BACTERIAL PANICLE BLIGHT: A NEW CHALLENGE OF RICE

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ABSTRACT

Monira, U. S., Rashid, M. O., Parvin, R. and Doha, S. 2020. Bacterial panicle blight: a new challenge of rice. Bangladesh J. Plant Pathol. 36(1&2):61-68

Bacterial Panicle Blight (BPB) is an economically important emerging disease of rice in the world, especially in south-east Asia. Combination of high night temperature with high relative humidity at heading stage favors BPB infection in rice. BPB infected panicle bears blighted kernels (light gray with a dark brown margin), whereas the rachis or panicle branches stay green. However, neither an effective control measure nor a resistant rice variety is currently available against BPB. Oxolinic acid is frequently used in Japan to control BPB of rice, but its use on rice is restricted in many other countries including USA. Therefore, it is a great challenge for the scientist to evaluate an effective management strategy against this important disease. Assessment of BPB resistant rice cultivars and lines, rice genomics, transcriptomes and different other molecular techniques like CRISPR Cas9 may act as powerful tools to develop BPB resistance rice varieties in the future

Key word: Bacterial Panicle Blight, Rice

INTRODUCTION

Bacterial Panicle Blight (BPB) of rice, also known as grain rot of rice in Asia, resulted by the infection of *Burkholderia glumae* (earlier *Pseudomonas glumae*) and/or *B. gladioli*, is one of the most devastating seed-borne bacterial diseases of rice throughout the world (Xie *et al.* 2003). It causes significant yield losses in most of the rice producing countries in the world (Sayler *et al.* 2006, Zhou 2019). Seedling blight, sheath rot, floral sterility, and aborted grains may result by the infection of BPB, causing yield losses up to 75%, in association with reduction milling quality (Nandakumar *et al.* 2009, Zhou 2019). BPB infected seeds act as the primary inoculum for BPB infection (Nandakumar *et al*. 2009, Tsushima 1996, Sayler *et al.* 2006).

Currently, BPB has reported as a potential high-risk bacterial disease of rice in more than 21 countries in the world, particularly in tropical and subtropical countries (Ham *et al*. 2011, Cui *et al.* 2016, Table 1). BPB of rice was first reported in Japan in the 1950s, causing grain rot and seedling blight (Xie *et al*. 2003, Rush 2007), and since then, it has also been reported in other rice-growing countries in Asia, South and Central America and Africa (Tsushima 1996, Nandakumar *et al.* 2007, Wang *et al.* 2006, Kim *et al.* 2010, Quesada-González and García-Santamaría 2014, Riera-Ruiz *et al.* 2014, Zhou 2014, Mondal *et al.* 2015). High temperature (30–35°C) and relative humidity above 80% are considered as optimum for the BPB development (Syahri *et al.* 2019**)**. However, there have no effective control measure against BPB. Effective management strategies for BPB is time demanding to diminish the yield loss of rice caused by BPB. Therefore, the aim of this review is to summaries recent works on the symptoms, epidemiology, infectivity and management of BPB.

Symptoms

The BPB symptoms include seedling blight, sheath rot and panicle blight causing an enormous yield loss of rice in each year in the world (Nandakumar *et al.* 2009, Zhou and Jo 2014). Toxoflavin a toxin produced by the bacterium is an important factor to induce symptoms development on rice seedlings and grains (Jeong *et al.* 2003, Matsuda and Sato 1988).

BPB symptoms can be observed on plantlets, leaf sheath and panicles (Figure 1). The BPB infected panicles bear light to dark brown, moderately or completely discolored glumes. It may cause unfilled or aborted grains under severe infection (Ham *et al.* 2011).

The bacteria make damage by inhibiting seed germination or producing panicle blight or sheath rotting or flower sterility or grain abortion at severe infection (Wamishe 1914, Ham *et al.* 2011). The rachis or panicle branches remain green at early infection and at later stage, heavily infected panicles remain upright due to empty glumes (Wamishe 1914). A dark brown lesion may be observed on the flag leaf sheath of certain tillers resulting severe panicle damage.

Table 1. Geographic distribution of bacterial panicle blight (BPB) of rice caused by *Burkholderia glumae* and *B. gladioli*

Country	**Causal agent**	**Year**	**Reference**
Japan	*B. glumae*	1955	Goto and Ohata 1956
Taiwan (China)	*B. glumae*	1983	Chien *et al.* 1983
Columbia	*B. glumae*	1989	Zeigler and Alvarez 1989
Latin America	B. glumae	1989	Zeigler and Alvarez 1989
Vietnam	*B. glumae*	1993	Trung *et al.* 1993
Japan	*B. gladioli*	1996	Ura *et al.* 2006
Malaysia	*B. glumae*	1996	Tsushima 1996
Philippines	*B. glume* and *B. gladioli*	1996	Cottyn *et al.* 1996
Sri Lanka	*B. glumae*	1996	Tsushima 1996
Thailand	*B. glumae*	1996	Tsushima 1996
Louisiana (USA)	*B. glumae* and B. gladioli	2001	Nandakumar *et al.* 2009
Korea	*B. glumae*	2003	Jeong *et al*. 2003
China	*B. glumae*	2007	Luo *et al.* 2007
Panama	*B. glumae* and *B. gladioli*	2007	Nandakumar *et al.* 2007
Nicaragua	*B. glumae*	2008	CIAT 2008
Arkansas (USA)	*B. glume* and *B. gladioli*	2009	Nandakumar *et al.* 2009
Mississippi (USA)	*B. glumae*	2009	Nandakumar *et al.* 2009
Texas (USA)	B. glumae	2009	Nandakumar *et al.* 2009
Honduras	*B. glumae*	2011	Zhou 2019
Mississippi (USA)	*B. gladioli*	2012	Lu and Allen 2012
Costa Rica	*B. glumae*	2014	Quesada-González and García-Santamaría 2014
Ecuador	*B. glumae*	2014	Riera-Ruiz *et al.* 2014
South Africa	*B. glumae*	2014	Zhou 2014
India	*B. glumae*	2015	Mondal *et al.* 2015
Indonesia	*B. glumae*	2017	Baharuddin *et al.* 2017
China	*B. gladioli*	2018	Mirghasempour *et al.* 2018

Figure 1. Symptoms of Bactrial Panicle Blight of rice ((Wamishe, 1914; Fory *et al.*, 2014; Donald Groth, Louisiana State University AgCenter, Bugwood.org)

Table 2. Technical data on Bacterial Panicle Blight

Common name	Bacterial Panicle Blight
Causal organisms	*Burkholderia glumae* and/or *B. gladioli* (Xie *et al.* 2003)
Nature of bacteria	Rod shape, gram negative, aerobic, motile with two to four polar flagella and non-florescent in culture media (Ham *et al*. 2011)
Host	Rice, eggplant, pepper, tomato, chinese basil and sesame (Jeong *et al.* 2003, Nandakumar *et al.* 2007)
Symptoms	Panicle blanking, which shows straw colored spikelet's, grain discoloration and green colored rachis, it remains (Wamishe 1914, Nandakumar *et al*. 2009)
Dissemination	Disseminated by contaminated seed, irrigation water, the wind , flying insects and crop residue (Zhou 2019)
Predisposing conditions	Temperature between 30–35°C, relative humidity above 80%, high doses of nitrogen fertilizer and highly dense cropping (Syahri *et al.* 2019).

Epidemiology

Both *B. glumae* and *B. gladioli* have been recognized as the causal agents of BPB. However, the earlier one distributed widely in the world (Table 1) as well as more virulent, causing more economic losses than the latter one (Ham *et al.* 2011). Bacterial pathogens causing BPB are frequently observed in the air, water, and soil. Survival of these pathogens in soil usually affected by soil type, soil pH, and weather conditions (Tsushima 1996). Host vulnerability, inoculum density, and climatic factors play the vital roles in these bacterial infection process (Tsushima and Naito 1991, Tsushima 1996). BPB is frequently observed at the heading stage of rice when the night temperature is high and rainfall occurs frequently. With an appropriate environmental conditions (30–35°C temperature and above 80 % relative humidity), BPB can be increased rapidly and may cause serious epidemics (Cha *et al.* 2001, Syahri *et al.* 2019). However, the thermal death point for the causal agents of BPB is at 70°C (Kurita *et al.* 1964). The flowering and heading time of the variety may also affect plant susceptibility. Rice plants are vulnerable to BPB infection within 1–3 days of flowering (Tsushima, 2011). Plants are also susceptible to BPB after 4–5 days of heading to subsequent 11 days (Syahri *et al.* 2019). Both the bacterial species were widely observed in rice seed lots in China, Japan, Philippines, and USA (Cui *et al.* 2016, Cottyn *et al.* 2001, Sayler *et al.* 2006) and these infected seeds serve as the primary inoculum source (Nandakumar *et al.* 2009). Upon seed germination bacterial pathogens initiate infection that occupies the roots and lower sheaths and then moves up as an epiphytic way (Tsushima 1996, Hikichi 1993). Primary infection occurs once *B. glumae* or *B. gladioli* contaminated seeds are sown and then transplanted to the main fields (Nandakumar *et al.* 2009). Secondary infection of nearby plants occurs at heading stage (Mizobuchi *et al.* 2018). Recently, Li (2016) observed that *B. glumae* can infect the rice plant directly by colonizing the vascular bundle of lateral roots and then disseminated to the upper part of the plants through vascular system. The bacterium colonizes and multiplies in spikelets immediately after invasion through stomata or wound in the glume epidermis by using storage sugars in developing grains (Hikichi 1993, Hikichi *et al.* 1994). Jeong *et al.* (2003) further reported that *B. glumae* could also infect some other crops including eggplant, tomato, perilla, sesame and hot pepper. The bacteria can survive on both host plants and soils under varied environmental conditions (Compant 2008, Nandakumar *et al.* 2009).

As BPB incidence and severity is highly influence by the weather conditions, the relationship between the BPB occurrence and pathogens survival with the climatic factors, such as temperature, relative humidity and rainfall, need to be studied in order to manage BPB effectively.

Management

Use of BPB-free rice seed is the key constant to reduce yield loss caused by BPB. Besides, farmers could use partially resistant rice cultivars or may apply available chemicals or biocontrol agents, together with proper cultural practice to reduce BPB infection. For effective and sustainable control of BPB, these available management strategies should be used integrative. Integrated practice of the existing management strategies can be an effective and sustainable way to manage the BPB of rice.

Chemical control

Oxolinic acid (5-ethyl-5, 8-dihydro-8-oxo-[1,3] dioxolo [4,5-g] quinoline-7-carboxylic acid, Starner®), an antibacterial substance is the first reported chemical used for control of the BPB disease of rice. This quinolone derivative antibacterial compound was first introduced in Japan to control seeding rot and grain rot of rice in 1989 (Hikichi *et al.* 1989). Hikichi *et al.* (2001) further reported that combined use of oxolinic acid during seed treatment and foliar sprays at the heading stage is the best approach for effective control of both seedling rot and gain rot of rice. Foliar spray at the heading stage of rice effectively inhibit multiplication of bacteria on spikelets and eventually control BPB (Hikichi *et al.* 1989). A field trial conducted in Louisiana state of Texas showed that application of oxolinic acid at the booting stage to heading stages reduced BPB infection up to 88% (Groth *et al.* 2001, Zhou *et al.* 2011). In Japan, generally Oxolinic acid used for three times in each season to control BPB of rice (Maeda *et al.* 2007). Unfortunately, oxolinic acid resistant strain of *B. glumae* have been reported in Japan since 1998 (Hikichi *et al.* 1998). It also has been observed that the bacterial strains resistant to oxolinic acid are similarly cross-resistant to other quinoline derivatives (Hikichi *et al.* 1998). However, oxolinic acid is not considered for the use on rice in some countries including USA (Nandakumar *et al.* 2009). This resistance capacity of BPB might lessen the use and new registrations of oxolinic acid for management of BPB. Copper and copper-containing compounds have also been described to effectively control BPB in rice (Groth *et al.* 2001 Zhou *et al.* 2011).

Biological control

Numerous studies have been conducted to evaluate effective biological control agents for sustainable management of BPB in rice. Tsushima and Torigoe (1991) set up an experiment for the first time in Japan to screen bacterial antagonists to control BPB of rice under field condition. Furuya *et al.* (1991) further observed that rice seedling rot was diminished by treating seed with avirulent strains of *B. glumae*. Miyagawa and Takaya (2000) showed that an avirulent strain of *B. gladioli* could effectively reduce BPB severity in rice. It has already been proved that five *Bacillus amyloliquefaciens* strains from the Louisiana state of USA were effective to control *B. glumae*, *in vitro* as well as they could decrease BPB infection at the field condition when applied at the heading stage of rice (Shrestha *et al.* 2016). In Japan, along with the bacterial biocontrol agents, several bacteriophages have also been used for the management of rice seedling rot (Adachi *et al.* 2012). They also showed that two bacteriophages were capable to lyse *B. glumae* and seed treatment with these bacteriophages could effectively control seeding rot of rice. They further evaluated that one of them was even more effective than the bactericide ipconazole/copper (II) hydroxide in reducing seeding rot of rice.

Cultural practice

Very few studies have been reported on cultural practices that could reduce the incidence and severity of BPB in rice. Applications of high levels of nitrogen fertilizer tend to increase the susceptibility of rice to BPB infection. Therefore, avoiding extreme use of nitrogen fertilizer in rice field can help to minimize the infection of BPB. Wamishe (2014) validated that the BPB severity in rice was 1.6 times higher at the high nitrogen rate (247 kg/ha) than that of low nitrogen rate (168 kg/ha) applied in the course of a cropping season.

However, in order to acquire consistent results with the official laboratory studies, the following recommendations are important for commercial field crop application:

i. Application with appropriate dose of the active ingredient, as well as, keeping in mind the quantity and quality of the product.
ii. Application of the product at the proper time.
iii. Introducing an integrated management practice to control *B. glumae*, including:
    a. The use of highest quality certified seeds.
    b. Seed treatment and foliar management especially at the panicle emergence stage.
    c. Timely irrigation and fertilization with proper dose.
    d. The use of resistance or partial resistance cultivars.
    e. Removal of crop residue.
    f. Crop rotation.
    g. Following appropriate planting time.

Conclusions

With the increase of global trade, bacterial panicle blight is wide spreading all over the world in recent years. Due to the global warming, BPB be the next major disease of rice in the near future especially in South-East Asia. As severe outbreak of BPB could be devastating yield losses, actual disease forecasting should be done and special efforts should be made to develop effective control methods. A better understanding of bacterial epidemiology, virulence factors and host resistance mechanisms are essential to achieve these goals. As, the high temperature triggers the outbreak of BPB and the world is warming day-by-day, effective management of this disease is challenging. More study is needed to understand the genetic control of BPB resistance in available resistant rice cultivars and lines, especially hybrids. Recent progresses in rice genomics and newly developed genome editing tools like CRISPR-Cas9 may provide powerful tools to better understand the mechanisms associated with BPB resistance to develop BPB resistance new rice cultivars in the future. Use of resistant cultivars is the best approach to minimize the damage caused by BPB infection. These studies inform us about the importance of BPB-resistance in the national and international rice markets and also help breeders to focus future breeding toward climate change impact resilience.

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