



An Overview of Major Bacterial Diseases of Rice and Management Strategies for Their Control in Malaysia

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Abstract:

Rice (*Oryza sativa* L.) is consumed as excellent food in many countries worldwide, in Malaysia as well. Unfortunately, though, rice production is acknowledged to decrease owing to the attack of several emerging diseases-causal agents is a bacterial pathogen. Among all the bacterial diseases, Malaysia is experiencing few primary bacterial infections. However, two devastating diseases, particularly bacterial leaf blight (BLB) and bacterial panicle blight (BPB) affect rice production and reduces commercial and economic activities challenging the nation's food security. Even though the improvement of resistance cultivars or chemical control to mitigate the impairment triggered by bacterial pathogens is in advancement, very little is known about the virulence mechanisms and the most

significant phases of the bacterium cycle of disease. Therefore, this review has objected to the primary bacterial infection, causal agents, pathogenic variations, symptoms, overwintering, and sustainable environment-friendly management tactics.

Keywords: Rice, Bacterial Disease, Causal organisms, Symptoms, Disease management.

1. Introduction

Rice (*Oryza sativa* L.) is the most significant crop worldwide after wheat (Matthews 1995 and Banik 1999), and Asia is the leading consumer and supplier (Gumma 2011). In contrast, it is the third most important crop in Malaysia after rubber and palm oil. Production of paddy rice is expanding from year to year in rice-producing countries, according to a market monitor reported by FAO (FAO 2017). More significant than 3.5 billion consumers directly rely on rice as their leading food and supply of daily calories globally (Cheng 2007); furthermore, this crop is Malaysia's most essential staple food (Brown 1973). According to (FAO 2013), 565.6 million metric tons of rice paddy were ingested, mainly in Asia, this province produces and consumes nearly 90% of the world's rice (Gumma 2011), whereas less than 9% of rice production has done outside Asia.

In Malaysia, the Kedah and Perlis are familiar with rice cultivation very much, and they have recognized as rice granaries, which simultaneously manage more than half of Malaysia's harvested area. The total cultivated area operated by the Muda Agricultural Development Authority (MADA) is 130,282 hectares; among these 100,685 hectares are rice paddy fields. This paddy field covers two (2) states such as Kedah occupied (82,968 hectares) and the State of Perlis occupied (17,717 hectares) of the cultivable land area. Therefore, approximately 35.13% of the land's rice paddy area represents the Rice Field Paddy. In Malaysia, one survey report depicts that rice production volume was about 1.7 million metric tons during the year 2018. However, there is only a slight increase in rice production in 2017 caused by several diseases and the invasion of pathogens. Like other crops, the rice paddy field is also suffering from various diseases. The researchers reported that more than 70 diseases are known to attack the rice field, among which bacteria cause five or six diseases. These diseases attack different rice plant sections and cause diseases such as seedling, foliar, leaf sheath, grain, and culm and root. The major bacterial diseases of rice in Malaysia are Bacterial blight diseases caused by *Xanthomonas*

oryzae pv. *oryzae*, *X. campestris* pv. *oryzae*, Bacterial leaf streak causal agent is *Xanthomonas oryzae* pv. *oryzicola*, rice Foot rot disease causal agent is *Erwinia chrysanthemi*, Panicle Blight causal organism is *Burkholderia glumae*, and Sheath brown rot caused by *Pseudomonas fuscovaginae* pathogen. Bacterial blight, Bacterial leaf streak, and Panicle Blight three are among the major diseases in nearly all rice planting areas worldwide, including peninsular Malaysia. This pathogen leads to lowered yield and inferior quality of the affected plants (Nino et al. 2006). The current study aims to highlight the most significant and leading rice bacterial diseases their life cycle and control strategies in Malaysia.

2. Bacterial leaf blight

2.1. History and Distribution

Bacterial leaf blight (BLB) disease has been caused by the infectious microorganism *Xanthomonas oryzae* pv. *oryzae* is among the foremost widespread severe disease poignant rice business in Asia since the Nineteen Sixties (Ou 1985); additionally, this disease is also accountable for vital yield reduction in rice. Previously the bacterium *Xanthomonas oryzae* pv. *oryzae* (Xoo) was identified as *Xanthomonas campestris* pv. *Oryzae* causing the BLB disease. This devastating disease of rice is generally observed both in tropical and temperate territories. BLB was first discovered in the late twentieth century in various locations of southern Japan, and has only been recognized as a severe disease in 1922 (Mew et al. 1993), later according to economic importance in several alternative Asia countries (Mizukami 1969), including Malaysia. Farmers in Japan, notably, in 1884, the urban center Fukuoka prefecture on Kyushu Island was the first to notice microbial blight (BLB) in its rice fields (Mannan 2013). In the middle of the 1960s, bacterial blight befell widespread in more rice-producing provinces of Asia with the initiation of high yield gathering cultivars line TNI and IR8, that were vulnerable to this disease infection. The disease has distributed to many other countries as wide-reaching (Ezuka and Kaku 2000; Anonymous 2007; Ghasemie et al. 2008).

2.2. Economic Importance

Infections of vulnerable plants affected by Xoo of BLB can cause severe yield losses, a total of up to 50% in tropical Asia (Anonymous 2007); however, at the highest tillering stage, yield losses result in 20-40% reduction whereas in the early infection stage loss encountered about 50% (Yasmin and Hafeez 2017). During the years 1988 and 1994, BLB invasion severely outbreaks and was reported in Malaysia, where over 40% of the cultivated land has invaded, a

calculable yield loss regarding 10-50% because of the disease suffering (Saad et al. 2000). Depending on the geographic position and seasonal circumstances, yield losses estimated about 70% in irrigated and low-lying rice areas causing Xoo (Wonni et al., 2016).

2.3.Symptoms

BLB is almost invading the foremost rice-growing zones entirely in Malaysia and results in moderate to severe infection that could lead to overall crop collapse in the field. The disease is a vascular disease where may observe the condition at all stages of the plant, such as seedling, vegetative growth, and reproductive stages. The disease can quickly expand via the distribution of plant straw, rain, hail, wild rice, wind, weeds (Nino-Liu et al., 2006), irrigation water, and seeds (Nywal 1999). Bacterial inoculum penetrates host plants via wound openings or injuries or water openings in the leaf, and then it moves successively all through the plant xylem (Nino-Liu et al., 2006). The symptom of bacterial blight can be categorized into leaf blight wilting (Kresek) and whitish-yellow leaf. The leaf blight symptoms described by longitudinal lesions developed along the leaf edge. The lesion starts as small water-soaked steaks a few centimeters from the tip, where water pores are distributed. It rapidly enlarges in length and width, forming a yellow to greyish white in a color lesion with a wavy margin along the leaf edge until the entire leaf dries up (Agrios 1997) (Fig. 1b). If the infection appears at matured stages, lesions develop and leaves become greyish brown (Kini et al., 2017). Once the disease occurs in severe form, the entire field is a blighted in white.

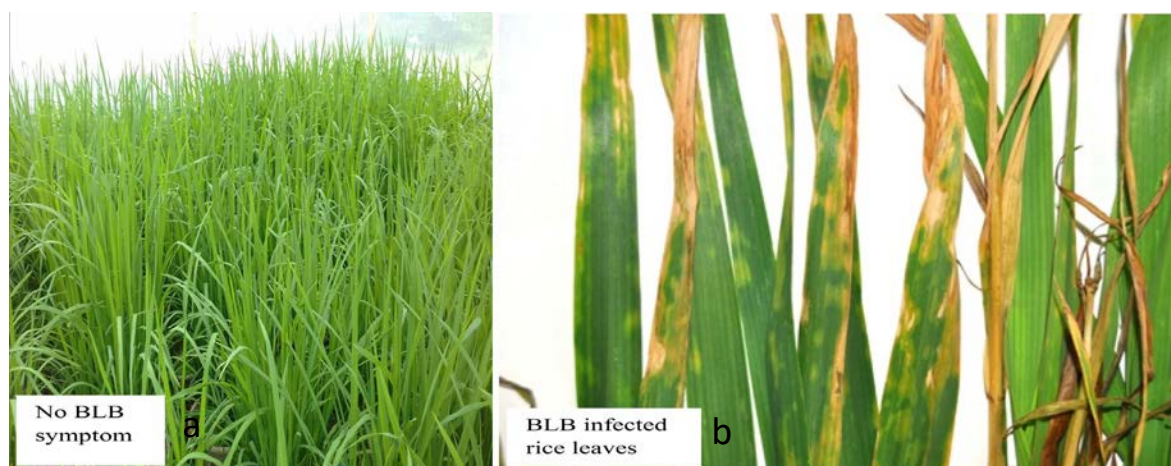


Fig. 1: a) Healthy rice field, and b) greyish, brown-colored lesions develop at the border of the

leaves (Chukwu et al. 2019)

In the tropical regions, when infection occurs on juvenile plants at the early tillering stage of susceptible cultivars, the most devastating phase of the disease is 'kresek,' or the wilt stage is resulting in rapid wilting, roll up, turning greyish green. The leaves turn yellow and wither, and the entire plant dies as a result of the premature infection in the nursery. When the temperature was between 28°C and 34°C, the disease manifested itself. This symptom was first called kresek in Indonesia.

2.4.Causal organism

BLB has caused by the pathogen *Xanthomonas oryzae* pv. *oryzae*. (Xoo). The rod-shaped bacterium is Gram-negative, non-sporogeneses, motile, and polar flagellated, also measured 1.75X0.60 µm in size. The pathogen forms single yellowish pigmented colonial growth on culture media (Fig. 2). It is aerophilic and grows up best at a temperature of 25°C-30°C, and the optimum pH is 6.5-7.5. Recently, numerous works done on Xoo were targeted at reviewing additional unknown genes associated with its virulence (Ryan 2011) interactions between the organism and the host, whereas highly thought was given to the genes related to thiamine complex synthesis. Yu et al. (2015) stated that the thiG gene is essential for the full virulence of Xoo by blocking cell accumulation. In addition, it has been observed that Iron is to improve the virulence of *X.oryzae* pv. *oryzae* (Ansari and Sridhar 2001).

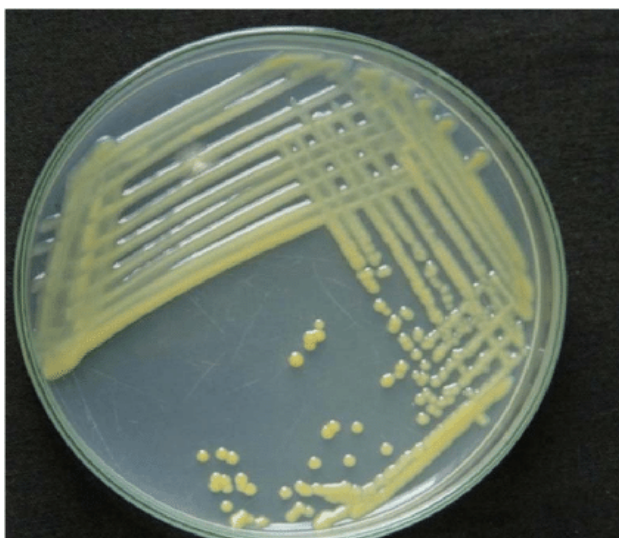


Fig. 2: Colony formation of *Xanthomonas oryzae* pv. *oryzae*. (Xoo), single yellowish pigmented colonial growth on culture media (Ranju et al. 2018)

2.5.Pathogenic Variation

Plant pathogens could fit speedily after the establishment of any non-virulent genes, which is because of their population's adaptability. The inhabitant's level where assortment and

adjustment ensued referred to as pathotype (Limpert et al. 1994), and several pathotypes of *Xanthomonas oryzae* pv. *oryzae* (Xoo) has been recognized in distinct Asian territories (Mew and Vera Cruz 1979). Several studies conducted by the scientist and stated that noticed variations in virulence among the isolates of Xoo. Strains distributing in tropical areas are generally more virulent than those in temperate zones. (Yang et al. 2012) and (Gonzalez et al. 2007) described those populations of Xoo in many Asian nations differ considerably, pondering the virulence sizes and DNA polymorphism. In recent times, stated an epidemic of BLB was in Guangxi Zhuang Autonomous province of China (Liu 2009). The bacterium has been classified into several races based on pathogenic reactions to the differential cultivars. There are no rice cultivars that are immune to the bacteria Xoo that have been recommended in Malaysia. In December 2016, 4440 hectares of rice fields under Sabak Bernam were overrun with Xoo causing a rapid loss in rice yield of measured 30–50% (Anonymous 2016).

2.6.Disease Cycle and Epidemiology

Disease cycle or overwintering of the species bacteria *oryzae* pv. *oryzae* (Xoo) mainly completes in/on plagued seeds, ratoons, stubbles, self-seeded plants, straw, and perennial wild plants, namely; *Leersia oryzoides*, genus *Zizania latifolia*, *Leptochloa chinensis*, *L. panacea*, *nutsedge*, and wild *liliopsid* genus species *O.rufipogon* and *O. australiensis* (Devadath 1982; Singh et al. 1980; Sundar and Dodan, 1989; Thrimurthy and Devadath 1981). The pathogen overwintered on the rhizosphere of these alternative hosts multiplies in spring when new shoots of the weeds begin to emerge (Fig. 3). The microorganism is distributed through irrigation water by splashing or crooked rain, pruning tools for transferring and managing during transplanting. It infects rice seedlings in lowland nurseries or those transplanted in paddy (Devadath 1982). This is the primary infection.

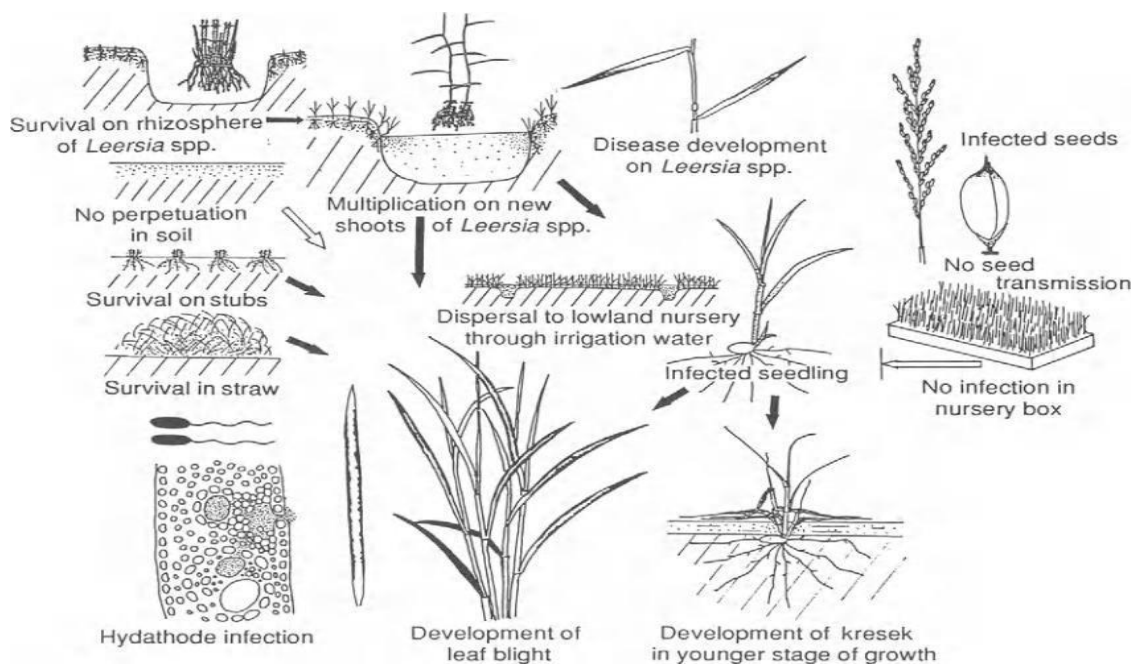


Fig. 3: Disease cycle/ overwintering of BLB of rice initiated by *Xanthomonas oryzae* pv. *oryzae* (Xoo) (Masao Goto 1992. Pp-269)

Secondary blow-out of the disease in severe form happens in summer to early autumn under humid weather conditions. Epidemics can readily be induced by rainstorms or flooding of paddy fields in this season. Excess application of Nitrogen fertilizer also increases disease severity.

2.7.Integrated disease management of BLB

Disease management of BLB instigated by *Xanthomonas oryzae* pv. *oryzae* (Xoo) consists of:

- i) Use of host resistance cultivars.
- ii) Biological management.
- iii) Use of natural harvests or botanicals extracts.
- iv) Chemical treatments.

i) Use of host resistance cultivars

Resistant cultivars utilization as a management alternative is highly accepted to minimize pests and diseases. This method is relatively cheaper than using chemicals and environmentally sound to use. Variable individuals of *X. oryzae* have been identified in their specificity of infectivity to different cultivars. (Mew and Vera Cruz 1979; Eamchit and Mew 1982). (Naveed

et al. 2010) observed the BLB disease resistance gene (xa5) in one individual rice cultivar using markers connected to the gene. Using rice resistance varieties is much more efficient and cost-effective. Significant importance is being conferred to detect and integrate bacterial blight resilient or tolerance gene donors in trade cultivars using molecular tactics.

ii) **Biological management**

BLB disease in paddy is the foremost devastating illness in the rice-growing regions globally. Numerous Xoo strains have been detected from many rice farming areas. Actinomycete strains that can prevent all major Xoo isolate approximately 2960 actinomycete strains. Some beneficial bacteria, namely, *Bacillus subtilis*, *Pseudomonas fluorescens*, and *Trichoderma harzianum* having aggressiveness to the microorganism and decrease the disease strength while using a sprinkle and a mixture of sprays through seed treatment and pre-soaked nursery treatment (Manav and Thind 2002). Their embargo essays on indicator microorganisms, *E. coli* NBRC 14237, *S. cerevisiae* NBRC 10217, *B. subtilis* NBRC 3134, and beneficial microbes *P. puttida* VTCC-B-657 and *Azotobacter sp* VTCC-B-106 are emphasized that directed to the selection of single one strain, specifically VN08-A-12, for more than rice field research for its future benefits. A survey conducted by (Ji et al. 2008) reported an innovative strain of *Lysobacter antibioticus* (strain 13-1) was originated to effectively defeat the infection up to 69.7% in the glasshouse and 73.5%, 78.3%, and 59.1% distinctly in the field circumstances.

iii) **Natural harvests or botanicals extracts use**

Managing BLB disease using natural products or botanicals extracts can play a crucial role in controlling rice disease. Various plant extract (botanical) showed antagonistic activity and significantly effective against *X. oryzae* (Xoo). The disease primarily affects nursery seedlings after transplantation and afterwards at the flowering stage. Its Kresek phase angle lasts for a more extended period and the most devastating period. Very few chemical compounds are beneficial to inhibit the Xoo, but chemicals are not economically favorable, whereas it leaves harmful residual effect in soil and plant. (Manav and Thind 2002) experimented and proved that when Nutrient Agar well-plated technique is used, the botanical and novel chemical have antagonistic action against preceding isolates of BLB disease. Botanical extracts and new chemical control of BLB are essential in rice disease management (Singh et al. 2010).

(Madhiahagan et al. 2002) stated that *Adhatoda vasica* leaf extract is most effective in lowering BLB disease prevalence surveyed by *Curcuma longa*, *Allium cepa*, *Prosopis juliflora* and *Azadirachta indica*. Some botanicals extract such as neemzal, tricure (neembased), achool, neemgold, wanis (*Cymbopogon sp*), ovis (*Lantana camara*), and spictaf reduced BLB incidence by 20% (Eswamurthy et al. 1993; Singh and Sunder 2001).

iv) Chemical treatment

BLB is an emerging and severe problem globally. Malaysia's food security is under threat day by day; however, its management practice is critical to reducing the disease incidence by this pathogen. The application of chemicals is the most significant part of minimizing plant disease successively. (Tagami and Mizukami 1962; Hori 1973) testified that bacterial growth gets retarded when a mixture of copper oxychloride and streptomycin solution is applied as a spray-on diseased plant. (Chand et al. 1979) suggested that lesions development can effectively be checked produced by the bacterium in rice by using bleaching powder along with 30% chlorine @ 2kg/hectare.

3. Bacterial Panicle Blight

3.1. History and distribution

Bacterial panicle blight (BPB) is an emergent severe disease of rice in Malaysia caused by the bacterium *Burkholderia glumae* (*B. glumae*). This devastating disease was first observed in the Kyushu region of Japan in the 1960s, and it has since evolved into one of the world's most serious rice diseases (Xie et al., 2003; Kumar et al. 2017). Hereafter, BPB disease has been prevalent throughout in many rice-producing countries and has become a severe problem in South and Central America (Venezuela, Dominican Republic, Brazil, Colombia, Panama, Costa Rica, and Nicaragua Ecuador), in Africa (countries of South Africa and Tanzania) and Asia (Japan, Malaysia, Indonesia, the Philippines, Korea, India, Sri Lanka, Thailand, Vietnam, and China) (Tsushima 1996; Nandakumar et al. 2005, 2007; Wang et al. 2006; Kim et al. 2010; Riera-Ruiz et al. 2014; Zhou 2014; Quesada-González and García-Santamaria, 2014; Mondal et al. 2015).

Unfortunately, in recent years the prevalence of *B. glumae* has expanded because of several variables such as high genetic diversity of the species, climate change (Schaad 2008; Karki et al. 2012; Nandakumar et al. 2009; Seo et al. 2015), and a want of proper supervision and control policies (Cui et al. 2016). Malaysia is among the countries in Asia reporting to currently experiencing the BPB outbreaks (DOA 2018). In the crop field, the disease manifests as grain or panicle rot at the mature stage, as well as seedling rot in nursery boxes. (Chien et al. 1983; Azegami 1987; Rush 2003).

3.2.Economic Importance

Burkholderia glumae is a seed-borne emerging rice bacterium and capable of inducing 40% to 75% yield loss in severely infested fields in several tropical and subtropical countries (Trung et al. 1993) as an outcome of a decrease in grain weight, infertile florets, arrest seed germination and depletion of stands (Ham et al. 2011). Thus, invasion of *B. glumae* affects the sustainability of rice production and reduces commercial and economic activities. However, although the disease is significantly significant worldwide, minimal works have been conducted on *B. glumae*, from early phases of the inoculum reservoirs of plant infectivity, to pursue the contamination all through the plant's vegetative and maturity development phases (Li et al. 2016; Hikichi 1993).

3.3.Symptom

Panicle blighting has become a significant challenge in several rice-growing areas in Malaysia for many years. However, until 1996-1997, panicle blighting was caused by a physiological problem (Shahjahan et al. 2000). Soon After, *B. glumae*, all together with *B. gladioli*, were isolated and recognized to cause BPB as the significant pathogen (Nandakumar et al. 2005; Nandakumar et al. 2009). BPB mainly includes specific panicle blight, seedling blight, and sheath rot (Sayler et al., 2007; Tsushima 1996).

3.3.1. Grain rot phase

Symptoms include tiny (1 to 5 mm) tan lesions on the leaves and spikelets, with brown margins, result in the abortion of infected kernels with partial filling. The hull of disease-ridden grains on juvenile panicles swiftly fades in color from the bottom. Turning greening white at

first, and afterward dusty pink to yellowish-brown. They soon wilted and dried up. Infertile kernels or brown rice with dark brown discolor at the base are found in the afflicted areas. Symptoms with a brown margin show at the bottom of the kernels (Fig. 4); however, the panicle branches lasting with green (Nandakumar 2009; Wamishe et al. 2015). In severe cases, nearly all grains on panicles are infested to facilitate these white panicles to remain upright erect even. Symptoms may vary due to environmental restrictions such as temperature and the amount of nitrogen treatment prior to the panicle emergence. Panicles become erect in severe cases due to grain filling failure (Nandakumar et al., 2009).

3.3.2. Seedling rot phase

The seedling rot phase becomes prevalent in nursery boxes. It may eventuate on seedlings procured from the decayed seeds, on those Infected during pre-sowing water soaking, or to rice sheaths that become brown and develop necrotic lesions. Sheath symptoms comprise long, vertical greyish lesions enclosed by a dark reddish-brown edge (Fig. 5). With seedling blighting, affected panicles acquire straw-colored florets over time. Newly emergent seedlings around the decayed seeds may be infested, establishing infection foci in nursery boxes. Seedlings in the foci advanced with brown lesions on coleoptile and rotted very soon.



Fig. 4: Panicle blighting and grain rot, caused by *Burkholderia glumae*



Fig. 5: Flag leaf sheath rot, caused by *Burkholderia glumae*

(Xianglong 2004)

3.4.Causal organism

Pseudomonas glumae (*Burkholderia glumae*) bacterium was named by Kurita and Tabei in 1967. The temperature range for *B. glumae* growth and development has been reportable as 30-35°C contained by a range of 11-40°C and a thermally mortality point temperature at 70°C (Kurita et al. 1964). The bacterium *B. glumae* is a gram-negative, non-fluorescent, rod-shaped bacterium with polar flagella (Cho et al., 2007). *B. glumae* favors higher temperatures and moisture; these suitable factors will be one of the foremost pressing issues in agriculture as global warming rises (Ham et al., 2011). This pathogen initially infects seeds and then invades plumules via stomata and wounds. During seed germination, it propagates in the intercellular areas of parenchyma (Zhu et al. 2010). The multiplication of *B. glumae* in plumules directs to the mass production of toxic substances, such as toxoflavin, resulting in rice seedling rot. The bacterium can generate a yellow-green, water-soluble pigment on different media. The bacterial colony appears greyish white or yellow, convex, glossy because of the pigment present, and 3.0 to 6.0 mm in diameter. The bacterium can grow in a pH range of 5.5-8.5 (optimum, 6.5, and 7.0).



Fig. 6: *Burkholderia glumae* Colonies and yellow pigment (toxoflavin) production by *B. glumae* on King's B agar plate (right) vs. no pigmentation on control petri plate (left) (Zhou 2019)

For *B. glumae*, the arginine dehydrolase reaction, oxidase, and nitrate reduction reaction is all negative (Cottyn et al. 1996). Generally, the total genome size of a *Burkholderia* species is larger than 8 Mbp. *B. glumae* strains were studied comprehensively, and it was found the strain BGR1 has two chromosomes and four plasmids, along with 3,906,529 base pairs in chromosome 1 and 2,827,355 base pairs in chromosome 2, respectively (Lim et al. 2009).

3.5. Virulent factors of *B. glumae*

The pathogenesis of *B. glumae* is a highly complex procedure and involves numerous virulent factors. The molecular research groups have identified a few virulent factors. Amongst them, the most significant factors are phytotoxins and lipases. The most significant phytotoxins secreted by *B. glumae* are the bright yellow pigments toxoflavin and fervenulin, which are isomerized (Kim et al. 2004). *B. glumae* produces toxoflavin. The invasion of this bacterium promotes toxic materials toxoflavin, which is a crucial virulence factor for *B. glumae* in rice. Toxoflavin and fervunulin are indispensable for growth in plants, and grain rot pathogenicity, causes chlorotic signs on rice panicles by depleting the growth of leaves and roots in rice seedlings (Jeone et al. 2003). Remarkably, *B. glumae* cells can establish a system to detoxify ROS by either toxoflavin or host defense at the contagion sites. Recently, *B. glumae* Kat G was revealed to act as a catalase both to detoxify oxidative stress and function as a virulence factor (Chun et al., 2009). Bacterial movement mediated by flagella and lipase synthesis are crucial for *B. glumae* pathogenicity. (Devescovi et al. 2007; Kim et al. 2007). All these virulence factors cited over are measured by the cell-density-dependent manner of quorum sensing (QS).

3.6.Disease Cycle and Epidemiology

The disease is seed-borne. The pathogen invades glumes through stomata located outside lemmas, colonizes the stomatal cavity and parenchymatous tissues surrounding them, and survives until the next crop season. These bacteria multiply when seeds are soaked in water for the pre-sowing emergence of embryos and infect young germlings. When densely seeded nursery boxes are placed under high temperature, and an excess of humidity, the seedlings surrounding these rotted germlings are secondarily affected, forming disease foci in nursery boxes. In the booting stage, the bacterium quickly proliferates on the surface of a young panicle enveloped by leaf sheath and infects inflorescence at the flowering stage. Severe infection usually occurs when heading, and flowering of panicles occurs under high temperatures and frequent rains (Fig. 7).

BPB pathogenic bacteria can survive in numerous environmental conditions, such as water, plant, and soil. The researchers suggested that *B. glumae* is capable of replicating on the phylloplane of rice plants at all stages of growth. (Tsushima et al. 1996) and endures both inside and outward of rice tissue, rice seeds or weeds in the field overwinter (Tsushima et al. 1986). BPB can emerge effectively in subsequent years when the environmental conditions are favorable for its reproduction. Additionally, multiple factors, such as humidity, temperature, disease severity of former year, and host susceptibility. Bacteria can move to a long-distant path via the host vascular system (Yuan 2004).

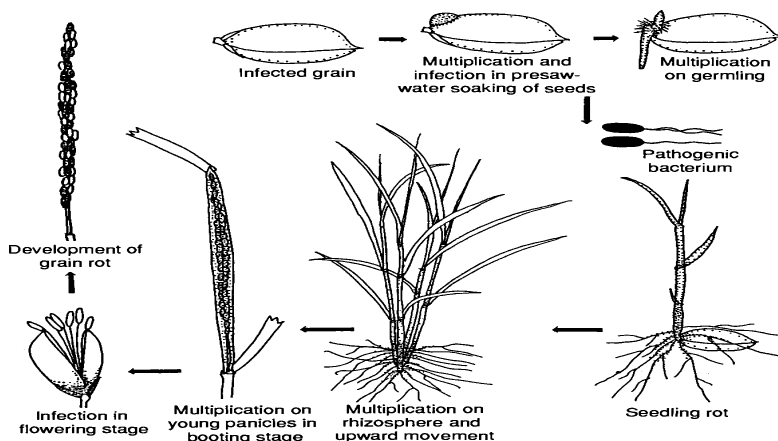


Fig. 7: Disease cycle of bacterial grain rot of rice causing by *Burkholderia glumae*
(Masao Goto 1992. Pp-274)

3.7.Disease management of BPB

i. Biological Control

Application of biological control approach can successfully check *Burkholderia. glumae* pathogen. In contrast, some of the avirulent isolates of *Burkholderia* are capable of impeding the expansion of rice grain rot has been established. Recently a study has been conducted using a metagenomics library to segregate *E. coli* mutants that were capable of producing in the company of toxoflavin, besides recognized a toxoflavin-degrading enzyme, TxeA (Choi et al. 2018). Hence, this toxoflavin-degrading enzyme has potential utilization to produce transgenic plants, which can reduce the bacterial poison or assemble antagonistic bacteria that could contest with the bacterium.

ii. Cultural Practices

Cultural practices are so far effective in minimizing the quantity of bacterial pathogen inoculum existing in the field, which includes planting pathogen-free seed as the microorganism can be seed-borne (Wamishe et al., 2015). In addition, an advanced forecast technique, BGRcast employed in Korea where temperature and humidity are taken into consideration to measure the prospect of a bacterial panicle blight prevalent, and recommendations are made to apply oxolinic

acid in a view to restrain BPB prevalent (Lee et al. 2015). The accuracy rate of this scheme has been estimated to 71.4% (Lee et al. 2015).

iii. Resistant rice cultivars

There are almost no rice varieties available that can depict a wide range of resistance to BPB pathogen; nevertheless, some varieties have limited resistance (Mizobuchi et al., 2016). Resistance sources are challenging to identify since various methods of inoculation generate divergent output (Mizobuchi et al., 2016). However, a gene encrypting a receptor-like kinase may deliberate resistance or tolerance to two-grain diseases: blast (*Magnaporthe oryzae*) in addition to leaf blight (*Xanthomonas oryzae* pv. *oryzae*) produced through transgenic rice lines overexpressing BSR1 (Broad-Spectrum Resistance 1) have been successfully achieved maximum levels of resistance against *B. glumae* (Debouzet et al. 2011; Maeda et al. 2016).

iv. Chemical Control

Several bactericides have been identified that can effectively prevent or restrain the manifestation of seedling rot and panicle rot inoculum produced by plant infective bacteria *Burkholderia* spp. comprising copper, and copper-containing mixtures, antibiotics (Shahjahan et al. 2000b). Oxolinic acid, a synthesized inhibitory and bactericidal antibiotic, is the only recommended chemical treatment widely used in Asia to control bacterial panicle blight, it is applied as a seed treatment and as foliar sprinkles. (Hikichi et al. 1993). However, recently, oxolinic acid has become limited in its use because of the detection of respective *B. glumae* strains resistant to this chemical.

Revolutionary approaches of chemical treatment could include using composites that restrict quorum sensing, such as those discouraging the combining of the autoinducer.

4. Rice Bacterial Leaf Streak

4.1. History and Distribution

The disease bacterial leaf streak is the origin and first identified in the Philippines in 1918 Reinking called it the stripe disease. Afterward, this disease was reported in China by (Fang et al. 1957), and he named it bacterial leaf streak, which is currently used to describe the disease. BLS is a recent disease, and the bacterium *Xanthomonas oryzae* pv. *oryzicola* (Xoc) is the causal organism related to the bacterial leaf blight (BLB) infection that had been notorious for occurring over a period (Mohd Said et al., 2017). Though BLS is rarely described in Malaysia, BLS's

occurrence has remarkably inhibited rice production in humid tropical and subtropical zones of Asia and Africa (Niño-Liu et al., 2006). Moreover, BLS was observed in the Philippines and China; the other neighboring countries such as Thailand, Malaysia, India, Vietnam, Indonesia, Indonesia, Cambodia, and Bangladesh) also detected the disease.

4.2.Economic importance

Dependent on the climatic circumstances and cultivar, it has been informed, and calculated yield is reduced due to the disease by approximately 1.5 to 17.1% (Opina and Exconde 1971). Lim et al. (2014) stated yield decreased highly up to 32% in 1000-grain weight by the bacterium *X. oryzae pv oryzae*.

4.3.Symptom

The characteristic symptom of the leaf disease is linear, water-soaked, translucent streak, 1 mm wide (Fig. 8), scattered in between leaf veins. Symptoms observed include yellowish to brown linear streak lesions (Fig. 9). Initially, the streaks are dark green, which later turns into a brown or yellowish-brown. When the leaves are severely affected, several streaks may coalesce and cause almost total blighting of the leaves. The leaf surface becomes covered with the copious, yellow, tiny bead-like encrustations of bacterial exudate. The streak diseases affect only the parenchyma tissues of the leaf sheath. Shekhawat and Srivastava (1972) narrated infection caused by BLS results in brown or black staining of seeds and florets, ultimately death of ovary, endosperm as well as stamens and browning of glumes.



Fig. 8: Water-Soaked lesions



Fig. 9: Linear lesions

[\(Rice knowledge bank; IRRI\)](#)

4.4.Causal organism

Disease-causing *X. oryzae* pv. *oryzicola* is a Gram-negative bacterium encapsulated rod-shaped non-spore-forming in conjunction with a particular polar flagellum for motility. Cell dimension measured 1.0-2.5 x 0.4-0.6 µm. Colonies are deliberate growing at 28 °C with shaking at 200 rpm in nutrient-rich medium NB, usually pale-yellow, smooth, entire, round, mucoid, and domed.

4.5.Disease Cycle and Epidemiology

Shekhawat et al. (1969) and Devadath (1971) reported that seed from an infected crop harbors the bacterium and is a potential source of the disease and its dissemination to a distant place.

The bacterium seems to survive the off-season under the glumes, and when the seed is sown but not in the debris or soil, it further contaminates the plumule during germination. Infection of coleoptile, leaf sheaths and first leaf occur through stomata. The bacterium is carried to the foliage by the first leaf. The bacterial exudates from the flag leaf cause seed infection in the panicles and are dispersed mostly by spattering and windblown rain in addition to leaf connection and water used for irrigation. The epidemiology of the disease has been studied by (Shekhawat and Shrivastava 1971c, 1972c).

Numerous wild species of rice cultivar might be infested by *X.oryzae* pv. *oryzicola* and may function as a primary source or accumulation of inoculum. Young leaves are more susceptible to the disease than older ones. Constant high humidity (RH 83-93%) prolonged for two to three successive days or dew during early morning hours favor the infection. The lesion development is high at moderate temperatures ranges from (26°C-30°C) and retarded at lower temperatures below (22°C) irrespective of relative humidity. The disease cycle of BLS can be broken instead of sowing summer seed in the winter season since the bacterium cannot establish during the cool, dehydrated, and winter weather (Rao 1987).

4.6.Disease management practices of BLS

Since BLS disease-causing pathogen is seed-borne, seed treatment has effectively worked to eradicate the bacterium. Seeds are soaked overnight in Streptocycline at 0.025%; further heated water treatment at 52°C for 30 minutes can successfully eliminate seed infection

(Shekhawat and Shrivastava 1971c). It is also recommended infection and lesion development by *X. oryzae* pv *oryzicola* was preventing by spraying Vitavax @ 0.15-0.30%. A copper-based fungicide such as Sankel, Captan, and fytolan spraying at the heading stage reported being effective in preventing the disease in severe infection. Agrimycin 100 or Streptocycline 100ppm at ten days breaks, three-time spraying from the initial exposure of the disease effective to reduce the incredible infection amount (Banerjee et al. 1984). Furthermore, plant-resistant cultivars keep the fields clean by following cultural methods such as removing straw, weed hosts, plow under rice stubble, volunteer seedlings, and rice ratoons, which the pathogen can infect.

5. Bacterial Sheath Brown Rot

5.1.History and Distribution

Sheath brown rot caused by *Pseudomonas fuscovaginae* bacterium is a recognized and notorious rice disease. It is a recent one and is currently become serious worldwide and getting prevalent very fast. *Pseudomonas spp.* causing SBR has been acknowledged as a devastating bacterial disease of rice among the bacterial pathogens also notorious to an extensive range of economically significant crops throughout the world. SBR was first identified in Hokkaido, Japan, a few decades ago and reported as a highly severe and bacterial disease of rice was ranking during the period in this area (Tanii 1976). In Asia, this disease has been comparatively new even though its prevalence has been reported globally in almost every area except Antarctica (Adorada et al., 2013; Miyajima, 1983). In Peninsular Malaysia, the disease had well spread; however, the primary occurrence was informed in Seberang Perak and printed in 1991 (Marzukhi et al. 1991). At present, SBR is threatening national food security since it can cause deterioration to the sheath and panicle of rice plants.

5.2.Economic importance

Pseudomonas fuscovaginae bacterium is drawing attention progressively owing to its harmful impact on yield. In Japan, the bacterium causes yield damage up to 58% (Jaunet 1996), in Indonesia estimated loss 72.2% and a surprisingly 100% in Madagascar (Razak 2009). Recent surveillance performed at the time of first rising periods in 2003 all over the country at main rice granary regions results revealed that SBR had highly dispersed in every part of Peninsular Malaysia (Saad et al. 2003). Estimates showed that a total of 4,571 ha. of rice cultivating zones in Selangor, Perak, and Johor had been infected by *P. fuscovaginae* bacterium. Maximum yield injury (ca. 20.0%) was reported in Tanjung Piandang, Perak.

5.3.Symptom

The disease symptoms have easily been identified at initial seedling phases, and usually, the diseased seedlings rotted and died after infection. Nevertheless, the infected rice field becomes yellow if the infection appears at advanced growing stages. Typical symptoms of SBR disease include sheath lesion, grain discoloration (Fig. 10), infertile grain, deformity, sometimes panicles partially filled with a grain (Razak. 2009). In addition, the disease symptoms causing necrosis of sheath and flag leaf along with this sterile spikelet (Cothier et al. 2009), lower parts of the leaf sheath generally turn light or dark brown. In severe case, as necrosis advances the whole leaf sheath become necrotized (Fig. 11). However, grain discoloration and spikelet sterility, on the other hand, have a direct impact on grain fresh weight and yield quality. (Cottyn et al. 1996; Vidhyasekaran et al. 1984).



Fig. 10: Rotting grains caused by sheath brown rot



Fig. 11: Necrotized sheath of SBR covered whole field

[\(Rice knowledge bank; IRRI\)](#)

5.4.Causal organism

Pseudomonas fuscovaginae is a Gram-negative, rod-shaped non-spore-forming pathogen, estimated cell dimension 0.5-0.8x2,0 x 3.5um with 1-4 polar flagella for motility (Tanii et al. 1976). The pathogen forms colonies consistently creamy color, round and elevated margin, diffused, smooth elevation, and developed yellowish-green pigments.

5.5.Disease Cycle and Epidemiology

Since the bacterium is seed-borne and continues to live on rice seed, it can thrive at a lower level and survive as an epiphytic plant on gramineous weeds in rice-producing zones. Disease infection and disease progression on matured plants are positively preferred if the

temperature at day becomes comparatively cool and gentle day time (17-23°C) results in an impediment of panicle emergence.

5.6. Control strategies of SBR

So far, several disease management practices have been applied to eliminate the prevalence of this bacterium of rice by several researchers. Among them, the use of disease-resistant or tolerant cultivars has proven to be the most effective and fruitful strategy to minimize disease severity. In addition, cultural control approaches: using healthy seeds, crop residue management, field sanitation, control of weeds (Sakthivel 2001) successfully reduce the incidence of sheath brown rot.

6. Conclusion

Almost all the rice bacterial diseases are causing severe yield loss problems and undoubtedly worrisome to rice-growing farmers throughout the world, including Malaysia, and playing an essential role in pushing back economic growth. However, further advanced research should be implemented on integrated control tactics and biomolecular approaches to accomplish practical and eco-friendly rice bacterial disease management in this field. Plant Pathologist is paying their supreme attempt to invent the best cure for the disease epidemic while enhancing sustainable rice production worldwide. The researchers have accomplished extensive and large-scale studies to identify the virulent factors causing the diseases in a view for future use in breeding scale to achieve improved control strategies to boost healthy rice production.

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