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Regular Article

Evaluation of the droplet deposition and control effect of a special adjuvant for unmanned aerial vehicle (UAV) sprayers

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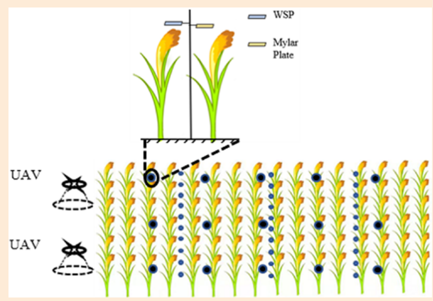
Unmanned aerial vehicle (UAV) sprayers have been widely used in agriculture. With the goals of using pesticides efficiently and reducing their dosage, we evaluated the effects of adding and not adding special adjuvants to UAV sprayers on droplet deposition and the control effect of leaf folder insects. The deposition quantity and coverage area of UAV sprayers with the Kao Adjuvant A-200® on rice leaves were better than those without the Kao Adjuvant A-200®. Regarding the control effect on rice leaf rollers, UAV sprayers with the Kao Adjuvant A-200® were also better, and they also met the pesticide residue limit for brown rice. Kao Adjuvant A-200® can improve the UAV sprayer's droplet deposition and pest control effect. When the pesticide dosage was reduced by 30%, UAV sprayers with Kao Adjuvant A-200® can achieve a good control effect, which is very helpful in reducing the pesticide dosage.



Keywords: UAV sprayer, control effect, spray deposition, rice, leaf folder insect.

Introduction

In recent years, unmanned aerial vehicles (UAVs) have been used to spray pesticides on farmlands because of their high efficiency, high safety, and water conservation. In contrast, traditional pesticide-spraying modes do some harm to the human body, and they also waste a lot of water resources and pesticides.[1,2] However, UAV sprayers also face many other problems. When a UAV sprayer is used in flight, the deposition and drift of droplets are seriously affected by the wind field, environment, and various factors[3]; these keep the droplets from contacting specific targets evenly, seriously affecting the utilization rate of pesticides. Improving the working efficiency of UAV sprayers has become the subject of many studies. Studies have shown that the drift and deposition of droplets on plants are affected by droplet size.[4,5] When the droplet size is $<50\,\mu$m, droplets will be suspended in the air, adsorbed by other particles, or will float away with the wind,[6,7] reducing the dosage of pesticides needed to reach the prevention target and control. When droplets are too large, although the droplet settlement effect is better, it will lead to a smaller or uneven deposition area and control effect.[8] The wind field caused by the wings of UAVs will affect the suspension state of droplets in the air. Droplets that are too large or too small will have inadequate deposition quantity and distribution.[9] Therefore, to maximize the UAV sprayer, it is necessary to investigate the interaction between the UAV sprayer, operating parameters, droplet size, and spray penetration. Previous studies have shown that droplet deposition is affected by spraying volume; however, no unified conclusion has been reached. Studies also showed that a low spraying rate of a UAV sprayer can result in a more trace deposition on wheat[10] and leguminous shrubs.[11] In contrast, Kirk *et al.* and Menechini *et al.* found that the trace deposition would be higher at a higher spraying rate.[12,13] Besides, the nozzle type and height can also affect droplet deposition. Wang *et al.* showed that using a coarse

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nozzle in a UAV sprayer at $>16.8\,L\,ha^{-1}$ was better than using a fine nozzle at $9\,L\,ha^{-1}$.[14] Zheng *et al.* studied the influence of the spraying height of a UAV sprayer on deposition, and their results showed that the deposition effect at a height of 1.0 m was better than that at 0.5 m or 1.5 m.[15]

Previous studies focused on the influence of a UAV sprayer's factors on deposition and control effects, while there have been few studies on chemical adjuvants added to UAV sprayers. Pesticide adjuvants can usually improve the physical properties of droplets or improve the activity of pesticides, but they have no biological activity. Pesticide adjuvants can reduce the surface tension of droplets and improve their morphology and spreading.[16] Adjuvants can also improve the insecticidal effect of UAV sprayers and reduce the dosage of imidacloprid by 20%.[17] Xiao *et al.* found that adjuvants added to a UAV sprayer improved the droplets' coverage and deposition quantity on cotton.[18] In this study, a special adjuvant for a UAV sprayer was evaluated. The adjuvant has good water solubility and can be mixed with any water-soluble pesticides to evaluate its use in a UAV sprayer. A knapsack sprayer, a UAV sprayer without an adjuvant, and a UAV sprayer with an adjuvant were used. The adjuvant was evaluated based on the deposition quantity and the distribution area of droplets, its control effect on pests, and its impact on pesticide residues. A water-sensitive paper (WSP) and mylar plate were used to measure the droplets' distribution area and deposition quantity. The control effects on leaf folder insects (*Cnaphalocrocis medinalis Guen.*) were also compared. Finally, pesticide residues were detected. This study aimed to determine the practicality of using a special adjuvant in UAV sprayers to reduce the dosage of pesticides while maintaining their control effects.

Materials and methods

1. *Unmanned aerial vehicle (UAV) and adjuvants*

The UAV used in this study was the Jifei P20. It adopted a SUPERX2 RTK flight control system and was equipped with a GNSS RTK positioning module and variable spraying system. Its non-spraying operations, such as take-off, landing, ferrying, and turning, were guided by satellite navigation systems. In a spraying operation, the forward trajectory of each row of spraying was parallel to the direction of the rice field; by rotating 90° clockwise twice and entering the starting position of the next strip. The flying altitude was 2.2–2.8 m, the speed was 4.5–5.5 m/s, the spraying range was 2.2–2.5 m, and the amount of pesticide sprayed was 22.5 L/ha.

The knapsack sprayer increased the pressure in the gas chamber by rocking the rocker parts, and the liquid at the bottom of the liquid box was passed through the outlet pipe and spray rod; finally, the spray nozzle was sprayed out of the fog. The capacity was 16 L, and the working pressure was 0.25–0.45 MPa. The recommended application rate was 450 L/ha at 0.4 MPa, and the traveling speed was about 0.3 m/s. The UAV sprayer and knapsack sprayer were used by regular trained professional operators.

The adjuvant used in this study was Kao Adjuvant A-200® for a UAV sprayer, which was produced by Shanghai Kao Chemical Co., Ltd. Kao Adjuvant A-200® is composed by 1.64% "Rheodol TW-L106" (polyoxyethylene sorbitan monolaurate, 5.78% "Latemul AD-25" (ammonium lauryl sulfate, 24.0 mass% aqueous solution), 38.89% "Sunsoft No.760-C" (glyceryl caprate), 16.66% "Carcol 1098" (*n*-decanol), and 37.03% DMSO. The percentage of Kao Adjuvant A-200® was fixed for all UAV spraying experiments. Twenty milliliter of Kao Adjuvant A-200® was mixed with 980 mL of water.

A leaf area analyzer (Shanghai Sintek International Trade Co., Ltd.), a nitrogen blowing instrument (Shanghai Zhisun Equipment Co., Ltd.), a Shimadzu GC-MS-QP2010 PLUS gas chromatography-mass spectrometry and high-speed homogenizer (Changzhou Longhe Instrument Manufacturing Co., Ltd.), a Laborota 4003 rotary evaporator (Heidolph, Germany), a PC 4000 electronic balance (Mettler Instruments, USA), and an ASPECXL automatic solid-phase extraction instrument (Gilson, USA) were used.

2. *Field plots and chemicals*

A trial was performed in 2020 and 2021 in an experimental paddy field in Duhu Town, Taishan City, Jiangmen City, Guangdong Province, China. A field methodology was adopted to evaluate the effect of adding Kao Adjuvant A-200® to a UAV sprayer on the control of *Cnaphalocrocis medinalis*.

The variety of rice was 'Xiangya Xiangzhan.' The rice was transplanted in mid-August of 2020. The first spraying was on September 24, 2020, and the second was on October 21, 2020. The harvest date was November 13. In 2021, the rice was transplanted in early April. The first spraying was on April 30, 2021, and the second was on May 21, 2021. The harvest date was July 25. At the first spraying in two years, the rice was in 23 (BBCH code), the rice grew well, and field pests were very light. At the second spraying, the rice was in 43 (BBCH code), and the growth condition was generally good. The two-year experiment was regarded as two independent experiments, and the experimental design was the same. The types and concentrations of pesticides used twice are listed.

The 100% dosage is recommended by the local Plant Protection Agency. For example, for 10% tetrachlorantraniliprole SC in a UAV sprayer per hectare, a 100% dosage means 600 mL of the 10% tetrachlorantraniliprole SC dissolved in 22.5 L of water with 450 mL of Kao Adjuvant A-200® then added. A 70% dosage means 420 mL of the 10% tetrachlorantraniliprole SC dissolved in 22.5 L of water with 450 mL of Kao Adjuvant A-200® then added. For the knapsack sprayer, 100% dosage means that 600 mL of the 10% tetrachlorantraniliprole SC is dissolved in 450 L of water per hectare.

3. *Characterization of spray deposition*

In 2020 and 2021, two pesticide treatments were carried out using a UAV sprayer and a knapsack sprayer in treatment groups 1, 2, 3, 4, 5, 6, 7, and 8. Treatment groups 1–8 used a UAV sprayer with a 30% dosage, a UAV sprayer with a 70% dosage, a UAV sprayer with a 100% dosage, a UAV sprayer with a 30% dos-

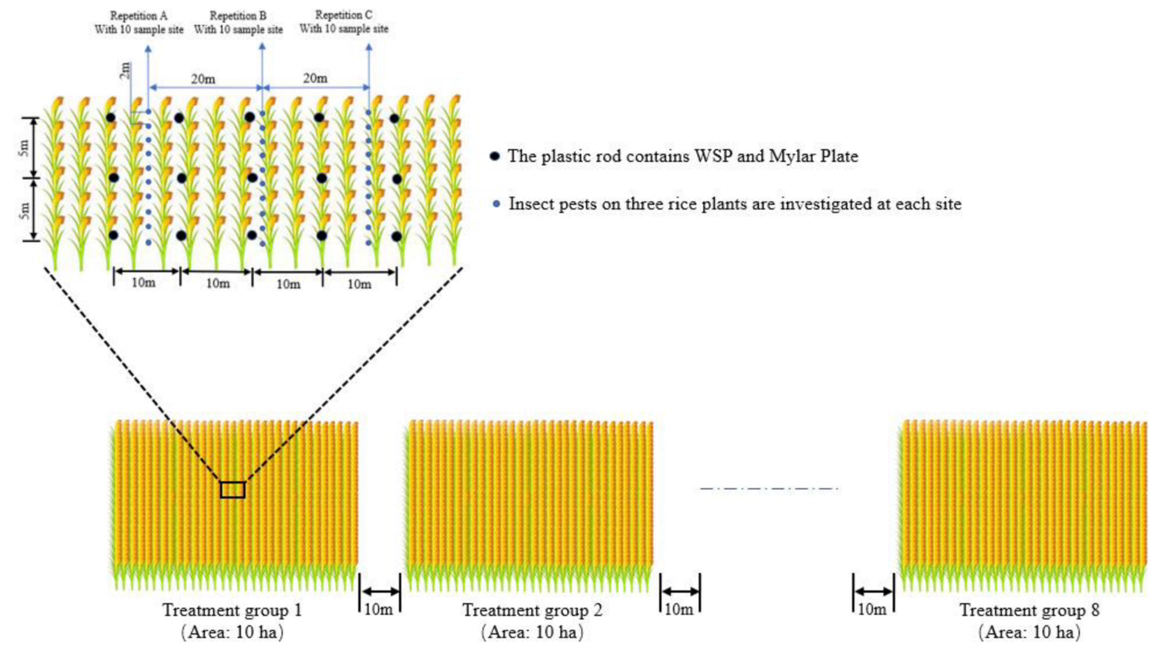

Fig. 1. Experimental layout of UAV sprayer and knapsack sprayer in paddy field.

age+Kao Adjuvant A-200®, a UAV sprayer with a 70% dosage+Kao Adjuvant A-200®, a UAV sprayer with a 100% dosage+Kao Adjuvant A-200®, a knapsack sprayer with a 100% dosage, and blank treatment, respectively. There was a buffer zone of 10 m between each treatment area.

With changes in the meteorological conditions and operation, the optical method of Fritz *et al.* was used to make the experimental data more scientific through modification.[19] Before each spray treatment, artificial samples were placed in five central samples in the spray treatment group. Each treatment group covered an area of 10 ha. To avoid cross-contamination between the groups and facilitate sampling, samples were taken only from the center of each group. Each sampling point was 10 m away. Samples were taken five times from each treatment group, and each sampling was repeated three times (Fig. 1, black spots in an enlarged drawing of treatment group 1). Each artificial sample was composed of WSP and a mylar plate (15 cm×20 cm). The WSP and mylar plate were fixed to a plastic rod using double-end clamps. (Fig. 2)

Before spraying, the WSP was placed horizontally, slightly higher than the surface of the rice leaf, and a mylar plate was placed horizontally on the opposite side. The main function of the WSP was to evaluate the chemical coverage, while that of the mylar plate was to measure the chemical's deposition. After spraying for 2 hr, the liquid on the leaf surface evaporated. WSPs and mylar plates were collected from each sampling point. To prevent WSPs from being affected by other factors, they were stored immediately in a separate dry plastic bottle. Recycled samples were placed in a zipper bag. Relevant processing information labels were pasted and transported to a laboratory in the dark for analysis. WSPs were scanned at a resolution of 600 dpi using a scanner, and DropletScan[20] imagery software was utilized to extract and analyze the coverage area on the WSPs.

The mylar plates were washed three times with methanol, and the washing solutions were combined. It was dried with a nitrogen blower at 45°C, and 1 mL of methanol was added to dissolve the dried solution. After filtration, the pesticide content was determined by GC-MS.

Using a five-point random sampling method, 12 rice plants were cut at each sampling point. Their leaves were cut into 1 cm sections, and the samples were treated using the QuEChERS method and analyzed by GC-MS.

4. *Characterization of pest controls*

The difference in control efficacy after the addition of Kao Adjuvant A-200® in a UAV sprayer and its help in reducing the pesticide dosage was analyzed. The hazard profile of leaf folder insects to rice was investigated according to the Pesticide Guidelines for Field Efficacy Trials. The investigated rice plants were all located in test field numbers 1 to 8. They were evaluated and

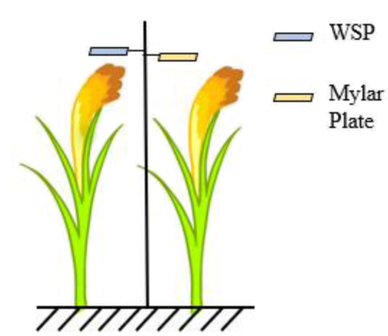

Fig. 2. The WSP and mylar plate are fixed to the plastic rod by a double ended clamp, which is slightly higher than the rice panicle.

classified into eight groups: untreated blank control, UAV sprayer 30% pesticide dosage, UAV sprayer 70% pesticide dosage, UAV sprayer 100% pesticide dosage, UAV sprayer 30% pesticide dosage+Kao Adjuvant A-200®, UAV sprayer 70% pesticide dosage+Kao Adjuvant A-200®, UAV sprayer 100% pesticide dosage+Kao Adjuvant A-200®, and knapsack sprayer (100% pesticide dosage). Pests were detected before the first application of pesticides. After the second application of pesticides after nine days, the hazard profile of leaf folder insects was examined. The types and dosages of pesticides are listed in Table 1.

Three investigations were conducted for each treatment group along a straight line. Each survey was repeated 10 times. Three rice plants were investigated at each sample site with intervals of 2 m. Ninety rice plants were evaluated in each treatment (Fig. 1, blue spots in the enlarged drawing of treatment group 1). The control effect was obtained according to the curling rate of each area before and after spraying.

$$\text{Leaf curling rate} = \text{number of leaves curled/total number of investigated leaves} \times 100\%$$

$$\text{Control effect} = \frac{\text{Blank leaf curling rate} - \text{Treated leaf curling rate}}{\text{Blank leaf curling rate}} \times 100\%$$

5. Residue detection

The knapsack sprayer, the UAV sprayer with a 100% pesticide dose, the UAV sprayer with a 100% pesticide dosage+Kao Adjuvant A-200®, and the blank control group were sampled by a 12-point random sampling method, taking 2 kg of brown rice at each sampling point. These samples were treated with a rice mill and brought back to the laboratory. About 10 g of each sample was mixed with 10 g of diatomite into an extraction tank; this was heated for 5 min under 10.34 MPa and 80°C, followed by a static extraction with acetonitrile for 3 min and two circulations. Then, the extraction tank was washed with acetonitrile with 60% of the tank volume, and it was purged with nitrogen for 100 sec. After extraction, the extraction solution was mixed evenly, and it was purified. Then, the liquid was evaporated to 1 mL by rotary evaporator. It was transferred to a series column, and the sample solution bottle was washed with acetonitrile. The washing solution was moved into the column, and a 50 mL liquid reservoir was added. Then, the series column was washed with acetonitrile. All of the above effluents were collected in pear-shaped bottles, rotated, and concentrated to about 0.5 mL in a 40°C water bath. The volume was then fixed to 1 mL using *n*-hexane. Finally, about 1 mL of liquid volume was made and mixed well. GC-MS determined the residues in brown rice; the process was repeated three times for each sample.

6. Statistical analysis

There is no repetition in the test treatment due to the large test area, but the survey sampling is set to repeat. The data includes n repeated samples of two independent tests. Data analysis considered spatially repeated measurements of the same treatment target. Biological performance was examined using one-way ANOVA at significant levels of 0.01 and 0.5. Characterizations of spray deposition data were compared using analysis of variance (ANOVA) (SPSS v. 22.0, SPSS Inc., Chicago, IL, USA). We put the two-year experimental data together.

Results

1. Coverage rate of droplets on plants under flight control conditions

The spray quantity plays a decisive role in the utilization rate of pesticides. Droplet coverage is an important parameter for determining droplet quantity. Better droplet coverage also means

Table 1. Type, dosage and date of pesticide application

Spraying time	Chemical preparation	100% Dosage* (ha^{-1})	70% Dosage (ha^{-1})	30% Dosage (ha^{-1})	Production company
September 24, 2020 and April 30, 2021	10% Tetrachlorantraniliprole SC	600 mL	420 mL	180 mL	Sinochem Agro Co., Ltd.
	325 g/L Difenoconazole·Azoxystrobin (125 g/L Difenoconazole +200 g/L Azoxystrobin) SC	300 mL	210 mL	90 mL	Syngenta Agriculture Co., Ltd.
	80% Nitenpyram·Pymetrozine (20% Nitenpyram +60% Pymetrozine) WP	150 g	105 g	45 g	Lianyungang Liben Pesticide Chemical Co., Ltd.
October 21, 2020 and May 21, 2021	6% Avermectin·Chlorantraniliprole (1.7% Avermectin +4.3% Chlorantraniliprole) SC	300 mL	210 mL	90 mL	Syngenta Agriculture Co., Ltd.
	325 g/L Difenoconazole·Azoxystrobin (125 g/L Difenoconazole +200 g/L Azoxystrobin) SC	450 mL	315 mL	135 mL	Syngenta Agriculture Co., Ltd.
	80% Nitenpyram·Pymetrozine (20% Nitenpyram +60% Pymetrozine) WP	150 g	105 g	45 g	Lianyungang Liben Pesticide Chemical Co., Ltd.
	5%Avermectin EC	750 mL	525 mL	225 mL	North China Pharmaceutical Group Aino Co., Ltd.
	0.01%14-Hydroxylated brassinosteroid AS	150 mL	105 mL	45 mL	Qingdao Shengshou Agricultural Materials Co., Ltd.

*The 100% dosage is recommended by local Plant Protection Agency.

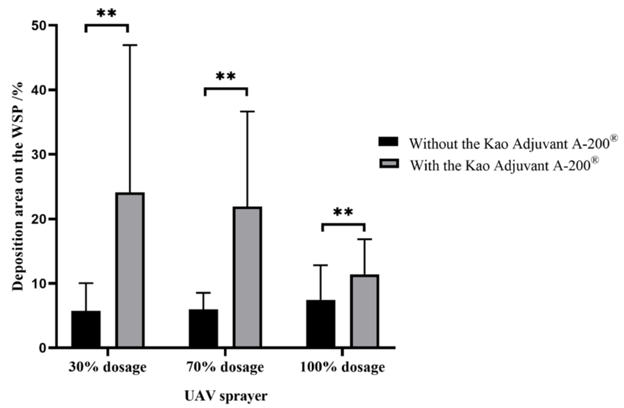

Fig. 3. Deposition area on the WSP by UAV sprayer with and without the Kao Adjuvant A-200® mixture. $p \leq 0.05$ (*), $p \leq 0.01$ (**), mean±S.D., mean=data/n, n=repeat ×2 independent.

less pesticide drift and environmental pollution. The deposition areas of a UAV sprayer with Kao Adjuvant A-200® and a UAV without Kao Adjuvant A-200® at a 30% dosage, 70% dosage, and 100% dosage were counted. The coverage rate of a UAV sprayer with Kao Adjuvant A-200® was significantly higher than that without Kao Adjuvant A-200® at 30%, 70%, and 100% dosages. The highest deposition area was observed at a 30% dosage for a UAV with Kao Adjuvant A-200®, followed by a UAV sprayer with Kao Adjuvant A-200® at a 70% dosage, a UAV sprayer with Kao Adjuvant A-200® at a 100% dosage, a UAV sprayer without Kao Adjuvant A-200® at a 100% dosage, a UAV sprayer without Kao Adjuvant A-200® at a 70% dosage, and a UAV sprayer without Kao Adjuvant A-200® at a 30% dosage. (Fig. 3)

2. Deposition quantity on mylar plates and rice leaves

The deposition quantity of pesticides also greatly affects its utilization rate. The deposition quantities of a UAV sprayer with Kao Adjuvant A-200® and those without Kao Adjuvant A-200® at a 100% dosage on mylar plates were tested. The deposition quantities of a knapsack sprayer, a UAV sprayer with Kao Adjuvant A-200®, and a UAV sprayer without Kao Adjuvant A-200® at a 100% dosage on rice leaves were also examined. The deposition quantity of a UAV sprayer with Kao Adjuvant A-200® was significantly higher than that without Kao Adjuvant A-200® at a 100% dosage. The deposition quantity results of various pesticides on the plate are consistent. (Fig. 4)

The deposition quantity of a UAV sprayer with Kao Adjuvant A-200® on rice leaves was significantly higher than that of the other two groups. However, no significant difference was observed in the deposition quantity of the knapsack sprayer and the UAV sprayer without Kao Adjuvant A-200® on rice leaves. (Fig. 5)

3. Experimental results on the control of rice leaf folder (Cnaphalocrocis medinalis Guen.)

After two spraying times, the curly leaves of each plot were evaluated. The control effects of adding Kao Adjuvant A-200® to the UAV sprayer at different pesticide dosages (30, 70, and 100%)

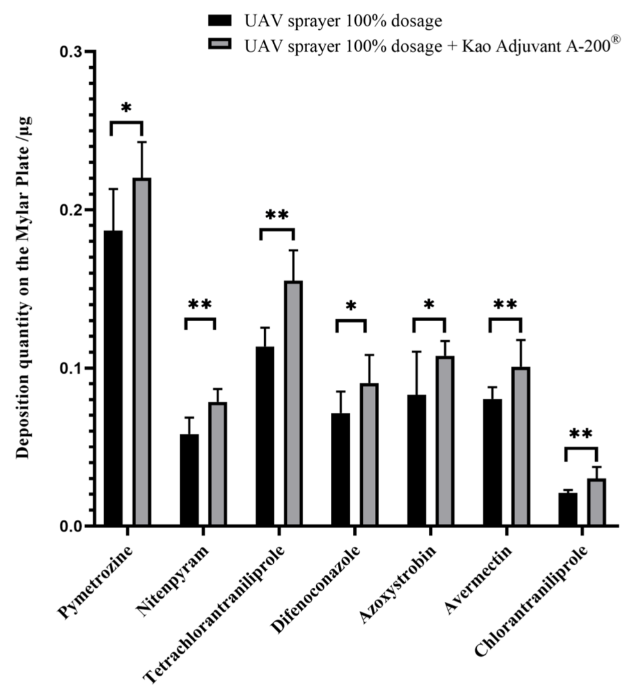

Fig. 4. Deposition quantity of pesticides sprayed on the mylar plate by UAV sprayer with and without the Kao Adjuvant A-200® mixture at 100% dosage. $p \leq 0.05$ (*), $p \leq 0.01$ (**), mean±S.D., mean=data/n, n=repeat ×2 independent.

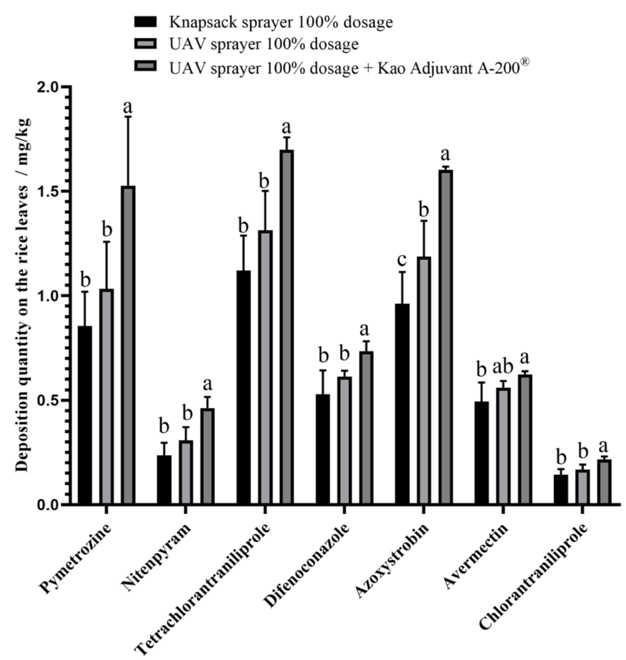

Fig. 5. Deposition quantity of pesticides on the rice leaves under three spraying conditions. (a, b and c represent the difference at the 5% significant level, mean±S.D., mean=data/n, n=repeat ×2 independent.).

are shown. The control effects of the knapsack sprayer at a 100% pesticide dosage were also compared. As shown in Fig. 6, the UAV sprayer with Kao Adjuvant A-200® had the best control ef-

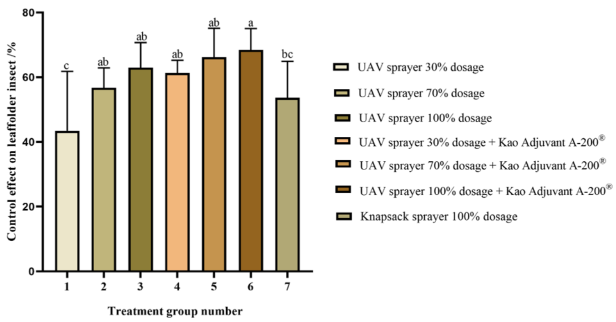

Fig. 6. Control effects of seven experimental groups spray with pesticides on leaf folder insect. (a, b and c represent the difference at the 5% significant level, mean ± S.D., mean = data/n, n = repeat ×2 independent.).

fect at a 100% pesticide dosage, which was significantly different from the other treatment groups ($p<0.05$); this was followed by the control effects of a 70% pesticide dosage+Kao Adjuvant A-200®, a 100% pesticide dosage, a 30% pesticide dosage+Kao Adjuvant A-200®, and a 70% pesticide dosage. The control effect of the knapsack sprayer with a 100% pesticide dosage was only better than that of the UAV sprayer with a 30% pesticide dosage (without Kao Adjuvant A-200®). The control effect of using a 70% pesticide dosage without Kao Adjuvant A-200® or a 30% pesticide dosage with Kao Adjuvant A-200® was better than that of the knapsack sprayer with a 100% pesticide dosage (Fig. 6).

The control effect of adding Kao Adjuvant A-200® to the UAV sprayer at the same pesticide dosage was also compared. At a 30% pesticide dosage, the control effect of the UAV sprayer with Kao Adjuvant A-200® was significantly better than that of the UAV sprayer without Kao Adjuvant A-200® ($p<0.05$). At 70% and 100% pesticide dosages, the control effect of the UAV sprayer with Kao Adjuvant A-200® was significantly better than that of the UAV sprayer without Kao Adjuvant A-200® ($p<0.10$) (Fig. 7).

4. Pesticide residues

Pesticide residues are a safety problem that cannot be ignored. Pesticide residues were detected in the experiment after adding Kao Adjuvant A-200®. It was determined that its addition will cause pesticide residues to exceed the maximum residue limits. Pesticide residues were detected in brown rice under three spraying modes (a knapsack sprayer with a 100% pesticide dosage, a UAV sprayer with a 100% pesticide dosage, and a UAV sprayer with a 100% pesticide dosage and Kao Adjuvant A-200®). Avermectin and tetrachlorantraniliprole were not detected in the three spraying modes. Azoxystrobin was detected in the UAV sprayer with a 100% pesticide dosage and Kao Adjuvant A-200® but not in the other two spraying modes. Difenoconazole was only detected in the knapsack sprayer with a 100% pesticide dosage. However, pymetrozine, nitenpyram, and chlorantraniliprole were detected in all three spraying modes, where the nitenpyram and chlorantraniliprole contents were less than 0.01 mg/kg (Table 2).

Discussion

This study compared the efficacy of a special adjuvant for a UAV sprayer and a UAV sprayer without this adjuvant. The reliability of Kao Adjuvant A-200® in a UAV sprayer was evaluated through two years of field experiments, proving that Kao Adjuvant A-200® could improve the spray distribution, final quantity, and control of rice leaf folder.

In the spray deposition coverage experiment, the droplet coverage of the UAV sprayer was significantly enhanced by the addition of Kao Adjuvant A-200®. The enhancement of deposition coverage was also more pronounced at lower pesticide doses, and the enhancement of deposition coverage by Kao Adjuvant A-200® was significantly negatively correlated with pesticide dose. A higher deposition mass meant less pesticide loss. For the deposition quantity on mylar plates, the UAV sprayer with Kao Adjuvant A-200® had a better deposition quantity. Mylar plates were placed horizontally, while rice leaves grew vertically. To be closer to reality, the deposition of droplets on rice leaves was further examined. At the same dosage, the addition of the adjuvant helped increase the adhesion of pesticides on rice leaves and improved the efficiency of pesticide utilization.

The distribution and deposition of spray droplets indicate that although the knapsack sprayer's volume was one order of magni-

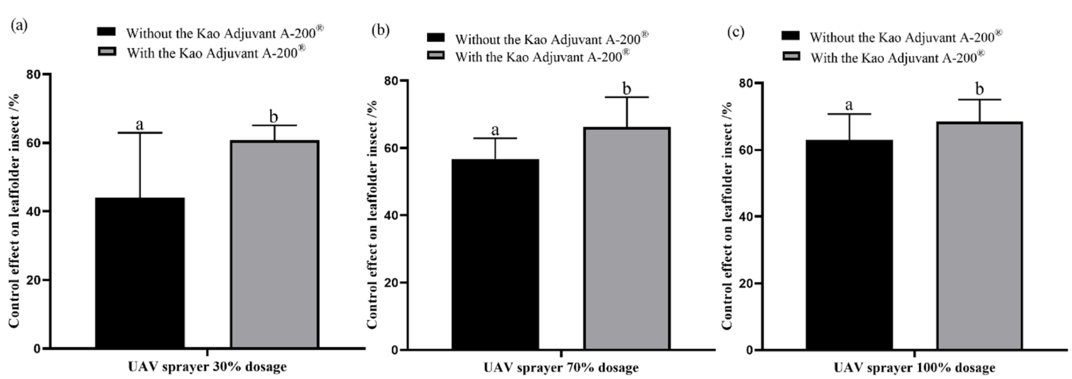

Fig. 7. When the pesticide dosage is 30%, 70% and 100%, there is a significant difference in the control effect between adding the Kao Adjuvant A-200® mixture and not adding the Kao Adjuvant A-200® mixture. (a) Significant difference at the level of 5%. (b) and (c) Significant difference at the level of 10%. Mean ± S.D., mean = data/n, n = repeat ×2 independent.

Table 2. Residue detection of several pesticides in brown rice under three spraying modes

Pesticides	Spraying mode	Residual value (mg/kg)	LSD (p=0.05)
Pymetrozine	Knapsack sprayer 100% pesticide dosage	0.0203±0.044	b
	UAV sprayer 100% pesticide dosage	0.0221±0.003	b
	UAV sprayer 100% pesticide dosage with the Kao Adjuvant A-200® mixture	0.0310±0.0100	a
Nitenpyram	Knapsack sprayer 100% pesticide dosage	<0.01	a
	UAV sprayer 100% pesticide dosage	<0.01	a
	UAV sprayer 100% pesticide dosage with the Kao Adjuvant A-200® mixture	<0.01	a
Tetrachlorantraniliprole	Knapsack sprayer 100% pesticide dosage	0	a
	UAV sprayer 100% pesticide dosage	0	a
	UAV sprayer 100% pesticide dosage with the Kao Adjuvant A-200® mixture	0	a
Difenoconazole	Knapsack sprayer 100% pesticide dosage	0.0119±0.0020	a
	UAV sprayer 100% pesticide dosage	0	b
	UAV sprayer 100% pesticide dosage with the Kao Adjuvant A-200® mixture	0	b
Azoxystrobin	Knapsack sprayer 100% pesticide dosage	0	b
	UAV sprayer 100% pesticide dosage	0	b
	UAV sprayer 100% pesticide dosage with the Kao Adjuvant A-200® mixture	0.0140±0.026	a
Avermectin	Knapsack sprayer 100% pesticide dosage	0	a
	UAV sprayer 100% pesticide dosage	0	a
	UAV sprayer 100% pesticide dosage with the Kao Adjuvant A-200® mixture	0	a
Chlorantraniliprole	Knapsack sprayer 100% pesticide dosage	<0.01	a
	UAV sprayer 100% pesticide dosage	<0.01	a
	UAV sprayer 100% pesticide dosage with the Kao Adjuvant A-200® mixture	<0.01	a

The experimental results were expressed as mean±standard deviation of the original data of the three independent experiments. The different lowercase alphabets indicate a significant difference between any two sets of treatments ($p \leq 0.05$).

tude larger than that of the UAV sprayer, the deposition of spray droplets in the UAV sprayer was better than that of the knapsack sprayer. This may be because the droplets produced by the UAV sprayer were smaller than those produced by the knapsack sprayer. Previous experiments also proved that the smaller the droplets produced by nozzles, the greater the number of spray deposits.[21] Moreover, the UAV sprayer containing Kao Adjuvant A-200® was significantly better than those without Kao Adjuvant A-200® in terms of droplet coverage area and quantity. Kao Adjuvant A-200® also greatly improved the spray capability of the UAV sprayer. It may be explained as follows: after adding adjuvants, pesticide molecules are separated into smaller particles to achieve more uniform dispersion and better adhesion. At the same time, more droplets would quickly spread out rather than bounce off when contacting a blade.

In the control experiments of leaf folder insects, the effects of the knapsack sprayer, the UAV sprayer with Kao Adjuvant A-200®, and the UAV sprayer without Kao Adjuvant A-200® were compared. Previous studies showed that only about 0.1% of the pesticide reaches the target area after spraying.[22] The spraying coverage of the UAV sprayer was greater, which indicates that there is more contact with the target area. In our experiments, the control effect was positively correlated with the pesticide dosage. At the same dosage, the control effect of pesticides with Kao Adjuvant A-200® was significantly better than that without Kao Adjuvant A-200®. The control effect of the UAV sprayer was significantly higher than that of the knapsack sprayer. This also confirmed that there is no need to use many solutions. As long as the spray deposition reaches a certain number, it can have a good control effect.[23] The increase in efficiency after using Kao Adjuvant A-200® was also found to be positively correlated with the decrease in pesticide dosage. This phenomenon may help reduce the dosage of pesticides. In this research, we paid attention to the safety of pesticide residues. The experimental results showed that the residues of all kinds of pesticides on brown rice were different; they were also different under different spraying modes. Nonetheless, all pesticide residues were within the maximum residue limits. Thus, the addition of Kao Adjuvant A-200® will not cause excessive pesticide residues.

Conclusion

Here, the quantity and area of spray deposition were compared using WSPs and mylar plates, and the control effects on leaf folder insects and the detection of pesticide residues were studied. Extensive field experiments showed that farmers who use knapsack sprayers need large quantities of solution and result in low pesticide attachment to leaves; the control effect was also not ideal. The UAV sprayer's volume was one order of magnitude lower than that of the knapsack sprayer. Moreover, the control effect of the UAV sprayer at a 70% dosage was better than that of the knapsack sprayer at a 100% dosage, which further improved the control effect after adding Kao Adjuvant

A-200®. After adding Kao Adjuvant A-200®, the control effect at 30% was significantly higher than that of the knapsack sprayer at a 100% dosage. In addition, in the case of a reduced pesticide dose, the control effect of adding Kao Adjuvant A-200® to the UAV sprayer was still significantly higher than that of the UAV sprayer without Kao Adjuvant A-200®.

Thus, after adding Kao Adjuvant A-200® to the UAV sprayer, the droplet deposition distribution, deposition quantity, and prevention and control effect on leaf folder insects were improved. Excessive pesticide residues were also not found.

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Conflict of interest statement

The authors declare that they have no conflict of interest.

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