International Journal of Agricultural Technology 2024 Vol. 20(4):1687-1708
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Efficiency of AI drone, air-blast, and long hose pump sprayers in spraying fungicide to manage leaf sheath blight caused by *Rhizoctonia solani* in durian

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Wiangsamut, B., Anutrakinchai, S., Makhonpas, C., Wiangsamut, M. E. L. and Thongkamngam, T. (2024). Efficiency of AI drone, air-blast, and long hose pump sprayers in spraying fungicide to manage leaf sheath blight caused by *Rhizoctonia solani* in durian. International Journal of Agricultural Technology 20(4):1687-1708.

Abstract The application of AI drones reduced the use of chemical fungicides and water compared to the control method (long hose pump sprayer) during the treatement of a 20-year-old 'Monthong' durian cultivar. Consequently, the AI drone sprayer used 0.84 to 1.67 L/ha of chemical fungicides and 835.16 L/ha of water, both significantly lower than the air-blast sprayer (7.19 L/ha with 7,184.81 L/ha of water) and the control method (4.49 L/ha with 4,491.51 L/ha of water). The AI drone had the lowest fungicide application, no solution loss, and required the least amount of time as compared to the air-blast sprayer and the control. Conversely, the air-blast sprayer used significantly higher amounts of chemical fungicide and water than the control. It also had a higher fungicide application rate and greater solution loss . After 10 days of using fungicide, the use of AI drones improved the health of durian trees and reduced the disease incidence. The EA-30X model AI drone proved to be the most cost-effective method for spraying fungicide, labor, fungicide use, water consumption, and electricity compared to the air-blast sprayer and the control. It effectively manages costs by providing efficient automated spraying, fungicide application, and water delivery, thereby reducing losses. The best settings for the EA-30X drone in unmanned aerial vehicle spray applications to combat leaf sheath blight caused by *R. solani* in durian are at a speed of 0.5 m/s and a flight height of 2.7 m above the tree canopy tip. This advancement in disease control outperforms conventional long hose pump and air-blast sprayers.

Keywords: Artificial intelligence, Drone, Durian, Efficiency, Leaf sheath blight

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Introduction

Durian (*Durio zibethinus* Murr.) is an energy-dense seasonal tropical fruit (Aziz and Jalil, 2019), and holds a substantial economic importance as a fruit crop across several Southeast Asian nations (Wiangsamut and Wiangsamut, 2023), including Vietnam, Indonesia, Malaysia, the Philippines, and Thailand as the main suppliers of durian to China (Xijia, 2023). Thailand also holds the distinction of being the largest global exporter of the renowned durian fruit, commanding an impressive 93.3% share of the international market (Abhasakun, 2023). The value of Thailand's fresh durian exports in the year 2022 exceeded 1.1 billion baht, marking the highest level of durian exports witnessed in the past three decades (Adair, 2023). This notable accomplishment can be primarily attributed to enhanced transportation infrastructure, the implementation of rigorous quality control measures, and the exceptional taste of Thai durians, especially the taste of durian cv. 'Monthong'. This durian cultivar has been found to be the preferred choice among consumers, primarily due to its subtle aroma, delicately sweet flavor, and the desirable texture of its crispy yet tender golden-yellow flesh (Wiangsamut and Wiangsamut, 2023), and aborted seeds (Wiangsamut *et al*., 2021). In the present year, there has been continuous growth in Thailand's durian exports as stimulated by the escalating demand for durians in the Chinese market that led to a notable surge in durian prices within recent years (Pongpisutta *et al*., 2023). Accordingly, Zang (2023) reports that the durian prices observed in the Chinese market during the initial half of 2023 exhibited a notable increase of 19.8% in comparison to the corresponding period of 2022.

The cultivation of durian in Thailand has experienced a significant rise particularly in the southern and eastern regions. This expansion has led to a total plantation area of 168,778 hectares (ha), marking an increase of 12,768 ha (8.18%) from the previous year. According to a recent report issued by OAE (2023), the average fruit yield recorded was 233.12 kg/ha, exhibiting a notable increase of 6.58% (14.4 kg/ha) in comparison to the yield observed in the year 2022. While the cultivation of durian has experienced significant growth, it has also been affected by various plant diseases, especially the leaf sheath blight disease caused by *Rhizoctonia solani* (Abbas *et al*., 2019; Abbas *et al*., 2022). This disease affects the quality and quantity of agricultural products and have directly an impact on food safety (Chin *et al*., 2023), and this effect results in a loss of income in the production sectors which are particularly critical for developing countries. The leaf sheath blight disease impacts both juvenile and mature leaves, across both small-scale plantations and expansive durian orchards (Lim *et al*., 1987; Preecha, 2014; Tuyen, 2021; DAS, 2023). However, Ciba-Geigy AG in 1989 discovered that the difenoconazole is an absorption of triazole fungicides, broad fungicidal spectrum, seed treatment or foliar treatment could improve crops quality and yield (Allen *et al*., 2004). Abdul *et al*. (2008) proved that propiconazole is a kind of protective and therapeutic adsorption triazole fungicide, which could be absorbed by root, stem, leaf and transmission in plant quickly. There has been a notable recommendation for the utilization of fungicide containing the active ingredients difenoconazole and propiconazole for the effective management of *R. solani* and it revealed that its inhibitory capacity greatly affects the development and germination of sclerotia (Leng *et al*., 2012).

The utilization of long hose pump sprayers by farmers for spraying fungicide in the management of durian diseases leads to substantial expenditure of time, energy, and manpower resources. Foreign labour has serves as the foundation of the agricultural management practices. The shortage of labour is one of the major issues facing durian production in Thailand. Recently, in large orchard management by spraying fungicide with the air-blast sprayers is most often applied (Bock and Hotchkiss, 2020). More recently, interest in using unmanned aerial vehicles (UAVs) for spray applications in bush or tree crops has also been rising in Asia, Europe and America with some experiments performed in olives (Aru *et al*., 2019; Martinez-Guanter *et al*., 2020), vineyards (Giles and Billing, 2015; Sarri *et al*., 2019; Wang *et al*., 2021), almonds (Li *et al.,* 2020), apples (Li *et al*., 2018; Liu *et al*., 2020), peaches (Meng *et al*., 2020), citrus (Martinez-Guanter *et al*., 2020; Tang *et al*., 2018; Zhang *et al*., 2016), pineapples (Wang *et al*., 2018), arecas (Wang *et al*., 2020), and sugar canes (Zhang *et al*., 2020) but EA-30X model artificial intelligence (AI) drone has not been utilized in the cultivation of durian as of yet. To tackle these concerns, the objective was to evaluate the efficiency of various spraying techniques namely artificial intelligence (AI) drone, air-blast sprayer, and long hose pump sprayers, in the application of fungicide solution for the control of leaf sheath blight caused by *Rhizoctonia solani* in durian trees.

Materials and methods

Place and period of study, climate condition, sampling, identification and evaluation of the disease

The experiment was conducted in a durian orchard located at Rajamangala University of Technology Tawan-Ok at Chanthaburi Campus, Chanthaburi, Thailand. The orchard consisted of twenty-year-old trees of the 'Monthong' cultivar. The geographical coordinates of the orchard were

12.83343 (12°50'0.34368"N) latitude and 102.10913 (102°6'32.88492"E) longitude, with an elevation of 49 meters above sea level. During the experimental period, from October 2022 to December 2022, the precipitation levels varied from high to low, with recorded values of 380.5 mm, 186.5 mm, and 27.3 mm for the months of October, November, and December 2022, respectively. The relative humidity ranged from 72.5% to 89.8%. The daytime temperature ranged from 33.5 °C to 37.7 °C, while the nighttime temperature ranged from 15.7 °C to 24.4 °C. The evaporation rate of water during this period was observed to be between 3.9-4.7 mm/day. The soil was a sandy loam type (OARDR, 2015), that had a pH of 4.96, electrical conductivity of 0.04 mS/cm, organic matter content of 3.10%, phosporus level of 36.21 mg P/kg, potassium level of 49.52 mg K/kg, calcium level of 190.34 mg Ca/kg, and magnesium level of 50.58 mg Mg/kg (OARDR, 2023). The outbreak of leaf sheath blight disease was observed on the leaves of durian trees on October 1, 2022 and then leaf samples of its exhibiting symptoms were collected and taken to the laboratory for disease type analysis. The mycelia were cultured on potato dextrose agar (PDA) at room temperature (27 - 30 °C) for a week to determine the type of disease fungi by examining its morphological characteristics, colony, and mycelium based on Younesi *et al*.'s research (2021).

A pathogenicity test was conducted to verify the presence of *Rhizoctonia solani* on detached durian leaves. The experiment was laid out in a completely randomized design (CRD) with two treatments: 1) Mycelial plugs and 2) Sterile PDA plugs (used as the control treatment). Each treatment was replicated five times. A single detached leaf from 'Monthong' durian tree was used for each replication, totaling ten detached leaves for testing the pathogenicity of *R. solani* (five detached leaves per treatment). Fifteen mycelial plugs (each 5 mm in diameter) were taken from the edges of a 3-day-old colony. These plugs were positioned on the midrib wound of a leaf, mycelia facing downwards, with 4 cm intervals (three mycelial plugs per leaf). Similarly, fifteen sterile PDA plugs (each with a diameter of 5 mm) were taken from the edges of a 3-day-old potato dextrose agar (PDA) culture. These sterile plugs were then positioned on the midrib wound of a leaf, maintaining 4 cm intervals (three sterile PDA plugs per leaf). Throughout a span of 9 days, the durian leaves underwent a normality assessment through the Kolmogorov-Smirnov Test ($P < 0.01$). Following this, a T-test was conducted to compare the means of treatment. In order to satisfy Koch's postulates, the fungus was isolated once again from the inoculated leaves and characterized based on the morphology of its colony and conidia.

Experimental design and selection of durian trees infested with leaf sheath blight disease

The experiment was conducted using a completely randomized design (CRD) (Figure 1). There were four treatments, each representing a different type of sprayer: 1) AI Drone1, or artificial intelligence (AI) drone sprayer (EA-30X model) for fungicide solution at the concentration of 1 ml/L [or 1 millimeter (ml) per 1 liter (L) of clean water]; 2) AI Drone2, or AI drone sprayer (EA-30X model) for fungicide solution at the concentration of 2 ml/L; 3) Air-blast, or air-blast sprayer for fungicide solution at the concentration of 1 ml/L; and 4) Long hose pump, or long hose pump sprayer for fungicide solution at the concentration of 1 ml/L. The long hose pump served as the control (controlled treatment). It is important to note that the chemical fungicide used in all treatments contained the active ingredients of difenoconazole 15% + propiconazole 15% W/V EC. Each treatment was replicated five times, with one durian tree per replication, in a total of 20 trees (20-year-old tree of durian cv. 'Monthong', one tree per planting hole with tree spacing of 10 m x 10 m, 100 trees/ha). Tree height ranged from 9.35 to 11.00 m and tree canopy ranged from 8.65 to 9.75 m. In each treatment, the chemical fungicide solution was sprayed twice, with the first application occurring on October 25, 2022, and the second on November 9, 2022. The interval between applications was 15 days, and spraying took place at 0700H for all 20 trees.

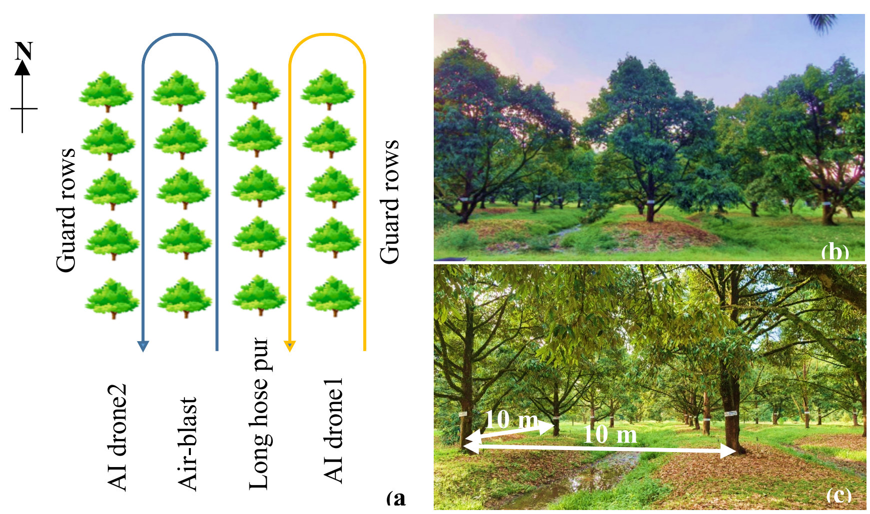

Figure 1. The experimental layout in a completely randomized design (CRD): (a) four treatments comprised of AI drone1, AI drone2, air-blast, and long hose pump sprayers; (b) twenty durian trees used and; (c) durian tree spacing of 10 m x 10 m

Artificial intelligence (AI) drone sprayer

An AI drone, the EA-30X model, with a cruise speed of 0.5 m/s and maintaining a flight height of 2.7 m above the tip of the tree canopy was utilized to test its efficiency (Figure 2a). To enhance the effectiveness of the drone's spraying capabilities, it was equipped with two spray passages for each row, with each passage covering a width of 5 m. The drone utilized centrifugal mist spray nozzles, incorporating two active nozzles, which contributed to improved canopy deposition and coverage.

Air-blast sprayer

The air-blast method was utilized to effectively distribute fungicide solution onto the targeted durian trees. This technique combined both air and liquid to ensure precise delivery. The air-blast sprayer utilized a 45.7-hp engine, which was operated at a speed of 1.10 km/h with a spraying pressure of 1.5 megapascal (Mpa) (Figure 2b). The sprayer employed two spray passages per row per time, ensuring thorough coverage. To achieve optimal canopy deposition and coverage, six nozzles were employed during the spraying process.

Figure 2. The application of the fungicide solution by: (a) AI drone sprayer; (b) air-blast sprayer and; (c) long hose pump sprayer

Long hose pump sprayer

The skid pump sprayer, equipped with a 5.5-horsepower, was utilized for the long hose pump application. It featured a 3-cylinder pump with a 1-inch suction cup, and a 50-m long hose with a diameter of 3/8 inch (Figure 2c). The spraying pressure could reach up to 560 pound-force per square inch (psi), ensuring effective canopy deposition and coverage. This setup allowed for the precise delivery of a fungicide solution to the target durian trees.

Plant measurement and data gathered

Twenty durian trees of 'Monthong' cultivar that were naturally infected with *Rhizoctonia solani* were chosen for this study. The trees were selected by similar tree height size, close canopy diameter, and identical tree health status. The tree parameters were measured using a measuring tape attached to the stem of the tree from the base of the stem on the ground to the tip of the tree in meters (m) for tree height, and from one edge of the leaf canopy to the opposite through the stem's center of the tree in meters (m) for canopy diameter (Wiangsamut and Wiangsamut, 2022). Chemical fungicide use refers to the total amount of chemical fungicide that is dissolved in clean water and sprayed on durian trees to treat leaf sheath blight disease in a one-hectare area, which is measured in liters per hectare (L/ha). Water consumption refers to the amount of clean water used to dilute chemical fungicides for spraying on durian trees affected by leaf sheath blight disease in a one-hectare area, which is measured in units of L/ha. Fungicide solution application refers to the amount of chemical fungicide mixed with clean water; this mixture is then used to treat the leaf sheath blight disease on durian trees in a one-hectare area, which is measured in L/ha. Fungicide solution loss refers to the amount of fungicide solution that falls on the ground after spraying it on durian trees infected with leaf sheath blight disease in a one-hectare area basis, which is measured in L/ha. The amount of fungicide solution loss was collected using transparent plastic sheets on the ground in durian fields. Percentage of fungicide solution loss is computed by multiplying the amount of fungicide solution loss by 100 and divide it by the amount of fungicide solution applied. Time consumption refers to the duration it takes for sprayers to complete the task of spraying fungicide solution on durian trees infected with leaf sheath blight disease in a one-hectare area, which is measured in hours per hectare (h/ha). Durian tree health and disease incidence were evaluated on October 5, 2020, which took place during the stage of mature leaf growth at 10 days prior to the application of a fungicide solution, or spraying. Subsequently, these two parameters were re-evaluated at intervals of 10, 30, and 60 days after the spraying process. Durian tree health refers to the evaluation of the durian trees based on the percentage of the color of their leaves, the growth of their branches, and the size of their canopy, which was divided into three levels: low health (0-35% score), moderate health (36 - 70% score), and high health (71 - 100% score). Leaf sheath blight disease incidence refers to the assessment of disease severity based on the percentage of affected leaves per tree, and the ratings were determined using the modified disease severity scale introduced by Orji *et al*. (2015) categorized the severity into four ratings: no disease (0%); leaves infected with small sheath blight lesions exhibit spreading on the leaf surface (1 - 35%); the presence of extensive lesions caused by leaf sheath blight, indicating a severe infection that affected nearly all leaflets (36 - 70%); and a thorough infestation of the entire plant, with leaf sheath blight disease present on every leaf and some leaves exhibiting holes and tearing (71 - 100%). Cost of chemical fungicide spraying to manage leaf sheath blight disease caused by *R. solani* as sprayed by AI drone, air-blast, and long hose pump was based on all expenses for two rounds of spraying, with a 15-day interval, which was recorded in US dollars per hectare (USD/ha).

Data analysis

The software Statistix 10 (SXW) was used to analyze the data. The one-way analysis of variance (ANOVA) was conducted to compare the means of four treatments and determine if there were any significant differences. Duncan's multiple range test (DMRT) was used to compare the means at a 0.01 probability level. Correlation analysis was used to establish the relationships between fungicide solution application, time consumption, and fungicide solution loss.

Results

The appearance of disease symptoms, specifically sheath blight caused by *Rhizoctonia solani*, was observed on the leaves (Figure 3a - b). After culturing the mycelium of *R. solani* on potato dextrose agar (PDA) for seven days, it was confirmed that the strain responsible for the disease on the durian leaves was *R. solani* (Figure 3c). The morphological characteristics, colony, and mycelium of the *R. solani* strain were subsequently identified. This fungus strain had the ability to produce specific sterile mycelia, which branch out in T-shape cells and had a partition wall called dolipore septum. When fully developed, the mycelia of the fungus compacted tightly together, forming a mass known as sclerotia (Figure 3d). Throughout the 9-day pathogenicity trial of *R. solani*, symptoms were detected on detached leaves cultured with mycelial plugs, brought about by the inoculated fungus. The mean size of symptomatic regions was 5.4 cm^2 (Figure 4b), which showed a significant difference ($P \leq 0.01$) from the control treatment where no mycelial growth was present on healthy leaves cultured with sterile PDA plugs (Figure 4a).

Figure 3. Morphological characteristics of *Rhizoctonia solani* associated with leaf sheath blight in durian trees: (a - b) Preliminary signs of leaf sheath blight as small brown spots with a light brown or white center; (c) The colony on potato dextrose agar (PDA) observed at 7 days and; (d) The mycelium shows right-angled branching

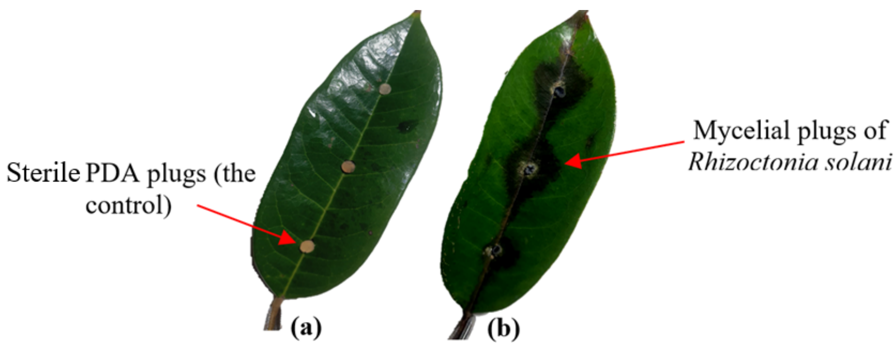

Figure 4. Pathogenicity test of *Rhizoctonia solani* on detached leaves of 'Monthong' durian: (a) Healthy leaves placed on sterile PDA plugs served as the control and; (b) Symptoms were observed on detached leaves following inoculation with *Rhizoctonia solani* over a 9-day observation period

The result indicated that the range of tree height of a 20-year-old durian cv. 'Monthong', which was between 9.77 to 10.16 m, and the range of tree height did not vary significantly ($P > 0.01$) (Table 1). Its canopy diameter ranged from 9.37 to 9.56 m and these values did not differ significantly ($P > 0.01$). There was no statistically significant difference ($P > 0.01$) observed in the measurements of tree height and canopy diameter of the durian trees used in the study (Table 1). The utilization of AI drone1 and AI drone2 sprayers resulted in a statistically significant reduction in the quantity of chemical fungicide use ($P \leq 0.01$), particularly in the case of AI drone1. Additionally, these sprayers required a lower volume of water consumption ($P \leq 0.01$) for diluting the chemical fungicide compared with the control (long hose pump sprayer). Conversely, the air-blast sprayer necessitated a significantly higher amount of chemical fungicide use ($P \leq 0.01$), and water consumption ($P \leq 0.01$) in comparison to the control (Table 1).

Table 1. Tree height, canopy diameter, chemical fungicide use, and water consumption that were used in the experiment

Type of sprayer	Tree height (m)[1/]	Canopy diameter (m)[1/]	Chemical fungicide use (L/ha)[1/]	Water consumption (L/ha)[1/]
AI drone1	10.16[a]	9.37[a]	0.84[d]	835.16[c]
AI drone2	9.77[a]	9.51[a]	1.67[c]	835.16[c]
Air-blast	9.80[a]	9.56[a]	7.19[a]	7,184.81[a]
Long hose pump (control)	10.11[a]	9.51[a]	4.49[b]	4,491.51[b]
F-test (0.01)	ns	ns	**	**
CV(%)	4.98	3.14	0.38	0.33

[1/] in treatment column, means with the same letter is not significantly different; CV, coefficient of variation; ns, non-significant difference at 0.01 probability level ($P > 0.01$) through Duncan's multiple range test (DMRT); ** significantly different at 0.01 probability level ($P \leq 0.01$)

Table 2. Fungicide solution application, fungicide solution loss, percentage of fungicide solution loss, and time consumption associated with various types of sprayers

Type of sprayer	Fungicide solution application (L/ha)[1/]	Fungicide solution loss (L/ha)[1/]	Percentage of fungicide solution loss[1/]	Time consumption (h/ha)[1/]
AI drone1	836[c]	0.00[c]	0.00[c]	2.23[c]
AI drone2	837[c]	0.00[c]	0.00[c]	2.23[c]
Air-blast	7,192[a]	2,613.00[a]	36.33[a]	3.62[b]
Long hose pump (control)	4,496[b]	1,303.80[b]	29.00[b]	8.31[a]
F-test (0.01)	**	**	**	**
CV(%)	0.24	0.35	0.00	0.14

L/ha, liter per hectare; h/ha, hours per hectare, % , percentage; ns, non-significant; CV, coefficient of variation; ** significantly different at 0.01 probability level ($P \leq 0.01$); [1/]in treatment column, the means with the different letter are significantly different at 0.01 probability level ($P \leq 0.01$) as determined by Duncan's multiple range test (DMRT)

The results showed that AI drone sprayers had the lowest fungicide solution application ($P \leq 0.01$) with no loss of solution ($P \leq 0.01$), and the least time consumption ($P \leq 0.01$) compared with the air-blast sprayer and the control (long hose pump sprayer or long hose pump) (Table 2). On the other hand, the air-blast sprayer demonstrated a significantly higher application of fungicide solution ($P \leq 0.01$) and a greater loss of fungicide solution ($P \leq 0.01$) when compared with the control (long hose pump) and AI drone sprayers (Table 2). Correlation analysis also revealed a positive association between fungicide solution loss and both fungicide solution application ($r = 1.00$) and time consumption ($r = 0.39$). This suggests that an increase in fungicide solution application and time consumption leads to an increase in fungicide solution loss as indicated by the positive correlation efficient (r) values. These findings are statistically significant with a P-value of less than or equal to 0.01.

At ten days prior to spraying, the durian trees' health level remained consistent at 88% across all trees examined in the study (Figure 5) and disease incidence did not differ significantly, which ranged from 52 - 54%. This disease incidence was determined by the presence of extensive lesions caused by leaf sheath blight, indicating a severe infection that affected nearly all leaflets (Figure 6). At ten days after fungicide solution application (or days after spraying: DAS), the use of AI drone2 resulted in significantly improved durian tree health ($P \leq 0.01$) and the lowest incidence of disease ($P \leq 0.01$) as evidenced by the presence of minimal sheath blight lesions. This was followed by the use of AI drone1, air-blast, and long hose pump sprayers, as indicated by the percentages of durian tree health and disease incidence (Figures 5 and 6). In general, the durian trees exhibited optimal health and minimal disease incidence at 10 DAS. However, as the number of days after spraying increased to 30 DAS and 60 DAS, the health of the durian trees gradually declined. Notably, the durian trees sprayed with AI drone2 exhibited the slowest deterioration in health and remained in high level of health as evidenced by the remaining green leaves, enhanced branch development, sustained canopy size, and the lowest disease incidence; followed by those sprayed with AI drone1 and air-blast sprayers (Figures 5 and 6). Conversely, the durian trees treated with the control method, which involved a long hose pump, experienced the fastest deterioration in health (health level dropped from a high level to a moderate level), and the highest disease incidence, as evidenced by the number of days after spraying at 60 DAS (Figures 5 and 6). The utilization of AI drone sprayers, particularly the AI drone2 sprayer, demonstrated a considerably higher level of efficacy in managing leaf sheath blight caused by *R. solani* as compared to the utilization of long hose pump and air-blast sprayers. This was determined by assessing the durian tree's health and the incidence of disease.

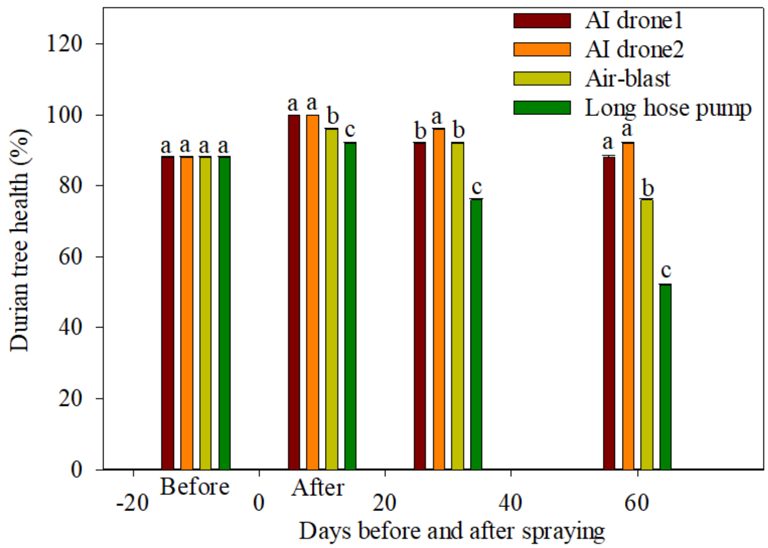

Figure 5. Percentage of durian tree health before and after spraying fungicide solution by drones, air-blast, and long hose pump sprayers to manage leaf sheath blight lesions; In each day before, and after spraying (DAS), means comparisons conducted through Duncan's multiple range test (DMRT) at a 0.01 probability level

All four types of sprayers, namely AI drone1, AI drone2, air-blast, and long hose pump had shown a price of 27.43 USD/ha for spraying chemical fungicide in the management of leaf sheath blight caused by *R.solani* in durian (Table 3). AI drone sprayer incurred the lowest expenses in terms of laborers' employment (7.67 USD/ha), chemical fungicide usage (14.98 - 29.78 USD/ha), water consumption (13.78 USD/ha), and electricity consumption (0.82 USD/ha) as compared to the control (long hose pump), which incurred costs of 28.57 USD/ha, 80.01 USD/ha, 74.11 USD/ha, and 8.87 USD gasoline/ha, respectively (Table 3). In contrast, the utilization of the air-blast sprayer resulted in increased expenses for chemical fungicide usage (128.20 USD/ha), water consumption (118.55 USD/ha), and diesel fuel consumption (44.02 USD/ha), while exhibiting reduced costs for laborers' wages (12.45 USD/ha) when compared to the control group. On the other hand, the AI drone sprayers, namely AI drone1 and AI drone2, demonstrated a significantly lower gross cost for chemical fungicide spraying ranging from 64 - 71% (139.47 - 154.36 USD/ha) less than that of the control group (long hose pump). However, when compared to the air-blast sprayer, the cost increased by 50.95% (111.61 USD/ha). Consequently, the AI drone sprayers exhibited considerably higher work efficiency than both the long hose pump and air-blast sprayers, as evidenced by their lower gross cost of chemical fungicide spraying per unit area of durian plantation (Table 3).

Table 3. Simple cost analysis of chemical fungicide spraying by AI drone, air-blast, and long hose pump to control leaf sheath blight caused by *Rhizoctonia solani* in durian trees based on the recent data from the year 2023

Costs	Cost/unit	Unit number	Expenses (USD/ha)			
			AI drone 1	AI drone 2	Air-blast	Long hose pump
1. Rental sprayer (AI drone or air-blast or long hose pump	27.43 USD /sprayer/ha	1 sprayer/ha	27.43	27.43	27.43	27.43
2. Labourer (exclusive of meal), 1.72 USD/h, using AI drone1, AI drone2, air-blast, and long hose pump	2.23, 2.23, 3.62, and 8.31 h/man-day, respectively	2 man-day/ha	7.67	7.76	12.45	28.57
3 Chemical fungicide (solute) used and its price as sprayed by AI drone1, AI drone2, air-blast, and long hose pump	17.83 USD/L of chemical fungicide	0.84, 1.67, 7.19, and 4.49 L/ha, respectively	14.98	29.78	128.20	80.06
4. Water (solvent) used to dilute the fungicide concentration as sprayed by AI drone1, AI drone2, air-blast, and long hose pump	0.0165 USD/ L of water	835.16, 835.16, 7,184.81, and 4,491.51 L/ha, respectively	13.78	13.78	118.55	74.11
5. Electricity use from battery charge for AI drone1 and AI drone2; diesel fuel for the air-blast; gasoline for long hose pump sprayer	0.1372 and 0.1372 USD/unit, 0.8212 USD/L of diesel fuel, and 1.26 USD/L of gasoline, respectively	6 and 6 units/ha, 53.6 L of diesel fuel/ha, and 7.04 L of gasoline/ha, respectively	0.82	0.82	44.02	8.87
Gross cost of chemical fungicide spraying (USD/ha)	-	-	64.68	79.57	330.65	219.04

h, hours; USD, United States dollar; 1 USD was equivalent to 36.46 Thai baht (THB) based on 12th of October 2023 (BB, 2023); each sprayer was operated for a duration of 8 hours per day from 0700H to 1200H and from 1400H to 1700H except on a rainy day; 100 durian trees per hectare

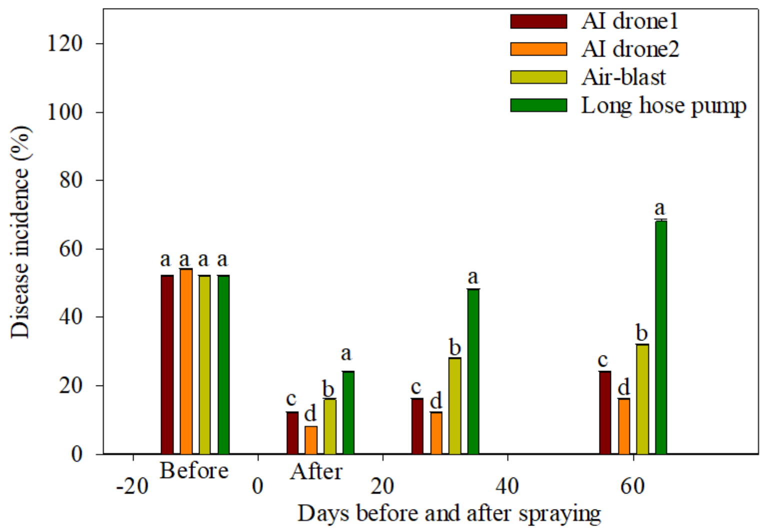

Figure 6. Percentage of disease incidence of *Rhizoctonia solani* on durian leaves before and after spraying fungicide solution by drones, air-blast, and long hose pump sprayers to manage leaf sheath blight disease; In each day before, and after spraying (DAS), means comparisons conducted through Duncan's multiple range test (DMRT) at a 0.01 probability level

Discussion

The present study revealed that the leaf sheath blight caused by *Rhizoctonia solani* was found in durian plantation in Chanthaburi, Thailand, particularly of the 'Monthong' durian cultivar. Thuan *et al*. (2008) reported the first occurrence of this leaf sheath blight in a durian plantation in Vietnam. The *R. solani* exhibited robust growth under conditions of excessive moisture and generated copious amounts of sclerotia at temperatures exceeding 24 °C, with an optimal growth observed at 28 °C; however, growth was impeded at 35 °C and ultimately ceased at 10 °C (Lim *et al*., 1987). Under warm humid conditions, the lesions present on the leaves caused by *R. solani* lack a distinct shape, which then initially manifest as diminutive bluish spots, that subsequently expand to brown color, and ultimately transition into gray coloration (Tuyen, 2021). With this, yellowish white hyphae appear on the lesions, and mycelium spreads to adjoining leaves (Thuan *et al*., 2008), and then the affected leaves turn dark brown and wilt then leaf drop and twig dieback occur during severe infection (DAS, 2023). In the absence of suitable hosts, Abbas *et al*. (2022) reported that *R. solani*, a plant pathohenic fungus, is able to persist in the soil through the formation of sclerotia. *R. solani* belongs to the AG 1-ID group due to hyphal anastomosis (Lim *et al*., 1987). AG 1-ID has only been reported causing foliar blight on durian that showed the lowest lesion heights (Pascual *et al*., 2000). Gonzalez *et al*. (2011) reported that hyphae of *R. solani* are variable in size, ranging from 3 to 17 µm in diameter. Although the fungus does not produce any conidial structure. Sclerotia are irregularly shaped, up to 8 - 10 mm in diameter and light to dark brown in colour. In general, water-soaked lesions start on leaves and extend up the stem. Stem lesions vary in colour from brown to black. In the late stages, diseased leaves are easily separated from the plant due to severe wilting. According to Safe'i *et al*. (2022), the most common damage occurs in the leaves of durian. This leaf damage disrupts physiological processes (Pertiwi *et al*., 2019), particularly in durian plantations where high-value fruit crops are grown. Researchers have effectively resolved the problem of *R. solani* disease using AI drones, specifically AI drone1 and AI drone2. These drones have proven to be suitable sprayers for effectively managing leaf sheath blight caused by *R. solani* in durian crops. By accurately calibrating the sprayers, the AI drones were able to apply the appropriate amount of fungicide solution. The AI drones demonstrated a remarkable reduction in the application of fungicide solution by 81%, without any compromise in the solution's efficacy. Additionally, they exhibited a decrease in time consumption by 6.08 h/ha, a decrease in the quantity of chemical fungicide used by 2.82 - 3.65 L/ha (equivalent to a reduction of 63 - 81%), and a substantial decrease in water usage by 81% when compared to the traditional long hose pump sprayer. In contrast, the air-blast sprayer exhibited a significantly elevated level of chemical fungicide utilization, amounting to a 60% increase (or 2.7 L/ha), along with a 60% higher water consumption, a 60% greater application of fungicide solution, and a 100% greater loss of fungicide solution when compared to the long hose pump sprayer. The utilization of AI drone2 sprayer, specifically for the application of a fungicide solution with a concentration of 2 ml/L, exhibited a notable enhancement in the overall health of durian trees. Furthermore, it demonstrated the least occurrence of leaf sheath blight caused by *R. solani*, as observed 10 days after the application of the fungicide solution [or days after spraying (DAS)]. Subsequently, the AI drone1, air-blast, and long hose pump sprayers followed suit, albeit with varying degrees of effectiveness. As the number of days after spraying reached 30 and 60 days, there was a gradual decline in the health of the durian trees, accompanied by an increase in disease incidence. However, the durian trees that were sprayed with AI drone1 and AI drone2 exhibited a slower deterioration in health and a lower disease incidence. This can be attributed to the effective coverage of the fungicide solution by the AI drones, which ensured that the upper to lower canopies and both the front and back leaves of the 20-year-old durian cv. 'Monthong' trees were fully and uniformly treated. These trees were spaced 10 meters apart in both directions, had a height ranging from 9.35 to 11.00 m and a canopy height of 8.65 to 9.75 m. In comparison, the air-blast and long hose pump sprayers did not provide the same level of coverage. Based on the water-sensitive papers (data not shown), it was observed that the two recent fungicide applications only provided coverage to the upper canopies and front leaves of the durian trees. However, there was no coverage observed in the lower canopy and the back leaves by these sprayers. Spray coverage was measured using water-sensitive papers (Bock *et al*., 2015). The utilization of AI drone1 and AI drone2 sprayers, which applied fungicide solution at concentrations of 1 ml/L and 2 ml/L respectively, led to an enhanced management of leaf sheath blight caused by *R. solani*. This improvement was determined by evaluating the tree health and disease incidence values. In a study conducted by Wise *et al*. (2021), it was found that the utilization of drone fungicide applications effectively mitigated the occurrence of gray leaf spots in corn. These applications not only ensured sufficient coverage of the fungicide but also led to a notable decrease in disease severity. Moreover, in cases where the disease was particularly severe, the application of fungicide proved to be instrumental in safeguarding crop yield, ultimately resulting in a substantial increase in overall yield. The results of this research investigation indicate that the AI drone2 sprayer exhibited superior efficacy in managing leaf sheath blight caused by *R. solani* in durian compared to the AI drone1 sprayer. This can be attributed to the utilization of a marginally higher concentration of fungicide solution by the AI drone2 sprayer.

The results of this study indicate that both AI drone sprayers, namely AI drone1 and AI drone2, demonstrated a remarkable reduction in the concentration of fungicide solution applied (8.36 and 8.37 L/tree, respectively). Moreover, these AI drone sprayers exhibited significantly superior efficiency and effectiveness in managing leaf sheath blight caused by *R. solani* compared to the air-blast sprayers (71.92 L/tree) and long hose pump sprayers (44.96 L/tree). This assessment is based on the values of durian tree health, disease incidence, and the cost associated with chemical fungicide spraying. According to the study conducted by Biglia *et al*. (2022), the flight mode of unmanned aerial vehicles (UAVs) has a significant impact on the efficiency of spray application. The band spray mode, in comparison to the broadcast spray modes, was found to significantly improve the average amount of spray that reaches the canopy, increasing it from 0.052 to 0.161 $\mu L/cm^2$ (+ 309%). Additionally, this mode also contributed to a reduction in average ground losses from 0.544 to 0.246 $\mu L/cm^2$, indicating a decrease of 54%. These findings highlight the importance of adopting the band spray mode for enhancing the effectiveness of spray application in agriculture. However, previous studies conducted by Bock

(2013), Bock *et al*. (2015), and Bock *et al*. (2017) have demonstrated that ground-based air-blast sprayers effectively managed the disease up to a height of approximately 12.5 m. Beyond this height, the effectiveness of control measures decreased, resulting in disease severity comparable to that observed in untreated trees. In a recent study conducted by Bock and Hotchkiss (2020), it was demonstrated that the implementation of air-blast and aerial treatments effectively reduced the severity of scab across various tree heights. According to the Ovako working posture analysis system, it was determined that 63.86% of the overall tasks involving the utilization of agricultural drone sprayers pose a minimal risk of musculoskeletal injury (Umeda *et al*., 2022). The results of this study demonstrated that the application of a high volume of fungicide solution, specifically 7,192 L/ha (or 71.92 L/tree), using an air-blast sprayer, was more effective in controlling leaf sheath blight disease compared to the low volume of 4,496 L/ha (or 44.96 L/tree) applied with a long hose pump sprayer. This superiority can be attributed to the air-blast sprayer's ability to provide sufficient coverage of fungicide in the upper canopy and front leaves of durian trees, leading to a reduction in disease severity. The economic and technical viability of spray applications can be assessed by comparing the production costs of AI drone sprayers (AI drone1 and AI drone2) with conventional spray application methods such as air-blast and long hose pump sprayers. It is evident that the cost of production using AI drone sprayers is significantly lower. This is primarily due to the fact that AI drone sprayers incur lower expenses in terms of chemical fungicide use, labor employment, water consumption, and electricity consumption compared to the long hose pump sprayer. On the other hand, the air-blast sprayer resulted in increased expenses for the utilization of chemical fungicides, water, and diesel fuel. However, it incurred lower costs for the employment of laborers when compared to the long hose pump sprayer. In a similar manner to Qin *et al*. (2018), fungicides were administered using an Unmanned Aerial Spray Systems (UASS) at a minimal volume rate of 15 L/ha, while a knapsack sprayer was utilized at a moderate volume rate of 300 L/ha. In their study, Meng *et al*. (2018) conducted an experiment where they utilized a UASS at a significantly reduced volume rate of 12.6 L/ha, in comparison to a medium-volume backpack sprayer which operated at 270 L/ha. In our study, the EA-30X drone's optimal parameters for UAV-spray applications to manage leaf sheath blight caused by *R. solani* in durian were a cruise speed of 0.5 m/s and a flight height of 2.7 m above the tip of the tree canopy, as indicated by the results obtained.

Therefore, the utilization of AI drone sprayers to administer a fungicide solution has proven to be a highly effective and efficient method in controlling and eradicating the detrimental impact of *R. solani* on durian production. To maintain the overall health of durian trees and minimize the occurrence of leaf sheath blight caused by *R. solani*, it is imperative to consistently apply the chemical fungicide solution every 15 days using the AI drone sprayers.

Acknowledgements

The lecturers and technicians at Rajamangala University of Technology Tawan-ok at Chanthaburi Campus (RMUTTO), the staff at Eavision Robotic Technologies Company Limited for their AI drone (EA-30X model), and the durian farmers who provided the air-blast, are all greatly appreciated for their contribution to this study.

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(Received: 30 December 2023, Revised: 27 June 2024, Accepted: 2 July 2024)