Kamel A. Abd-Elsalam
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We'd like to dedicate this book to Prof. Aly A. Aly, my father in agricultural research, for his guidance, direction, and pearls of wisdom, but more importantly, for putting up with my panic attacks and questions while providing amazingly timely feedback and encouragement precisely when needed, without which it would have been nearly impossible to produce this piece of work.

Kamel A. Abd-Elsalam and Heba I. Mohamed

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About the Editors

Kamel A. Abd-Elsalam, Ph.D., is currently a Research Professor at the Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt. Dr. Kamel's research interests include developing, improving, and deploying plant biosecurity diagnostic tools; understanding and exploiting fungal pathogen genomes, plant genome editing using CRISPR technique; and developing eco-friendly hybrid nanomaterials for controlling toxicogenic fungi, plant diseases, and nanobiotechnology applications in agroecosystems. He published 20 books related to nano-biotechnology applications in agriculture and plant protection, which were published by the world's major publishing houses such as Springer. He has published more than 160 scientific research articles in international and regional specialized scientific journals with a high impact factor and has an h-index of 36 and an i-10 index of 95, with 5206+ citations. In 2014, he was awarded the Federation of Arab Scientific Study Councils Prize for excellent scientific research in biotechnology (fungal genomics) (first ranking). In addition, according to Stanford University's worldwide database rating in 2021, Kamel A. Abd-Elsalam has been listed among the top 2% of the world's most influential scientists by Stanford University. Dr. Kamel earned his Ph.D. in Molecular Plant Pathology from Christian Albrechts University of Kiel (Germany) and Suez Canal University (Egypt), and in 2008, he was awarded a postdoctoral fellowship from the same institution. Dr. Kamel was a visiting associate professor at Mae Fah Luang University in Thailand, the Institute of Microbiology at TUM in Germany, the Laboratory of Phytopathology at Wageningen University in the Netherlands, and the Plant Protection

Department at Sassari University in Italy and Moscow University in Russia. **He was ranked within the top 2% of the most influential scientists in the world in nanobiotechnology for the year 2020 by Stanford University.**

Heba I. Mohamed is a Professor of Plant Physiology, Faculty of Education, Biological and Geological Sciences Department, Ain Shams University. Dr. Heba completed her M.Sc. and Ph.D. in Plant Physiology, Faculty of Education, Ain Shams University. Dr. Heba's research interests include biotic and abiotic stresses, plant biochemistry, use of eco-friendly compounds to alleviate plant stress, plant secondary metabolites, and genetic differences between different genotypes. She edited five books. She has published 24 book chapters, 5 review articles, more than 88 scientific research in international peer-reviewed journals, and has an h-index of 32 in Scopus. Dr. Heba is a reviewer of international peer-reviewed journals. She also is editor of the *Microbial Biosystems* journal. Dr. Heba has obtained a certificate of recognition in honor of achievement in international publication that supports Ain Shams University World. In addition, according to Stanford University's worldwide database rating in 2021, Heba I. Mohamed has been listed among the top 2% of the world's most influential scientists by Stanford University.

Part I

Identification and Diagnosis

1 An Introduction to Rice Diseases

Parteek Prasher and Mousmee Sharma

Abstract

Rice (*Oryza sativa*) represents the major food, feeding more than half of the world population every day. The dependence of such a large population to meet their daily dietary requirements on this tropical crop causes large-scale production in different parts of the world. Since the crop thrives comfortably in humid climates, the areas differing in such environmental conditions require the application of agrochemicals and require an extensive crop management programme to efficiently manage the diseases that hamper the crop's growth. The rice diseases, mainly caused by bacteria, fungi, and viruses, lead to significant damage and loss in the crop yield. The fungal diseases mainly attack stems, roots, grains, and foliage. The level of plant damage caused by these diseases depends on the innate capacity of the crop species to withstand the disease, severe environmental conditions, soil fertility and composition, the effect of agrochemicals, and the stage of plant growth. This chapter provides a concise discussion of the various diseases caused by bacteria, fungi, and viruses that impede rice crop growth.

Keywords

Oryza sativa · Diseases · Crop yield · Foot rot · Blast · Bacterial diseases · Fungal diseases

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1.1 Introduction

Disease is an abnormal condition of the plant species that deters the optimal functioning of its cells, tissues, enzymes, and biological and biochemical pathways (Nazarov et al. 2020). Disease in plants occurs via biotic factors or pathogens such as nematodes, bacteria, fungi, viruses, and mycoplasma. In addition, the abiotic or physical factors such as temperature, soil pH, nutrient deficiency, moisture content, presence of toxic elements in soil, water stress, heavy metal stress, and amount of light readily influence the plant's growth and development or the progression of diseased conditions (Hasan et al. 2020; Pautasso et al. 2012; Elad and Pertot 2014). The rice diseases cause an approximate 10% loss in annual production, with main diseases as 'blast' and 'helminthosporium' caused by *Pyricularia oryzae* Cav. and *Cochliobolus miyabeanus*, respectively (Asibi et al. 2019), while 'stem rot' and 'foot rot' diseases caused by *Leptosphaeria salvinii* Catt. and *Gibberella fujikuroi*, respectively, deter the production of rice adversely. The incidence of blast epidemic reportedly claims 60–70% loss in the rice production or even 100% crop loss in the individual fields (Nalley et al. 2016; Kihoro et al. 2013; Kirtphaiboon et al. 2021). Blast disease causes severe leaf infection, especially in the post-transplanting stage, causing total destruction of the foliage. Due to this disease, the half-filled rice earheads that form tend to break and fall off. The treatment of "foot rot" includes application of the seedlings with organo-mercurial fungicides (Kongcharoen et al. 2020), whereas the "blast" disease is much more widespread and requires immediate attention to prevent its spread. The popularisation of the breeding of resistant varieties of rice seedlings represents another desirable approach to prevent the outburst of diseases and to obtain a good yield (Laha et al. 2017; Miah et al. 2013; Dubina et al. 2020). Figure 1.1 illustrates the major diseases in rice. This chapter deals with a succinct discussion of the various diseases of rice and their causal pathogens.

1.2 Fungal Diseases in Rice

Nearly 20,000 fungal species reportedly cause plant diseases globally. These fungal species remain active or dormant on both living and dead tissues of the plants depending on the conditions favouring their growth and proliferation. Pathogenic fungi produce spores that, when dispersed by air, water, soil, invertebrates, and insects, may affect the whole crop. Certain fungi, such as mycorrhizae, provide significant benefits to plants by forming mutualistic relationships with their roots (Iqbal et al. 2021). Majority of the fungal species cause plant diseases, including rust, wily, blight, canker, leaf spot, anthracnose, mildew, and root rot. Fungal diseases such as rice blast serve as an alarming threat to global food security owing to their widespread distribution and destruction of the rice crop. *Magnaporthe oryzae* causes rice blast disease, which is the most devastating fungal disease, infecting the plant

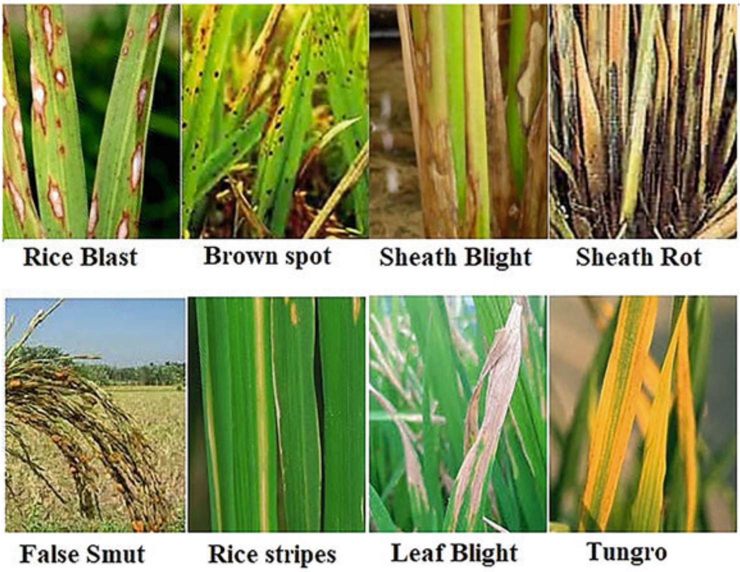

Fig. 1.1 Various diseases in rice crop that affect its yield

during all the growth stages and hampering the crop yield by 10–35%. Countering this pathogen encompasses cultural, biological, and molecular approaches that lead to the development of tolerant and resistant rice varieties by adopting effective breeding programs (Hirooka and Ishii 2013; O'Brien 2017; Sabri et al. 2020). Identification, isolation, and characterisation of several blast-resistant genes resulted in the emergence of allelic variants via molecular breeding and transgenic approaches such as miRNA and genome editing (Tabassum et al. 2021). Similarly, in the management of fungal resistance in rice, breeding techniques such as gene rotation, pyramiding, and multiline varieties proved highly profitable (Ramalingam et al. 2020). However, the co-evolution of the pathogens and their variable nature necessitate consistent research aimed at the advancement of sustainable, resistant cultivators. Table 1.1 presents the various fungal diseases in rice, their causal organisms, symptoms, and the affected plant parts.

1.3 Bacterial Diseases in Rice

Bacterial blight caused by gram-negative bacteria *Xanthomonas oryzae* pv. *oryzae* and bacterial leaf streak disease caused by the gram-negative bacteria *Xanthomonas oryzae* pv. *oryzicola* represent the deadliest bacterial disease in rice that affect the overall rice production worldwide (Yugander et al. 2017; Pradhan et al. 2020). Nevertheless, the rice plant too has adopted innate potency to counter the bacterial

Table 1.1 Symptoms and causal organism for the various fungal diseases in rice

Disease	Symptoms	Causing organism	Ref.
Rice blast	• Above ground parts of rice get effected • Elliptical or spindle-shaped legions occur on leaf blade • Lesions enlarge and coalesce eventually killing the leaf • Stem node turns blackish and becomes fragile • Brown lesions appear on branches of panicles and spikelets	*Pyricularia grisea*	Greer et al. (1997)
Sheath blight	• Ellipsoid or ovoid lesions appear on leaf sheath • Lesions coalesce and become bigger thereby causing leaf death • Waterline in the low land fields serve as favourable condition for fungal growth	*Rhizoctonia solani*	Li et al. (2021)
Brown spot	• Small, circular, brown coloured lesions on seedlings • Black discoloration of root occurs • Fungus causes dark brown to black oval spots on glumes • Black discoloration of grain occurs • Affected seedlings show stunted growth	*Bipolaris oryzae*	Shabana et al. (2008)
Leaf scald	• Zonate lesions, alternating light tan and dark brown spots starting from leaf edges • Enlargement and coalescing of lesions causes blight of leaf blade • Scalded appearance of leaf occurs	*Microdochium oryzae*	Manandhar (1999)
Narrow brown spot	• Short, linear, and brown lesions on leaf sheath, pedicels, and glumes • Net blotch-like pattern appears on leaf sheath as the cell wall turns dark brown, while intercellular areas turn tan to yellow • Diseases mainly appear in the mature stages of the rice crop	*Cercospora janseana*	Simanjuntak et al. (2020)
Stem rot	• Disease symptoms appear in the field after mild tillering stage • Small, blackish, irregular lesion appears on outer leaf sheath near water line • Fungus penetrates into the inner leaf sheath and causes partial/entire rotting • Fungus penetrates and rots the culm • Infection of the culm causes lodging, chalky grains, unfilled panicles, and death of the tiller • Infected stem contains dark greyish mycelium • Tiny, black sclerotia embed the diseased leaf sheath tissue	*Sclerotium oryzae*	Ghosh et al. (2020)

(continued)

Table 1.1 (continued)

Disease	Symptoms	Causing organism	Ref.
Sheath rot	• Leaf sheath containing young panicles gets rotted • Whitish powdery growth occurs inside affected sheath • Panicle fails to emerge as they remain inside the sheath • Grains become sterile, shriveled, and discoloured • Panicles that fail to emerge become rot • Florets turn red brown to dark brown	*Sarocladium oryzae*	Ayyadurai et al. (2005)
Bakanae	• Hypertrophic effect or abnormal elongation of plant occurs • Affected plants produce adventitious roots at the lower nodes of the culm • Affected plants contain very few tillers, and leaves dry quickly • Diseased tillers die quickly even before reaching maturity • Surviving infected plants bear empty panicles	*Fusarium fujikuroi*	Singh et al. (2019)
False smut	• Individual grains of the panicle turn into greenish spore balls with velvety appearance • Membrane around the spore balls eventually bursts as the spore grows while being enclosed in the floral parts • The outermost layer of the ball contains mature spores and the remaining fragments of the mycelium	*Ustilaginoidea virens*	Fan et al. (2020)

attack. The plant's immune response consists of dual mechanisms to counter the bacterial attack. Cell surface-localized pattern recognition receptors play a central role in the detection of pathogen-associated molecular patterns, including the highly conservative flagella of bacteria essential for sustaining the life of the pathogen (Mendes et al. 2018; Yuan et al. 2021a, b; Kim et al. 2020). These microbial components cause a variety of responses, including reactive oxygen species (ROS) generation, increased calcium ion concentrations, callose aggregation in the cell wall, activation of mitogen-activated protein kinases (MAPKs), and production of antimicrobial components such as phytoalexins (Jeandet 2015). Mainly, the broad-spectrum resistance shown by plants overcomes the intruding pathogens. It comprises a defence mechanism chiefly localised within the plant cell based on polymorphic resistance proteins that identify the specific virulence effectors secreted by the pathogens within the host cells, thereby prompting effector-triggered immunity (ETI) (Meng et al. 2020; Wang et al. 2016). ETI represents a robust resistance mechanism associated with cellular senescence at the infection site (Liu et al. 2013;

Table 1.2 Symptoms and causal organism for the various bacterial diseases in rice

Disease	Symptoms	Causing organism	Ref.
Bacterial blight	• Water-soaked lesions appear at the leaf margin • Increase in the size of affected region • Yellowish border appears between dead and green areas of the leaf • Withering of leaves or entire young plant occurs • Leaves become pale yellow at later stage of growth	*Xanthomonas oryzae*	He et al. (2010)
Bacterial leaf streak	• Water-soaked streaks appear between the leaf veins • Later, these become longer and translucent and become light brown coloured • Large areas of leaf become dry due to numerous streaks	*Xanthomonas oryzae*	Jiang et al. (2020)
Foot rot	• Infected plants become taller • Plants become thin, with yellowish green leaves • Seedlings dry at an early tillering • Partially filled grains	*Dickeya zeae*	Pu et al. (2012)
Grain rot	• Wilting and rotting of leaves • Discoloration of panicle • Shrivelled leaves • Lesions on seeds • Lesions on glumes	*Burkholderia glumae*	Zhou et al. (2016)
Sheath brown rot	• Appearance of necrotic areas on leaves • Discolouration of seeds occurs • Leaves show abnormal colours • Spikelets of emerging panicles become discoloured	*Pseudomonas fuscovaginae*	Razak et al. (2009)

Yuan et al. 2021a, b). This hypersensitive response serves as the strongest immune retort against the invading pathogen. Nonetheless, the approaches to mitigating the bacterial blight of rice present only trivial effectiveness. Chemical disease control is generally discouraged due to its environmental and human toxicity (Zhai et al. 2002; Amoghavarsha et al. 2021). The development of resistance among the pathogenic bacterial strains further questions the chemical methods of disease control (Ellur et al. 2016). Breeding of rice varieties with sturdy genes against the bacterial infection presents a viable option to ensure a healthy crop (Tao et al. 2021; Kumar et al. 2020a, b). The introduction of these genes to the genomes of commercial rice strains presents a highly desirable strategy to counter bacterial infection in the tropical countries that produce huge yields of rice every year (Wang et al. 2020; Oliva et al. 2019). Table 1.2 presents the various bacterial diseases in rice, their causal organisms, symptoms, and the affected plant parts.

1.4 Virus Diseases in Rice

In India, four virus types primarily affect the rice crop, with tungro being the most widespread virus disease affecting the rice crop in more than ten Indian states (Sharma et al. 2017; Nguyen et al. 2021). The virus diseases such as grassy stunt and strains such as GCV4 are confined to the southern part of the country (Ta et al. 2013; Zhao et al. 2021). Virus diseases like ragged stunt and necrotic mosaic are among the most damaging to rice production in India (Ghosh 1980; Bhattacharya et al. 2020). The majority of rice disease-causing viruses thrive in Asian and American continents, but rice stripe necrosis furovirus, maize streak germivirus, African cereal streak virus, rice yellow mottle sobemivirus, and rice crinkle disease persist in Africa and neighbouring countries (Awodero 1991; Liu et al. 2020). Intensified rice cultivation and the application of high-yield varieties, mechanical contamination, unregulated use of pesticides, fertilizers, and practise of crop monoculture serve as the determining factors for the evolution of virus diseases in rice (Ichiki et al. 2013; Rybicki 2015; Chen et al. 2020). The japonica rice varieties in the Americas and the Asian continents show vulnerability to the virus diseases, while the indica rice varieties show susceptibility to the virus-borne diseases (Cho et al. 2013; Orasen et al. 2020). Breeding and screening resistant rice varieties, plant quarantine, integrated pest management strategies, and the development of genetically engineered resistant rice varieties are all important approaches for effective disease management in rice (Savary et al. 2012; Chatterjee et al. 2021). Table 1.3 presents the various virus diseases in rice, their causal organisms, symptoms, and the affected plant parts.

1.5 Nematode Diseases in Rice

Nematodes predominantly cause a huge economic loss, mainly to two crops, maize and rice. The nematodes cause significant cellular changes inside the root-knot nematode-induced feeding sites upon interaction with the rice crop (Kyndt et al. 2014). The transcriptome analyses, exogenous hormone application, and mutant analyses suggested comprehensive models depicting the interactions of plant hormone pathways, such as jasmonate, in response to the innate defence adopted by rice against nematodes (Zhou et al. 2020; Gheysen and Mitchum 2019; Wang et al. 2014a, b). The nematodes represent soil-borne pathogens that pose a threatening loss to rice cultivators due to the emergence of new cultivation practises that include less water usage for growing the rice crop (Khan and Ahamad 2020). Reportedly, the nematode pathogens cause an alarming 10–25% loss to the rice crop worldwide (Kumar et al. 2020a, b). The havoc of pathogenic nematodes is mainly confined to tropical and subtropical regions with a large variety of species (Porazinska et al. 2012; Reddy 2021). In addition, the lack of proper resources for effective crop management and control and the ideal conditions for the thriving of nematode populations serve as determining factors for the nematode diseases in the rice crop grown in these areas (Prasad et al. 1987; Khan et al. 2021). Table 1.4 presents the

Table 1.3 Symptoms and causal organism for the various virus diseases in rice

Disease	Symptoms	Causing organism	Ref.
Tungro	• Affected areas exhibit stunted growth and reduced tillering • Leaves become orange-yellow coloured and develop rust-coloured spots • Leaf become discoloured starting from the tip that extends till the lower part of leaf blade • Young leaves display mottled appearance • Old leaves show rust-coloured specks of various sizes • Affected plants show a delayed flowering • Panicles bear partially filled grains covered with dark brown specks • Transmitted by green leafhoppers	*Rice tungro bacilliform virus* and spherical virus	Zarreen et al. (2018)
Grassy stunt	• Plant show severe stunting • Plants show excessive tillering • Leaves may be mottled or striped • Transmitted by brown plant hopper	Rice grassy stunt virus	Satoh et al. (2013)
Ragged stunt	• Plant show severe stunting • Plants show reduced tillering • Leaves show ragged appearance • Leaf blades twist to form a spiral • Vein swelling appear on leaf sheath, leaf blade, and culm • Transmitted by brown plant hopper	*Rice ragged stunt virus*	Wang et al. (2014a, b)

Table 1.4 Symptoms and causal organism for the various nematode diseases in rice

Disease	Symptoms	Causing organism	Ref.
Ufra or stem nematode	• Affected seedlings and plant show chlorosis • Stunted plant growth • Deformation and twisting of leaves occur • Exserted panicles, with unfilled grains	*Ditylenchus angustus*	Ali and Ishibashi (1996)
White tip	• Chlorosis of leaf occurs • Infected leaf dries up and shreds • Flag leaf becomes twisted • Panicles do not emerge • If panicles emerge, they display high sterility, distorted kernels, and distorted glumes	*Aphelenchoides besseyi*	Ou et al. (2014)
Root knot	• Infected plants display stunted growth and become yellow • Infected plants show reduced tillering • Infected plants show the appearance of root galls • Disease mostly occurs in upland, as compared to the lowland rice	*Meloidogyne graminicola*	Tian et al. (2018)

various virus diseases in rice, their causal organisms, symptoms, and the affected plant parts.

1.6 Conclusion

Oryza sativa, grown mainly as an annual plant, survives as a perennial crop in tropical areas. The rice crop in these areas faces vulnerability to a variety of diseases caused by bacteria, fungus, and nematodes, mainly due to the climatic conditions. Excessive use of fertilizers and chemicals to increase crop production and yield in order to feed the world's population exacerbates the crop's susceptibility to disease. The overuse of chemicals increases the incidence of microbial resistance and causes biomagnification in the higher trophic levels. However, plant breeding techniques, integrated pest management, biological methods of crop management, genome culturing, and the cultivation of resistant varieties of rice have contributed towards the effective management of rice disease. The production of flood-resistant rice, drought-resistant rice, and salt-tolerant rice also made sure there was enough of the crop to go around.

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References

Ali MR, Ishibashi N (1996) Growth and propagation of the rice stem nematode, *Ditylenchus angustus*, on rice seedlings and fungal mat of *Botrytis cinerea*. Jpn J Nematol 26:12–22

Amoghavarsha C et al (2021) Chemicals for the management of paddy blast disease. In: Nayaka SC, Hosahatti R, Prakash G, Satyavathi CT, Sharma R (eds) Blast disease of cereal crops. Fungal biology. Springer, Cham. https://doi.org/10.1007/978-3-030-60585-8_5

Asibi AE, Chai Q, Coulter JA (2019) Rice blast: a disease with implications for global food security. Agronomy 9:451

Awodero VA (1991) Rice yellow mottle virus in west Africa. Trop Pest Manag 37:356–362

Ayyadurai N, Kirubakaran SI, Srisha S, Sakthivel N (2005) Biological and molecular variability of *Sarocladium oryzae*, the sheath rot pathogen of rice (*Oryzae sativa* L.). Curr Microbiol 50:319–323

Bhattacharya S, Mukherjee A, Phadikar S (2020) A deep learning approach for the classification of rice leaf diseases. In: Bhattacharyya S, Mitra S, Dutta P (eds) Intelligence enabled research. Advances in intelligent systems and computing, vol 1109. Springer, Singapore. https://doi.org/10.1007/978-981-15-2021-1_8

Chatterjee S, Gangopadhyay C, Bandopadhyay P, Bhowmick MK, Roy SK, Majumder A, Gathala MK, Tanwar RK, Singh SP, Birah A, Chattopadhyay C (2021) Input-based assessment on integrated pest management for transplanted rice (*Oryza sativa*) in India. Crop Prot 141:105444

Chen J, Zhang D, Nanehkaran YA, Li D (2020) Detection of rice plant diseases based on Depp transfer learning. J Sci Food Agric 100:3246–3256

Cho WK, Lian S, Kim S-M, Park S-H, Kim K-H (2013) Current insights into research on *Rice stripe virus*. Plant Pathol J 29:223–233

Dubina EV, Kostylev PI, Garkusha SV, Ruban MG (2020) Development of blast resistant rice varieties based on application of DNA technologies. Euphytica 216:162

Elad Y, Pertot I (2014) Climate change impacts on plant pathogens and plant diseases. J Crop Improv 28:99–139
Ellur RK, Khanna A, Yadav A, Pathania S, Rajashekara H, Singh VK, Krishnan SG, Bhowmick PK, Nagarajan M, Vinod KK, Prakash G, Mondal KK, Singh NK, Prabhu KV, Singh AK (2016) Improvement of basmati rice varieties for resistance to blast and bacterial blight diseases using marker assisted backcross breeding. Plant Sci 242:330–341
Fan J, Liu J, Gong Z-Y, Xu P-Z, Hu X-H, Wu J-L, Li G-B, Yang J, Wang Y-Q, Zhou Y-F, Li S-C, Wang L, Chen X-Q, He M, Zhao J-Q, Li Y, Huang Y-Y, Hu D-W, Wu X-J, Li P, Wang W-M (2020) The false smut pathogen *Ustilaginoidea virens* requires rice stamens for false smut ball formation. Environ Microbiol 22:646–659
Gheysen G, Mitchum MG (2019) Phytoparasitic nematode control of plant hormone pathways. Plant Physiol 179:1212–1226
Ghosh SK (1980) Rice necrosis mosaic. Proc Plant Sci 89:291–299
Ghosh T, Pradhan C, Das AB (2020) Control of stem-rot disease of rice caused by *Sclerotium oryzae* catt and its cellular defense mechanism—a review. Physiol Mol Plant Pathol 112:101536
Greer CA, Scardaci SC, Webster RK (1997) First report of rice blast caused by *Pyricularia grisea* in California. Plant Dis 81:1094
Hasan RI, Yusuf SM, Alzubaidi L (2020) Review of the state of the art of deep learning for plant diseases: a broad analysis and discussion. Plan Theory 9:1302
He Y-W, Wu J, Cha J-S, Zhang L-H (2010) Rice bacterial blight pathogen *Xanthomonas oryzae* pv. *oryzae* produces multiple DSF-family signals in regulation of virulence factor production. BMC Microbiol 10:187
Hirooka T, Ishii H (2013) Chemical control of plant diseases. Australas Plant Pathol 79:390–401
Ichiki TU, Shiba T, Matsukura K, Ueno T, Hirae M, Sasaya T (2013) Detection and diagnosis of rice-infecting viruses. Front Microbiol 4:289
Iqbal MT, Ahmed IAM, Isik M, Sultana F, Ortas I (2021) Role of mycorrhizae inoculations on nutrient uptake in rice grown under aerobic and anaerobic water management. J Plant Nutr 44: 550–568
Jeandet P (2015) Phytoalexins: current progress and future progress. Molecules 20:2770–2774
Jiang N, Yan J, Liang Y, Shi Y, He Z, Wu Y, Zeng Q, Liu X, Peng J (2020) Resistance genes and their interactions with bacterial blight/leaf streak pathogens (*Xanthomonas oryzae*) in rice (*Oryza sativa* L.)—an updated review. Rice 13:3
Khan MR, Ahamad F (2020) Incidence of root-knot nematode (*Meloidogyne graminicola*) and resulting crop losses in paddy rice in northern India. Plant Dis 104:186–193
Khan MR, Haque Z, Zaidi AB (2021) Biomanagement of rice root-knot nematode *Meloidogyne graminicola* using five indigenous microbial isolates under pot and field trials. J Appl Microbiol 130:424–438
Kihoro J, Bosco NJ, Murage H, Ateka E, Makihara D (2013) Investigating the impact of rice blast disease on the livelihood of the local farmers in greater Mwea region of Kenya. Springer Plus 2: 308
Kim W, Prokchorchik M, Tian Y, Kim S, Jeon H, Segnzac C (2020) Perception of unrelated microbe-associated molecular patterns triggers conserved yet variable physiological and transcriptional changes in *Brassica rapa* ssp. *pekinensis*. Hortic Res 7:186
Kirtphaiboon S, Humphries U, Khan A, Yusuf A (2021) Model of rice blast disease under tropical climate conditions. Chaos Soliton Fract 143:110530
Kongcharoen N, Kaewsalong N, Dethoup T (2020) Efficacy of fungicides in controlling rice blast and dirty panicle diseases in Thailand. Sci Rep 10:16233
Kumar A, Kumar R, Sengupta D, Das SN, Pandey MK, Bohra A, Sharma NK, Sinha P, Hajira AK, Ghazi IA, Laha GS, Sundaram RM (2020a) Deployment of genetic and genomic tools towards gaining a better understanding of Rice-*Xanthomonas oryzae* pv. *oryzae* interactions for development of durable bacterial blight resistance rice. Front. Plant Sci 11:1152
Kumar V, Khan MR, Walia RK (2020b) Crop loss estimations due to plant-parasitic nematodes in major crops in India. Natl Acad Sci Lett 43:409–412

Kyndt T, Fernandez D, Gheysen G (2014) Plant-parasitic nematode infections in rice: molecular and cellular insights. Annu Rev Phytopathol 52:135–153

Laha GS et al (2017) Importance and management of rice diseases: a global perspective. In: Chauhan B, Jabran K, Mahajan G (eds) Rice production worldwide. Springer, Cham

Li D, Li S, Wei S, Sun W (2021) Strategies to manage rice sheath blight: lessons from interactions between rice and *Rhizoctonia solani*. Rice 14:21

Liu W, Liu J, Ning Y, Ding B, Wang X, Wang Z, Wang G-L (2013) Recent progress in understanding PAMP- and effector-triggered immunity against the rice blast fungus *Magnaporthe oryzae*. Mol Plant 6:605–620

Liu X, Cai W-J, Yin X, Yang D, Dong T, Feng Y-Q, Wu Y (2020) Two slender and crinkly leaf dioxygenases play an essential role in rice shoot development. J Exp Bot 71:1387–1401

Manandhar JB (1999) Isolation of *Microdochium oryzae* and *Pinatubo oryzae* from rice seeds and their survival on stored seeds. Eur J Plant Pathol 105:139–145

Mendes GPA, Adjemian S, Branco LM, Zanetti LC, Weinlich R, Bortoluci KR (2018) Pattern recognition receptors and the host cell death molecular machinery. Front Immunol 10:3389

Meng X, Xiao G, Yanoria MJT, Siazon PM, Padilla J, Opulencia R, Bigirimana J, Habarugira G, Wu J, Li M, Wang B, Lu G-D, Zhou B (2020) The broad-spectrum rice blast resistance (R) gene Pita2 encodes a novel R protein unique from Pita. Rice 13:19

Miah G, Rafii MY, Ismail MR, Puteh AB, Rahim HA, Asfaliza R, Latif MA (2013) Blast resistance in rice: a review of conventional breeding to molecular approaches. Mol Biol Rep 40:2369–2388

Nalley L, Tsiboe F, Morat AD, Shew A, Thoma G (2016) Economic and environmental impact of rice blast pathogen (*Magnaporthe oryzae*) alleviation in the United States. PLoS One 11: e0167295

Nazarov PA, Baleev DN, Ivanova MI, Sokolova LM, Karakozova MV (2020) Infectious plant diseases: etiology, current-status, problems and prospects in plant protection. Acta Nat 12:46–59

Nguyen TH, Wang D, Rahman SU, Bai H, Yao X, Chen D, Tao S (2021) Analysis of codon usage patterns and influencing factors in rice tungro bacilliform virus. Infect Genet Evol 90:104750

O'Brien PA (2017) Biological control of plant diseases. Australas Plant Pathol 46:293–304

Oliva R, Ji C, Grande GA, Tapia JCH, Quintero AP, Li T, Eom JS, Li C, Nguyen H, Liu B, Auguy F, Sciallano C, Luu VT, Dossa GS, Cunnac S, Schmidt SM, Loedin HIS, Cruz CV, Szurek B, Frommer WB, White FF, Yang B (2019) Broad-spectrum resistance to bacterial blight in rice using genome editing. Nat Biotechnol 37:1344–1350

Orasen G, Greco R, Puja E, Pozzi C, Stile MR (2020) Blast resistant *R* genes pyramiding in temperate japonica rice. Euphytica 216:40

Ou SQ, Gao J, Peng DL, Qi CY, Zhang JH, Meng Y, Lu BH (2014) First report of *Aphelenchoides besseyi* causing white tip disease of rice in Jilian province, China. Plant Dis 98:1165

Pautasso M, Doring TF, Garbelotto M, Pellis L, Jeger MJ (2012) Impacts of climate change on plant diseases—opinions and trends. Eur J Plant Pathol 133:295–313

Porazinska DL, Giblin-Davis RM, Powers TO, Thomas WK (2012) Nematode spatial and ecological patterns from tropical and temperate rainforests. PLoS One 7:e44641

Pradhan SK, Barik SR, Nayak DK, Pradhan A, Pandit E, Nayak P, Das SR, Pathak H (2020) Genetics, molecular mechanisms and deployment of bacterial blight resistance genes in rice. Crit Rev Plant Sci 39:360–385

Prasad JS, Panwar MS, Rao YS (1987) Nematode problems of rice in India. Trop Pest Manag 33: 127–136

Pu XM, Zhou JN, Lin BR, Shen HF (2012) First report of bacterial foot rot of rice caused by a *Dickeya Zeae* in China. Plant Dis 96:1818

Ramalingam J, Raveendra C, Savitha P, Vidya V, Chaitra TL, Velprabhakaran S, Saraswathi R, Ramanathan A, Pillai MPA, Arumugachamy S, Vanniarajan C (2020) Gene pyramiding for achieving enhanced resistance to bacterial blight, blast, and sheath blight diseases in rice. Front Plant Sci 11:591457

Razak AA, Zainudin NAIM, Sidiqe SNM, Ismail NA, Izham NM, Mohamad N, Salleh B (2009) Sheath brown rot disease of rice caused by *Pseudomonas fuscovaginae* in the Peninsular Malaysia. J Plant Prot Res 49:244–249

Reddy PP (2021) Nematode diseases of crop plants: an overview. In: Nematode diseases of crops and their management. Springer, Singapore. https://doi.org/10.1007/978-981-16-3242-6_1

Rybicki EP (2015) A top ten list for economically important plant viruses. Arch Virol 160:17–20

Sabri RS, Rafii MY, Ismail MR, Yusuff O, Chukwu SC, Hasan NA (2020) Assessment of agro-morphologic performance, genetic parameters and clustering pattern of newly developed blast resistant rice lines tested in four environments. Agronomy 10:1098

Satoh K, Yoneyama K, Kondoh H, Shimizu T, Sasaya T, Choi IR, Yoneyama K, Omura T, Kikuchi S (2013) Relationship between gene responses and symptoms induced by *Rice grassy stunt virus*. Front Microbiol 4:313

Savary S, Willocquet FHL, Heong KJ (2012) A review of principles for sustainable pest management in rice. Crop Prot 32:54–63

Shabana YM, Fattah GMA, Ismail AE, Rashad YM (2008) Control of brown spot pathogen of rice (*Bipolaris oryzae*) using some phenolic antioxidants. Braz J Microbiol 39:438–444

Sharma S, Kumar G, Mangrauthia S, Neeraja CN, Krishnaveni D, Dasgupta I (2017) Characteristics of Tungrovirus occurring in India. In: Mandal B, Rao G, Baranwal V, Jain R (eds) A century of plant virology in India. Springer, Singapore

Simanjuntak FAS, Safni I, Bakti D (2020) Distribution of narrow brown leaf spot disease of rice (*Cercospora oryzae* Miyake) in north Sumatra. IOP Conf Ser Earth Environ Sci 454:012163

Singh R, Kumar P, Laha GS (2019) Present status of bakanae of rice caused by *Fusarium fujikuroi* Nirenberg. Ind Phytopathol 72:587–597

Ta HA, Nguyen DP, Causse S, Nguyen TD, Ngo VV, Hebrard E (2013) Molecular diversity of *Rice grassy stunt virus* in Vietnam. Virus Genes 46:383–386

Tabassum J, Ahmad S, Hussain B, Mawia AM, Zeb A, Ju L (2021) Applications and potential of genome-editing systems in rice improvement: current and future perspectives. Agronomy 11: 1359

Tao H, Shi X, He F, Wang D, Xiao N, Fang H, Wang R, Zhang F, Wang M, Li A, Liu X, Wang G-L, Ning Y (2021) Engineering broad-spectrum disease-resistant rice by editing multiple susceptibility genes. J Integr Plant Biol 63:1639–1648

Tian Z-L, Maria M, Barsalote EM, Castillo P, Zheng J-W (2018) Morphological and molecular characterization of the rice root-knot nematode, *Meloidogyne graminicola*, Golden and Birchfeild, 1965 occurring in Zhejiang, China. J Integr Agric 17:2724–2733

Wang F, Li D, Wang Z, Dong A, Liu L, Wang B, Chen Q, Liu X (2014a) Transcriptomic analysis of the rice white tip nematode, *Aphelenchoides besseyi* (Nematoda: Aphelenchoididae). PLoS One 9:91591

Wang H, Xu D, Pu L, Zhou G (2014b) Southern rice black-streaked dwarf virus alters insect vectors' host orientation preferences to enhance spread and increase *Rice ragged stunt virus* co-infection. Phytopathology 104:196–201

Wang R, Ning Y, Shi X, He F, Zhang C, Fan J, Jiang N, Zhang Y, Zhang T, Hu Y, Bellizzi M, Wang G-L (2016) Immunity to rice blast disease by suppression of effector-triggered necrosis. Curr Biol 26:2399–2411

Wang S, Liu W, Lu D, Lu Z, Wang X, Xue J, He X (2020) Distribution of bacterial blight resistance genes in the main cultivators and application of Xa23 in rice. Front Plant Sci 11:555228

Yuan M, Jiang Z, Bi G, Nomura K, Liu M, Wang Y, Cai B, Zhou J-M, He SY, Xin X-F (2021a) Pattern-recognition receptors are required for NLR-mediated plant immunity. Nature 592:105–109

Yuan M, Ngou BPM, Ding P, Xin X-F (2021b) PTI-ETI crosstalk: an integrative view of plant immunity. Curr Opin Plant Biol 62:102030

Yugander A, Sundaram RM, Ladhalakshmi D, Hajira SK, Prakasam V, Prasad MS, Madhav MS, Babu VR, Laha GS (2017) Virulence profiling of *Xanthomonas oryzae* pv. *oryzae* isolates, causing bacterial blight of rice in India. Eur J Plant Pathol 149:171–191

Zarreen F, Kumar G, Johnson AMA, Dasgupta I (2018) Small RNA-based interactions between rice and the viruses which cause the tungro disease. Virology 523:64–73

Zhai W, Wang W, Zhou Y, Li X, Zheng X, Zhang Q, Wang G, Zhu L (2002) Breeding bacterial blight-resistant hybrid rice with the cloned bacterial blight resistance gene *Xa21*. Mol Breed 8: 285–293

Zhao S, Wu Y, Wu J (2021) Arms race between rice and viruses: a review of viral and host factors. Curr Opin Virol 47:38–44

Zhou C, Bo Z, Lin XG, Bin L, Shi H (2016) Research status and prospect of *Burkholderia glumae*, the pathogen causing bacterial panicle blight. Ric Sci 23:111–118

Zhou Y, Zhao D, Shuang L, Xiao D, Xuan Y, Duan Y, Chen L, Wang Y, Liu X, Zhu X (2020) Transcriptome analysis of rice roots in response to root-knot nematode infection. Int J Mol Sci 21:848

Bacterial Disease of Rice

2

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Abstract

Rice bacterial infections are a serious stumbling block to long-term output, and they are quite important on a worldwide scale, particularly in Asian countries. The management of these diseases, particularly bacterial diseases, has included extensive research, including infection and disease development and chemical therapy. By employing proper disease management approaches, bacterial infection can be overcome. Farmers are increasingly using chemical management strategies to prevent output loss. When the disease condition and infection rate in the infected area are out of control, chemical management is required. The appropriate use of selective antibiotics and combinations of antibiotics will help manage bacterial infections and prevent yield loss. Excessive and poor antibiotic combination selection may disrupt the natural system's balance, posing a health risk to humans and animals. Chemicals used for longer periods may cause disease-causing germs to develop resistance. Natural and chemical management

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strategies should be used together in a controlled way to achieve eco-friendly results, so this is what you should do.

Keywords

Bacterial leaf blight · Bacterial leaf streak · Bacterial panicle blight · Antibiotics · Management

2.1 Introduction

The paddy crop (*Oryza sativa*) is widely grown in India and Asian countries. Rice is one of the world's most significant cereal crops, providing nutrition to the vast majority of people in Africa, Asia, and Latin America (US Department of Agriculture 2021; Kadu et al. 2015). Rice consumption has increased marginally in recent crop years when compared to previous crops. India consumed roughly 504.3 million metric tonnes of rice in the years 2020 and 2021 compared to the worldwide average. In 2008/2009, 437.18 million metric tonnes of crop were consumed globally. After China, India is the world's second-largest rice producer. According to the area, rice comprises about 23.3% of farmed land. It contributes 43% to food grain output and 46% to cereal production in the United States. Rice refers to a different number of grain species. There are about 40,000 different varieties of *Oryza sativa* worldwide, divided into four broad categories: indica, japonica, aromatic, and glutinous. Increasing rice consumption means expanding rice-growing areas and increasing rice production, both of which have made rice more vulnerable to disease (Fargette et al. 2013; Dai et al. 2010).

Droughts, weather fluctuations, floods, and illnesses are among the variables that affect rice yield. Rice is susceptible to a range of diseases caused by bacteria, viruses, or fungi; the most devastating are bacterial infections, resulting in yield losses of up to 50% depending on the rice variety, growth stage, geographic location, and environmental conditions.

By implementing eco-friendly measures at an early stage, we can decrease or eliminate the use of carcinogenic and toxic chemicals and reduce or eliminate the discharge of such chemicals in agricultural land. When the condition has progressed beyond the point where it is cost-effective, chemicals should be used. It will support and promote the natural competitors of harmful bacteria in the ecosystem.

Bacterial leaf blight (BLB), bacterial leaf streak (BLS), and bacterial panicle blight (BPB) are three main bacterial diseases of rice caused by Gram-negative bacteria of the *Xanthomonas oryzae* genus: *X. oryzae* pv. *oryzae* (Xoo), *X. oryzae* pv. *oryzicola* (Xoc), and *Burkholderia*. The bacterial leaf blight (BLB) disease can cause yield losses of up to 50% in favourable situations (Ou S. Rice Infections). In 1884, farmers in the Fukuoka district of Kyushu, Japan, discovered BLB illness (Tagami and Mizukami 1962) (Tagami and Mizukami 1962). Tagami and Mizukami, the first cases of bacterial leaf streak (BLS), were discovered in Mali in 2003 and Burkina Faso in 2009 (Wonni I) (Wonni II) (Wonni III). BPB was first

Table 2.1 Major bacterial diseases which are causing maximum yield loss in the rice crop

Bacterial disease name	Pathogenic bacterial species	First reported year
Leaf blight	*Xanthomonas oryzae* pv. *oryzae*	1884
Leaf streak	*Xanthomonas oryzae* pv. *oryzicola*	2003
Panicle blight	*Burkholderia glume*	1967

identified as the principal cause of grain rotting and a seedling blight on rice in Japan in 1967 and was dubbed bacterial grain rot. These illnesses are now considered emergent diseases that can result in a significant decrease in gross rice yield. Different species of *Pantoea* (Doni et al. 2019) and *Sphingomonas* (Kini et al. 2017) genera reduced the rice gross yield.

Xanthomonas oryzae has been identified as being responsible for bacterial leaf blight-like symptoms in rice. *Pantoea*, *P. stuartii*, *P. ananatis*, and *P. agglomerans* have all been identified as BLB disease-causing pathogens in different nations. (HB Lee and AD Gonza'lez) Only a few isolates of *Sphingomonas* species have been identified as plant pathogens and have been linked to BLB disease symptoms (Kini et al. 2017).

Extensive research studies are on the *Pantoea* and *Sphingomonas* species to establish the information and documentation of well-known *Xanthomonas* bacteria. In rice, the bacterial sheath brown disease is caused by *Pseudomonas fuscovaginae* through seed transmission. However, recently other pathogens like *Sarocladium oryzae* and *Fusarium* spp. also showed similar sheath rot symptoms. Based on the reported evidence in this chapter, we focused on the three bacterial diseases causing divesting in the yield of rice. Table 2.1 contains the list of major bacterial diseases and Table 2.2 the other stains of the bacterial species.

2.2 Rice Leaf Blight Disease

2.2.1 Disease Development

Xanthomonas oryzae infects the rice plants by invading through the water pores and taking advantage of newly formed wounds (Mukoo et al. 1957). The pores for water percolation in the plant can be found on the edges of the leaf's upper section. Lesions usually begin on the upper section of the leaf, at the leaf margins. The water-soaked lesions became yellowish-white in hue, spreading from the square form's equal sides to form elongated circular to uneven lesions. The wavy margins of the leaf blades were plainly visible on the leaves, which are an indication of the condition. Under humid conditions, the lesions usually begin on both leaf margins and can even be seen on newly infected leaf veins. The disease's progression and the emergence of symptoms in the rice field are both influenced by the environment. The illness can be divided into two different phases, the leaf blight phase and kresek phase, which is the harmful phase of the epidemic (Reddy and Ou 1976; Ou 1985) (Fig. 2.1).

Table 2.2 List of the various bacterial stains

Species	Type of bacteria	Strain
X. oryzae pv. *oryzae*	Gram-negative bacterium	OS225
		OS198
		OS86
		Z173
		JS158-2
		CJO13-1
		BAI3
		ABB27
		ABB37
X. oryzae pv. *oryzicola*	Gram-negative bacterium	BAI10
		BAI119
		BLS256
		AHB4-75
		JSB3-22
		YNB10-32
		GXB3-14
		SCB4-1
		CJOC13-1
B. glumae	Gram-negative bacterium	CU-1
		CU-2
		CU-3
		LMG2196
		NCPPB3923
		CFBP3831
		3252–8
P. ananatis	Gram-negative bacterium	ARC22
		ARC315
		ARC593
P. stewartii	Gram-negative bacterium	ARC903
		ARC10
P. agglomerans	Gram-negative bacterium	ARC982
		ARC1000
		ARC282
		ARC933

2.2.1.1 Leaf Blight Phase

After the tillering stage reaches its maximum peak position, the leaf blight phase of the rice leaf blight disease becomes more obvious in the tropical and temperate zones, with the initial symptoms on the leaf blades. Bacterial infection normally begins in the lower sections of the plant and expansions up to the leaf upperside portion (Goto 1992; Cha et al. 1982). The upper half or entire portion of the leaf

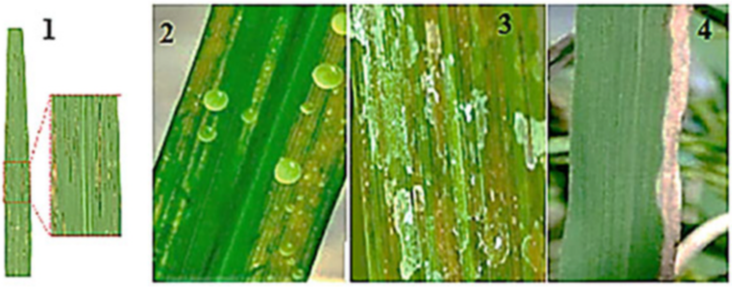

Fig. 2.1 1. Bacterial light caused by *Xanthomonas oryzae* pv. *oryzae*, 2. yellow droplets of bacteria on the leaf, 3. dried bacteria on the leaf, 4. dried leaf margins (Jiang et al. 2020)

blade acquires a pale yellow colour before drying up depending on the severity of the disease (Mizukami and Wakimoto 1969).

2.2.1.2 Kresek Phase

The word "Kresek", which means "the sound of dead leaves," were rubbed together (Wakimoto 1969). This stage of the disease was originally documented in Indonesia in the twentieth century in the context of a separate bacterial rice disease (Reitsma and Schure 1950). The "Kresek" phase of the bacterial leaf blight illness appeared 1–2 weeks after the nursery plants were transplanted into the field. The plant's leaves turn grey-green to yellowish in extreme conditions. The disease's "Kresek" phase can also emerge in mature plant stages (Goto 1992; Watanabe 1975). Symptoms on the foliar sections of the plant are similar to those on younger plants during the Kresek phase, but the rotting of the stem also reaches the upper part of the leaf.

In the roots of the weed "*Leersia hexandra*", the bacteria *Xanthomonas Oryzae* will be detected. Bacteria infiltrate rice nursery beds during the growing season and spread across the beds and channels as water is watered to the immature plants. The pathogen might enter the rice nursery by infected straw or infected seeds in the field (Mizukami and Wakimoto 1969). The pathogen accumulates on the surface of the roots and travels towards the crown once it reaches young plants. The bacterium begins to multiply by consuming the plant compounds released by the roots (Mizukami 1957, 1959, 1961) (Mizukami 1957, 1959, 1961) (Mizukami). Under moist conditions, the pathogen entered the stomata of coleoptiles and leaf sheath, where it multiplied in the intercellular spaces of parenchyma. It was also speculated and reported that the infection could be spread by insects or bugs, such as *Leptocorisa acuta*, which was found in the rice crop (Mohiuddin et al. 1976).

2.2.2 Rice Bacterial Leaf Blight Management

Rice leaf blight can be controlled through hygienic conditions, the selection of resistant seed variants, the application of appropriate pesticides, and the use of biological control approaches. Cultural management methods such as using healthy seeds, removing old and diseased straws and stubbles, maintaining an appropriate water level, using nitrogenous compounds properly, and adopting a proper water drainage system can aid in pathogen control.

2.2.3 Chemical Management

According to the literature and documented evidence, substantial research has been conducted to establish the efficacy of various pesticides in controlling and managing bacterial leaf blight in rice and reducing yield loss. Varying combinations of antibiotics in various strengths have been recommended for disease inhibition by various workers over the years. Table 2.3 lists some of the medications and combinations used to treat BLB.

2.3 Bacterial Leaf Streak

2.3.1 Disease Development

Bacterial leaf streak is a seed-borne disease and is mainly infected by the pathogen *Xanthomonas oryzae* pv. *oryzicola*. It can spread or infect through seed and physical contact of the infected plant to other plants. The presence of moisture content around the seed as a film facilitates the release of bacteria from the diseased seed and attacks the inside tissue where it grows further as colonies. The bacterium enters through the

Table 2.3 Antibiotics and combination of antibiotics used in the chemical management of BLB disease

S. No	Antibiotics/combination of antibiotics	Reference year
1	Streptomycin sulphate 200 ppm + copper oxychloride (0.25%)	Kumar et al. (2009)
2	Streptocycline + copper sulphate were effective at 1000 ppm concentration	Patel et al. (2009)
3	Amistar at 0.1%	Mustafa et al. (2013)
4	Streptomycin + copper oxychloride highly effective under in vitro condition at 4%	Singh et al. (2015)
5	Azoxystrobin 25 SC	Swati et al. (2015)
6	Blitox 0.3% + streptocycline at 250 ppm	Ashish et al. (2016)
7	Mancozeb 500 ppm + streptocycline 100 ppm	Kamble et al. (2017)
8	Trifloxystrobin 25% + tebuconazole 50% at 50 ppm	Bala et al. (2017)
9	Nativo 75 WG at 0.65%	Qudsia et al. (2017)
10	Streptomycin at concentration of 0.03% and 0.05% was effective	Prasad et al. (2018)
11	Carbendazim at 500 ppm concentration	Jadhav et al. (2018)
12	Mancozeb at 500 ppm	Jadhav et al. (2018)
13	Streptocycline at 250 ppm	Jadhav et al. (2018)