
Efficacy of mangosteen peel extract combined with phosphonic acid for controlling *Phytophthora palmivora* in durian

Pitisom, P.¹, Lertsuchatavanich, U.², Wiangsamut, B.³, Thongkamngam, T.⁴ and Mongkontanawat, N.^{1*}

¹Department of Food Innovation and Business, Faculty of Agro-Industrial Technology, Rajamangala University of Technology Tawan-Ok, Chanthaburi Campus, Chanthaburi, Thailand 22210; ²Department of Plant Pathology, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand 10900; ³Department of Agricultural Technology, Faculty of Agro-Industrial Technology, Rajamangala University of Technology Tawan-Ok, Chanthaburi Campus, Chanthaburi, Thailand 22210; ⁴Department of Plant Protection Technology and Landscape, Faculty of Agro-Industrial Technology, Rajamangala University of Technology Tawan-Ok, Chanthaburi Campus, Chanthaburi, Thailand 22210.

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Abstract The efficacy of mangosteen peel extract (MPE) combined with phosphonic acid (PA) for controlling *Phytophthora palmivora*, the causal agent of durian trunk canker and root rot, was evaluated *in vivo* using durian (*Durio zibethinus*) leaves and seedlings. Results showed that PA alone significantly reduced lesion size and achieved the highest disease inhibition on both leaves (0.61 cm, 71.58%) and seedlings (4.08 cm, 35.91%) at 14 days after inoculation. The combination of MPE with PA at 10,000 ppm showed efficacy on leaves (0.93 cm, 57.93%), with no significant difference from PA alone. Moderate inhibition levels were observed with MPE at 1,000 and 100 ppm combined with PA, whereas 10 ppm MPE showed lower efficacy. On seedlings, higher concentrations of MPE ($\geq 1,000$ ppm) did not improve disease control and were associated with larger lesion diameters, suggesting a possible concentration-related adverse effect. The commercial MPE product provided the lowest efficacy among the treatments on seedlings. Overall, these results indicated that PA was effective against *P. palmivora* under the condition tested, while the effect of combining MPE with PA varied with MPE concentration and plant tissue.

Keywords: Durian, Mangosteen peel extract, Phosphonic acid, *Phytophthora* root rot

Introduction

Thailand is one of the world's largest producers and exporters of durian, particularly the 'Monthong' variety, which is highly valued in international

* **Corresponding Author:** Mongkontanawat, N.; **Email:** naruemon_mo@rmutto.ac.th

markets including China, Hong Kong, and Malaysia. Between 2020 and 2022, Thailand's durian exports were valued at approximately USD 3.3 billion annually. China is the world's largest durian importer, with imports reaching approximately 740,000 tons annually and accounting for a substantial proportion of global durian imports, with Thailand being one of its major suppliers (FAO, 2023).

Phytophthora palmivora is one of the major threats to durian production and can affect all stages of the cropping cycle (O'Gara *et al.*, 2004). High-rainfall conditions under which durian is grown are conducive to the development of trunk canker and root rot diseases in Southeast Asia. Although essentially a soil-borne pathogen, *P. palmivora* can attack aerial parts of the plant and, as a result, affect various organs of durian at different stages of the cropping cycle. The most important diseases include seedling dieback, foliar blight, patch canker of the trunk and branches, and pre- and postharvest fruit rots (Lim, 1990).

Durian farmers have extensively used metalaxyl-based fungicides because they are effective in suppressing and controlling diseases. However, their long-term use may lead to the development of pathogen resistance, which can reduce their effectiveness. Indeed, the occurrence of fungicide-resistant strains in pathogen populations has resulted in serious economic problems for farmers (Hewitt, 1998; Deising *et al.*, 2008). Changes in pathogen propagation and evolutionary dynamics may contribute to the emergence of isolates with different levels of pathogenicity (Chowdappa and Chandramohan, 1997). In Thailand, the occurrence of metalaxyl-resistant *P. palmivora* isolates in durian (*Durio zibethinus*) has been reported. For example, Kongtragoul *et al.* (2023) found that nearly 50% of the *P. palmivora* isolates studied were resistant to metalaxyl in durian orchards in southern Thailand, with an EC₅₀ greater than 100 mg/L, indicating high resistance. Metalaxyl was also found to be ineffective against resistant isolates in disease-control tests on durian leaves. Therefore, alternative agents and integrated disease-control approaches are recommended to delay the development of resistance and minimize environmental impacts. Given the growing concern over metalaxyl-resistant *P. palmivora* isolates, researchers and farmers have considered alternative chemical agents, such as phosphonic acid, which has a different mode of action in disease management.

Phosphonic acid is a chemical used by durian farmers to prevent and control plant diseases, particularly durian trunk canker and root rot. It has several modes of action, including inhibiting growth by disrupting fungal metabolism, stimulating plant defense responses, and facilitating movement through the plant vascular system. Therefore, it can be used to manage pathogens in roots and leaves (Grant *et al.*, 1990; Ouimette and Coffey, 1990). However, phosphonic acid has limitations in controlling durian root rot. Griffith *et al.* (1990) noted that

although phosphonic acid can inhibit the growth of *P. palmivora*, it may not eliminate all pathogen propagules, particularly dormant or zoospore stages. Similarly, Ramallo *et al.* (2019) reported that phosphonates can effectively control *Phytophthora* infection during its initial stages but have limited curative activity once infection is established. Continuous use of metalaxyl over a long period may also contribute to the development of resistance in *Phytophthora* spp. For this reason, alternative substances that can be used in rotation or in combination with phosphonic acid may be useful for improving the management of durian trunk canker and root rot.

Mangosteen (*Garcinia mangostana* Linn.), known as the “Queen of Fruits”, is valued for its medicinal properties in traditional Thai medicine. Its peel contains compounds with antimicrobial properties, including xanthenes (e.g., α -mangostin, β -mangostin, and gartanin), flavonoids, tannins, and saponins. (Pedraza-Chaverri *et al.*, 2008). Ye *et al.* (2020) studied the antifungal activity of xanthenes from mangosteen peel and found that α -mangostin mainly reduced the sporulation of *C. gloeosporioides* in a concentration-dependent manner. In addition, Pitisom *et al.* (2025) investigated the efficacy of crude mangosteen peel extract in inhibiting the growth of *P. palmivora* mycelium *in vitro*. Mangosteen peel extract at concentrations of 1,000–10,000 ppm significantly inhibited *P. palmivora*. When combined with phosphonic acid at a low concentration (≥ 10 ppm), it produced 100% inhibition in the tested treatments compared with the control. These findings support future evaluation of mangosteen peel extract as a potential component of a more environmentally friendly disease-management approach.

The study evaluated the efficacy of mangosteen peel extract combined with phosphonic acid for controlling *P. palmivora*, the causal agent of durian trunk canker and root rot, on durian leaves and seedlings. The study aimed to evaluate the effectiveness of different MPE concentrations when combined with PA and to identify concentrations suitable for further development of an integrated disease-control approach.

Materials and methods

Sources of mangosteen peel materials

Mangosteen peel was obtained from the Department of Food Innovation and Business, Faculty of Agro-Industrial Technology, Rajamangala University of Technology Tawan-Ok, Chanthaburi Campus, Chanthaburi, Thailand. The peels were transported to the laboratory and dried in a hot-air oven at 65°C for

48 hours before extraction. A commercial mangosteen peel extract product (MPE) was purchased from First Organic Farm Co., Ltd. in Thailand.

Preparation of mangosteen peel extract

The extraction method was based on Pongpisutta *et al.* (2011). Dried mangosteen peels were soaked in 95% ethanol at a ratio of 1 g to 7 mL for 48 hours. The mixture was then filtered through two layers of cheesecloth. The filtrate was concentrated using a rotary vacuum evaporator at 45 °C and 50 rpm until a thick, viscous, reddish-brown extract was obtained.

Preparation and maintenance of *Phytophthora palmivora* isolate CI5-F11

Phytophthora palmivora isolate CI5-F11, previously characterized and reported as a highly aggressive isolate by Pitisom *et al.* (2025), was obtained from the Department of Plant Pathology, Faculty of Agriculture, Kasetsart University, Thailand. The isolate was subcultured on potato dextrose agar (PDA) in sterile 9-cm Petri dishes and incubated at 28 ± 2 °C for 7 days. Mycelial plugs (5 mm in diameter) were excised from the actively growing margins of the colonies and used as the inoculum source for the subsequent experiments. The isolate was selected because it had previously been characterized as highly aggressive and had shown rapid disease development and greater pathogenicity than isolate CI5-F12 (Pitisom *et al.*, 2025).

Efficacy of mangosteen peel extract combined with phosphonic acid for controlling *P. palmivora* on durian leaves

Fully expanded, mature leaves from 1-year-old Monthong durian seedlings were selected. The durian leaves were cleaned with a cotton swab soaked in 70% alcohol and then wiped with a cotton swab soaked in sterilized distilled water. The leaves were allowed to dry before inoculation. Two puncture wounds were made on each leaf using a sterile syringe. A 5-mm-diameter mycelial plug of *P. palmivora* isolates CI5-F11, grown on 7-day-old V8 medium, was placed on the treated leaf surface with the mycelial surface facing the leaf. The incubated leaves were incubated in a moist bag for 24 hours. The mycelial plugs were then removed, and the leaves were sprayed to runoff with MPE at concentrations of 10, 100, 1,000, and 10,000 ppm, each combined with 40% phosphonic acid at a rate of 50 mL/20 L.

The experiment was laid out in a completely randomized design (CRD). The leaf assay comprised seven treatments: (1) distilled-water control, (2)

commercial MPE at 50 mL per 20 L of distilled-water, (3) PA alone at 50 mL per 20 L of distilled-water, and (4–7) MPE at 10, 100, 1,000, and 10,000 ppm, each combined with PA. Each treatment was represented by four biological replicates, with one leaf sampled per replicate, resulting in four leaves per treatment and 28 leaves in total across the seven treatments. Treatments were applied twice at a 7-day interval, while the control treatment received distilled water. Lesion diameter was measured at 7 and 14 days after inoculation. Disease inhibition (DI) was calculated using the following formula, as described by Rizwana *et al.* (2021).

$$DI = [(L_1 - L_2)/L_1] \times 100$$

DI = percentage disease inhibition

L_1 = lesion diameter in the control treatment

L_2 = lesion diameter in the treatment

Efficacy of mangosteen peel extract combined with phosphonic acid for controlling *P. palmivora* on durian seedlings

The experiment was arranged in a completely randomized design (CRD). The trunk assay comprised seven treatments: (1) distilled-water control, (2) commercial MPE at 50 mL per 20 L of distilled-water, (3) PA alone at 50 mL per 20 L of distilled-water, and (4–7) MPE at 10, 100, 1,000, and 10,000 ppm, each combined with PA. Each treatment replicated four times, with one durian seedling serving as one experimental unit, resulting in a total of 28 seedlings. One-year-old Monthong durian seedlings, approximately 100–120 cm in height and 0.5–1 cm in trunk diameter, were grown in 10 × 14-inch grow bags. Seedlings with upright trunks, healthy and fully developed leaves, and no visible symptoms of disease or insect damage were selected. A wound was made on the trunk using a sterilized blade by carefully removing a small area of bark. A 5-mm-diameter mycelial plug obtained from a 7-day-old culture of *P. palmivora* isolate Cl5-F11 grown on V8 medium was placed onto the wound, with the mycelial surface in direct contact with the wounded tissue. The inoculated area was covered with Parafilm and incubated under 12-h photoperiod at 95–100% relative humidity. After 48 h, the mycelial plug was removed. MPE at concentrations of 10, 100, 1,000, and 10,000 ppm, each combined with 40% phosphonic acid at a rate of 50 mL/20 L, was then sprayed onto the inoculated seedlings until runoff. The treatments were applied twice at a 7-day interval. The distilled-water control was treated in the same manner. Lesion diameter on the durian trunk was measured at 7 and 14 days after inoculation. In addition, the bark surrounding the diseased areas was carefully scraped to assess the presence of internal symptoms.

Statistical analyses

Data were expressed as the mean $\pm$ standard error (SE). Treatment effects were evaluated using one-way analysis of variance (ANOVA). When significant differences among treatment means were detected, Duncan's multiple range test (DMRT) was used for mean separation at $p < 0.05$. All statistical analyses were performed using statistical software (Statistix 10).

Results

Characterization of *Phytophthora palmivora* isolate C15-F11

Phytophthora palmivora isolate C15-F11 showed colony growth on PDA (Figure 1a). Microscopic examination showed sporangia consistent with the morphological characteristics of *P. palmivora* (Figure 1b). Sequence analysis of the internal transcribed spacer (ITS) region showed high similarity to reference sequences of *P. palmivora* deposited in GenBank. ITS-based phylogenetic analysis placed isolate C15-F11 within the *P. palmivora* clade together with reference sequences, whereas *Fusarium oxysporum* (JK989157.1) formed a distinct outgroup (Figure 1c). Therefore, C15-F11 was selected for the subsequent experiments. These results supported to identify the isolate used in the present study.

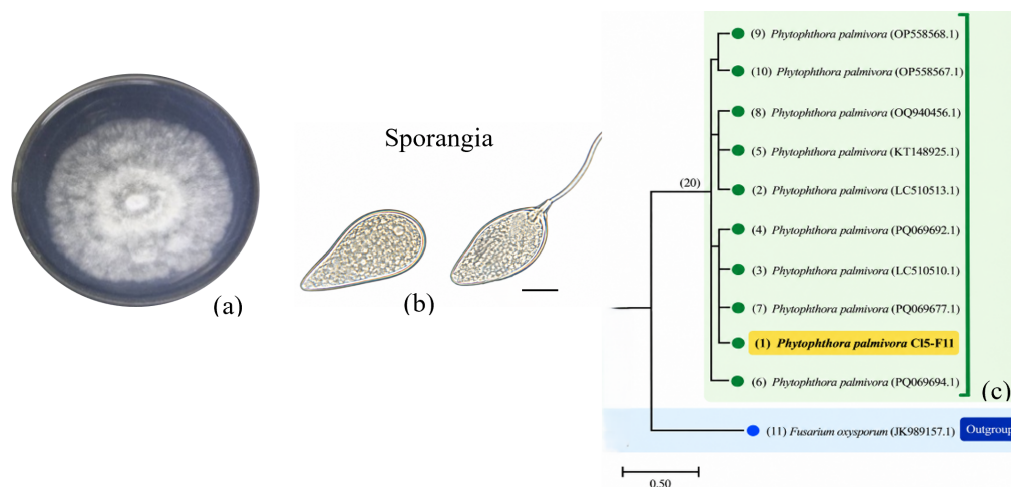


Figure 1. Morphological characteristics and ITS-based phylogenetic placement of *Phytophthora palmivora* isolate C15-F11: (a) Colony morphology on PDA, (b) sporangial morphology, and (c) phylogenetic tree based on ITS sequences showing the placement of isolate C15-F11 among reference sequences of *P. palmivora*

*Efficacy of mangosteen peel extract combined with phosphonic acid for controlling *P. palmivora* on durian leaves*

The efficacy evaluation of MPE combined with PA against *P. palmivora* on durian leaves was evaluated based on lesion diameter and the percentage disease inhibition at 7 and 14 days after inoculation. The results are presented in Table 1 and Figure 2. The control group had the largest mean lesion diameter, measuring 0.79 ± 0.09 cm at 7 days after inoculation and 2.22 ± 0.36 cm at 14 days after inoculation. PA alone produced the smallest mean lesion diameter, 0.43 ± 0.05 cm and 0.61 ± 0.39 cm, respectively, and the highest disease inhibition percentages, $44.56 \pm 12.37\%$ and $71.58 \pm 20.63\%$, respectively. When MPE was combined with PA at 10,000 ppm, the disease inhibition was the second highest. The mean lesion diameter was 0.49 ± 0.05 cm at 7 days and 0.93 ± 0.26 cm at 14 days, while disease inhibition was $38.37 \pm 5.20\%$ and $57.93 \pm 9.84\%$, respectively. These values did not differ significantly from those of the PA-alone treatment. MPE at 1,000 and 100 ppm combined with PA showed moderate disease inhibition, with inhibition percentages at 14 days of $35.75 \pm 19.38\%$ and $51.83 \pm 16.48\%$, respectively. MPE at 10 ppm combined with PA showed lower disease inhibition, with a value of $21.89 \pm 19.95\%$ at 14 days. The commercial MPE treatment showed the lowest efficacy among the tested treatments, with a lesion diameter of 1.74 ± 0.37 cm and disease inhibition of $21.36 \pm 15.82\%$ at 14 days after inoculation.

Table 1. Effect of different concentrations of mangosteen peel extract (MPE) and phosphonic acid (PA) on disease inhibition of *P. palmivora* on durian leaves

Treatments	Lesion diameter (cm)		Disease inhibition (%)	
	7 DAI	14 DAI	7 DAI	14 DAI
Control	0.79 ± 0.09^d	2.22 ± 0.36^d	0.00 ± 0.00^d	0.00 ± 0.00^d
Commercial MPE	0.65 ± 0.05^c	1.74 ± 0.37^{cd}	17.07 ± 12.20^{cd}	21.36 ± 15.82^{cd}
Phosphonic acid (PA)	0.43 ± 0.05^a	0.61 ± 0.39^a	44.56 ± 12.37^a	71.58 ± 20.63^a
MPE 10 ppm+PA	0.51 ± 0.09^{ab}	1.69 ± 0.23^c	34.85 ± 17.10^{abc}	21.89 ± 19.95^{cd}
MPE 100 ppm+PA	0.60 ± 0.08^b	1.03 ± 0.24^{ab}	22.17 ± 18.75^{bc}	51.83 ± 16.48^{ab}
MPE 1,000 ppm+PA	0.52 ± 0.03^{bc}	1.40 ± 0.42^b	33.04 ± 9.89^{abc}	35.75 ± 19.38^{bc}
MPE 10,000 ppm+PA	0.49 ± 0.05^a	0.93 ± 0.26^a	38.37 ± 5.20^a	57.93 ± 9.84^a

Means with different letters are significantly different ($p \leq 0.05$) according to Duncan's multiple range test. DAI = days after inoculation.

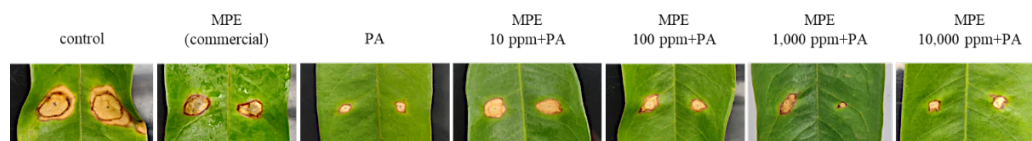


Figure 2. Disease symptoms on durian leaves caused by *P. palmivora* in the control treatment and after treatment with different concentrations of mangosteen peel extract (MPE) combined with phosphonic acid (PA)

Study of the efficacy of mangosteen peel extract combined with phosphonic acid for controlling *P. palmivora* on durian seedlings

The efficacy of MPE combined with PA at various concentrations against *P. palmivora* on durian seedlings was evaluated based on lesion diameter and percentage disease inhibition at 7 and 14 days after inoculation, as shown in Table 2 and Figure 3. At 7 days after inoculation, the control group had the largest mean lesion diameter (4.90 ± 0.34 cm), which was significantly different from the other treatment groups. The PA-alone treatment had the smallest lesion diameter (3.55 ± 0.46 cm) and the highest disease inhibition percentage ($27.22 \pm 10.56\%$), although it did not differ significantly from the treatments with MPE + PA at 10 and 100 ppm. At 14 days after inoculation, the control group still had the largest mean lesion diameter (6.40 ± 0.55 cm). The PA treatment had the smallest lesion diameter (4.08 ± 0.16 cm) and the highest disease inhibition ($35.91 \pm 6.60\%$), which were significantly different from the control and commercial MPE treatments. MPE + PA at 10, 100, and 1,000 ppm produced moderate disease inhibition values of 25.17%, 24.41%, and 25.09%, respectively. In contrast, MPE + PA at 10,000 ppm produced lower disease inhibition (21.05%) and a larger lesion diameter than the lower-concentration treatments. Overall, PA alone provided the greatest disease control under conditions tested, whereas the addition of MPE did not consistently improve disease control in durian seedlings.

Table 2. Effect of different concentrations of mangosteen peel extract (MPE) and phosphonic acid (PA) on the disease inhibition of *P. palmivora* on durian seedling branches

Treatments	Lesion diameter (cm)		Disease inhibition (%)	
	7 DAI	14 DAI	7 DAI	14 DAI
Control	4.90 ± 0.34^b	6.40 ± 0.55^c	0.00 ± 0.00^b	0.00 ± 0.00^c
Commercial MPE	3.80 ± 0.68^a	5.77 ± 0.39^c	21.43 ± 18.76^a	9.54 ± 8.33^{bc}
Phosphonic acid (PA)	3.55 ± 0.46^a	4.08 ± 0.16^a	27.22 ± 10.56^a	35.91 ± 6.60^a
MPE 10 ppm+PA	3.70 ± 0.61^a	4.75 ± 0.83^{ab}	24.23 ± 13.38^a	25.17 ± 16.49^{ab}
MPE 100 ppm+PA	4.15 ± 0.68^{ab}	4.83 ± 0.31^{ab}	15.57 ± 9.87^{ab}	24.41 ± 2.15^{ab}
MPE 1,000 ppm+PA	4.45 ± 0.41^{ab}	4.74 ± 0.55^{ab}	8.59 ± 12.85^{ab}	25.09 ± 14.10^{ab}
MPE 10,000 ppm+PA	4.30 ± 0.49^a	5.01 ± 0.32^b	12.23 ± 6.25^{ab}	21.05 ± 10.74^{ab}

Means with different letters are significantly different ($p \leq 0.05$) according to Duncan's multiple range test. DAI = days after inoculation.

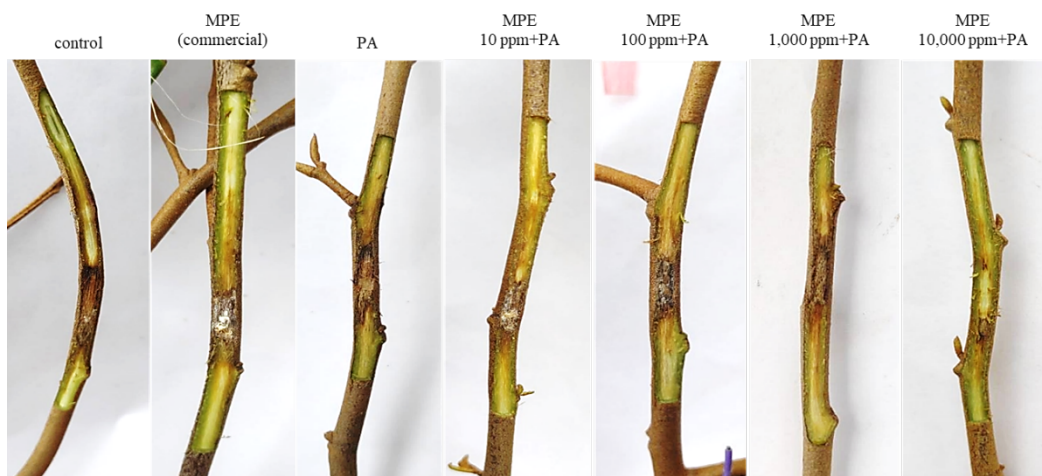


Figure 3. Disease symptoms on durian seedling branches caused by *P. palmivora* in the control treatment and after treatment with different concentrations of mangosteen peel extract (MPE) combined with phosphonic acid (PA)

Discussion

The experimental results showed that phosphonic acid (PA) produced the greatest reduction in lesion diameter and the highest percentage of disease inhibition on both durian leaves and seedlings at 7 and 14 days after inoculation. On durian leaves, PA alone produced 71.58% disease inhibition and the smallest lesion diameter (0.61 cm) at 14 days. This finding is consistent with Guest and Grant (1991), who reported that phosphonates can inhibit *Phytophthora* spp. through both direct effects on the pathogen and stimulation of plant defense responses. MPE combined with PA at 10,000 ppm provided the second-highest disease control on durian leaves and did not differ significantly from PA alone. This effect may be related to the antimicrobial activity of phenolic compounds, particularly xanthenes (Jang *et al.*, 2010; Pedraza-Chaverri *et al.*, 2008). However, increasing the concentration of MPE did not consistently increase disease inhibition. In the seedlings assay, the higher concentrations tested did not improve disease control and, at 10,000 ppm, were associated with a larger lesion diameter than some lower-concentration treatments. This pattern may indicate a concentration-related adverse effect; however, phytotoxicity was not directly assessed in the present study. The commercial MPE treatment showed relatively low disease-control efficacy on seedlings, with only 9.54% disease inhibition at 14 days. This lower efficacy may be related to differences in formulation or active-ingredient concentration, but these factors were not analyzed in the present study. The present study was limited to one previously characterized *P.*

palmivora isolate and to in vivo assays on durian leaves and seedlings. Therefore, the results should not be interpreted as sufficient evidence for broad field-level disease-control recommendations.

In conclusion, phosphonic acid provided the greatest disease-control efficacy against *P. palmivora* under the condition tested. Combining MPE with PA at 10,000 ppm produced disease-control results comparable to PA alone on durian leaves, but the addition of MPE did not consistently improve disease control on seedlings. Further studies should evaluate additional *P. palmivora* isolates and other relevant *Phytophthora* species, confirm pathogenicity when new isolates are used, optimize MPE and PE concentrations using *in vitro* assays, and evaluate the treatments under field conditions, including naturally infested durian orchards. These studies are necessary before practical recommendations for disease management can be made.

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Conflicts of interest

The authors declare no conflict of interest.

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