of the disease gives satisfactory results for some time but it increases production costs, pollutes the environment, causes fungicide resistance among the pathogens, and leaves fungicide residue.

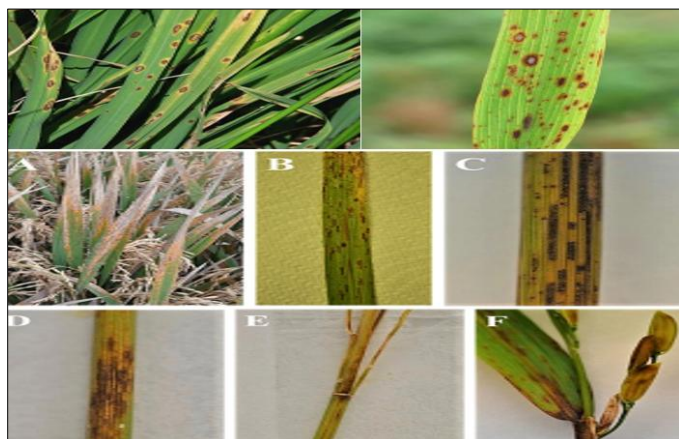
Hence, the sustainable disease management needs to be integrative and should include more than one approach. Resistance rice varieties are believed to be the most economical, ecological, and sustainable approach to the management of this problem. The presence of resistant genotypes does not involve additional expenses related to the production and does not harm the environment and can be used within the framework of integrated disease management. However, complete resistance is rare; moreover, the fungus shows high genetic variability; therefore, it is necessary to implement additional techniques to manage the disease. Fungicides still remain one of the most effective techniques of managing the disease during outbreaks. Systemic fungicides like triazoles and strobilurins as well as selected contact fungicides demonstrated their effectiveness against *Helminthosporium oryzae* under specific crop growth periods. Proper use of this technique within integrated disease management allows decreasing disease pressure and preventing resistance formation. One more promising method of controlling this fungal disease is biological control that can be described as an environmentally friendly and sustainable tool. Useful microorganisms such as *Trichoderma harzianum*, *Trichoderma viride*, *Pseudomonas fluorescens*, and *Bacillus subtilis* inhibit the development of this pathogen due to various processes (antibiosis, competition, mycoparasitism, systemic resistance of rice plants). Besides, biological control agents increase the growth of the plant and promote soil health. Combining resistant genotypes, efficacious fungicides, biological control agents, proper nutrition, disease-free seed, seed treatments, crop residues, and agronomic practices represents a holistic approach to managing brown leaf spot. The adoption of such an approach will lead to minimal reliance on chemical fungicides and increase disease suppression and quality grain yields, ensuring the production of sustainable rice crops. It is for this reason that this paper will review the contribution of resistant genotypes, fungicides, and biological control agents in managing brown leaf spot of rice caused by *Helminthosporium oryzae*.

Importance of Rice and Economic Significance

Fungicides provide quick and efficient suppression of the disease during the epidemic phase, saving the crop yield by using them at the right growth stage. Biological control methods include beneficial fungi and bacteria like *Trichoderma* species, *Pseudomonas fluorescens*, and *Bacillus subtilis* that suppress the pathogen via antagonism, competition, and plant defense response mechanism and minimize the severity of the disease without causing any harm to the environment. Use of these management options not only improves disease management but also cuts down on the cost of production, delays the onset of fungicide resistance, prevents pollution of the environment, and ensures sustainable development of the rice crop. Therefore, the use of resistant varieties, selective use of fungicides, and biological control agents is regarded as the best strategy for brown leaf spot disease. Rice (*Oryza sativa* L.) is a major cereal crop in the world and forms the staple food of more than 50% of the world's population. It is grown in varied agro-climatic zones and is an important crop for food security, nutrition, employment generation, and economic growth. In countries like India, rice accounts for a significant share in the agricultural GDP of the country. The productivity of rice is restricted due to many biotic stresses, and brown leaf spot disease caused by *Helminthosporium oryzae* (syn. *Bipolaris oryzae*) is one of them. Brown leaf spot is not only prevalent but also causes considerable yield loss to rice cultivation in many parts of the world. It infects rice seedlings and mature rice plants, resulting in brown spots on the leaves and decreasing photosynthesis, grain filling capacity, and ultimately the grain yield. Depending upon the environmental conditions, the yield losses due to this disease could be up to 10–40%. The disease can be controlled by using an integrated strategy based on resistant genotypes of rice along with fungicides and biological control agents. Resistant rice cultivars act as an environment-friendly strategy for reducing the incidence of this disease by limiting the use of chemicals.

Brown Leaf Spot Disease of Rice

S. No.	Aspect	Description
1.	Disease	Brown Leaf Spot of Rice
2.	Causative Organism	<i>Bipolaris oryzae</i> (Breda de Haan) Shoemaker, alternative name: <i>Helminthosporium oryzae</i> . It is a member of the phylum Ascomycota and one of the major fungal pathogens of rice.
3.	Symptoms of Disease	Small circular to oval dark brown spots occur on the leaves. The lesions increase in size and become elliptical spots with grey or light brown centers and dark reddish-brown borders. The symptoms caused by severe infection include leaf blighting, low photosynthesis, poor grain filling, seed color changes, and weak seedlings.
4.	Disease Cycle	The disease persists in infected seeds, crop residues, volunteer rice plants, and soil. Initial infection is caused by infected seed or crop residues. Conidia formed on the infected plant parts are spread through wind, rain splash, irrigation water, and insects. Subsequent infections take place continuously throughout the growing period.
5.	Epidemiology	The disease develops at temperatures of 25 – 30 °C, relative humidity of more than 90%, leaf wetness, rainfall, dense canopy, nutrient deficiencies (particularly potassium and silicon), drought, and susceptible varieties.
6.	Economic Damage	Brown leaf spot leads to 10–40% loss in grain production during the epidemics while a heavy incidence of this fungal disease can cause 50–90% damage in grain production in susceptible varieties. This disease decreases the quality of grain, germination capacity, milling yield, economic value, and income of farmers.
7.	Mode of Spread	Diseased seeds, air-dispersed conidia, splash dissemination, irrigation water, crop debris, and infected farm equipment
8.	Host Range	Specializes in rice (<i>Oryza sativa</i> L.) but can live on some types of grass and weeds, which act as an alternate host for the fungus.
9.	Methods of Management	Such as use of resistant varieties, clean seeds, seed treatment, balanced fertilization, crop residue disposal, cultural practices, proper irrigation, fungicidal spray, and biological control agents <i>Trichoderma harzianum</i> , <i>Pseudomonas fluorescens</i> , and <i>Bacillus subtilis</i> .



Interaction between Host and Pathogen

The interaction between the host and pathogen involves all biological, physiological, and molecular processes that take place after the pathogen attacks the host organism. In the case of rice (*Oryza sativa* L.), its interaction with the fungus *Bipolaris oryzae* (*Helminthosporium oryzae*), which causes brown leaf spot disease, decides the susceptibility or resistance of the plant to the pathogen. The development of disease is determined by the interaction between host and pathogen, environmental factors, and the defense mechanism of the plant. The infection process starts after the landing of the spores (conidia) of the fungus on the rice leaves under favorable environmental conditions. After germination, the conidia form germ tubes that penetrate into the leaf through the stomata, wounds, and natural openings with the

help of pressure and enzyme secretion. In the interior parts of the rice leaves, the fungus develops in the intercellular spaces, and the release of toxins and enzymes damages the host cells causing the development of brown spots with light centers. Such an infection process leads to a reduction in photosynthesis area that results in poor filling of grains, low quality, and low yields. For the restriction of pathogen invasion, rice has structural and biochemical defense systems. Structural defense includes a thick cuticle, wax layers, and enhanced cell walls that limit fungal penetration. Biochemical defense includes the production of reactive oxygen species (ROS), phenols, phytoalexins, lignin, and pathogenesis-related (PR) proteins such as chitinases and β -1,3-glucanases. The regulation of such a defense system is performed by plant hormones like salicylic acid (SA), jasmonic acid (JA), and ethylene (ET). The result of the interaction is dependent on the genetics of the rice plant and the pathogen. Resistant rice plants have resistance genes that detect effectors from pathogens and elicit immune reactions that inhibit growth of the fungi. Susceptible rice cultivars, on the other hand, lack a proper defense mechanism thus permitting rapid colonization and infection. Other factors like high moisture content, long wet leaves, temperatures of 25-30° C, improper nutrition especially potassium deficiency and drought conditions worsen the incidence of the disease. Host-pathogen interaction is crucial for formulating an effective disease management strategy. Understanding infection process, defense mechanisms of the host, and virulence of the pathogen will help in developing resistant rice genotypes and cultural management practices besides making the application of chemicals more efficient.

Role of Resistant Genotypes in the Management of Brown Leaf Spot of Rice

S. No.	Component	Description	Examples/Key Points
1.	Breeding Methods for Disease Resistance	Breeding for disease resistance involves the use of both conventional and molecular techniques to produce high yielding disease resistant varieties	Germplasm screening, crossing, recurrent selection, MAS, QTL stacking, genomic selection, CRISPR/Cas genome editing, participatory variety d
2.	Resistance Genetics	The resistance is quantitative in nature and involves many genes (polygenic or QTL-based) with some major resistance genes providing partial resistance. The resistance mechanism involves activation of pathogen recognition and synthesis of defense proteins.	Quantitative Trait Loci (QTLs), Pathogenesis-Related (PR) proteins, phenolics, lignin deposition, signaling pathways for salicylic acid (SA) and jasmonic acid (JA).
3.	Sources of Resistance	There are several resistant genotypes which include traditional landraces, wild rice varieties, breeding lines and improved varieties. These sources offer useful genes for resistance breeding.	<i>Oryza rufipogon</i> , <i>O. nivara</i> , traditional landraces, IRRI breeding lines, locally available resistant germplasm.
4.	Resistant Rice Varieties	Moderate to highly resistant cultivars will limit the occurrence of disease, prevent yield loss, and lower the use of fungicides	IR64, Swarna Sub-1, MTU-1010, Samba Mahsuri (moderately resistant), CO 51, ADT 43 (level of resistance depends on location)

The Role of Fungicides in the Management of Brown Leaf Spot in Rice

Management of brown leaf spot of rice caused by *Bipolaris oryzae* (synonym: *Helminthosporium oryzae*) involves the application of fungicides to complement disease management techniques that include resistant varieties, proper nutrient management, and agronomic practices. The timely application of fungicides reduces disease severity, avoids epidemic development and minimizes losses in terms of yield and quality of grain. Seed-treatment fungicides are the first option in controlling the pathogen. As *B. oryzae* is both seed-borne and soil-borne, the application of fungicides like carbendazim, thiram, captan, tebuconazole, or carboxin + thiram in seeds protects young seedlings from infection and enhances seed germination while reducing initial inoculum. Foliar fungicides are applied after crop emergence as soon as disease symptoms develop or during weather conditions favorable for disease development.

Systemic fungicides like propiconazole, hexaconazole, tebuconazole, azoxystrobin, and difenoconazole are absorbed by plants and protect plants from infection through their curative and protective actions by inhibiting growth of fungi. In addition, fungicides like mancozeb, chlorothalonil, and copper oxychloride that work at the surface of the leaves act as contact fungicides by preventing germination of spores and subsequent infection. In order to achieve lasting success, fungicides should be employed within the context of IDM. These entail alternation of fungicides with varying modes of actions, proper application of fungicide dosage at the right growth stages, avoidance of excessive use, and combination of chemical control with rice cultivars that are resistant to brown leaf spot, biological control measures, proper fertilizer management, and good cultural practices. Not only will the IDM approach reduce brown leaf spot disease incidence, but it will also increase yield and improve grain quality while delaying the emergence of fungicide resistance in pathogens.

Role of Biological Control Agents

BCAs play a significant role in the integrated management of brown leaf spot of rice due to *B. oryzae* (*Helminthosporium oryzae*). BCAs provide environmentally friendly ways to combat fungi without the use of chemical pesticides because BCAs suppress pathogens using biological methods. Application of BCAs can help reduce the presence of chemical pesticide residues and fungicide resistance in the environment. Beneficial microorganisms that effectively combat pathogens have been identified. Fungi *Trichoderma harzianum*, *T. viride*, and *T. asperellum*, as well as bacteria such as *Bacillus subtilis*, *Pseudomonas fluorescens*, and *Bacillus amyloliquefaciens*, are commonly used in the control of pathogens. Beneficial microorganisms inhibit the growth of pathogens using different methods: competition for food and space, antibiotic effects, production of extracellular enzymes, such as chitinases and glucanases, and mycoparasitism. Other than interfering with the pathogens directly, the biological control agents induce systemic resistance (ISR) in the plants thereby boosting the immunity of the plant. ISR causes activation of defense enzymes, accumulation of phenolic substances and phytoalexins, and increases the ability of the plant to withstand infection. The majority of biological control agents are used as plant growth-promoting microorganisms (PGPR). The biological control agents are best suited to be used in tandem with resistance varieties of rice, balanced nutrition, cultural practices, and use of fungicides as an Integrated Disease Management (IDM) approach. The combination of these practices will lead to long-lasting suppression of brown leaf spot and improvement in productivity and quality of the crops, as well as reduced pollution of the environment.

Integrated Disease Management (IDM)

IDM starts with planting disease-resistant or moderately resistant cultivars of rice, which minimizes chances for infection and disease pressure. Certified and healthy seeds free from diseases must be planted; the use of fungicides or biological products like *Trichoderma harzianum* and *Pseudomonas fluorescens* can help to destroy seed-borne inoculums and strengthen the germination of seeds. Cultural practices also play a significant role in IDM. They include planting non-host crops for pathogen alternation, destroying of infected residues of plants, the balanced fertilizer application (especially, potassium and silicon fertilizers), proper spacing, optimal irrigation regime, and timely planting of plants. All these practices help to create unfavorable conditions for pathogens development and spread. Chemical control is to be done in case of necessity. Seed treatment with fungicides like carbendazim or tebuconazole and spraying of plants with fungicides like propiconazole, hexaconazole, azoxystrobin or mancozeb at early stages of disease development provide effective suppression of the pathogen. Fungicides rotating with different modes of action can help to prevent development of fungicide resistance. Integrated Disease Management (IDM) is an environmentally safe and sustainable practice which employs the combination of various compatible methods of controlling the disease. The purpose of IDM is to reduce the incidence and severity of the disease and decrease reliance on synthetic fungicides with a view to increasing the productivity of the crop and maintaining the environmental safety. Regular field monitoring, disease forecasting, and intervention at an appropriate time are key aspects of the successful application of IDM. Resistant cultivar, biological control, proper agronomic techniques, optimal fertilization, and minimal use of fungicides offer effective, economical, and sustainable management of

brown leaf spot.

Recent Advances in Management of the Diseases

The recent advances in the management of brown leaf spot of rice caused by *Bipolaris oryzae* (syn. *Helminthosporium oryzae*) include the development of sustainable, targeted, and eco-friendly strategies that could help in reducing the incidence of disease and improving the productivity of rice. These innovations include the application of modern breeding methods, molecular techniques, biological control, precision agriculture, and digitalization in managing the diseases. One of the recent advancements in the management of the disease includes the development of disease resistant rice varieties using marker-assisted selection (MAS), QTL mapping, genomic selection and genome editing tools such as CRISPR/Cas9. In this way, the breeders can effectively identify and introgress resistance genes into their lines, thereby producing durable resistance to brown leaf spot. Biological control strategy has been improved with the development of enhanced formulations of bio agents such as *Trichoderma harzianum*, *T. asperellum*, *Bacillus subtilis*, *Pseudomonas fluorescens* and *Bacillus amyloliquefaciens*. The bioagents inhibit the growth of pathogen by antibiosis, competition, mycoparasitism and induce resistance in plants. Technological advancements in fungicides involve the introduction of novel active ingredients, combination fungicides which have more than one mode of action, nano-fungicides, and precision application techniques that increase efficacy while decreasing their environmental effect and fungicide resistance. Seed treatment technology has also advanced and offers longer period of protection during the initial stages of crop growth. Digital farming or precision farming is becoming more popular as far as disease scouting and management is concerned. Remote sensing, unmanned aerial vehicles or drones, satellite images, artificial intelligence (AI) and machine learning, and disease diagnosis using smartphones allow early disease detection and real-time scouting with accurate application of measures. Weather-based disease forecasting models and decision support systems improve prediction of diseases and application of fungicides. The combination of modern technologies such as those described above with resistant varieties, proper nutrition and cultural methods along with the use of biological agents increases efficiency of IDM system. Recent advancements make sustainable cultivation of rice possible with high grain yield and quality and decreased use of pesticides.

Conclusion

Brown leaf spot of rice, which is a result of infection with *Bipolaris oryzae* (syn. *Helminthosporium oryzae*), continues to be one of the most serious fungi diseases associated with the cultivation of rice across the world. The disease may lead to losses of grain yield and quality especially during conditions of deficient nutrients, drought, and high humidity. Successful management of brown leaf spot requires the knowledge of the pathogen, host-pathogen interaction, disease epidemiology, and other factors that impact the development of the disease. Integrated disease management (IDM) strategy is the most effective approach to control brown leaf spot disease. Using resistant varieties of rice represents the first level of defense, whereas balanced nutrients, healthy seeds, crop rotation, field sanitation, and irrigation prevent disease occurrence. Biological control is a good environmentally-friendly replacement for chemical control using *Trichoderma* spp., *Pseudomonas fluorescens*, and *Bacillus* spp. These methods reduce pathogen population and increase host resistance. Chemicals are used for disease control during

epidemic years, although this practice should be done with caution according to resistance management guidelines. Development of molecular breeding, marker-assisted selection, gene editing, precision farming, artificial intelligence, disease prediction, and biocontrol formulation has provided effective ways for brown leaf spot disease management. All these techniques help in early identification of the disease, development of resistant cultivars, and disease management, along with reduced impact on the environment. Some recommendations for future work could include discovery of new resistant genes, analysis of the pathogen variability, development of climate change-resistant rice plants, advancements in biological control, and integration of decision support technology in the management strategy. With the integration of advanced techniques and traditional agriculture, sustainable management of brown leaf spot disease can be achieved, leading to increased productivity of rice, improved grain quality, minimized use of fungicides, and food security under changing climatic conditions.

References

1. Abdel-Fattah GM, Shabana YM, Ismail AE, Rashad YM. *Trichoderma harzianum*: a biocontrol agent against *Bipolaris oryzae*. Mycopathologia. 2007;164:81-89.
2. Babu R, Jiang CJ, Xu X, Kottapalli KR, Takatsuji H, Miyao A, *et al.* Isolation, fine mapping and expression profiling of a lesion mimic genotype, spl NF4050-8 that confers blast resistance in rice. Theor Appl Genet. 2011;122:831-854.
3. Balai LP, Singh RB. Integrated management of *Alternaria* blight of pigeonpea with some fungicides and antagonists in pot condition. Bioscan. 2013;8(3):881-886.
4. Barnwal MK, Kotasthane A, Magculia N, *et al.* A review on crop losses, epidemiology and disease management of rice brown spot to identify research priorities and knowledge gaps. Eur J Plant Pathol. 2013;136:443-457.
5. Biswas C, Srivastava SSL, Biswas SK. Effect of biotic, abiotic and botanical inducers on crop growth and severity of brown spot in rice. Indian Phytopathol. 2010;63:187-191.
6. Chakrabarti NK. Epidemiology and disease management of brown spot of rice in India. In: Sreenivasaprasad S, Johnson R, editors. Major fungal diseases of rice: recent advances. Dordrecht: Kluwer Academic Publishers; 2001. p. 293-306.
7. Epstein E. Silicon: its manifold roles in plants. Ann Appl Biol. 2009;155:155-160.
8. Gade RM. Biological and chemical management of Phytophthora root rot/collar rot in citrus nursery. Bioscan. 2013;7(4):631-635.
9. Godoy CV, Koga LJ, Canteri MG. Diagrammatic scale for assessment of soybean rust severity. Fitopatol Bras. 2006;31:63-68.
10. James WC. An illustrated series of assessment keys for plant diseases, their preparation and usage. Can Plant Dis Surv. 1971;51:39-65.
11. Jonas B, Kathy S, Ingvar B, Shoshi K, Kayuki A, Monica H, David D. Primary metabolism plays a central role in molding silicon-inducible brown spot resistance in rice. 2015.
12. Joshi N, Brar KS, Pannu PP, Singh P. Field efficacy of fungal and bacterial antagonists against brown spot of rice. J Biol Control. 2007;21:159-162.
13. Kanokmedhakul S, Nasomjai P, Loungsysouphanh S, Soyong K, Isobe M, Kongsaree K, *et al.* Antifungal azaphilones from the fungus *Chaetomium cupreum* CC3003. J Nat Prod. 2006;69:891-895.
14. Kasem S. Bioformulation of *Chaetomium cochliodes* for controlling brown leaf spot of rice.
15. Lima GSA, Assunção IP, Martins RB, Santos HV, Michereff SJ. Development and validation of a standard area diagram set for assessment of *Alternaria* spot on the cladodes of the prickly pear cactus. J Plant Pathol. 2011;93:691-695.
16. Lorrain S, Vailleau F, Balagué C, Roby D. Lesion mimic mutants: keys for deciphering cell death and defense pathways in plants? Trends Plant Sci. 2003;8:263-271.
17. Ludwig J, Moura AB, Santos AS, Ribeiro AS. Seed microbiolization for the control of rice brown spot and leaf scald. Trop Plant Pathol. 2009;34:322-328.
18. Ma JF, Yamaji N. Silicon uptake and accumulation in higher plants. Trends Plant Sci. 2006;11:392-397.
19. Madden LV, Hughes G, Van den Bosch F. The study of plant disease epidemics. St Paul (MN): American Phytopathological Society Press; 2007.
20. Mina DK, Gade RM, Deshmukh AG. Antifungal activity of secondary metabolites produced by *Pseudomonas fluorescens*. Bioscan. 2013;8(2):723-726.
21. Mori M, Tomita C, Sugimoto K, Hasegawa M, Hayashi N, Dubouzet J, *et al.* Isolation and molecular characterization of a spotted leaf 18 mutant by modified activation-tagging in rice. Plant Mol Biol. 2007;63:847-860.
22. Ramteke PK, Kamble SS. Physiological studies in *Fusarium solani* causing rhizome rot of ginger (*Zingiber officinale* Rosc.). Bioscan. 2011;6(2):195-197.
23. Reddy CS, Laha GS, Prasad MS, Krishnaveni D, Castilla NP, Nelson A, *et al.* Characterizing multiple linkages between individual diseases, crop health syndromes, germplasm deployment and rice production situations in India. Field Crops Res. 2011;120:241-253.
24. Roxana Y, Parada W, Makoto U, Junichi K, Sakae A. Red-light-induced resistance to brown spot disease caused by *Bipolaris oryzae* in rice. 2014.
25. Sarkar D, Mandal R, Roy P, Taradari J, Dasgupta B. Management of brown spot disease of rice using safer fungicides and some biocontrol agents. 2014;9(1):437-441.
26. Savary S, Castilla NP, Elazegui FA, Teng PS. Multiple effects of two drivers of agricultural change, labour shortage and water scarcity, on rice pest profiles in tropical Asia. Field Crops Res. 2005;91:263-271.
27. Savary S, Nelson A, Sparks AH, Willocquet L, Duveiller E, Mahuku G, *et al.* International agricultural research tackling the effects of global and climate changes on plant diseases in the developing world. Plant Dis. 2011;48:1-40.
28. Savary S, Willocquet L, Elazegui FA, Castilla NP, Teng PS. Rice pest constraints in tropical Asia: quantification of yield losses due to rice pests in a range of production situations. Plant Dis. 2000;84:357-369.
29. Savary S, Willocquet L, Elazegui FA, Teng PS, Du PV, Zhu D, *et al.* Rice pest constraints in tropical Asia: characterization of injury profiles in relation to production situations. Plant Dis. 2000;84:341-356.
30. Savary S, Willocquet L, Elazegui FA, Teng PS, Du PV, Zhu D, *et al.* Rice pest constraints in tropical Asia: characterization of injury profiles in relation to production situations. Plant Dis. 2000;84:341-356.
31. Savary S, Willocquet L, Elazegui FA, Castilla NP, Teng PS. Rice pest constraints in tropical Asia: quantification of yield losses due to rice pests in a range of production situations. Plant Dis. 2000;84:357-369.
32. Savary S, Teng PS, Willocquet L, Nutter FW. Quantification and modeling of crop losses: a review of purposes. Annu Rev Phytopathol. 2006;44:89-112.
33. Spolti P, Schneider L, Sanhueza RMV, Batzer JC, Gleason

- ML, Del Ponte EM. Improving sooty blotch and fly speck severity estimation on apple fruit with the aid of standard area diagrams. *Eur J Plant Pathol*. 2011;129:21-29.
34. Thohinung S, Kanokmedhakul S, Kanokmedhakul K, Kukongviriyapan V, Tuszkorn O, Soyong K. Cytotoxic 10-(indol-3-yl)-[13]cytochalasans from the fungus *Chaetomium elatum* ChE01. 2010;33(8):1135-1141.
35. Vasudevan P, Kavita S, Priyadarisini VB, Babujee L, Gnanamanickam SS. Biological control of rice diseases. In: Gnanamanickam SS, editor. *Biological control of crop diseases*. 2002. p. 11-32.
36. Wu C. Heat shock transcription factors: structure and regulation. *Annu Rev Cell Dev Biol*. 1995;11:441-469.
37. Yadav NVS, de Vos SM, Bock CH, Wood BW. Development and validation of standard area diagrams to aid assessment of pecan scab symptoms on fruit. *Plant Pathol*. 2013;62:325-335.
38. Yamanouchi U, Yano M, Lin H, Ashikari M, Yamada K. A rice spotted leaf gene, *Spl7*, encodes a heat stress transcription factor protein. *Proc Natl Acad Sci U S A*. 2002;99:7530-7535.
39. Zeng LR, Qu S, Bordeos A, Yang C, Baraoidan M, Yan H, *et al*. Spotted leaf11, a negative regulator of plant cell death and defense, encodes a U-box/armadillo repeat protein endowed with E3 ubiquitin ligase activity. *Plant Cell*. 2004;16:2795-2808.