

Comparative study of disease tolerance on six rice cultivars against bacterial leaf blight and bacterial panicle blight

Fatma Azwani Abdul Aziz^{1*}, Azimah Hamidon¹, Mohd As'wad Abdul Wahab², Norida Mazlan^{1,2}, Siti Izera Ismail^{1,2}, and Nor Azura Husin³

¹Universiti Putra Malaysia, Institute of Tropical Agriculture and Food Security, 43400 UPM Serdang, Selangor, Malaysia.

²Universiti Putra Malaysia, Faculty of Agriculture, 43400 UPM Serdang, Selangor, Malaysia.

³Universiti Putra Malaysia, Faculty of Computer Science and Information Technology, 43400 UPM Serdang, Selangor, Malaysia.

*Corresponding author (fatma@upm.edu.my)

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ABSTRACT

Rice (*Oryza sativa* L.) production is significantly threatened by bacterial leaf and panicle blight, which can cause yield losses of up to 70% and 50%, respectively. Several rice cultivars (Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) were evaluated for tolerance to bacterial leaf blight (BLB) and bacterial panicle blight (BPB) under inoculations with *Xanthomonas oryzae* pv. *oryzae* (BLB), *Burkholderia glumae* (BPB), a combination of both, and a control. Key parameters, including plant height, number of tillers, leaf and lesion length, disease incidence, and disease severity, were measured at intervals from 10 to 60 d after transplanting (DAT). Results indicated significant variability in disease tolerance. 'Putra 2' recorded the tallest plant height (79.1 cm under BLB), while 'IS21' showed the shortest lesion lengths (13.0 cm under BLB). Conversely, 'Siraj 297' and 'MRQ 76' recorded the longest lesions (24.0 cm and 23.3 cm, respectively) and the highest disease incidence (> 38% under BLB). Disease severity peaked in 'Siraj 297' (score 3.6), whereas 'Putra 1' and 'IS21' remained lower (2.0-2.3). 'CL2' exhibited moderate lesion development but recorded the lowest incidence under BPB (16.6%). Overall, 'Putra 1', 'Putra 2' and 'IS21' showed greater resilience with minimal growth changes and shorter lesion lengths, while 'Siraj 297' and 'MRQ 76' were more susceptible. These findings emphasize the importance of selecting suitable cultivars for disease-prone regions to minimize losses, while providing agronomists and farmers with practical insights for variety selection and disease management. It also highlights the need for continued cultivar development to improve resistance and sustain productivity.

Key words: Bacterial leaf blight, bacterial panicle blight, BLB, BPB, *Burkholderia glumae*, disease tolerance, *Oryza sativa*, *Xanthomonas oryzae* pv. *oryzae*.

INTRODUCTION

Over half of the global population relies on rice (*Oryza sativa* L.) as a staple food crop, making it crucial for both livelihoods and food security, particularly in Asia (Bandumula, 2018). However, rice cultivation faces ongoing threats from diverse biotic challenges, such as bacterial diseases that can cause significant yield losses. Among these, bacterial leaf blight (BLB), triggered by *Xanthomonas oryzae* pv. *oryzae*, and bacterial panicle blight (BPB), caused by *Burkholderia glumae*, rank among the most destructive diseases limiting rice yields globally (Chen et al., 2021). According to Sabri et al. (2021), BLB and BPB are two of the most devastating diseases affecting rice production in Malaysia, resulting in yield losses of up to 70% and 50%, respectively. The management of these diseases remains challenging due to environmental conditions that favour pathogen survival and spread, limited efficacy of chemical controls, and the emergence of new, more virulent strains. Traditional disease management practices, such as chemical treatments and crop rotation, are often insufficient, costly, or

environmentally unsustainable (Rasheed et al., 2023). In contrast, the development and deployment of disease-resistant rice varieties represent an eco-friendly and sustainable approach to mitigating yield losses. Several breeding programs have focused on introgressing resistance genes and QTLs to improve varietal tolerance to BLB and BPB, with varying degrees of success (Wu et al., 2024). Evaluating traits such as lesion length, lesion percentage, disease incidence, disease severity, plant height, tiller production, and flag leaf morphology under controlled inoculation conditions provides essential data to support breeding programs. These evaluations help breeders identify lines with broad-spectrum or combined resistance, essential for integrated disease management in regions facing multiple bacterial threats (Yue et al., 2024).

This study focuses on a comparative analysis of six local paddy cultivars: Putra 1, Putra 2, IS21, CL2, Siraj 297, and MRQ 76. These cultivars were selected for their agronomic traits and potential resistance to bacterial diseases. 'Putra 1' and 'Putra 2' are two new high-yielding rice cultivars introduced by Universiti Putra Malaysia (UPM) in 2023. The blast resistance of 'Putra 1' was achieved by introgressing the broad-spectrum genes (*Piz*, *Pi2*, and *Pi9*) from the local 'Pongsu Seribu 1' into 'MR219', a high-yielding but susceptible line, through marker-assisted backcross breeding (Miah et al., 2017). 'Putra 2' is developed to withstand flooding, making it suitable for areas prone to submergence (Dorairaj and Govender, 2023). This trait was introduced through marker-assisted backcrossing, utilizing the submergence-tolerant 'Swarna-Sub1' as the donor parent. Both 'PUTRA 1' and 'PUTRA 2' have demonstrated strong agronomic performance in trials, showing high yields and resilience in various growing conditions. 'IS21' is a rice cultivar known for its resilience and resistance to major rice diseases, particularly BLB and BPB (Ahmad et al., 2023). It is bred to perform well under diverse environmental conditions and has high yield potential. 'IS21' has a moderate to high plant height and produces a substantial number of tillers. 'CL2' is a rice cultivar developed for its high yield and quality grain production, suitable for cultivation in various regions (Harun et al., 2018). It generally shows consistent growth with moderate plant height and a satisfactory tillering rate, and is bred to resist common rice diseases, including BLB and BPB. 'Siraj 297' is characterized by high yield potential, excellent grain quality and adaptability to different environments, exhibiting good growth with considerable plant height and tiller production (Esa et al., 2020). It has been developed to resist a range of diseases, notably BLB and BPB. 'MRQ 76' is a high-yield cultivar recognized for its robust growth and good grain quality, widely cultivated for its productivity and resilience (Noorzuraini et al., 2021). It has a tall plant stature with strong tillering ability, contributing to elevated yield levels and offering resistance to major rice diseases, including BLB and BPB.

Despite advances in breeding, there is a notable lack of comparative studies evaluating these local varieties under simultaneous BLB and BPB stress (Urooj et al., 2022). Although breeding programs have made progress in developing resistant varieties (Dileep Kumar et al., 2025), broader assessments are necessary to understand how different varieties perform under specific disease pressures, particularly BLB and BPB (Weny et al., 2019). Prioritizing these evaluations is critical for selecting varieties with enhanced tolerance or resistance. Varieties that consistently show lower lesion lengths and percentages, reduced disease incidence, and lower severity can be recommended for cultivation and targeted for further breeding work (Weny et al., 2019). These evaluations not only help mitigate yield losses but also support the development of resilient, farmer-friendly varieties essential for ensuring food security in disease-prone regions.

Therefore, this study aims to evaluate six paddy varieties for their tolerance to bacterial leaf blight (BLB) and bacterial panicle blight (BPB), identify varieties with superior disease resilience, and provide practical recommendations that help farmers reduce crop losses, and support the development of breeding programs and crop management strategies.

MATERIALS AND METHODS

Planting preparation

Experimental work was conducted in glasshouse facilities at the Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia, Serdang (2°59' N, 101°44' E; 32 m a.s.l.), Selangor, Malaysia. The planting process began in April and continued until July 2024. During this period, the weather was predominantly sunny, with temperatures ranging from 29 °C at night to 32.5 °C in the afternoon and humidity levels generally between 60% and 77%. The cultivation medium consisted of soil with a clay loam texture (59% sand, 24% silt, and 17% clay) and a pH of 5.2. The soil contained 0.46% total N, 40 mg kg⁻¹ available P, and 32 mg kg⁻¹ available K. The

rates and phased applications of fertilizers were determined based on guidelines from the International Rice Research Institute (IRRI, 2013), aligning with Malaysia's rice farming practices in soil management, pest control, and productivity enhancement.

Treatment applications

This study involved six local paddy varieties: Putra 1, Putra 2, IS21, CL2, Siraj 297, and MRQ 76, selected for their agronomic traits and potential resistance to bacterial diseases. Conducted using a randomized complete block design (RCBD) with four treatments and three replicates, each plot measured 4 m² and was planted with one of the six paddy varieties. The experimental design comprised four treatments: Bacterial leaf blight (BLB) inoculation (*Xanthomonas oryzae* pv. *oryzae*), bacterial panicle blight (BPB) inoculation (*Burkholderia glumae*), simultaneous BLB and BPB inoculation, and a control without inoculation. Inoculation was performed at the tillering and flowering stages (on 15 DAT) using the respective bacterial pathogens, following standard protocols (Nayak et al., 2021). For the inoculation with BLB, the pathogen *X. oryzae* pv. *oryzae* (Xoo) was cultured on nutrient agar plates. A suspension with a concentration of 10⁸ CFU mL⁻¹ was prepared. The leaf clipping method involved dipping the scissor tips in Xoo suspension and clipping 2 to 3 cm from the fully extended first and second leaves or only the second leaf in seedlings before the tillering stage. During the experiment, gloves were worn to ensure safety and prevent contamination. At each step, one to two leaves were cut using scissors with tips dipped in the Xoo suspension. For statistical analyses, nine leaves per pot (three leaves per plant) were inoculated, and at least five data points for lesion length were obtained. For the inoculation with BPB, the pathogen *Burkholderia glumae* was cultured on nutrient agar, and a 10⁸ CFU mL⁻¹ suspension was prepared for use. The syringe method was used for this inoculation. A 1 mL syringe was filled with bacterial suspension and used to inject the suspension directly into the panicles at the flowering stage. The needle was inserted into the panicle, and approximately 0.5 mL suspension was injected per panicle. The process was repeated for each panicle to ensure consistent inoculation. Field preparation and all other agronomic practices were followed as recommended, except for plant protection measures.

Data collection and experimental design

Data were collected at the flowering and grain-filling stages to assess key plant agronomic parameters and disease-related parameters. These included plant height (Challur and Kumar, 2023), the number of fully expanded tillers per plant, leaf length and leaf width, number of panicles per plant, number of panicles showing symptoms, lesion length, disease incidence and disease severity, following the International Rice Research Institute (IRRI) standard evaluation system for Rice (SES) 2013 guidelines (IRRI, 2013). The study employed a factorial randomized complete block design (RCBD) with three replicates (three plants per replicate) to evaluate the disease tolerance of six paddy varieties (Putra 1, Putra 2, IS21, CL2, Siraj 297, and MRQ 76) against BLB and BPB.

Measurements of photosynthetic rate were taken on fully expanded young leaves positioned as the third from the top, between 09:00 and 11:00 h on a clear day using a portable photosynthesis system (Li-6400XT, LI-COR, Lincoln, Nebraska, USA). Assessments on the abaxial surface were conducted at 40 and 70 DAT, with a CO₂ reference level of 400 µmol m⁻² s⁻¹ and a photosynthetic photon flux density (PPFD) 900 µmol m⁻² s⁻¹. Stomatal conductance (g_s) and transpiration rate (E) were derived from the resulting photosynthetic data. The third fully expanded leaf from the top was used for measurements at 40 and 70 DAT, with three replicates per parameter. These gas exchange parameters provide insights into how paddy varieties respond to environmental conditions during critical growth stages. Statistical evaluation included ANOVA to identify significant differences among treatments and varieties. The LSD test ($P \leq 0.05$) was applied for mean separation, with all analyses conducted using SAS software (SAS Institute, Cary, North Carolina, USA).

RESULTS AND DISCUSSION

Plant height

Across the six measurement points, a general trend of increasing plant height is observed for most treatments and varieties (Table 1). The growth rate varies, with some combinations showing a steep increase in height during the initial 30 DAT, while others demonstrate more gradual growth. The variation in plant height by treatment revealed distinct growth patterns across different rice varieties. 'Putra 1' recorded its highest height (75.667 cm) under the

control treatment at 60 DAT, while notable early growth under bacterial leaf blight (BLB) and bacterial panicle blight (BPB) (43.000 cm at 30 DAT) reflected its resilience. These results align with findings by Zakaria and Misman (2024), who reported strong vegetative performance in 'Putra 1' under both control and disease stress conditions. Similarly, Mohanavel et al. (2024) emphasized the role of varietal traits in maintaining growth under biotic stress. 'Putra 2' demonstrated substantial growth with the BLB treatment, reaching 79.133 cm by day 60 DAT. Other treatments, such as control and BPB, also resulted in considerable heights, indicating their effectiveness. 'Putra 2' showed the highest plant height under the BLB treatment, indicating its potential resilience or a favourable response to this bacterial strain, corroborating findings by Subburaj et al. (2024). 'IS21' showed consistent growth, reaching 69.467 cm at 60 DAT under BLB, while the control resulted in lower heights. 'CL2' recorded its highest growth (66.400 cm) under BPB but generally lagged behind other varieties. 'Siraj 297' peaked at 64.267 cm with BLB, showing a moderate response. 'MRQ76' exhibited strong growth with BPB, reaching 71.000 cm at 60 DAT, while the control also supported significant height. This trend supports observations that plant vigour under stress may vary by variety and stress type (Mohanavel et al., 2024). 'Putra 1' reached 75.667 cm with control but only 43.000 cm with BLB at 30 DAT, while 'Putra 2' achieved 79.133 cm with BLB at 60 DAT. Generally, BLB + BPB treatments suppressed plant height more than individual infections, suggesting a compounded stress effect. Control treatments consistently supported taller plants, underscoring the negative impact of bacterial infections on vegetative growth (Subburaj et al., 2024).

Table 1. Plant height (cm) in six paddy cultivars (Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) across different bacterial inoculation treatments (control, BLB, BPB, BLB + BPB) at 10, 20, 30, 40, 50 and 60 d after transplanting (DAT). Distinct letters in the row indicate significant differences ($P \leq 0.05$). BLB: Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*); BPB: bacterial panicle blight (*Burkholderia glumae*). Means, followed by the same small letter within the column (combination treatment) and the same capital letter within the row (DAT), are not significantly different using LSD, $P = 0.05$ ($n = 3$).

	Days after transplanting (DAT)					
	10	20	30	40	50	60
Putra 1 + Control	23.333 ^{abcC}	33.000 ^{abBC}	39.233 ^{defB}	66.533 ^{abCA}	70.567 ^{abCA}	75.667 ^{abA}
Putra 1 + BLB	22.167 ^{bcC}	29.900 ^{bcC}	54.000 ^{abB}	66.500 ^{abCA}	70.600 ^{abCA}	74.700 ^{abA}
Putra 1 + BPB	22.000 ^{cC}	37.733 ^{abB}	43.000 ^{bcdefB}	62.333 ^{abCA}	67.000 ^{abdefA}	71.000 ^{abCA}
Putra 1 + BLB + BPB	30.000 ^{ab}	32.633 ^{abB}	36.900 ^{efB}	64.200 ^{abCA}	70.200 ^{abCA}	74.067 ^{abA}
Putra 2 + Control	18.333 ^{cD}	34.800 ^{abC}	39.800 ^{defBC}	52.667 ^{bcdeAB}	56.667 ^{efA}	63.000 ^{bcA}
Putra 2 + BLB	20.000 ^{cD}	31.333 ^{abC}	63.000 ^{ab}	70.500 ^{aAB}	73.800 ^{aA}	79.133 ^{aA}
Putra 2 + BPB	23.833 ^{abcC}	32.833 ^{abBC}	40.867 ^{cdefB}	68.667 ^{abA}	71.667 ^{abA}	75.467 ^{abA}
Putra 2 + BLB + BPB	19.833 ^{cE}	36.667 ^{abD}	43.000 ^{bcdefCD}	50.667 ^{cdeBC}	56.900 ^{defAB}	64.000 ^{bcA}
IS21 + Control	23.000 ^{abcD}	30.333 ^{bcD}	35.867 ^{fC}	48.333 ^{deB}	54.667 ^{fB}	63.600 ^{bcA}
IS21 + BLB	20.333 ^{cD}	40.567 ^{abC}	50.333 ^{bcdBC}	59.333 ^{abCA}	64.000 ^{abdefA}	69.467 ^{abCA}
IS21 + BPB	24.000 ^{abcE}	39.500 ^{abD}	46.333 ^{bcdefCD}	53.000 ^{bcdeBC}	60.000 ^{bcdeAB}	64.333 ^{bcA}
IS21 + BLB + BPB	22.000 ^{bcD}	38.300 ^{abC}	41.667 ^{cdefC}	53.333 ^{bcdeB}	60.333 ^{bcdeAB}	64.100 ^{bcA}
CL2 + Control	22.000 ^{bcE}	35.533 ^{abD}	41.567 ^{cdefC}	46.667 ^{eB}	54.000 ^{fA}	58.033 ^{cA}
CL2 + BLB	23.667 ^{abcD}	39.533 ^{abC}	45.933 ^{bcdefBC}	51.000 ^{cdeB}	59.667 ^{bcdeA}	65.467 ^{bcA}
CL2 + BPB	21.833 ^{bcD}	34.667 ^{abC}	41.700 ^{cdefC}	53.667 ^{bcdeB}	61.333 ^{abdefAB}	66.400 ^{abCA}
CL2 + BLB + BPB	23.333 ^{abcE}	35.333 ^{abDE}	41.767 ^{cdefCD}	52.000 ^{cdeBC}	60.000 ^{bcdeAB}	65.767 ^{bcA}
Siraj 297 + Control	19.000 ^{cE}	36.333 ^{abD}	42.000 ^{cdefCD}	52.333 ^{bcdeBC}	63.333 ^{abdefAB}	67.200 ^{abCA}
Siraj 297 + BLB	24.167 ^{abcD}	35.333 ^{abC}	41.233 ^{cdefC}	51.233 ^{cdeB}	58.800 ^{bcdeA}	64.267 ^{bcA}
Siraj 297 + BPB	23.333 ^{abcD}	38.900 ^{abC}	47.467 ^{bcdeBC}	56.300 ^{abCA}	63.167 ^{abdefA}	67.433 ^{abCA}
Siraj 297 + BLB + BPB	20.833 ^{bcD}	27.833 ^{bd}	36.600 ^{efC}	49.000 ^{deB}	58.000 ^{cdefA}	63.333 ^{bcA}
MRQ76 + Control	19.833 ^{cC}	35.167 ^{BC}	40.667 ^{cdefB}	61.333 ^{abCA}	68.000 ^{abCA}	73.000 ^{abA}
MRQ76 + BLB	20.167 ^{abcD}	32.533 ^{abC}	40.800 ^{cdefC}	53.267 ^B	60.600 ^{abdefAB}	64.667 ^{bcA}
MRQ76 + BPB	28.333 ^{abD}	44.000 ^{aC}	51.767 ^{abCB}	62.767 ^{abCA}	68.400 ^{abCA}	71.000 ^{abCA}
MRQ76 + BLB + BPB	23.000 ^{abcC}	36.333 ^{abB}	43.000 ^{bcdefB}	58.000 ^{abCA}	63.700 ^{abdefA}	68.000 ^{abCA}

Number of tillers

The number of tillers is a crucial indicator of plant health and productivity, particularly in cereal crops, and varied across six paddy varieties under different treatments (Table 2). A general increase in tiller numbers per plant was observed from 30 DAT onward, with significant growth at 50-60 DAT. The BLB + BPB treatment resulted in the highest tiller counts for 'Putra 1' (12), 'Putra 2' (12), and 'Siraj 297' (13) at 60 DAT, indicating a strong varietal response to combined bacterial stress. This aligns with Mubassir et al. (2016), who observed increased tillering under BLB stress. The BLB treatment also enhanced tiller production in 'IS21' and 'CL2' (13 tillers at 60 DAT), while 'Putra 2' performed best under control (12). Interestingly, bacterial inoculations, particularly BLB and BLB + BPB, often resulted in higher tiller numbers than the control, suggesting a possible stress-induced stimulatory effect (Subburaj et al., 2024). Notably, the BLB consistently increased tiller counts, especially in 'Putra 2' and 'IS21'. 'Siraj 297' recorded the highest tiller count with BLB + BPB, emphasizing the importance of treatment selection for optimizing tiller production and yield (Subburaj et al., 2024).

Table 2. Number of tillers per plant in six paddy cultivars ('Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) across different bacterial inoculation treatments (control, BLB, BPB, BLB + BPB) at 10, 20, 30, 40, 50 and 60 d after transplanting (DAT). Distinct letters in the row indicate significant differences ($P \leq 0.05$). BLB: Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*); BPB: bacterial panicle blight (*Burkholderia glumae*). Means, followed by the same small letter within the column (combination treatment) and the same capital letter within the row (days after transplanting), are not significantly different using LSD, $P = 0.05$ ($n = 3$).

	Days after transplanting (DAT)					
	10	20	30	40	50	60
Putra 1 + Control	4.333 ^{abC}	4.333 ^{abC}	8.333 ^{bcB}	8.333 ^{bcB}	10.667 ^{aA}	11.667 ^{abA}
Putra 1 + BLB	4.667 ^{aD}	4.667 ^{aD}	9.333 ^{abcC}	9.333 ^{abcC}	11.000 ^{aB}	12.667 ^{abA}
Putra 1 + BPB	3.333 ^{abcdC}	3.333 ^{abcdC}	8.333 ^{bcB}	8.333 ^{bcB}	10.000 ^{aAB}	11.333 ^{abA}
Putra 1 + BLB + BPB	3.667 ^{abcdC}	3.667 ^{abcdC}	9.667 ^{abB}	9.667 ^{abB}	11.667 ^{aA}	12.667 ^{abA}
Putra 2 + Control	4.333 ^{abC}	4.333 ^{abC}	9.333 ^{abcB}	9.333 ^{abcB}	10.000 ^{aAB}	10.667 ^{bA}
Putra 2 + BLB	4.000 ^{abcB}	4.000 ^{abcB}	10.333 ^{aA}	10.333 ^{aA}	11.000 ^{aA}	12.000 ^{abA}
Putra 2 + BPB	3.667 ^{abcdD}	3.667 ^{abcdD}	8.667 ^{abcC}	8.667 ^{abcC}	10.667 ^{aB}	11.667 ^{abA}
Putra 2 + BLB + BPB	4.000 ^{abcD}	4.000 ^{abcD}	8.667 ^{abcC}	8.667 ^{abcC}	10.667 ^{aB}	12.667 ^{abA}
IS21 + Control	3.667 ^{abcdC}	3.667 ^{abcdC}	8.333 ^{bcB}	8.333 ^{bcB}	10.667 ^{aA}	12.000 ^{abA}
IS21 + BLB	4.000 ^{abcD}	4.000 ^{abcD}	9.333 ^{abcC}	9.333 ^{abcC}	11.333 ^{aB}	13.000 ^{abA}
IS21 + BPB	3.333 ^{abcdD}	3.333 ^{abcdD}	9.333 ^{abcC}	9.333 ^{abcC}	11.333 ^{aB}	12.667 ^{abA}
IS21 + BLB + BPB	2.667 ^{cdD}	2.667 ^{cdD}	8.000 ^{bcC}	8.000 ^{bcC}	11.667 ^{aB}	13.667 ^{aA}
CL2 + Control	3.333 ^{abcdC}	3.333 ^{abcdC}	8.667 ^{abcB}	8.667 ^{abcB}	10.667 ^{aA}	12.333 ^{abA}
CL2 + BLB	4.000 ^{abcD}	4.000 ^{abcD}	9.667 ^{abC}	9.667 ^{abC}	11.333 ^{aB}	13.000 ^{abA}
CL2 + BPB	3.333 ^{abcdC}	3.333 ^{abcdC}	8.667 ^{abcB}	8.667 ^{abcB}	10.667 ^{aAB}	11.667 ^{abA}
CL2 + BLB + BPB	3.000 ^{bcdD}	3.000 ^{bcdD}	9.000 ^{abcC}	9.000 ^{abcC}	10.667 ^{aB}	12.000 ^{abA}
Siraj 297 + Control	2.667 ^{cdC}	2.667 ^{cdC}	9.333 ^{abcB}	9.333 ^{abcB}	10.333 ^{aAB}	11.667 ^{abA}
Siraj 297 + BLB	3.667 ^{abcdC}	3.667 ^{abcdC}	9.000 ^{abcB}	9.000 ^{abcB}	11.333 ^{aA}	12.333 ^{abA}
Siraj 297 + BPB	3.000 ^{bcdC}	3.000 ^{bcdC}	9.333 ^{abcB}	9.333 ^{abcB}	11.333 ^{aAB}	12.333 ^{abA}
Siraj 297 + BLB + BPB	3.000 ^{bcdD}	3.000 ^{bcdD}	8.666 ^{abcC}	8.666 ^{abcC}	11.000 ^{aB}	13.333 ^{aA}
MRQ76 + Control	3.333 ^{abcdD}	3.333 ^{abcdD}	8.333 ^{bcC}	8.333 ^{bcC}	10.667 ^{aB}	12.333 ^{abA}
MRQ76 + BLB	3.000 ^{bcdD}	3.000 ^{bcdD}	7.666 ^{cC}	7.666 ^{cC}	9.667 ^{aB}	11.333 ^{abA}
MRQ76 + BPB	2.333 ^{dD}	2.333 ^{dD}	9.333 ^{abcC}	9.333 ^{abcC}	10.333 ^{aB}	11.333 ^{abA}
MRQ76 + BLB + BPB	3.000 ^{bcdD}	3.000 ^{bcdD}	9.333 ^{abcC}	9.333 ^{abcC}	10.333 ^{aB}	11.333 ^{abA}

Flag leaf length

Flag leaf length increased progressively across all varieties and treatments from 10 to 60 DAT (Table 3), reflecting general vegetative growth. 'Putra 1' under control showed substantial elongation, reaching 74.067 cm at 60 DAT, while 'Putra 2' recorded the highest value (75.000 cm) under BLB, suggesting a positive physiological response to bacterial stress. This supports findings by Ding et al. (2014), who found that flag leaf elongation can be linked to bacterial stress response mechanisms involving cellulose synthase-like genes. 'IS21' reached 70.333 cm at 60 DAT under BLB, while 'CL2' had a lower maximum of 69.200 cm with 'CL2' + BPB, while 'MRQ76' reached 74.000 cm under control at 60 DAT, indicating good adaptability. Notably, the most significant flag leaf elongation occurred between 50 and 60 DAT, with BLB and BLB + BPB treatments enhancing growth in selected varieties. These patterns align with recent findings by Yue et al. (2024), who reported genetic loci associated with flag leaf expansion in stress-tolerant rice. Overall, 'Putra 1' and 'Putra 2' exhibited the strongest responses, reinforcing their potential for high biomass accumulation under disease pressure, suggesting that specific treatments, especially BLB and BPB combinations, enhance growth in specific varieties (Yue et al., 2024).

Table 3. Flag leaf length (cm) in six paddy cultivars (Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) across different bacterial inoculation treatments (control, BLB, BPB, BLB + BPB) at 10, 20, 30, 40, 50 and 60 d after transplanting (DAT). Distinct letters in the row indicate significant differences ($P \leq 0.05$). BLB: Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*); BPB: bacterial panicle blight (*Burkholderia glumae*). Means, followed by the same small letter within the column (combination treatment) and the same capital letter within the row (days after transplanting), are not significantly different using LSD, $P = 0.05$ ($n = 3$).

	Days after transplanting (DAT)					
	10	20	30	40	50	60
Putra 1 + Control	30.833 ^{abcdeD}	32.833 ^{dCD}	39.267 ^{eC}	63.000 ^{abcB}	68.333 ^{abcAB}	74.067 ^{abA}
Putra 1 + BLB	30.833 ^{abcdeC}	37.833 ^{bcdC}	55.000 ^{BB}	58.333 ^{bcdeB}	66.000 ^{abcda}	70.700 ^{abcdA}
Putra 1 + BPB	28.833 ^{abcdeFG}	43.000 ^{abcD}	49.533 ^{bcC}	60.933 ^{abcdB}	67.900 ^{abcA}	72.267 ^{abcA}
Putra 1 + BLB + BPB	30.000 ^{abcdeFF}	37.700 ^{cdE}	42.667 ^{cdeD}	64.000 ^{abC}	69.100 ^{abB}	73.433 ^{abA}
Putra 2 + Control	28.500 ^{bcdeFG}	40.400 ^{abcB}	45.100 ^{cdeB}	58.000 ^{bcdeA}	63.333 ^{abcdeA}	67.700 ^{abcdeA}
Putra 2 + BLB	27.833 ^{defgD}	38.667 ^{bcdC}	63.333 ^{aB}	68.000 ^{aAB}	71.333 ^{aA}	75.000 ^{aA}
Putra 2 + BPB	32.333 ^{abE}	39.000 ^{abcdD}	46.100 ^{cdeC}	60.667 ^{abcdB}	65.233 ^{abcdeAB}	69.367 ^{abcdeA}
Putra 2 + BLB + BPB	28.500 ^{bcdeFG}	38.733 ^{abcdDE}	44.233 ^{cdeCD}	54.000 ^{deBC}	60.667 ^{cdeAB}	67.000 ^{bcdeA}
IS21 + Control	29.167 ^{abcdeFGD}	37.000 ^{cdCD}	40.333 ^{deC}	51.667 ^{eB}	58.667 ^{deAB}	65.000 ^{cdeA}
IS21 + BLB	28.667 ^{bcdeFG}	39.100 ^{abcdD}	49.667 ^{bcC}	60.000 ^{abcdB}	64.667 ^{abcdeAB}	70.333 ^{abcdA}
IS21 + BPB	29.333 ^{abcdeFGD}	41.133 ^{abcC}	43.633 ^{cdeC}	56.667 ^{bcdeB}	62.000 ^{bcdeAB}	67.433 ^{bcdeA}
IS21 + BLB + BPB	32.667 ^{aD}	43.333 ^{abcC}	47.333 ^{cdC}	56.333 ^{bcdeB}	61.867 ^{bcdeAB}	67.800 ^{abcdeA}
CL2 + Control	25.500 ^{gE}	43.167 ^{abcD}	46.667 ^{cdeCD}	52.667 ^{deBC}	57.000 ^{eAB}	62.733 ^{eA}
CL2 + BLB	27.000 ^{efgE}	46.167 ^{aD}	48.333 ^{bcCD}	56.333 ^{bcdeBC}	62.200 ^{bcdeAB}	66.967 ^{bcdeA}
CL2 + BPB	27.667 ^{defgD}	45.167 ^{abC}	48.667 ^{bcC}	59.333 ^{bcdeB}	63.333 ^{abcdeAB}	69.200 ^{abcdeA}
CL2 + BLB + BPB	28.167 ^{cdefgD}	43.433 ^{abcC}	48.567 ^{bcC}	57.667 ^{bcdeB}	62.000 ^{bcdeAB}	68.133 ^{abcdeA}
Siraj 297 + Control	27.500 ^{defgD}	39.167 ^{abcdC}	43.100 ^{cdeC}	57.000 ^{bcdeB}	62.333 ^{bcdeAB}	68.333 ^{abcdeA}
Siraj 297 + BLB	26.333 ^{fgD}	38.667 ^{bcdC}	44.967 ^{cdeC}	55.167 ^{cdeB}	61.000 ^{bcdeAB}	66.967 ^{bcdeA}
Siraj 297 + BPB	28.000 ^{defgD}	38.167 ^{bcdC}	46.700 ^{cdeC}	59.933 ^{abcdeB}	63.667 ^{abcdeAB}	69.867 ^{abcdeA}
Siraj 297 + BLB + BPB	26.500 ^{fgD}	37.500 ^{cdC}	42.500 ^{cdeC}	53.100 ^{deB}	58.100 ^{deAB}	64.767 ^{deA}
MRQ76 + Control	32.000 ^{abcC}	39.667 ^{abcdBC}	46.333 ^{cdeB}	63.000 ^{abcA}	67.000 ^{abcA}	74.000 ^{abA}
MRQ76 + BLB	31.000 ^{abcdD}	37.333 ^{cdCD}	43.067 ^{cdeC}	56.733 ^{bcdeB}	62.333 ^{bcdeAB}	68.733 ^{abcdeA}
MRQ76 + BPB	28.333 ^{cdefgC}	40.500 ^{abcBC}	47.000 ^{cdB}	63.000 ^{abcA}	66.333 ^{abcdA}	71.000 ^{abcdA}
MRQ76 + BLB + BPB	30.667 ^{abcdeC}	39.000 ^{abcdBC}	44.333 ^{cdeB}	60.667 ^{abcdA}	64.333 ^{abcdeA}	70.667 ^{abcdA}

Flag leaf width

Flag leaf width increased steadily from 10 to 60 DAT across all varieties and treatments (Table 4). ‘Putra 1’ expanded from 0.83 to 1.90 cm under control, with comparable final widths under BLB (1.80 cm), BPB (1.87 cm), and BLB + BPB (1.80 cm), indicating stable growth. ‘Putra 2’ exhibited the highest flag leaf width of 1.97 cm at 60 DAT under the BLB, suggesting a strong morphological response to bacterial stress, that maintains leaf dimensions while enhancing BLB resistance (Yue et al., 2024). The flag leaf width for ‘IS21’ increased from 0.70 cm at 10 DAT to 1.70 cm at 60 DAT under the control treatment. The BLB, BPB, and BLB + BPB treatments resulted in final widths of 1.80, 1.90, and 2.00 cm, respectively, highlighting the cultivar’s resilience and adaptability to bacterial stress. ‘CL2’ showed the highest flag leaf width under control, increasing from 0.80 cm at 10 DAT to 2.00 cm at 60 DAT. The BLB, BPB, and BLB + BPB also contributed to growth, with final widths of 1.77 and 1.83 cm. ‘Siraj 297’ and ‘MRQ76’ maintained growth across treatments, with final widths ranging from 1.90 to 1.93 cm, even under combined stress, showing no adverse effects compared to individual treatments. These results mirror observations in BLB-resistant hybrids where flag leaf dimensions were preserved under infection (Zhang et al., 2024), reinforcing the resilience of ‘Putra 1’ and ‘Putra 2’ under bacterial challenge.

Table 4. Flag width (cm) in six paddy cultivars (Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) across different bacterial inoculation treatments (control, BLB, BPB, BLB + BPB) at 10, 20, 30, 40, 50 and 60 d after transplanting (DAT). Distinct letters in the row indicate significant differences ($P \leq 0.05$). BLB: Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*); BPB: bacterial panicle blight (*Burkholderia glumae*). Means, followed by the same small letter within the column (combination treatment) and the same capital letter within the row (days after transplanting), are not significantly different using LSD, $P = 0.05$ ($n = 3$).

	Days after transplanting (DAT)					
	10	20	30	40	50	60
Putra 1 + Control	0.83 ^{abcE}	1.07 ^{bcdefD}	1.33 ^{bcdeC}	1.47 ^{abcdBC}	1.60 ^{abcB}	1.90 ^{abcA}
Putra 1 + BLB	0.83 ^{abcD}	1.10 ^{abcdefC}	1.43 ^{abcB}	1.43 ^{bcdeB}	1.50 ^{bcB}	1.80 ^{abcA}
Putra 1 + BPB	0.93 ^{aD}	1.20 ^{abcC}	1.43 ^{abcB}	1.47 ^{abcdB}	1.63 ^{abB}	1.87 ^{abcA}
Putra 1 + BLB + BPB	0.90 ^{abD}	1.03 ^{cdefD}	1.27 ^{cdefC}	1.47 ^{abcdB}	1.57 ^{abcB}	1.80 ^{abcA}
Putra 2 + Control	0.73 ^{abcE}	1.13 ^{abcdeD}	1.30 ^{bcdefC}	1.40 ^{bcdeC}	1.57 ^{abcB}	1.87 ^{abcA}
Putra 2 + BLB	0.80 ^{abcD}	1.23 ^{abC}	1.60 ^{aB}	1.60 ^{aB}	1.67 ^{aB}	1.97 ^{abA}
Putra 2 + BPB	0.83 ^{abcD}	1.13 ^{abcdeC}	1.33 ^{bcdeB}	1.47 ^{abcdB}	1.50 ^{bcB}	1.70 ^{cA}
Putra 2 + BLB + BPB	0.80 ^{abcD}	1.10 ^{abcdefC}	1.37 ^{bcdeB}	1.43 ^{bcdeB}	1.50 ^{bcB}	1.83 ^{abcA}
IS21 + Control	0.70 ^{bcE}	1.13 ^{abcdeD}	1.30 ^{bcdefC}	1.30 ^{eC}	1.47 ^{cB}	1.70 ^{cA}
IS21 + BLB	0.90 ^{abE}	1.10 ^{abcdefD}	1.30 ^{bcdefC}	1.33 ^{deC}	1.50 ^{bcB}	1.80 ^{abcA}
IS21 + BPB	0.90 ^{abD}	1.27 ^{aC}	1.47 ^{abB}	1.50 ^{abcB}	1.57 ^{abcB}	1.90 ^{abcA}
IS21 + BLB + BPB	0.90 ^{abD}	1.23 ^{abC}	1.40 ^{bcdBC}	1.47 ^{abcdBC}	1.63 ^{abB}	2.00 ^{aA}
CL2 + Control	0.80 ^{abcE}	1.17 ^{abcdD}	1.33 ^{bcdeCD}	1.47 ^{abcdBC}	1.63 ^{abB}	2.00 ^{aA}
CL2 + BLB	0.93 ^{aD}	1.23 ^{abC}	1.40 ^{bcdB}	1.43 ^{bcdeB}	1.47 ^{cB}	1.77 ^{bcA}
CL2 + BPB	0.80 ^{abcD}	1.20 ^{abcC}	1.33 ^{bcdeBC}	1.43 ^{bcdeB}	1.53 ^{abcB}	1.83 ^{abcA}
CL2 + BLB + BPB	0.90 ^{abD}	1.20 ^{abcC}	1.40 ^{bcdBC}	1.43 ^{bcdeB}	1.50 ^{bcB}	1.83 ^{abcA}
Siraj 297 + Control	0.70 ^{bcE}	0.97 ^{efD}	1.20 ^{efC}	1.40 ^{bcdeBC}	1.57 ^{abcB}	1.90 ^{abcA}
Siraj 297 + BLB	0.70 ^{bcE}	1.10 ^{abcdefD}	1.30 ^{bcdefCD}	1.47 ^{abcdBC}	1.57 ^{abcB}	1.83 ^{abcA}
Siraj 297 + BPB	0.70 ^{bcE}	0.97 ^{efD}	1.20 ^{efC}	1.40 ^{bcdeBC}	1.47 ^{cB}	1.83 ^{abcA}
Siraj 297 + BLB + BPB	0.67 ^{cE}	0.93 ^{fd}	1.13 ^{fcD}	1.37 ^{cdeBC}	1.50 ^{bcB}	1.77 ^{bcA}
MRQ76 + Control	0.93 ^{aE}	1.13 ^{abcdeDE}	1.30 ^{bcdefCD}	1.53 ^{abBC}	1.57 ^{abcB}	1.93 ^{abA}
MRQ76 + BLB	0.87 ^{abcD}	1.00 ^{defD}	1.23 ^{defC}	1.40 ^{bcdeBC}	1.50 ^{bcB}	1.80 ^{abcA}
MRQ76 + BPB	0.80 ^{abcD}	1.23 ^{abC}	1.40 ^{bcdBC}	1.53 ^{abB}	1.57 ^{abcB}	1.83 ^{abcA}
MRQ76 + BLB + BPB	0.93 ^{aC}	1.07 ^{bcdefC}	1.33 ^{bcdeB}	1.50 ^{abcB}	1.53 ^{abcB}	1.93 ^{abA}

Number of panicles per plant

Significant differences in panicle number were observed across varieties and treatments at 40, 50, and 60 DAT (Table 5). 'Putra 2' and 'IS21' under control conditions exhibited the highest number of panicles per plant at 60 DAT, with 24.33 and 24.00 panicles, respectively. In contrast, Putra 1' showed the lowest values, particularly under BPB (19.00) and combined BLB + BPB (19.33). This pattern aligns with Rasheed et al. (2023), who noted BPB and dual infections tend to reduce panicle formation in most varieties. Although panicle numbers generally increased over time, BPB and BLB + BPB treatments consistently reduced panicle formation across most varieties. Statistical analysis confirmed significant differences among cultivar-treatment combinations ($P \leq 0.05$), with 'Putra 2' consistently outperforming other varieties even under stress. The results highlight differential varietal responses to bacterial inoculation in rice, especially to bacterial panicle blight (BPB), which has been linked to up to 75% yield loss globally (Azzahra et al., 2024). Among the varieties tested, 'Putra 2' and 'IS21' consistently performed well, maintaining higher panicle numbers and showing lower disease incidence across leaf and panicle measurements, supporting their suitability for cultivation in BPB-prone areas and use in breeding programs (Rasheed et al., 2023).

Table 5. Total number of panicles per plant in six paddy cultivars (Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) across different bacterial inoculation treatments (control, BLB, BPB, BLB + BPB) at 40, 50 and 60 d after transplanting (DAT). Distinct letters in the row indicate significant differences ($P \leq 0.05$). BLB: Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*); BPB: bacterial panicle blight (*Burkholderia glumae*). Means, followed by the same small letter within the column (combination treatment) and the same capital letter within the row (days after transplanting), are not significantly different using LSD, $P = 0.05$ ($n = 3$).

	Days after transplanting (DAT)		
	40	50	60
Putra 1 + Control	17.667 ^{bcB}	19.6667 ^{hA}	19.6667 ^{hA}
Putra 1 + BLB	17.333 ^{bcB}	19.3333 ^{hA}	19.6667 ^{hA}
Putra 1 + BPB	16.667 ^{cB}	19.0000 ^{hA}	19.0000 ^{hA}
Putra 1 + BLB + BPB	17.333 ^{bcB}	19.3333 ^{hA}	19.3333 ^{hA}
Putra 2 + Control	20.333 ^{aB}	24.3333 ^{aA}	24.3333 ^{aA}
Putra 2 + BLB	20.333 ^{aB}	23.3333 ^{abcdA}	23.3333 ^{abcdA}
Putra 2 + BPB	19.000 ^{abcB}	22.0000 ^{efgA}	22.0000 ^{efgA}
Putra 2 + BLB + BPB	19.000 ^{abcB}	23.0000 ^{bcdeA}	23.0000 ^{bcdeA}
IS21 + Control	20.667 ^{aB}	24.0000 ^{abA}	24.0000 ^{abA}
IS21 + BLB	16.667 ^{cA}	22.6667 ^{cdefA}	22.6667 ^{cdefA}
IS21 + BPB	19.000 ^{abcB}	22.6667 ^{cdefA}	22.6667 ^{cdefA}
IS21 + BLB + BPB	19.333 ^{abB}	22.6667 ^{cdefA}	22.6667 ^{cdefA}
CL2 + Control	18.333 ^{abcB}	21.6667 ^{ghA}	21.6667 ^{fgA}
CL2 + BLB	17.000 ^{bcB}	20.0000 ^{hA}	20.0000 ^{hA}
CL2 + BPB	17.333 ^{bcB}	19.0000 ^{hA}	19.0000 ^{hA}
CL2 + BLB + BPB	18.333 ^{abcB}	20.0000 ^{hA}	20.0000 ^{hA}
Siraj 297 + Control	17.000 ^{bcB}	23.0000 ^{bcdeA}	23.0000 ^{bcdeA}
Siraj 297 + BLB	17.000 ^{bcB}	22.3333 ^{defgA}	22.3333 ^{defgA}
Siraj 297 + BPB	18.333 ^{abcB}	21.3333 ^{gA}	21.3333 ^{gA}
Siraj 297 + BLB + BPB	19.333 ^{abB}	21.3333 ^{gA}	21.3333 ^{gA}
MRQ76 + Control	19.000 ^{abcB}	23.6667 ^{abcA}	23.6667 ^{abcA}
MRQ76 + BLB	19.000 ^{abcB}	24.0000 ^{abA}	24.0000 ^{abA}
MRQ76 + BPB	18.667 ^{abcB}	22.3333 ^{defgA}	22.3333 ^{defgA}
MRQ76 + BLB + BPB	18.667 ^{abcB}	22.3333 ^{defgA}	22.3333 ^{defgA}

Number of symptomatic panicles

Table 6 shows that BPB and BLB + BPB treatments significantly increased symptomatic panicles across all varieties. At 60 DAT, 'Putra 1' and 'CL2' inoculated with BPB or BLB + BPB exhibited the highest number of symptomatic panicles (7.67 to 8.33), whereas control and BLB-only treatments consistently resulted in no symptoms. This pattern was consistent across all varieties, indicating the major role of BPB in panicle symptom development (Rasheed et al., 2023). 'Putra 1', 'IS21', and 'Siraj 297' showed a comparatively lower number of symptomatic panicles in the same treatments, suggesting some level of tolerance. In contrast, 'CL2' and 'MRQ76' displayed high susceptibility to BPB, evident through elevated symptomatic panicle counts and disease incidence levels (Sekhar et al., 2022). Interestingly, BLB had minimal impact on panicle development or symptom expression across all varieties, but its combination with BPB often exacerbated panicle disease, suggesting a synergistic or compounding effect under dual infection scenarios (Singh et al., 2024). Furthermore, interspecies microbial interactions play a fundamental role in shaping microbial community responses to stress and competition. These outcomes may also be influenced by interspecies microbial dynamics, which affect microbial colonization and plant stress resilience (Fatma et al., 2015).

Table 6. Number of panicles with symptoms in six paddy cultivars (Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) across different bacterial inoculation treatments (control, BLB, BPB, BLB + BPB) at 40, 50 and 60 d after transplanting (DAT). Distinct letters in the row indicate significant differences ($P \leq 0.05$). BLB: Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*); BPB: bacterial panicle blight (*Burkholderia glumae*). Means, followed by the same small letter within the column (combination treatment) and the same capital letter within the row (days after transplanting), are not significantly different using LSD, $P = 0.05$ ($n = 3$).

	Days after transplanting (DAT)		
	40	50	60
Putra 1 + Control	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
Putra 1 + BLB	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
Putra 1 + BPB	4.0000 ^{abC}	6.6667 ^{aB}	8.3333 ^{aA}
Putra 1 + BLB + BPB	4.0000 ^{abC}	6.0000 ^{abcB}	7.6667 ^{aA}
Putra 2 + Control	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
Putra 2 + BLB	0.0000 ^{eA}	1.6667 ^{dA}	2.6667 ^{bA}
Putra 2 + BPB	3.3333 ^{cdC}	5.6667 ^{abcB}	7.6667 ^{aA}
Putra 2 + BLB + BPB	3.0000 ^{dC}	5.3333 ^{cB}	8.0000 ^{aA}
IS21 + Control	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
IS21 + BLB	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
IS21 + BPB	3.0000 ^{dB}	5.0000 ^{cA}	7.3333 ^{aA}
IS21 + BLB + BPB	3.3333 ^{cdC}	5.6667 ^{abcB}	7.6667 ^{aA}
CL2 + Control	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
CL2 + BLB	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
CL2 + BPB	4.0000 ^{abC}	6.0000 ^{abcB}	7.6667 ^{aA}
CL2 + BLB + BPB	4.3333 ^{aC}	6.3333 ^{abB}	8.3333 ^{aA}
Siraj 297 + Control	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
Siraj 297 + BLB	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
Siraj 297 + BPB	3.6667 ^{bcC}	5.6667 ^{abcB}	7.0000 ^{aA}
Siraj 297 + BLB + BPB	3.6667 ^{bcC}	5.6667 ^{abcB}	7.6667 ^{aA}
MRQ76 + Control	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
MRQ76 + BLB	0.0000 ^{eA}	0.0000 ^{eA}	0.0000 ^{cA}
MRQ76 + BPB	4.0000 ^{abC}	6.0000 ^{abcB}	8.0000 ^{aA}
MRQ76 + BLB + BPB	4.0000 ^{abC}	6.0000 ^{abcB}	8.3333 ^{aA}

Leaf lesion length

Leaf lesion length is a key indicator of disease severity in rice. As shown in Table 7, lesions began appearing from 30 DAT onward, with no symptoms observed at 10 and 20 DAT. By 30 DAT, lesion lengths start to appear, with varying severity. 'Putra 1' + BPB (10.667 cm) and 'IS21' + BLB (13.000 cm) showed early lesion development, aligning with evidence that resistant varieties delay symptom expression (Ding et al., 2024). The highest lesion severity is observed at 60 DAT, with 'Siraj 297' + BLB reaching 24.000 cm, indicating greater susceptibility over time. Generally, 'Putra 1' treatments show steady increases in lesion lengths, with 'Putra 1' + BLB reaching 21.000 cm at 60 DAT, while the control treatment shows the lowest lesion lengths. 'Putra 2' also exhibits progressive increases, with 'Putra 2' + BLB + BPB combination reaching 21.000 cm at 60 DAT. 'IS21' and 'CL2' tend to have lower lesion lengths compared to 'Putra 1' and 'Putra 2', particularly in control groups, indicating greater resilience. 'Siraj 297' and 'MRQ76' show the highest lesion lengths in certain combinations, particularly with BLB treatment, with 'Siraj 297' + BLB reaching 24.000 cm and 'MRQ76' + BLB 23.333 cm at 60 DAT. 'Putra 1' and 'Putra 2' showed progressive lesion development, especially under BLB + BPB, while 'IS21' and 'CL2' maintained shorter lesion lengths, suggesting better resilience. Control treatments consistently exhibited the lowest lesion levels across all varieties. These patterns reflect not only genetic resistance but also possible shifts in microbial interactions under stress. Fatma et al. (2021) noted that bacterial communities may adapt their coexistence mechanisms even in stable conditions, influencing host-pathogen dynamics. Additionally, BPB treatments were generally associated with lower lesion severity, supporting recent findings on *B. glumae* management efficacy (Rasheed et al., 2023).

Table 7. Leaf Lesion length (cm) in six paddy cultivars (Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) across different bacterial inoculation treatments (control, BLB, BPB, BLB + BPB) at 40, 50 and 60 d after transplanting (DAT). Distinct letters in the row indicate significant differences ($P \leq 0.05$). BLB: Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*); BPB: bacterial panicle blight (*Burkholderia glumae*). Means, followed by the same small letter within the column (combination treatment) and the same capital letter within the row (days after transplanting), are not significantly different using LSD, $P = 0.05$ ($n = 3$).

	Days after transplanting (DAT)					
	10	20	30	40	50	60
Putra 1 + Control	0.000 ^{aC}	0.000 ^{aC}	11.667 ^{cdefgB}	17.000 ^{abcdeFA}	18.233 ^{abcdeA}	19.333 ^{abcdeA}
Putra 1 + BLB	0.000 ^{aC}	0.000 ^{aC}	11.000 ^{efgB}	17.667 ^{abcdA}	18.900 ^{abcA}	21.000 ^{abcA}
Putra 1 + BPB	0.000 ^{aB}	0.000 ^{aB}	10.667 ^{fgA}	16.000 ^{abcdeFGH}	17.500 ^{abcdeFGA}	18.000 ^{abcdeFA}
Putra 1 + BLB + BPB	0.000 ^{aC}	0.000 ^{aC}	12.333 ^{bcdeFB}	17.333 ^{abcdeAB}	18.533 ^{abcdA}	19.667 ^{abcdA}
Putra 2 + Control	0.000 ^{aD}	0.000 ^{aD}	11.000 ^{efgC}	12.667 ^{defghiB}	13.900 ^{cdefghiAB}	15.000 ^{cdefghA}
Putra 2 + BLB	0.000 ^{aC}	0.000 ^{aC}	12.333 ^{bcdeFB}	16.667 ^{abcdeFGA}	18.067 ^{abcdeFA}	18.000 ^{abcdeFA}
Putra 2 + BPB	0.000 ^{aD}	0.000 ^{aD}	11.333 ^{defgC}	12.000 ^{efghiBC}	12.933 ^{defghiAB}	14.000 ^{defghA}
Putra 2 + BLB + BPB	0.000 ^{aC}	0.000 ^{aC}	14.000 ^{abB}	18.667 ^{abcAB}	19.933 ^{abA}	21.000 ^{abcA}
IS21 + Control	0.000 ^{aC}	0.000 ^{aC}	10.000 ^{gB}	11.333 ^{ghiA}	11.967 ^{ghiA}	12.333 ^{ghA}
IS21 + BLB	0.000 ^{aD}	0.000 ^{aD}	13.000 ^{abcdeC}	14.333 ^{bcdeFGHBC}	16.467 ^{abcdeFGHAB}	18.000 ^{abcdeFGA}
IS21 + BPB	0.000 ^{aB}	0.000 ^{aB}	10.667 ^{fgA}	10.667 ^{hiA}	11.533 ^{iA}	11.667 ^{hA}
IS21 + BLB + BPB	0.000 ^{aC}	0.000 ^{aC}	14.667 ^{aB}	15.667 ^{bcdeFGH}	17.367 ^{abcdeFGA}	18.000 ^{abcdeFA}
CL2 + Control	0.000 ^{aC}	0.000 ^{aC}	11.667 ^{cdefgB}	13.667 ^{cdefghiA}	14.800 ^{bcdeFGH}	15.000 ^{cdefghA}
CL2 + BLB	0.000 ^{aD}	0.000 ^{aD}	13.667 ^{abcC}	15.000 ^{bcdeFGHBC}	16.200 ^{bcdeFGHAB}	18.000 ^{abcdeFA}
CL2 + BPB	0.000 ^{aC}	0.000 ^{aC}	10.000 ^{gB}	10.000 ^{iB}	11.100 ^{iA}	11.333 ^{hA}
CL2 + BLB + BPB	0.000 ^{aB}	0.000 ^{aB}	15.000 ^{aA}	17.333 ^{abcdeA}	18.533 ^{abcdA}	19.000 ^{abcdeFA}
Siraj 297 + Control	0.000 ^{aB}	0.000 ^{aB}	11.000 ^{efgA}	11.000 ^{hiA}	11.667 ^{hiA}	12.000 ^{ghA}
Siraj 297 + BLB	0.000 ^{aC}	0.000 ^{aC}	14.000 ^{abB}	21.333 ^{aA}	22.233 ^{aA}	24.000 ^{aA}
Siraj 297 + BPB	0.000 ^{aC}	0.000 ^{aC}	10.333 ^{fgB}	10.667 ^{hiAB}	12.000 ^{ghiA}	11.666 ^{AB}
Siraj 297 + BLB + BPB	0.000 ^{aD}	0.000 ^{aD}	13.333 ^{abcdeC}	16.667 ^{bcdeFGHBC}	18.433 ^{abcdeAB}	21.333 ^{abA}
MRQ76 + Control	0.000 ^{aB}	0.000 ^{aB}	11.666 ^{cdefgA}	11.667 ^{fgHiA}	12.533 ^{efghiA}	13.000 ^{fgH}
MRQ76 + BLB	0.000 ^{aC}	0.000 ^{aC}	13.000 ^{abcdeB}	19.667 ^{abA}	20.300 ^{abA}	23.333 ^{aA}
MRQ76 + BPB	0.000 ^{aC}	0.000 ^{aC}	11.666 ^{cdefgB}	11.667 ^{fgHiB}	12.433 ^{fgHiB}	13.333 ^{efghA}
MRQ76 + BLB + BPB	0.000 ^{aD}	0.000 ^{aD}	14.000 ^{abC}	14.666 ^{bcdeFGHBC}	15.800 ^{bcdeFGHAB}	16.333 ^{bcdeFGA}

Leaf disease incidence

Table 8 shows that the highest disease incidence occurred in 'Siraj 297' under BLB, reaching 38.37% at 40 DAT and remaining above 35% through 60 DAT. 'MRQ76' showed similar trends. 'Putra 2' exhibited notable susceptibility to the combined BLB + BPB treatment, with incidence declining from 34.47% to 30.93% over time, suggesting increased vulnerability to dual infections. In contrast, BPB alone generally resulted in lower disease incidence, particularly in 'CL2' and 'IS21', with 'CL2' recording the lowest value (16.57% at 60 DAT). 'Putra 1' and 'Putra 2' showed relatively stable or slightly decreasing trends across treatments. These results underscore varietal differences in susceptibility, with 'Siraj 297' and 'MRQ76' particularly vulnerable to BLB. Interestingly, BLB + BPB did not consistently increase disease incidence, suggesting complex pathogen interactions, possibly involving competitive exclusion or induced resistance (Islam et al., 2022). The low incidence of 'CL2' under BPB implies potential genetic resistance, supported by recent findings linking specific QTLs and genes to pathogen defense in rice (Zhang et al., 2024). Further research is warranted to uncover the molecular mechanisms involved.

Table 8. Disease incidence (%) for leaf in six paddy cultivars (Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) across different bacterial inoculation treatments (control, BLB, BPB, BLB + BPB) at 40, 50 and 60 d after transplanting (DAT). Distinct letters in the row indicate significant differences ($P \leq 0.05$). BLB: Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*); BPB: bacterial panicle blight (*Burkholderia glumae*). Means, followed by the same small letter within the column (combination treatment) and the same capital letter within the row (days after transplanting), are not significantly different using LSD, $P = 0.05$ ($n = 3$).

	Days after transplanting (DAT)		
	40	50	60
Putra 1 + Control	26.800 ^{bcdeA}	26.500 ^{bcdeA}	25.933 ^{cdefgA}
Putra 1 + BLB	30.433 ^{bcA}	28.567 ^{bcdA}	29.500 ^{bcdeA}
Putra 1 + BPB	26.233 ^{cdefgA}	25.700 ^{bcdefA}	24.767 ^{defghA}
Putra 1 + BLB + BPB	27.000 ^{bcdeA}	26.633 ^{bcdeA}	26.667 ^{bcdefA}
Putra 2 + Control	22.333 ^{defghiA}	22.367 ^{defgA}	22.433 ^{fghiA}
Putra 2 + BLB	24.500 ^{cdefghiA}	25.300 ^{cdefA}	23.967 ^{defghiA}
Putra 2 + BPB	20.133 ^{efghiA}	19.933 ^{efgA}	20.267 ^{fghiA}
Putra 2 + BLB + BPB	34.467 ^{abA}	32.567 ^{abA}	30.933 ^{abcdA}
IS21 + Control	22.300 ^{defghiA}	20.633 ^{efgAB}	19.033 ^{ghiB}
IS21 + BLB	24.000 ^{cdefghiA}	25.567 ^{bcdefA}	25.567 ^{cdefgA}
IS21 + BPB	18.933 ^{ghiA}	18.667 ^{gB}	17.233 ^{iC}
IS21 + BLB + BPB	27.933 ^{bcdA}	18.667 ^{bcdA}	26.567 ^{bcdefA}
CL2 + Control	25.933 ^{cdefghA}	25.967 ^{bcdefA}	23.900 ^{efghiB}
CL2 + BLB	26.700 ^{bcdefA}	26.067 ^{bcdefA}	27.000 ^{bcdefA}
CL2 + BPB	17.200 ^{iA}	17.800 ^{gA}	16.567 ^{iA}
CL2 + BLB + BPB	30.433 ^{bcA}	30.267 ^{abcAB}	28.133 ^{bcdeB}
Siraj 297 + Control	19.767 ^{efghiA}	18.967 ^{fgA}	17.600 ^{hiA}
Siraj 297 + BLB	38.367 ^{aA}	36.267 ^{aB}	35.633 ^{aB}
Siraj 297 + BPB	18.133 ^{iA}	19.033 ^{fgA}	16.733 ^{iA}
Siraj 297 + BLB + BPB	31.433 ^{abcA}	31.733 ^{abcA}	32.667 ^{abcA}
MRQ76 + Control	18.667 ^{ghiA}	18.833 ^{fgA}	17.633 ^{hiA}
MRQ76 + BLB	34.200 ^{abA}	32.167 ^{abB}	33.700 ^{abAB}
MRQ76 + BPB	18.600 ^{hiA}	18.800 ^{fgA}	18.800 ^{ghiA}
MRQ76 + BLB + BPB	24.367 ^{cdefghiA}	24.667 ^{cdefgA}	23.200 ^{efghiA}

Panicle disease incidence

Panicle disease incidence differed significantly ($P \leq 0.05$) across varieties and treatments at 40, 50, and 60 DAT (Table 9). 'Putra 1' exhibited the highest susceptibility to BPB, with the incidence rising from 24.00% at 40 DAT to 43.87% at 60 DAT. 'CL2' also showed high incidence under BPB (40.33%) and BLB + BPB (41.83%), confirming their vulnerability to panicle-associated pathogens. In contrast, 'Putra 2' and 'IS21' displayed moderate but significantly lower incidence ($\sim 35\%$), while 'Siraj 297' and 'MRQ76' recorded intermediate responses (33%-36%), with a nonsignificant difference between these two. The observed variation in disease incidence and severity across cultivars underscores the importance of genotype-specific responses in bacterial disease progression. Elevated incidence rates in 'Putra 1' and 'CL2' suggest heightened susceptibility, reinforcing the need for targeted resistance breeding in these lines. In contrast, the relatively lower and more stable incidence observed in 'Putra 2' and 'IS21' indicates partial genetic tolerance, which may be governed by underlying physiological or molecular mechanisms. These findings align with previous studies demonstrating that cultivar-specific resistance is often linked to differential expression of defense-related traits and pathogen response pathways (Mirsam et al., 2025). Further molecular characterization of tolerant genotypes could facilitate the identification of resistance-associated markers and inform breeding strategies for durable disease resistance. Additionally, the comparatively low disease incidence observed under BLB alone across all varieties points to BPB as the primary driver of panicle symptoms, consistent with findings by Chen et al. (2021).

Table 9. Disease incidence (%) for panicle in six paddy cultivars (Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) across different bacterial inoculation treatments (control, BLB, BPB, BLB + BPB) at 40, 50 and 60 d after transplanting (DAT). Distinct letters in the row indicate significant differences ($P \leq 0.05$). BLB: Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*); BPB: bacterial panicle blight (*Burkholderia glumae*). Means, followed by the same small letter within the column (combination treatment) and the same capital letter within the row (days after transplanting), are not significantly different using LSD, $P = 0.05$ ($n = 3$).

	Days after transplanting (DAT)		
	40	50	60
Putra 1 + Control	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
Putra 1 + BLB	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
Putra 1 + BPB	24.000 ^{aC}	35.067 ^{aB}	43.867 ^{aA}
Putra 1 + BLB + BPB	23.067 ^{abC}	31.067 ^{abcB}	39.633 ^{abcdA}
Putra 2 + Control	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
Putra 2 + BLB	5.000 ^{fA}	7.233 ^{eA}	11.600 ^{eA}
Putra 2 + BPB	17.567 ^{cdeC}	25.733 ^{dB}	34.867 ^{bcdA}
Putra 2 + BLB + BPB	15.833 ^{eC}	25.733 ^{dB}	34.967 ^{bcdA}
IS21 + Control	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
IS21 + BLB	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
IS21 + BPB	15.833 ^{eC}	22.033 ^{dB}	32.400 ^{dA}
IS21 + BLB + BPB	17.300 ^{deC}	25.033 ^{dB}	33.867 ^{cdA}
CL2 + Control	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
CL2 + BLB	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
CL2 + BPB	23.067 ^{abC}	31.600 ^{abcB}	40.333 ^{abcA}
CL2 + BLB + BPB	23.867 ^{abC}	31.800 ^{abB}	41.833 ^{abA}
Siraj 297 + Control	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
Siraj 297 + BLB	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
Siraj 297 + BPB	20.000 ^{bcdC}	26.567 ^{dB}	32.800 ^{cdA}
Siraj 297 + BLB + BPB	18.967 ^{cdeC}	26.633 ^{bcdB}	35.933 ^{bcdA}
MRQ76 + Control	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
MRQ76 + BLB	0.000 ^{gA}	0.000 ^{fA}	0.000 ^{fA}
MRQ76 + BPB	21.467 ^{abcC}	26.900 ^{bcdB}	35.867 ^{bcdA}
MRQ76 + BLB + BPB	21.467 ^{abcB}	26.867 ^{bcdB}	37.367 ^{abcdA}

Disease severity

Disease severity patterns varied significantly among the six rice varieties and treatments ($P \leq 0.05$), reflecting their differential tolerance to bacterial infections (Table 10). No symptoms were observed at 10 and 20 DAT across all treatments. By 30 DAT, severity began to manifest, ranging from mild symptoms (1.3) in 'Putra 2', 'IS21', and 'CL2' under BPB, to high severity scores (3.0) in 'Siraj 297' and 'MRQ76' under BLB and BLB + BPB. From 40 to 60 DAT, severity values remained relatively stable but significantly distinct among varieties. 'Siraj 297' + BLB consistently recorded the highest severity (up to 3.6), followed by 'MRQ76' + BLB (up to 3.0), indicating their heightened susceptibility to BLB. In contrast, 'Putra 1' and 'IS21' exhibited significantly lower severity (2.0-2.3), particularly under BPB and control treatments, suggesting a more robust response. 'Putra 2' showed moderate severity under combined BLB + BPB but maintained significantly lower values compared to 'Siraj 297' and 'MRQ76', demonstrating partial tolerance. The BLB was the main contributor to high severity scores, while BPB consistently resulted in lower severity across all varieties. The observed differences in varietal performance were significant ($P \leq 0.05$), emphasizing the importance of genotype in disease response. These findings align with earlier studies that reported varietal variation in BLB and BPB tolerance (Singh et al., 2024). Across treatments, 'Putra 1', 'Putra 2', and 'IS21' showed significantly better disease resilience, particularly under BPB, making them strong candidates for cultivation and breeding programs aimed at enhancing tolerance to bacterial diseases in rice (Islam et al., 2022).

Table 10. Disease severity in six paddy cultivars (Putra 1, Putra 2, IS21, CL2, Siraj 297, MRQ 76) across different bacterial inoculation treatments (Control, BLB, BPB, BLB + BPB) at 10, 20, 30, 40, 50 and 60 d after transplanting (DAT). Distinct letters in the row indicate significant differences ($P \leq 0.05$). BLB: Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*); BPB: bacterial panicle blight (*Burkholderia glumae*). Means, followed by the same small letter within the column (combination treatment) and the same capital letter within the row (days after transplanting), are not significantly different using LSD, $P = 0.05$ ($n = 3$).

	Days after transplanting (DAT)					
	10	20	30	40	50	60
Putra 1 + Control	0.0000 ^{aB}	0.0000 ^{aB}	2.3333 ^{abcA}	2.333 ^{bcdA}	2.333 ^{abcA}	2.3333 ^{abcA}
Putra 1 + BLB	0.0000 ^{aC}	0.0000 ^{aC}	1.3333 ^{dB}	2.667 ^{bcdA}	2.333 ^{abcA}	2.3333 ^{abcA}
Putra 1 + BPB	0.0000 ^{aB}	0.0000 ^{aB}	1.6667 ^{cdA}	2.333 ^{bcdA}	2.000 ^{bcdA}	2.0000 ^{bcdA}
Putra 1 + BLB + BPB	0.0000 ^{aB}	0.0000 ^{aB}	2.3333 ^{abcA}	2.333 ^{bcdA}	2.333 ^{abcA}	2.3333 ^{abcA}
Putra 2 + Control	0.0000 ^{aB}	0.0000 ^{aB}	2.0000 ^{bcdA}	1.667 ^{deA}	1.667 ^{cdeA}	1.6667 ^{cdA}
Putra 2 + BLB	0.0000 ^{aB}	0.0000 ^{aB}	1.6667 ^{cdA}	2.000 ^{cdeA}	2.000 ^{bcdA}	2.0000 ^{bcdA}
Putra 2 + BPB	0.0000 ^{aC}	0.0000 ^{aC}	2.0000 ^{bcdA}	1.333 ^{eB}	1.333 ^{deB}	1.3333 ^{deB}
Putra 2 + BLB + BPB	0.0000 ^{aB}	0.0000 ^{aB}	2.6667 ^{abA}	3.000 ^{abA}	3.000 ^{aA}	2.6667 ^{abA}
IS21 + Control	0.0000 ^{aC}	0.0000 ^{aC}	2.0000 ^{bcdA}	1.667 ^{deA}	1.667 ^{cdeA}	1.0000 ^{eB}
IS21 + BLB	0.0000 ^{aB}	0.0000 ^{aB}	2.3333 ^{abcA}	1.667 ^{deA}	2.333 ^{abcA}	2.0000 ^{bcdA}
IS21 + BPB	0.0000 ^{aC}	0.0000 ^{aC}	2.0000 ^{bcdA}	1.333 ^{eB}	1.000 ^{eB}	1.0000 ^{eB}
IS21 + BLB + BPB	0.0000 ^{aC}	0.0000 ^{aC}	3.0000 ^{aA}	2.000 ^{cdeB}	2.000 ^{bcdB}	2.0000 ^{bcdB}
CL2 + Control	0.0000 ^{aB}	0.0000 ^{aB}	2.0000 ^{bcdA}	2.000 ^{cdeA}	2.000 ^{bcdA}	2.0000 ^{bcdA}
CL2 + BLB	0.0000 ^{aB}	0.0000 ^{aB}	2.0000 ^{bcdA}	2.000 ^{cdeA}	2.000 ^{bcdA}	2.0000 ^{bcdA}
CL2 + BPB	0.0000 ^{aC}	0.0000 ^{aC}	2.0000 ^{bcdA}	1.333 ^{eB}	1.333 ^{deB}	1.0000 ^{eB}
CL2 + BLB + BPB	0.0000 ^{aB}	0.0000 ^{aB}	2.6667 ^{abA}	2.667 ^{bcA}	2.333 ^{abcA}	2.3333 ^{abcA}
Siraj 297 + Control	0.0000 ^{aC}	0.0000 ^{aC}	2.0000 ^{bcdA}	1.333 ^{eB}	1.333 ^{deB}	1.0000 ^{eB}
Siraj 297 + BLB	0.0000 ^{aC}	0.0000 ^{aC}	2.6667 ^{abB}	3.667 ^{aA}	3.000 ^{aB}	3.0000 ^{aB}
Siraj 297 + BPB	0.0000 ^{aC}	0.0000 ^{aC}	2.0000 ^{bcdA}	1.333 ^{eB}	1.333 ^{deB}	1.0000 ^{eB}
Siraj 297 + BLB + BPB	0.0000 ^{aB}	0.0000 ^{aB}	3.0000 ^{aA}	3.000 ^{abA}	3.000 ^{aA}	2.6667 ^{abA}
MRQ76 + Control	0.0000 ^{aC}	0.0000 ^{aC}	2.0000 ^{bcdA}	1.333 ^{eB}	1.333 ^{deB}	1.0000 ^{eB}
MRQ76 + BLB	0.0000 ^{aB}	0.0000 ^{aB}	2.6667 ^{abA}	3.000 ^{abA}	2.667 ^{abA}	2.6667 ^{abA}
MRQ76 + BPB	0.0000 ^{aC}	0.0000 ^{aC}	2.3333 ^{abcA}	1.333 ^{eB}	1.000 ^{eB}	1.0000 ^{eB}
MRQ76 + BLB + BPB	0.0000 ^{aC}	0.0000 ^{aC}	2.6667 ^{abA}	2.000 ^{cdeB}	2.000 ^{bcdB}	2.0000 ^{bcdB}

Overall, 'Putra 2' and 'Siraj 297' demonstrated the most significant responses to treatments, with 'Putra 2' showing strong growth and 'Siraj 297' displaying higher susceptibility to disease stress. Chukwu et al. (2022) reviewed the resistance of rice to BLB, emphasizing the importance of conventional breeding and molecular approaches in developing resistant varieties and identifying resistance genes for breeding programs. Their findings also highlighted the higher susceptibility of 'Siraj 297' to disease stress compared to other rice varieties, underscoring the need for targeted breeding efforts.

Photosynthesis rates

During the first period of analysis, conducted at 40 DAT, the study of six paddy varieties under four treatments (control, BLB, BPB, and a combination of BLB+BPB) revealed significant variations in photosynthesis rates (Figure 1a)). 'MRQ76' and 'Putra 2' exhibited higher photosynthesis rates, showing better tolerance to bacterial stress, while 'IS21' and 'CL2' had lower rates, indicating greater susceptibility. At 70 DAT (Figure 1b), all varieties experienced a decline in photosynthesis, though 'MRQ76' and 'Putra 2' remained relatively resilient. 'CL2' and 'IS21' showed consistently low rates, particularly under BLB and BLBP treatments, highlighting their vulnerability. This trend suggests that cumulative stress effects are reducing photosynthesis, with 'MRQ76' and 'Putra 2' maintaining better adaptability, while 'IS21' and 'CL2' may require additional protective measures or genetic improvements for enhanced productivity. 'MRQ76' and 'Putra 2' demonstrated resilience to bacterial infections at both 40 and 70 DAT. Notably, 'Putra 2', developed by Universiti Putra Malaysia (UPM) with the *Sub1* gene from 'Swarna-Sub1', exhibits submergence tolerance, suggesting potential resistance to flooding and bacterial stress. 'MRQ76' also shows resistance to major rice diseases BLB and BPB, enhancing its resilience and reliability in production (Abd Rahman et al., 2021).

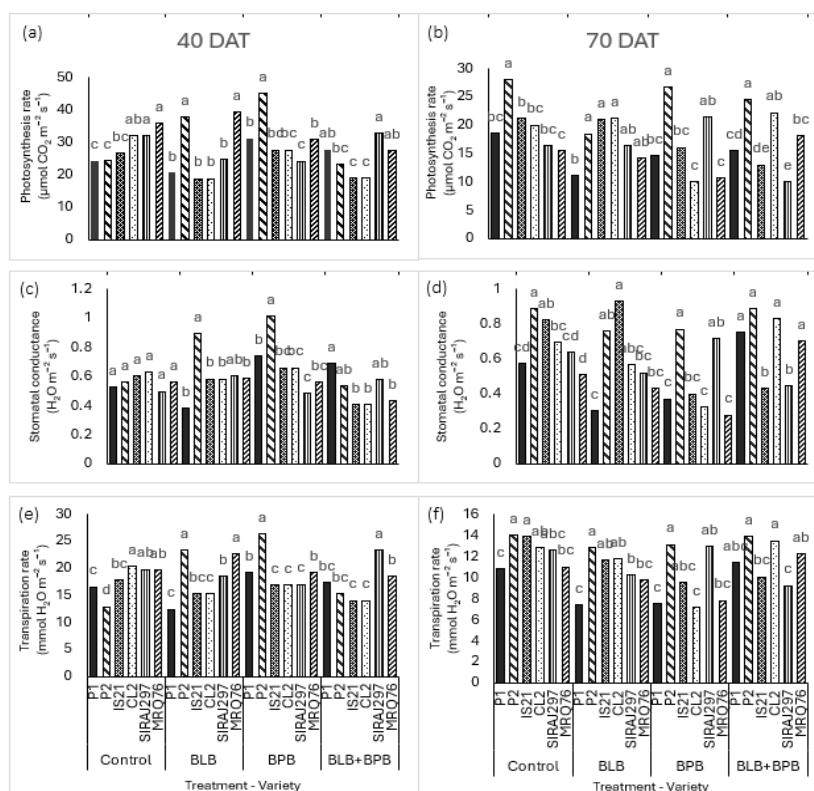


Figure 1. Photosynthesis rate (a)(b), stomatal conductance (c)(d), and transpiration rate (e)(f) of 40 and 70 d after transplanting (DAT) on six paddy cultivars (P1: Putra 1, P2: Putra 2, IS21, CL2, Siraj 297, MRQ76) under the four treatments: Control, bacterial leaf blight (BLB; *Xanthomonas oryzae* pv. *oryzae*), bacterial panicle blight (BPB; *Burkholderia glumae*), and the combination of BLB and BPB (BLBP), $n = 3$. Different letters on bars corresponding to the same response variable ($P \leq 0.05$).

Stomatal conductance

Figure 1c shows the stomatal conductance (g_s) of six paddy varieties under four treatments at 40 DAT. Under control conditions, most varieties had similar conductance levels, with 'Putra 2' and 'Siraj 297' slightly higher, indicating better gas exchange. In the BLB treatment, 'Putra 2' had the highest g_s , while 'MRQ76' showed a notable decrease, suggesting a stress response. The BPB treatment caused moderate reductions in most varieties, but 'Putra 2' maintained the highest g_s . The combined BL+BP treatment led to a more significant reduction in g_s across all varieties, with 'Putra 2' and 'Siraj 297' showing some resilience, whereas 'IS21' and 'CL2' were more vulnerable. At 70 DAT, as depicted in Figure 1d, g_s values varied greatly among varieties and treatments, with 'Putra 2' and 'MRQ76' generally displaying the highest g_s , while 'IS21' and 'CL2' exhibited lower values, especially under BLB and BPB treatments. Under control and BLB+BPB conditions, 'Putra 1' and 'Putra 2' showed higher g_s , whereas 'IS21' and 'MRQ76' had lower g_s under the BLB treatment. These patterns suggest that the varieties respond differently to bacterial stresses, with some, like 'Putra 2' and 'MRQ76', maintaining higher g_s under stress, which indicates potential tolerance. This aligns with findings from Zakaria et al. (2024), which reported that "Putra 1" had higher photosynthesis rates, g_s , and transpiration rates under water limitation compared to other varieties.

Transpiration rates

Figure 1e illustrates significant variation in transpiration rates (E) among rice varieties under different bacterial treatments at 40 and 70 DAT. 'Putra 2' consistently recorded the highest transpiration rates, particularly under control and BLB treatments, indicating robust physiological resilience and efficient water regulation under both non-stressed and bacterial stress conditions. This sustained transpiration suggests that 'Putra 2' maintains active stomatal function, supporting its photosynthetic performance and growth even under pathogen challenge. Conversely, 'Putra 1' showed markedly lower transpiration rates, especially under control and BLB+BPB treatments, suggesting a more conservative water-use strategy or potential stomatal limitation under combined stress. 'Siraj 297' and 'MRQ76' exhibited elevated transpiration rates under BPB and BLB+BPB treatments, which may reflect an adaptive response to maintain cooling and gas exchange under bacterial stress, albeit potentially at the cost of increased water loss. By 70 DAT, 'Putra 2' continued to outperform other varieties in transpiration rates across treatments, while 'Putra 1' remained the lowest, and 'IS21' and 'MRQ76' displayed moderate rates, as shown in Figure 1a. These trends are consistent with Hashim et al. (2022), who reported that 'Putra 2' maintains higher transpiration under abiotic stress, while 'Putra 1' adopts a more conservative physiological profile. Together, these results highlight varietal differences in water regulation strategies under biotic stress, with 'Putra 2' demonstrating superior adaptability, and 'Putra 1' and 'IS21' showing stable but less dynamic responses. Such insights are critical for guiding the selection of rice varieties suited for disease-prone environments where physiological resilience is essential for maintaining yield.

CONCLUSIONS

Based on a comprehensive evaluation of six Malaysian paddy varieties under various bacterial stresses, this study revealed distinct differences in growth performance, physiological responses, and disease tolerance among six Malaysian rice varieties under bacterial leaf blight (BLB) and bacterial panicle blight (BPB) stress. Among the varieties, 'Putra 1' and 'Putra 2' emerged as the most resilient, exhibiting superior plant height, tillering, and stable physiological traits, including higher photosynthesis rates, stomatal conductance, and transpiration rates, particularly under BLB and combined BLB + BPB infections. Notably, 'IS21' also maintained low lesion severity, reinforcing its potential as a tolerant line. Conversely, 'Siraj 297' showed the highest susceptibility, with pronounced lesion development and severity, especially under BLB. 'CL2' while showing relatively lower physiological performance, displayed moderate disease resilience, with reduced lesion percentages and severity. This study is also among the first to assess the combined impact of BLB and BPB on Malaysian rice varieties in a controlled evaluation. These results not only underscore the promise of 'Putra 1', 'Putra 2' and 'IS21' as foundation lines for future breeding programs targeting dual resistance and yield stability, but also emphasize the value of these varieties for farmers. Their ability to maintain growth and yield components under pathogen pressure makes them excellent candidates for cultivation in high-risk areas, reducing yield losses, minimizing chemical dependency, and enhancing overall farm resilience.

Author contributions

Conceptualization: F.A.A., N.M., A.H. Methodology: F.A.A., S.I.I. Software: F.A.A., A.H. Validation: F.A.A. Formal analysis: F.A.A., A.H. Investigation: F.A.A., M.A.W. Resources: F.A.A., N.M., S.I.I., M.A.W., N.A.H. Data curation: F.A.A. Writing-original draft: F.A.A., A.H. Writing-review & editing: F.A.A. Visualization: F.A.A. Supervision: F.A.A. Project administration: F.A.A., N.M. All co-authors reviewed the final version and approved the manuscript before submission.

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