

Drone-based application of inflorescence-inducing chemicals in longan orchards: Effects of flight altitude and mixing ratios

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Abstract

Drone-assisted chemical application in longan orchards is feasible but requires refined methods for efficient and uniform aerosol delivery. This research aimed to determine the optimal drone flight altitude and chemical-to-water mixing ratio for inducing inflorescence in longan trees. Three chemical mixtures were tested: the conventional farmer-used ratio (50 g/10 L), a higher concentration (50 g/5 L), and a reduced dosage (25 g/5 L). Droplet deposition at different flight altitudes above the longan canopy was evaluated using water-sensitive paper to identify the most effective spraying conditions. The results revealed that at a drone flight altitude of 2 m above the longan canopy, the droplet deposition percentage from the drone sprayer reached a maximum of 76.22% on water-sensitive paper. This flight altitude was selected for the flight test to determine the appropriate mixing ratio of inflorescence-inducing chemicals for spraying in longan orchards. The reduced dosage treatment (25 g/5 L) resulted in the greatest number of inflorescences and the highest yield. Although the conventional and reduced treatments share the same chemical concentration (5 g/L), the latter involved a lower total amount of chemical applied per tree due to the reduced spray volume during drone operation. This approach enables farmers to decrease total chemical usage and operational costs while enhancing inflorescence induction and yield in longan orchards. Additionally, it enables faster drone operation, effectively doubling the treatment area per flight.

Keywords: Agricultural drones, Flight altitude, Droplet deposition, Inflorescence induction, Longan orchard

1. Introduction

Longan (*Dimocarpus longan* Lour.) is an economically important fruit tree in northern Thailand. During the flowering phase, there is a substantial utilisation of stored nutrients. The flowering of plants is influenced by various environmental factors, including chilling, drought and light. Current, advances in science and technology have facilitated the identification of chemical agents that can promote the flowering process [1]. Fertilizer applied to the soil may not be sufficient to promote more flowering. However, foliar fertilization makes it possible to rapidly supply plants. It was discovered that foliar fertilization is one of the most widely used and successful techniques for biofortifying plants because it is a cost-effective and ecologically safe process that enables the delivery of the proper quantity of particular elements at a particular stage of plant development [2, 3]. In Thailand, most foliar fertilizer and chemical spraying in longan orchards is currently performed by human labor, which is significantly time-consuming and labor-intensive. Consequently, this has led to an increase in production costs. Furthermore, the longan tree's considerable height can reach up to 20 meters [4], making it difficult for humans to spray and hinders the tree's ability to absorb nutrients effectively.

Longan possesses the ability to effectively induce the flowering process. As a result, applying chemical agents to the foliage to promote flowering in longan is a viable strategy. It is important to investigate the optimal methodology for using agricultural drones to apply flowering stimulants to the leaves to achieve the highest efficiency.

An unmanned aerial vehicle (UAV), commonly referred to as a drone, is a compact aircraft without an onboard pilot. It is controlled by an automatic remote system [5]. In agriculture, drones are capable of applying fertilizers or chemicals to crops at various heights. Agricultural spraying drones also enhances the safety of farmers in relation to chemical exposure. Spraying drones are now playing an important role in agriculture, serving to substitute human labor and decrease spraying duration.

Drones have played a significant role in various aspects of agriculture. For instance, Li et al. [6] used drones to capture video images of a longan canopies at the mature stage, combining the collected data with deep learning and regression analysis to predict yield. In addition to yield estimation, drones equipped with multispectral cameras have been employed to assess crop parameters through canopy reflectance. In sugarcane, for example, studies have compared NDVI thresholds, PCA, and DSM methods for canopy detection, with the PCA threshold approach achieving the highest accuracy in distinguishing crop canopy from soil background [7]. Drones are also widely utilized as specialized equipment for plant protection. Chen et al. [8] used a drone to detect and photograph a longan pest, *Tessaratoma papillosa* (Drury). This technology facilitates the real-time identification of the pest's location, which

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subsequently informs the planning of optimal pesticide spraying routes for agricultural drones. Moreover, Qin et al. [9] investigated the effect of spray working height and concentration on the deposition of droplets on the wheat canopy and the prevention of powdery mildew using a drone. Their findings revealed that the height of the spray significantly affected the distribution of droplet within the upper canopy of the wheat. Similarly, Berner et al. [10] reported that operating drones at low altitudes substantially increases the volume of liquid applied to wheat crops and improved the application uniformity at plant levels. Therefore, the altitude of drone flights can have an impact on the spraying of chemicals on plants [11].

Drones are a technological frontier that is suitable for agricultural applications. However, to date, no research has been conducted on the use of drones to spray inflorescence-inducing chemicals in longan orchards. Thus, this research focuses on determining the optimal spraying altitude and the appropriate mixing ratio of the longan inflorescence inducer and on developing a technique for spraying longan orchards with agricultural drones. The findings will be utilized to increase the yield and reduce the costs of longan production. Additionally, developing human resources with advanced knowledge and skills in fruit trees ultimately maximizes benefits in the future.

2. Materials and methods

2.1 Examination of the morphological attributes of longan trees

The height and width of the longan canopy were measured using a tap measure. A 25-year-old longan tree variety E-Daw located at Maejo University farm office, Chiang Mai Province, Thailand (18° 91' 77" latitude and 99° 05' 21" longitude with an elevation of 372 meters above sea level) was studied. To determine the average height and width of the canopies of longan trees, a sample of 30 longan trees exhibiting similar physical characteristics were selected.

2.2 Examination of the flight altitude on the distribution of droplet on the longan canopy

Water-sensitive papers (SpotOn® Paper, USA) measuring 76×52 mm was attached to assess droplet deposition from the drone sprayer across twelve designated points on the longan canopy. The canopy was divided into three vertical levels (top, middle and bottom), and at each level, papers were clipped to leaves at the canopy edge in four orientations (front, back, left and right) (Figure 1). One paper was used per point for each spray event, and three longan trees were assessed per flight height. Papers were collected immediately after spraying to avoid evaporation or droplet displacement. All papers were scanned in black-and-white mode using a Brother MFC-T810W scanner. Droplets appeared as black pixels, whereas areas without droplets remained white. The image analysis involved configuring the black/white pixel reading to interpret black pixels as 1 and white pixels as 0 using image processing techniques employing Binary Image software. The software then calculated the coverage percentage of black pixels on the water-sensitive paper. This analysis was applied to all twelve points per tree, and the resulting data were used to determine the average droplet dispersion.

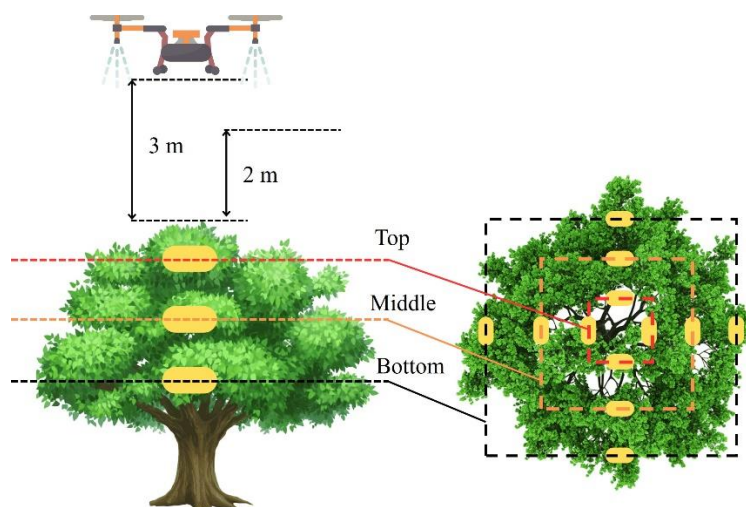


Figure 1 The flight altitudes and arrangement of water-sensitive papers on longan trees at different canopy levels and orientations to evaluate droplet deposition from the drone sprayer

A DJI drone, model MG-1S (Shenzhen DJI Sciences and Technologies Ltd., China), was used to spray water at 2 m and 3 m flight altitudes above the longan canopy in order to collect the droplet deposition data (Figure 1). The drone is equipped with four factory-installed fan-shaped spray nozzles, one beneath each rotor and all oriented downward. The spray angle of the nozzles ranged from 65° to 110°, and the spray was applied at a pressure of approximately 40–60 psi. During operation, the nozzles released droplets while the rotor-induced airflow helped drive the spray into the canopy, ensuring uniform coverage of the longan trees. Water was used instead of chemicals with a flow rate of 2.6 L/min and a spraying time of 67 s/plant. The experiment was conducted on three plants for each flight altitude.

2.3 Examination of the mixing ratio on longan flowering inducers sprayed by drones

Three mixing ratios were tested using three flowering induction agents—sodium chlorate, monopotassium phosphate, and thiourea fertilizers: the conventional mixture used by farmers (50 g/10 L), a mixture with twice the concentration of the conventional mixture (50 g/5 L), and a reduced-dosage mixture (25 g/5 L) was also applied. Although both the conventional and reduced treatments had the

same chemical concentration (5 g/L), the reduced treatment delivered a smaller total dosage per tree due to the lower spray volume used during drone application. The spraying was executed using DJI MG-1S drones two times, with a seven-day interval. After 30 to 45 days, a 1 x 1-m square frame was randomly placed on all four sides of each longan tree canopy (Figure 2). The number of longan inflorescences within the quadrat was counted and marked. At harvest, the marked longan fruit clusters were removed and weighed to determine yield.



Figure 2 Placement of a 1 × 1 m sampling frame on the longan canopy to quantify inflorescence number and assess yield

2.4 Statistical analysis

The effect of drone flight altitude above the canopy on droplet deposition percentage was analyzed using an Independent Samples T-test at a significance level of 0.05. The effects of different mixing ratios of inflorescence-inducing agents were analyzed using a one-way analysis of variance (ANOVA) based on the F-test. When significant differences were found, mean comparisons were conducted using Duncan's New Multiple Range Test (DMRT) at a significance level of 0.05. All statistical analyses were performed using IBM SPSS Statistics version 28.0, with the significance level set at 0.05.

3. Results and discussion

3.1 Longan tree morphological characteristics

The DJI MG-1S drone utilizes the ground to serve as a reference level (baseline) for the determination of flight altitude. Consequently, collecting morphological data on the longan trees used in the experiment is critical for accurately determining the flight altitude above the canopy. The longan plantation used in the experiment had a planting distance between trees and rows of 6×6 m. The average height of the trees was recorded at 3.5 ± 0.1 m, while the average canopy width measured 4.5 ± 0.2 m. The longan tree canopy is pruned into a cone-shaped cover and the drone operates in a circular flight pattern around the canopy to ensure that the aerosols are distributed throughout the foliage.

3.2 Effect of flight altitude on the distribution of droplet on the longan canopy

The examination of droplet deposition at various spraying altitudes was conducted by evaluating droplet outcomes on water-sensitive paper by an image processing technique using Binary Image software. The image analysis requires configuring the black/white contrast pixel reading to interpret black pixels as 1 and white pixels as 0 (Figure 3), with black pixel color intensity reading established at more than 90%. The software then calculates the coverage percentage of black pixels on the water-sensitive paper (Figure 4).

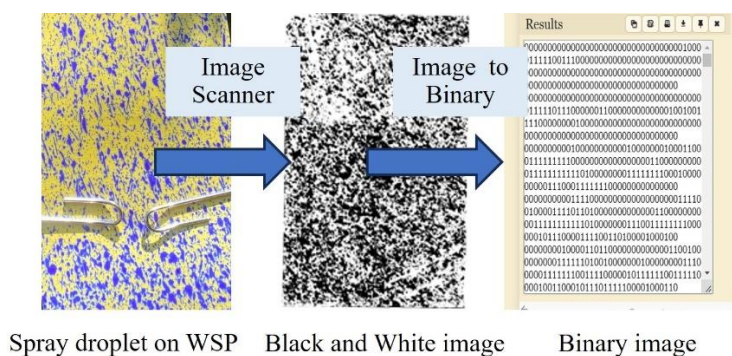


Figure 3 Digital image processing procedure used to quantify droplet deposition on water-sensitive papers. Black pixels represent deposited droplets (value = 1), while white pixels indicate non-deposited areas (value = 0). This analysis was performed to determine spray coverage under different flight altitudes

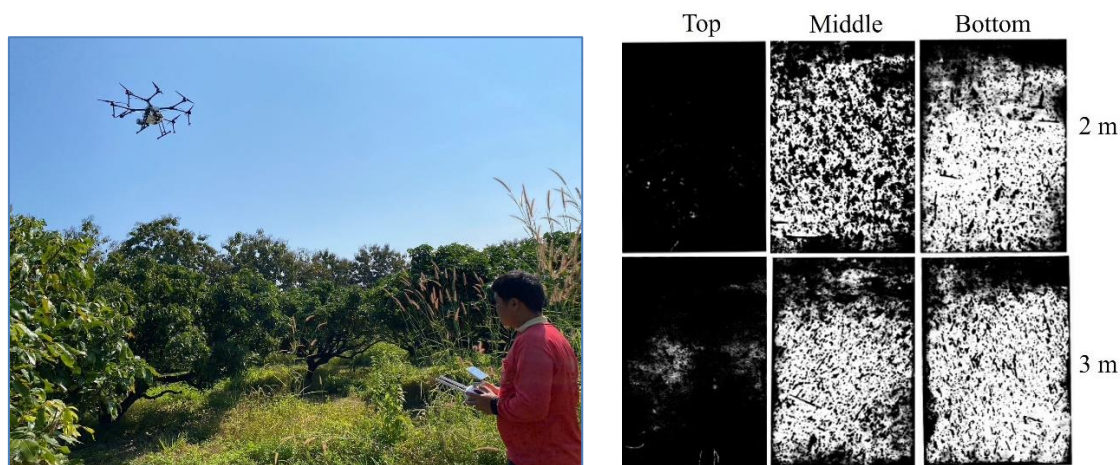


Figure 4 Drone spraying operation in a longan orchard (left) and scanned water-sensitive papers showing droplet deposition patterns from flight altitudes of 2 m and 3 m at the top, middle, and bottom canopy levels (right), demonstrating the effect of flight altitude on droplet coverage

The optimal altitude for drone-based chemical spraying was evaluated at heights of 2 m and 3 m above the longan canopy. The wind speed during the experiment was 5 km/hr, the relative humidity was 66%, and the temperature was 31°C. Spraying was performed using water to investigate the impact of spraying flight altitude on droplet dispersion, as measured on water-sensitive paper. The study indicated that spraying at an altitude of 2 m above the canopy resulted in an average droplet deposition rate of 76.22%. This rate was found to be better than that observed at a flight altitude of 3 m across all height positions (top, middle, and bottom). (Figure 4, Table 1)

Table 1 Comparison of water droplet dispersal at two altitudes above the longan canopy

Height above the canopy (m)	Dispersion of water droplets (%)			Average of water droplets dispersion
	Top	Middle	Bottom	
2.0	97.27 ± 0.31	75.68 ± 9.32	55.72 ± 5.37	76.22 ± 18.78 ^a
3.0	92.12 ± 3.09	71.72 ± 9.27	54.11 ± 3.00	72.65 ± 17.25 ^a

Mean values (mean ± SD, n = 4) within a column with the same superscript letter are not significantly different at $P \leq 0.05$ (data from three longan trees).

Given that the spraying altitude is set at 2 m above the longan canopy, the proximity of the drone's spray nozzle to the canopy results in an increased deposition of water droplets. Similarly, Ranabha and Price [12] reported that lower flight heights significantly increased spray deposition and coverage in the upper canopy levels of cotton and sugarcane. This phenomenon can be attributed to the enhanced wind force generated by the propeller, which directs the liquid more effectively towards the canopy. Consequently, the loss of spraying water droplets is reduced in comparison to a spraying altitude of 3 m. This finding is comparable to the research carried out by Mat Su et al. [13] which assessed the distribution and uniformity of drone spray applications in rice cultivation. The study concluded that agricultural drones should operate at altitudes ranging from 1.5 m to 2 m above the crop canopy to achieve optimal liquid distribution. Furthermore, it was determined that the most effective droplet distribution and uniformity are attained at lower flight velocities. Zheng et al. [14] employed computational fluid dynamics models to assess the airflow generated by propellers of a spraying drone. The results demonstrated that increased flight heights create limitations on factors such as spraying distance, uniformity of deposition, and penetration of aerosols into the plant canopy.

Nonetheless, these outcomes of drone operation depend on the specific design and the downward thrust produced by its rotors. The operation of a drone for spraying purposes at an altitude of 2 m is associated with lower battery power consumption compared to flying at higher altitudes. This phenomenon can be attributed to the necessity for the drone's propellers to generate lift while simultaneously increasing forward velocity. This observation aligns with the findings of Beigi et al. [15] and Tennekes [16], which investigated drone energy consumption patterns and concluded that various external factors can influence energy usage. These studies indicate that energy consumption increases when flying against wind resistance and at high altitudes due to, the increased thrust required for upward lift as the drone transitions from a stationary hover to forward flight.

3.3 Effect of the mixing ratio on longan flowering inducers sprayed by drones

This section explores the optimal concentration ratio of longan flower inducer for application using drone spraying at a flight altitude of 2 m by determining the chemical to water mixing ratio for inducing inflorescence in longan trees, compared to the traditional manual spraying technique. Three chemical mixtures were evaluated: the standard ratio used by conventional farmers (50 g/10 L), a higher concentration (50 g/5 L), and a reduced dosage (25 g/5 L). The effectiveness of each treatment was assessed by measuring both the number of inflorescences and yield.

The results revealed no statistically significant differences in the number of longan inflorescences or in longan yield between the conventional manual spraying at 50 g/10 L and drone spraying at 50 g/10 L and 50 g/5 L. In contrast, drone application at the reduced dosage of 25 g/5 L resulted in the highest number of inflorescences, with a significant average of 21 ± 2.15 inflorescences/m². This treatment also produced the greatest yield, with a significant average of 26 ± 2.02 kg/m², as shown in Table 2. Therefore, the optimal concentration ratio of longan inflorescence inducer to water for drone spraying per longan tree is determined to be 25 g/5 L, since this

ratio yields the greatest quantity of inflorescence and yield compared with traditional manual spraying (50 g/10 L) and drone applications at 50 g/10 L and 50 g/5 L.

Table 2 Number of longan inflorescences and yield at 2 m above the canopy under drone and manual spraying at different chemical concentrations.

Spray application	Proportion of mixture per plant (g/L)	Number of longan inflorescences (inflorescences/m ²)	Yield (kg/m ²)
Conventional manual spraying	50/10	16 ± 3.75 ^b	18 ± 3.49 ^b
Drone-based spraying	50/10	16 ± 3.78 ^b	20 ± 4.80 ^b
	50/5	14 ± 2.98 ^b	18 ± 4.06 ^b
	25/5	21 ± 2.15 ^a	26 ± 2.02 ^a

Mean values (mean ± SD, n = 4) within a column with different superscript letters indicate statistically significant differences at $P \leq 0.05$ (data from three longan trees).

Although the drone application at a concentration of 25 g/5 L for longan inflorescence induction was equivalent in concentration to the conventional mixture commonly used by farmers (50 g/10 L), both representing 5 g/L, the reduced treatment involved a lower total chemical amount applied per tree due to the smaller spray volume during drone operation. This reduced dosage likely contributed to the superior inflorescence induction and yield observed in drone-treated trees. In contrast, the conventional application rate (50 g/10 L) often caused phytotoxic symptoms, such as leaf abscission and marginal leaf burn (Figure 5), which may have resulted from the excessive total dosage applied per tree.



Figure 5 Leaf responses of E-daw longan to inflorescence induction agents applied at different dosage and application methods. Leaf burn was observed following both manual and drone-assisted spraying at 50 g/10 L (left). No visible damage was observed after drone-assisted spraying at 25 g/ 5 L (right). Photographs were taken 7 days after application. This comparison demonstrates that a reduced total chemical dosage in drone application can minimize phytotoxic effects while maintaining effective inflorescence induction.

Moreover, increasing the concentration of the longan inflorescence induction to 50 g/5 L using drone application resulted in more severe leaf damage, with more pronounced leaf drop and burn. These findings suggest that both high chemical concentration and excessive spray dosage contribute to phytotoxic effects in longan. Since leaves are critical organs for photosynthesis and hormone biosynthesis, both of which are essential for floral initiation and development [17]; thus, leaf damage may negatively affect inflorescence formation and ultimately reduce yield. These results are consistent with previous reports for other flowering-inducing agents; for instance, appropriate concentrations of potassium chlorate promote flowering, whereas excessive concentrations may reduce flowering or induce leaf burn [18]. These findings highlight the importance of optimizing both concentration and application method of chemical inducers to enhance flowering while minimizing phytotoxicity.

The utilization of drones to apply chemicals to promote flowering in longan trees not only enhances the safety of farmers by minimizing their direct exposure to these substances, but also contributes to a reduction in the overall quantity of chemicals employed [19]. Furthermore, this method increases operational efficiency, as agricultural drones are capable of treating two trees per flight, in contrast to the previous capability of spraying only one tree at a time. Drones provide a more efficient option, potentially decreasing spraying time [20]. Qin et al. [9] indicated that agricultural drone spraying has the potential to enhance efficiency while simultaneously decreasing pesticide use by 30%. Another study on pineapple farms reported by Wan Jamaludin et al. [21] observed the use of autonomous drones in pineapple plantations and found that these drones can reduce fertilizer costs by 41.6%. This reduction presents a significant advantage for industrial agricultural systems. However, this study was conducted using only the E-daw cultivar, a single location, and the DJI MG-1S drone, which may limit the wider applicability of the results. Nevertheless, the experimental framework developed here could be applied to other cultivars, locations, and drone models. Future research involving multiple cultivars and diverse settings would help strengthen the generalizability of these findings.

The effectiveness of spraying is crucial in agriculture as it affects both the environment and operational costs. Interestingly, the findings of this study are expected to reduce the use of chemical agents for inducing flower in longan cultivation, resulting in reduced production costs and enhancing environmental sustainability by reducing environmental impacts, sustainable resource use, and maintaining ecological balance. These outcomes align with the principles of the Bioeconomy, Circular Economy, and Green Economy (BCG) frameworks. Furthermore, the use of drones in the agricultural sector is an appropriate approach for large-scale farming in the industrial agriculture system.

4. Conclusions

This study focused on the application of agricultural drones to enhance the efficiency of longan inflorescence induction and yield, examining the physical characteristics of longan trees to provide data to determine the optimal altitude for drone operations. The optimal altitude for spraying longan inflorescence inducer was determined to be 2 m above the canopy. The data indicates that the

average percentage of droplet deposition was higher when spraying from an altitude of 2 m above the canopy. As a result, the upper portion of the canopy had the highest values for droplet deposition, while the middle and lower sections of the canopy showed comparatively lower dispersion values. The optimal ratio of longan flower inducer to water is established to be 25g /5 L (equivalent to 5 g/L), representing a 50% reduction compare to the conventional spraying technique. This enables farmers to reduce the expenses of using inflorescence inducers and facilitates their rapid application, resulting in increased inflorescence and yield. Consequently, this study provides valuable insights for longan cultivators seeking to transition from conventional inflorescence induction spraying techniques in order to the implement drone spraying technology.

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6. References

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