



Agricultural Chemical Exposure Risks and Safety Practices Among Drone Operators in Kanchanaburi Province, Thailand: A Cross-Sectional Descriptive Study

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Abstract

Background: The use of agricultural drones is expanding rapidly in Thailand, improving pesticide application efficiency and potentially reducing farmers' direct exposure to agricultural chemicals. However, drone operators may remain exposed during chemical preparation, loading, equipment cleaning, and waste disposal. **Objective:** This cross-sectional descriptive study assessed operational safety practices, chemical-handling behaviors, and personal protective equipment (PPE) use among agricultural drone operators in Kanchanaburi Province, **Methods:** Thailand. Forty operators were purposively selected. Data were collected using a researcher-developed questionnaire covering demographic characteristics, drone operation, safety training, chemical-handling practices, and PPE use. Descriptive statistics were used to summarize the data. Associations between safety training and selected safety practices were examined using Fisher's exact test, while relationships involving ordinal or continuous variables were assessed using Spearman's rank correlation coefficient. **Results:** Most participants were male (72.5%), with a mean age of 33.53 years. DJI drones were used by 95.0% of participants, and the mean operating duration was 5.66 hours per day. Although

82.5% had received drone safety training, PPE use remained inconsistent. Long-sleeved shirts and long pants were commonly worn, whereas chemical-resistant gloves, appropriate respiratory protection, and protective aprons were used less consistently. Most operators followed basic pre-spraying procedures; however, 27.5% reported mixing agricultural chemicals without checking chemical compatibility. Post-spraying practices, particularly equipment cleaning and waste disposal, were also inconsistently followed. **Conclusions:** The findings demonstrate a notable gap between having received safety training and consistently applying comprehensive protective practices. Specifically, deficiencies were identified in PPE use, chemical compatibility checks, and post-spraying waste management. These results support the need for competency-based training focused on chemical preparation, appropriate PPE selection, equipment decontamination, and waste disposal. Future studies should use larger, probability-based samples and direct workplace observations to identify factors influencing safety compliance.

Keywords: Agricultural drones, Agricultural chemical exposure, Occupational safety, Personal protective equipment, Agricultural drone operators

What was Known

- Agricultural drones can reduce direct pesticide contact, but operators may still be exposed to agricultural chemicals.
- Proper Personal protective equipment and occupational safety practices are important for protecting Agricultural drone operators from chemical exposure.

What's New and Next

- This study provides new evidence on occupational exposure risks and safety practices among Agricultural drone operators during pesticide application.
- The findings support the development of improved training programs, safer work practices, and better use of Personal protective equipment to enhance occupational safety in drone-based agriculture.

Introduction

In recent years, the adoption of unmanned aerial vehicles (UAVs), commonly referred to as drones, has significantly increased within Thailand's agricultural sector. This trend aligns with the national "Agriculture 4.0" strategy, which emphasizes the integration of advanced technologies to enhance agricultural productivity and sustainability ⁽¹⁾. Agricultural drones are now widely utilized for

various applications, including crop monitoring, yield optimization, and pesticide application ⁽²⁾. These innovations have contributed to improved operational efficiency, reduced agrochemical usage, and minimized direct exposure of farmers to hazardous substances ⁽³⁾. Key advantages of drone usage in agriculture include accelerated task execution, improved time management, reduced physical labor, and greater precision in the application of agricultural chemicals ^(4–6).

Despite these benefits, many farmers face significant barriers to independently operating agricultural drones. Limited technical knowledge and the high initial investment required for drone acquisition and maintenance are primary obstacles ⁽⁷⁾. As a result, pesticide spraying is frequently outsourced to trained drone operators. While this practice effectively reduces direct chemical exposure among farmers, it imposes additional financial burdens on agricultural producers ⁽⁸⁾.

From an occupational health perspective, it is crucial to address the safety and well-being of drone operators, who are increasingly exposed to chemical hazards throughout various stages of drone operation. These stages include chemical preparation and mixing, aerial spraying, and equipment cleaning and maintenance. The preparation and mixing phase present the highest risk due to direct handling of highly concentrated agrochemicals, which are often more potent than those used in conventional application methods. The spraying stage carries the risk of indirect exposure via spray drift, particularly in the presence of poor flight planning or adverse wind conditions. Post-operation cleaning poses additional exposure risks from residual chemicals, especially when appropriate personal protective equipment (PPE) is not utilized.

Although the existing literature emphasizes the importance of emergency response protocols and first-aid measures for managing chemical exposure and technical malfunctions during drone operations ⁽⁹⁾, evidence from routine operations remains limited. In Thailand, drone spraying is commonly provided by fee-for-service operators who are paid per rai. These operators often mix concentrated agrochemicals in the field without standardized facilities and work under time and heat constraints that may discourage consistent PPE use ⁽¹⁰⁾. Moreover, existing training primarily focuses on drone operation rather than chemical safety. Previous Thai studies have assessed pesticide exposure among drone operators under controlled experimental conditions using dosimetry ^(11,12), whereas research conducted in routine agricultural settings has largely focused on conventional farmers ⁽¹³⁾. Given Thailand's tropical climate, regulatory context, and fee-for-service operating model, this study aimed to: (1) describe pesticide-exposure risks and safety practices during chemical mixing,

spraying, and equipment cleaning; (2) assess PPE use across these operational stages; and (3) identify specific unsafe practices that could inform targeted training and preventive interventions.

Materials and Methods

1. Methodology

This study was conducted among agricultural drone operators in Kanchanaburi Province, Thailand, and included both self-employed farmers and individuals providing drone spraying services as a business. Eligible participants were required to have at least one year of experience independently owning and operating an agricultural drone and to be currently engaged in spraying activities, either as a service provider or self-employed farmer. Individuals with medical conditions requiring ongoing treatment (e.g., respiratory disease or active infection during the study period) were excluded for participant safety and data integrity. No official registry of agricultural drone operators exists in Thailand, so the research team, in collaboration with local agricultural extension offices and drone operator networks, identified all operators meeting the eligibility criteria within the study area. A total of 40 operators were identified, representing the complete population of eligible operators in Kanchanaburi Province at the time of data collection; therefore, no separate sample-size calculation was performed, as this constituted a census rather than a sample. Participants were recruited through purposive sampling via referrals from local community networks and drone operator associations, given the limited and undocumented population of qualified operators in the region. We acknowledge that purposive sampling carries an inherent risk of selection bias, for example, operators identified through community networks may be more experienced, more established, or more safety-conscious than the broader population of informal operators, and the findings may therefore not be generalizable beyond this study area or to less-networked operators.

2. Research Instruments

Data were collected using a researcher-developed questionnaire entitled Assessment of Safe Agricultural Drone Use and Promotion of Health- and Environment-Conscious Practices. The questionnaire comprised 50 items across five sections: (1) personal characteristics, (2) general drone use, (3) operational behaviors, (4) safety procedures, and (5) personal protective equipment (PPE) use. Content validity was evaluated by three experts in occupational health, agricultural technology, and public health using the Item Objective Congruence (IOC) method, with values ranging from 0.78 to 1.00, indicating acceptable content validity. A formal pilot test and reliability assessment, such as

Cronbach's alpha, were not conducted before data collection; this was acknowledged as a limitation of the instrument-development process.

3. Data Collection Procedure

The research team collaborated with local drone operator networks to identify and invite eligible participants. An initial briefing was conducted to explain the study's objectives, methodology, and data collection procedures. Informed consent was obtained from all participants, who were assured of confidentiality and their right to withdraw at any time without consequence. Participants then completed a self-administered questionnaire, which took approximately 30 minutes. The data collected included information on drone operation behaviors, safety practices, use of personal protective equipment, and self-reported health conditions. Data collection was conducted during field visits by the research team. As data on PPE use and safety practices were self-reported, findings may be subject to recall bias, particularly for less frequent tasks such as equipment cleaning, and to social-desirability bias, whereby participants may over-report adherence to recommended safety practices. This limitation is inherent to self-administered questionnaires assessing safety behavior and should be considered when interpreting the prevalence estimates reported in this study.

Results

1. General characteristics

This study examined the safety practices and operational behaviors of forty agricultural drone operators. Table 1 summarizes their personal information. The average age was 33.53 years, with 72.5% male and 27.5% female. Participants had an average of 2.65 years of agricultural experience. Regarding marital status, 42.5% were single, and 57.5% were married. Only one participant (2.5%) had a pre-existing health condition. Monthly income distribution showed 50.0% earned less than 5,000 THB, 2.5% earned 5,000-10,000 THB, and 17.5% earned more than 10,000 THB, with 30.0% unsure of their income.

2. Agricultural Drone Usage Information

Agricultural drone usage information is presented in Table 2, and the application of agricultural drones by operators is illustrated in Figure 1. The majority of agricultural drone operators (95%) use DJI drones, while 5% use Nac drones. The average drone weight is 31.79 kg (± 9.71), and the average water capacity is 27.69 liters (± 10.99). Operators typically work an average of 5.66 hours per day (± 2.36). Regarding the types of sprayers, 42.5% use fan-type sprayers, 40% use jet nozzles, 10% use cone-type sprayers, and 2.5% each use needle spray nozzles, mist jet nozzles, or

jet spray systems. The average spraying height is 2.85 meters (± 0.90). Agricultural drones are used on various crops, including rice (82.5%), rubber (72.5%), sugarcane (55%), corn (7.5%), cassava (2.5%), and coconut (2.5%). The average area covered per flight is 41.26 rai (± 66.12), with an average flight duration of 27.95 minutes (± 34.89). The average distance from water sources is 2.87 km (± 3.27), and from residential areas, it is 5.84 km (± 10.55). Regarding chemical usage, 87.5% of operators use herbicides, 87.5% use insecticides or pest repellents, 85% use fungicides, and all participants (100%) use fertilizers or plant hormones.

3. Agricultural Drone Usage Behavior

Pesticide spraying procedures using agricultural drones vary. Most operators (57.5%) spray in the morning, 7.5% in the evening, and 35% both morning and evening. Regarding wind conditions, 82.5% report calm trees with smoke rising vertically, while 7.5% experience leaves shaking, and 7.5% observe small branches moving. The decision to spray is based on the presence of weeds or pests, with 65% spraying when observed, and others spraying based on need or timing. Most operators (80%) spray upwind, while 15% spray downwind, and 5% do not consider wind direction. In terms of safety procedures, 75% check weather conditions, 90% define the target area, 92.5% check equipment, 87.5% inspect personal protective equipment (PPE), and 82.5% ensure workers are fit. Regarding training, 82.5% have received drone pesticide spraying safety training, and 95% have received agricultural drone safety training. Training methods include online training (52.6%), local sites (15.8%), government agencies (2.6%), and private organizations (13.2%). Training frequency varies, with 76.5% receiving it once before use, 17.6% annually, and a small percentage receiving it monthly or with new pesticide use. The results of Agricultural Drone Usage Behavior are shown in Table 3.

4. Safe Operation Procedures

During the chemical mixing process, 90% of participants added leaf adhesive before applying pesticides, while 10% added it afterward. Prior to flight, 70% selected chemicals registered with the Department of Agriculture, 67.5% read the labels every time, and 95% followed the label instructions. Additionally, 87.5% mixed chemicals based on compatibility, while 27.5% mixed them for convenience. Seventy percent maintained a 200-meter distance from water sources, and 92.5% were cautious of both objects and people in the drone flight area. Safe operation procedures are summarized in Table 4, and an example of chemical mixing and personal protective equipment usage during agricultural drone operations is illustrated in Figure 2.

During drone flight, 100% of participants kept the drone in visual range, 95% used an appropriate speed, and 67.5% kept the drone below 3 meters from the plant canopy. 30% flew parallel to the road, 22.5% sprayed on slopes, and 72.5% used the appropriate water volume. 90% regularly checked equipment. After the flight, 80% avoided entering sprayed areas, 77.5% cleaned their bodies immediately, and 75% cleaned their clothing separately. 85% cleaned the drone and equipment with three washes, while 35% wiped them down.

For drone cleaning locations, 40% cleaned in the agricultural field, 17.5% cleaned outside the field, and 40% cleaned at home. Only 2.5% cleaned it in the equipment storage area. For storing equipment, 82.5% stored items at home, 7.5% outside the field, and 7.5% in storage areas. 51.3% stored unused chemicals at home, 23.1% in storage rooms, 20.5% outside the field, and 5.1% in the agricultural field.

In disposing of used chemical containers and damaged equipment, 40% disposed of them outside the field, 27.5% used hazardous waste bins, and 22.5% disposed of them at home. Only 2.5% disposed of them in the field or storage area.

4. Use of Personal Protective Equipment (PPE)

During agricultural drone activities, the use of Personal Protective Equipment (PPE) varied among participants. Long-sleeve shirts were worn by 95% during chemical mixing, 97.5% during spraying, and 75% during equipment cleaning. Long pants were worn by 95% during chemical mixing, 95% during spraying, and 82.5% during cleaning. Boots were worn by 45% during chemical mixing, 37.5% during spraying, and 50% during cleaning. Rubber gloves were worn by 82.5% during chemical mixing, 52.5% during spraying, and 85% during cleaning. Aprons were worn by 27.5% during chemical mixing, 17.5% during spraying, and 22.5% during cleaning. Glasses were worn by 52.5% during chemical mixing, 52.5% during spraying, and 40% during cleaning. Face shields were worn by 47.5% during chemical mixing, 37.5% during spraying, and 30% during cleaning. Chemical filter masks were worn by 57.5% during chemical mixing, 55% during spraying, and 37.5% during cleaning. Cloth masks were worn by 25% during chemical mixing, 20% during spraying, and 20% during cleaning. Surgical masks were worn by 57.5% during all activities. Cloth or face covers were worn by 30% during chemical mixing, 22.5% during spraying, and 17.5% during cleaning. Hats were worn by 77.5% during chemical mixing, 70% during spraying, and 37.5% during cleaning. Fabric gloves were worn by 17.5% during chemical mixing, 20% during spraying, and 15% during cleaning.

Table 1 Personal Information of Agricultural Drone Operators (n=40)

Description	Number	Percentage (%)
Age (years), Mean ($\pm$ SD)	33.53 ($\pm$ 9.58)	
Gender		
Male	29	72.5
Female	11	27.5
Agricultural Work Experience (years), Mean ($\pm$ SD)	2.65 ($\pm$ 1.21)	
Marital Status		
Single	17	42.5
Married	23	57.5
Pre-existing Health Conditions		
Yes	1	2.5
No	39	97.5
Average Monthly Income		
< 5,000 THB/month	20	50.0
5,000-10,000 THB/month	1	2.5
> 10,000 THB/month	7	17.5
Uncertain	12	30.0

Table 2 General Information on Agricultural Drone Practice

Description	Number	Percentage (%)
Drone Brand		
DJI	38	95.0
Nac drone	2	5.0
Drone Weight (kg), Mean ($\pm$ SD)	31.79 $\pm$ 9.71	
Drone Water Capacity (liters), Mean ($\pm$ SD)	27.69 $\pm$ 10.99	
Working Hours per Day (hours/day), Mean ($\pm$ SD)	5.66 $\pm$ 2.36	
Sprayer Type		
Fan type	17	42.5
Jet nozzle	16	40.0

Table 2 General Information on Agricultural Drone Practice (Cont.)

Description	Number	Percentage (%)
Cone type	4	10.0
Needle spray nozzle	1	2.5
Mist jet nozzle	1	2.5
Jet spray	1	2.5
Spraying Height (meters), Mean ($\pm$ SD)	2.85 $\pm$ 0.90	
Crops Served by Agricultural Drones (multiple answers possible)		
Rice (n=40)	33	82.5
Corn (n=40)	3	7.5
Rubber (n=40)	29	72.5
Sugarcane (n=40)	22	55.0
Cassava (n=40)	1	2.5
Coconut (n=40)	1	2.5
Average Area Covered per Flight (rai), Mean ($\pm$ SD)	41.26 $\pm$ 66.12	
Average Flight Duration (minutes/flight), Mean ($\pm$ SD)	27.95 $\pm$ 34.89	
Average Distance from Water Source (km), Mean ($\pm$ SD)	2.87 $\pm$ 3.27	
Average Distance from Residential Area (km), Mean ($\pm$ SD)	5.84 $\pm$ 10.55	
Types of Agricultural Chemicals Used (multiple answers possible)		
Herbicides (weed control) (n=40)	35	87.5
Insecticides and pest repellents (n=40)	35	87.5
Fungicides (n=40)	34	85.0
Fertilizers/Hormones (n = 40)	40	100.0

Table 3 Agricultural Drone Usage Behavior

Procedure	Number	Percentage (%)
Time of Pesticide Spraying with Agricultural Drones		
Morning	23	57.5
Evening	3	7.5
Morning, Evening	14	35.0
Wind Conditions During Pesticide Spraying		
Calm trees, smoke rising vertically from the ground	33	82.5
Leaves shaking, wind touching the face	3	7.5
Small branches and leaves begin moving, flags start to flutter	3	7.5
Calm trees, smoke rising vertically from the ground, leaves shaking, wind touching the face, small branches and leaves begin moving, flags start to flutter	1	2.5
Decision Time for Pesticide Spraying		
Spray when weeds/pests are observed	26	65.0
Spray when weeds/pests are observed and at other times	6	15.0
Spray at any time based on need	6	15.0
Spray when weeds/pests are observed, spray at any time based on need	1	2.5
Spray when weeds/pests are observed, spray even if no weeds/pests are found	1	2.5
Pesticide Spraying Direction		
Upwind	32	80.0
Downwind	6	15.0
No consideration of wind direction	2	5.0
Compliance with Safety Work Procedures (multiple answers possible)		
Check weather conditions before spraying (n=40)	30	75.0
Define the target area for spraying (n=40)	36	90.0

Table 3 Agricultural Drone Usage Behavior (Cont.)

Procedure	Number	Percentage (%)
Check the readiness of spraying equipment (n=40)	37	92.5
Check personal protective equipment (PPE) (n=40)	35	87.5
Worker must be physically fit (n=40)	33	82.5
Drone Pesticide Spraying Safety Training		
Have received training (n=40)	33	82.5
Have not received training (n=40)	7	17.5
Drone Safety Training for Agricultural Work		
Have received training (n=40)	38	95.0
Have not received training (n=40)	2	5.0
Training Methods for Drone Safety in Agriculture		
Online training (n=38)	20	52.6
Training at accessible local sites (n=38)	6	15.8
Government agencies (e.g., Department of Agriculture, Hospitals) (n=38)	1	2.6
Private sector organizations (e.g., chemical producers) (n=38)	5	13.2
Never heard about it (n=38)	6	15.8
Frequency of Drone Safety Training for Agriculture		
Only once before using the drone (n=34)	26	76.5
Annually (n=34)	6	17.6
Monthly (n=34)	1	2.9
Every time a new pesticide is used for the first time (n=34)	1	2.9

Table 4 Safe Operation Procedures

Procedure	Number	Percentage (%)
Chemical Mixing		
Adding leaf adhesive after pesticide (n=40)	4	10.0
Adding leaf adhesive before pesticide (n=40)	36	90.0
Before Drone Flight (multiple answers possible)		
Choose chemicals registered with the Department of Agriculture (n=40)	28	70.0
Read the label every time (n=40)	27	67.5
Follow label instructions (n=40)	38	95.0
Mix chemicals knowing which are compatible (n=40)	35	87.5
Mix chemicals without knowing compatibility for convenience (n=40)	11	27.5
Maintain 200-meter distance from water sources during spraying (n=40)	28	70.0
Be cautious of objects in the drone flight area (n=40)	37	92.5
Be cautious of people in the drone flight area (n=40)	37	92.5
During Drone Flight (multiple answers possible)		
Keep the drone in visual range during flight (n=40)	40	100.0
Use an appropriate flight speed (m/s) (n=40)	38	95.0
Do not exceed 3 meters in height from the plant canopy/top (n=40)	27	67.5
Fly parallel to the road (n=40)	12	30.0
Spray on slopes following the same altitude level (low to high) (n=40)	9	22.5
Use appropriate water volume for the plant and drone (n=40)	29	72.5
Choose the appropriate spraying pattern for each type of plant (n=40)	31	77.5
Check equipment regularly to ensure readiness (n=40)	36	90.0

Table 4 Safe Operation Procedures (Cont.)

Procedure	Number	Percentage (%)
After Drone Flight (multiple answers possible)		
Avoid entering sprayed areas (n=40)	32	80.0
Clean body immediately (n=40)	31	77.5
Clean clothing immediately and separately (n=40)	30	75.0
Clean drone and mixing equipment with triple rinses (n=40)	34	85.0
Wipe down drone and mixing equipment (n=40)	14	35.0
Cleaning the Drone (n=40)		
In the agricultural field	16	40.0
Outside the agricultural field	7	17.5
At home	16	40.0
In the agricultural equipment storage area	1	2.5
Storing the Drone and Chemical Mixing Equipment Chemicals (n=40)		
In the agricultural field	1	2.5
Outside the agricultural field	3	7.5
At home	33	82.5
In the agricultural equipment storage area	3	7.5
Storing Unused Chemicals (n=39)		
In the agricultural field	2	5.1
Outside the agricultural field	8	20.5
At home	20	51.3
In the agricultural equipment storage room	9	23.1
Disposing of Used Chemical Containers and Damaged Mixing Equipment (n=38)		
In the agricultural field	1	2.5
Outside the agricultural field	16	40.0
At home	9	22.5
In the agricultural equipment storage room	1	2.6
Hazardous waste bins (municipalities) / incineration	11	27.5

Table 5 Wearing Personal Protective Equipment (PPE)

Personal Protective Equipment (PPE)	Number (%)		
	During Chemical Mixing	During Spraying	During Drone Equipment Cleaning
Long-sleeve Shirt (n=40)	38 (95.0)	39 (97.5)	30 (75.0)
Long Pants (n=40)	38 (95.0)	38 (95.0)	33 (82.5)
Boots (n=40)	18 (45.0)	15 (37.5)	20 (50.0)
Rubber Gloves (n=40)	33 (82.5)	21 (52.5)	34 (85.0)
Apron (n=40)	11 (27.5)	7 (17.5)	9 (22.5)
Glasses (n=40)	21 (52.5)	21 (52.5)	16 (40.0)
Face Shield (n=40)	19 (47.5)	15 (37.5)	12 (30.0)
Chemical Filter Mask (n=40)	23 (57.5)	22 (55.0)	15 (37.5)
Cloth Mask (n=40)	10 (25.0)	8 (20.0)	8 (20.0)
Surgical Mask (n=40)	23 (57.5)	23 (57.5)	23 (57.5)
Cloth/Face Cover (n=40)	12 (30.0)	9 (22.5)	7 (17.5)
Hat (n=40)	31 (77.5)	28 (70.0)	15 (37.5)
Fabric Gloves (n=40)	7 (17.5)	8 (20.0)	6 (15.0)
Sneakers (n=40)	18 (45.0)	22 (55.0)	15 (37.5)

**Figure 1.** Agricultural Drone Operator



Figure 2 Chemical Mixing and Personal Protective Equipment Usage During Agricultural Drone Operations

Discussion

The findings suggest that while agricultural drone operators in Thailand are generally aware of basic safety protocols, adherence to specific safety and operational procedures remains inconsistent. The majority of participants were male (72.5%), with an average age of 33.53 years, indicating that the field is dominated by younger, tech-savvy individuals. With an average of 2.65 years of agricultural experience, most operators are familiar with farming tasks, though their limited experience may contribute to gaps in safety knowledge. These results align with Peng et al. ⁽¹⁴⁾, who found that younger operators tend to be more proficient with technology. However, they also reported that female operators perceived higher difficulty in drone operation, especially in accessing flight information, suggesting gender-related challenges that warrant further attention.

The study also highlights economic challenges among drone operators, with 50% earning less than 5,000 THB per month. This low-income level may limit their ability or willingness to invest

in personal protective equipment (PPE) and safety training. Given that operating agricultural UAVs requires both technical knowledge and specialized skills, this economic constraint could hinder safe and effective drone use. Previous studies emphasize the need for skilled labor to manage UAV technologies effectively, especially as their use becomes more complex with advancing precision agriculture tools ^(15, 16).

The drones used by participants had an average weight of 31.79 kg and a water capacity of 27.69 liters, which is typically suitable for medium-scale agricultural spraying, depending on the type of drone and its manufacturer. Most operators cover significant areas per flight, averaging 41.26 rai, which demonstrates that drone technology can improve operational efficiency in agriculture. However, the variability in the areas covered and flight durations suggests that there are opportunities to better optimize drone usage according to specific crop needs and environmental conditions. This could further enhance both productivity and safety in agricultural operations ⁽¹⁷⁾.

The study revealed significant variability in pesticide spraying practices among operators. Approximately 57.5% of operators spray in the morning, while 35% spray both in the morning and evening. This variation could affect the effectiveness of pesticide application, as the time of day can influence the dispersal and absorption of chemicals in the ecosystem ⁽¹⁸⁾. Most participants (80%) spray upwind, which follows recommended safety practices to reduce pesticide drift. However, 20% of operators did not consider wind direction, potentially posing safety risks for both the operators and nearby communities. This oversight could also affect unsprayed buffer zones and other protective measures, leading to pesticide contamination in unintended areas ⁽¹⁹⁾.

The decision-making process for pesticide spraying varied among operators, with 65% choosing to spray when weeds or pests are visually observed. This suggests that many operators rely on visual cues rather than following a more systematic or preventive spraying schedule, which may lead to inefficiency or the overuse of pesticides. Furthermore, a study by Kuster et al. highlighted that even with drone applications, pesticide mixer and loaders are still exposed to pesticide-related risks ⁽²⁰⁾.

The study revealed relatively high compliance with essential safety practices among agricultural drone operators. Most participants reported consistently checking weather conditions, defining target spraying areas, and ensuring equipment readiness before operation—practices that reflect awareness of minimizing operational risks. However, 27.5% of the respondents admitted to mixing chemicals without knowing their compatibility, which increases the risk of harmful exposure.

This finding aligns with the study by Chantaramanee N., which reported that many farmers exhibited unsafe behaviors, such as not wearing rubber gloves while handling pesticides, thereby increasing their risk of chemical exposure during work ⁽²¹⁾.

While the majority of operators (82.5%) had received drone safety training, the frequency and quality of the training varied. Notably, only 52.6% of participants received online training, which may be less effective than hands-on training or programs tailored to local agricultural conditions. This observation is supported by the study of Wongta A. et al. which emphasized the critical role of education and training in enhancing pesticide safety knowledge and practices among farmers in Thailand. The lack of safety training may affect operators' ability to respond effectively to unexpected situations during pesticide application ⁽²²⁾.

Regarding post-spraying procedures, most operators demonstrated awareness of personal safety by avoiding re-entry into sprayed areas and cleaning themselves immediately after drone operation. However, only 85% of respondents reported using the recommended method of triple rinses to clean their drones and mixing equipment, suggesting that a risk of chemical contamination may still exist among the remaining operators ⁽²³⁾.

The use of PPE among agricultural drone operators varied across different tasks. Although long-sleeved shirts and long pants were commonly worn (by more than 95% of operators during chemical mixing and spraying), the use of more protective equipment, including boots, aprons, face shields, and chemical-filtering respirators, was less frequent. For example, only 45.0% of operators wore boots and 47.5% used face shields during chemical mixing. PPE use declined further during equipment cleaning, despite the continued risk of exposure to pesticide residues. These findings are consistent with those of Kuster et al. [20] and Chittrakul et al. ⁽²⁴⁾, who reported inconsistent PPE use and its association with increased pesticide exposure among agricultural workers. The findings highlight the need for comprehensive, task-specific safety training covering PPE selection, correct use, removal, cleaning, maintenance, and replacement throughout pesticide mixing, spraying, and equipment cleaning. Training should incorporate practical demonstrations, competency assessments, and periodic refresher sessions rather than relying solely on theoretical instruction. At the policy level, relevant authorities should consider establishing standardized training curricula, operator certification requirements, practical operating guidelines, and mechanisms for routine monitoring. These individual- and policy-level measures may promote consistent safety practices and reduce occupational and environmental risks. Future intervention studies should evaluate whether such

measures improve safety behaviors and reduce pesticide exposure among agricultural drone operators.

Conclusion

This study provides preliminary evidence on pesticide-handling practices, safety behaviors, and PPE use among agricultural drone operators, an understudied occupational group in Thailand. Although most operators followed essential safety protocols, inconsistencies remained in pesticide-application timing, chemical handling, PPE use, and safety training. Standardized procedures, competency-based training, and periodic refresher courses are therefore needed to promote safer practices and reduce occupational and environmental risks.

A key strength of this study is its identification of specific unsafe practices that can inform targeted preventive interventions. However, the small, purposively selected sample from Kanchanaburi Province limits generalizability, while the cross-sectional design precludes causal inferences. Self-reported data may also be affected by recall and social-desirability biases. Finally, although Syngenta Crop Protection had no role in the study design, conduct, analysis, interpretation, or manuscript preparation, the industry funding may be perceived as a potential conflict of interest. Future studies should include larger, more diverse samples and incorporate direct observations and objective exposure measurements.

Ethical Approval Statement

Ethical approval for this study was obtained from the Ethical Review Committee for Human Research, Sakon Nakhon Rajabhat University (Approval No. HE 67-004). Written informed consent was obtained from all participants before data collection.

Author Contributions

SP, SA, CT, and GB conceived and designed the study and developed the questionnaire. SP, KK, CT, and GB conducted the study under the supervision of SA. GB, SP, KK and CT performed the descriptive analyses with methodological guidance from SA. SP, CT, KK, and GB drafted the manuscript, while SA critically reviewed and revised the manuscript for important intellectual content. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

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Conflicts of Interest

The authors declare that there are no other conflicts of interest related to this work.

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