Control efficacy of different pesticide formulations and fan-nozzle model on wheat aphids by UAVs

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Abstract: The use of unmanned aerial vehicles (UAVs) has been significantly increased in wheat pest control in China. The formulation of pesticide and the type of nozzle are the important parameters in UAVs spraying application. The droplet density, deposition and control efficacy on wheat aphids of four formulation of imidacloprid (20% imidacloprid SL, 25% imidacloprid WP, 5% imidacloprid EC, 70% imidacloprid WDG) and three models of fan-nozzle (teejet11001vs, teejet110015vs, teejet11002vs) applied by UAVs were determined in this paper. The droplet density and deposition of four imidacloprid formulation was not significantly different. However, the control efficacy of different formulation was 5% imidacloprid EC (7DAT=97.7%) > 20% imidacloprid SL (7DAT=95.7%) > 70% imidacloprid WDG (7DAT=93.2%) > 25% imidacloprid WP (7DAT=85.1%). With regard to the factor of fan-nozzle, teejet11001vs treatment performed better in droplet density and deposition than the other two nozzles, and the control efficacy of teejet11001vs was higher than teejet110015vs, teejet11002vs with the margin of 10.7%, 9.9% respectively. The deposition uniformity on wheat plant from top to bottom of three nozzles was teejet11001vs (CV=22.8%) > teejet11002vs (CV=27.1%) > teejet110015vs (CV=57.4%).

Keywords: unmanned aerial vehicles, pesticide formulation, fan nozzle model, wheat aphids, droplet density, deposition, control efficacy

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1 Introduction

Wheat aphids are one of the main pests in wheat production in China. They largely gather in leaves, stalks and panicle of wheat to consume plant juices. They can cause plant disease directly like wheat yellow dwarf disease and indirectly affect wheat yield[1]. At present, the chemical control of wheat aphids is mainly adopted. The traditional application method is difficult to meet the control requirements due to many factors. With the advancement of agricultural modernization, the control of wheat aphids should not use the traditional high-capacity spray technology, but should reduce the amount of pesticide application, so as to improve the efficiency and pesticide utilization[2]. As a typical representative of low-volume spray technology, Unmanned aerial vehicles (UAVs) has developed rapidly in spraying applications in recent years especially in China[3]. According to incomplete statistics from Chinese Ministry of Agriculture, the UAV holdings have reached 50,000 by 2019. UAV has become the important choice of pesticide application for wheat, rice, corn and other crops to control diseases and pests at present. UAVs is widely and maturely used in wheat pest control[4].

Imidacloprid is a kind of neonicotinoid insecticide, which is one of the most frequently insecticides used in China and even in the world. It is a highly absorbent insecticide which has the characteristics of low toxicity, wide spectrum, high efficiency, long effective period and not easy to develop drug resistance[5]. Moreover, it is effective control pests such as wheat aphids. However, the biological activity of pesticide products is not only related to its active ingredients and chemical structure, but also closely related to its formulation[6].

At present, the formulation of imidacloprid registered inland includes: water powder (WP), flowable concentrate for seed coating (FS), granule (GR), suspension concentrate (SC), soluble concentrate (SL), water dispersible granule (WDG), wet seed coating (WS), emulsifiable concentrate (EC) and microemulsion (ME), etc[7]. Therefore, it is necessary to make clear the difference of control effect of several kinds of imidacloprid formulation through the efficacy trial. Li et al. selected five kinds of formulation of imidacloprid as the test insecticides, and compared the biological activities indoor and field of of four species of aphids by spraying. The experimental results showed that the biological activity of suspension concentrate (SC) was basically the same as microemulsion (ME) and soluble concentrate (SL), while the activity of water powder (WP) was the lowest [5]. Similar to Li, Chen et al. studied four different dosages of 600 g/L imidacloprid SC and three different dosages of 25% imidacloprid WP. The results demonstrated that the control effect of 600 g/L imidacloprid SC were better than 25% imidacloprid WP[6]. In this study, we selected four frequently used imidacloprid formulation (EC, SL, WP, WDG) in UAV spray operation to evaluate which kinds of imidacloprid formulation performed preferable deposition properties and control effect to wheat aphids.

Except pesticide formulation, pesticide dosage and application

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volume, mechanical capacities and operating parameters of applicators also affect the deposition distribution[8]. Since the 1950s, scholars at home and abroad began to research the atomization characteristics of nozzles. Aviation atomizing nozzle is one of the core parts of plant protection UAVs[9]. The nozzle with good atomization performance can improve deposition and reduce the risk of drift. The pesticide solution is dispersed by atomizing components and forms droplets which accumulate on the target of the crop to have its efficacy[10]. The spray nozzle commonly used in UAV is divided into two categories: hydraulic nozzle and centrifugal nozzle. Hydraulic spray nozzle has fan-nozzle and cone-nozzle[11]. Sun et al. studied the relationship between the volume median diameter, the spray angle and the spray pressure by taking the fan nozzle and the hollow cone nozzle as the object[10]. The results showed that the atomization performance of fan-nozzle ST-110-01 is better than ST-110-02 and ST-110-03. Miller et al. fully studied the spray droplets and atomization performance of nozzles classified and applied it to agricultural practice[12]. So far, there are few studies focus on the relationship between nozzle model and control effect. In this study, we selected different models of same type nozzle to spray same pesticide under the same flight parameters to research the most suitable nozzle model to wheat aphids.

2 Materials and methods

To compare the influence of pesticide formulation to deposition and control efficacy of wheat aphids, we selected four types frequently-used imidacloprid including soluble concentrate (SL), water powder(WP), water dispersible granules (WDG) and emulsifiable concentrates(EC). The spray deposition was compared from two aspects including droplet deposition and droplet density.

2.1 Experimental agent

20% imidacloprid soluble concentrate (Ningbo Sunjoy Cropscience Co., Ltd.), 25% imidacloprid water powder (Hebei Zhonggu Pharmaceutical Co., Ltd.), 70% imidacloprid water dispersible granules (Zhejiang Sega Science and Technology Co., Ltd.) and 5% imidacloprid emulsifiable concentrates (Jiangsu KWIN Group Co., Ltd.) were used in this study. Allure red (85% purity, purchased from Zhejiang dragoi colour Technology Co., Ltd) were added into the tank with pesticide solution as a tracer which have been confirmed applicable to determine spray deposition.

2.2 Spray equipment

A four-rotor MG-1P electric UAV (SZ DJI Technology Co., Ltd. Shenzhen, China) (Figure 1) was used in this study. There are four fan nozzles (XR11001vs) installed on UAV. We tried to change the model of nozzles to explore the most suitable spray droplet to wheat aphids, including XR11001 vs (flow rate was 0.39 L/min), XR110015 vs (flow rate was 0.59 L/min) and XR11002 vs (flow rate was 0.79 L/min). All the flow rate tests of nozzles were conducted before spray. The traveling height from nozzles to the top of wheat canopy was 2 m. The traveling speed in the study was approximately 1.8-2 m/s. UAV flight parameters were handled by technical trained operator.

Figure 1 MG-1P four-rotor electric unmanned aerial vehicle (UAV) sprayer

2.3 Experiment design

2.3.1 Experimental field

The experiment was carried out in Wanrong County, Shanxi Province (elevation: 1193 m, east longitude: 105°38'47.13″ north latitude: 28°07′50.85″) on May 24, 2018. The variety of experimental wheat was Jimai 35 (filling stage). The average wheat crop height was about 0.8 m, and planting density of the whole wheat field was 705 plants/m^2. Experimental meteorological factors were as follows: temperature 21~30°C, humidity 48%~62%, wind speed 1.29~1.93 m/s.

2.3.2 Droplet deposition and density measurements

This study consists of six treatments: four kinds of imidacloprid formulation treatments, three kinds of fan-nozzle types treatments (Table 1). Among them, the datas of treatment 4 was utilized twice. The area of each treatment field was 10 m× 66.7 m. The droplet density, the droplet deposition, the deposition utilization rate and the control efficacy on wheat aphids were detected parameters. The total length of the wheat field was long enough so that all the treatments were arranged side by side. To avoid droplet drift there were 20 meters area as a buffer zone between every two treatment plots.

Before spraying test, three rows of droplet test cards were arranged as sample collectors in the perpendicular direction to the spray swath of UAV in each plot. Each row of sample collectors consisted of ten Polyvinyl chloride (PVC) which horizontal spacing was 1 meter. The MG-1P UAV spray swath was 4 m, so that make sure every test plot contained a spray swath. The droplet test cards were fixed to a PVC pole with three universal clamps included water-sensitive papers (3 cm×7 cm, made by Institute of Plant Protection Chinese Academy of Agricultural Sciences) and filter papers (9cm in diameter). Among them, water-sensitive paper was used to detect the droplet density and filter paper was used to determine the droplet deposition of wheat. The position of three universal clamps were adjusted according to wheat height and angle of the leaves to ensure that those three clamps were attached at the head of wheat, top-flag leaf and bottom-third top leaf (Figure 2).

Table 1 Treatment design

Treatment number	Spray volume /L·a mu^{-1}	Pesticide formulation	Nozzle model
1	1	EC	teejet11001vs
2	1	WP	teejet11001vs
3	1	WDG	teejet11001vs
4	1	SL	teejet11001vs
5	1	SL	teejet110015vs
6	1	SL	teejet11002vs

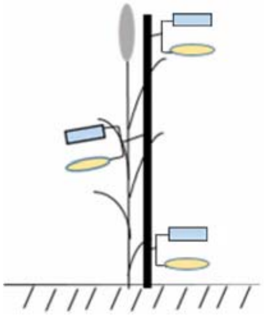

Figure 2 Placement of water-sensitive paper and filter paper

For all treatments the pesticide was prepared according to the recommended dose, and the additive amount of allure red was 450 g/hm^2. Previous research through the laboratory test and field trial confirmed that the developed method of using Allura Red as a tracer for spray deposition assessment is practicable[13,14].

After spraying , water-sensitive papers and filter papers were collected and placed into the separate 5# ziplock bags. Each plot was sampled according to "Z" of 5 points, and ten wheat plants were taken from each site then packed plant into 10# ziplock bags. All samples were washed and detected in our laboratory. Filter paper and wheat were shocked and washed for 3min in the ziplock bags using 2 mL and 10 mL distilled water respectively. The syringe then absorbed the eluent through the filtering membrane into centrifuge tubes to remove impurities from the solution. Pipette taken 200 µL filtered eluent to ELISA plates to measure the absorbance values by the ELIASA (Molecular Devices meigu Molecular instrument sco. LTD Shanghai, China) at the absorption wavelength of 514 nm. Tracer standard curve of Allura Red should be prepared well before calculating deposition.

The standard curve was made as follows: accurately weighed tracer 0.0200 g (accurate to 0.0001 g) in a 100mL volumetric bottle, and the volumetric was fixed with distilled water, namely 200 mg/L tracer mother liquor. Then the tracer mother liquor was diluted step by step to 50, 20, 10, 5, 2, 1, 0.5 mg/L standard solution. The absorbance value of the ELIASA was detected at the wavelength of 514 nm so that we could get the relation of absorbance of tracer with concentrations. The tracer mass concentration of samples could be calculated according to the standard curve. Finally, the deposition rate (*DR*) on wheat was calculated using equation (1)

$$DR\ (\%)=(C\times V\times N\times S/10\times M)\times 100 \quad (1)$$

where, C is the calculated concentration for ten wheat plants in one site according to the Allura Red standard curve (g); V is the volume of elution water added to the zipper bag (5 mL); N is the number of wheat plants per m^2 (705); S is the area of the treatment plot (667 m^2), ten is the number of wheat per treatment, and M is the amount of Allura Red added to the tested field (20 g a mu).

Using scanner to scan all water-sensitive paper under 300 dpi and then droplet parameters could get through software Deposit Scan (USDA, USA) such as droplet coverage, droplet size, droplet density. In this study we only selected pesticide droplet density as the evaluation indicator due to its vital association with the control efficacy on target.

2.3.3 Investigation of control efficacy

Five-point sampling method was used for each treatment site, with ten aphid wheat plants fixed at each site and aphid numbers recorded in the light of the relevant requirements of pesticide experiments. The control of wheat aphids is based on the premise that the number of aphids must not be less than 500 on ten plants. If the aphids infestation was slight, it could be operated on the basis of local conditions. This research investigated the base number of the aphids and their main natural enemy insects before application, and investigated again on 1st, 3rd and 7rd day after application. More investigations were conducted if necessary. The control efficacy was calculated using equations (2) and (3)

Mortality(%)=(The number of pests before application – The number of pests after application)/The number of pests before application × 100 (2)

Control effect(%)=[Observed mortality(%) – Control mortality(%)]/[100 – Control mortality(%)]×100 (3)

3 Results and discussions

3.1 Droplet density

Formulation properties and droplet spectra are significant for quantifying pesticide deposition[13]. It is very important to select the appropriate pesticide formulation according to different targets and the applications. As shown in Figure 3, there were no significant differences between four kinds of imidacloprid formulation in droplet density. However we could found that deposition decreases at the lower location of wheat. Considering that UAV spray is a low-capacity spray, with high concentration pesticide solution and small model of nozzles which may lead to blockage of nozzles or infusion pipe. The fan-nozzle hole diameter is smaller than that of standard nozzle, and the probability of nozzle blockage is higher. Therefore, solid pesticide formulation for instance water powder (WP) and water dispersible granules (WDG) are not recommended to be a priority selection because of they are insoluble in water and may lead to impurities correspondingly.

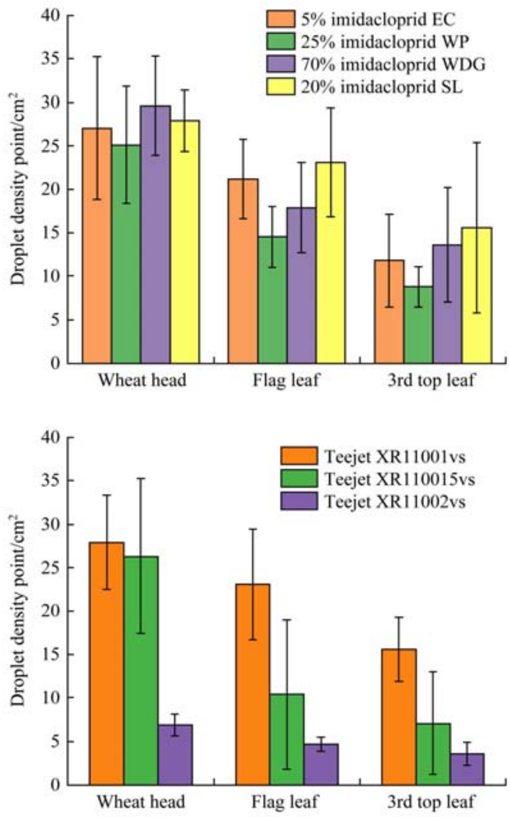

Figure 3 Droplet density of spraying four imidacloprid formulation and using 3 nozzles at different locations of wheat

For three nozzles, as was shown in Figure 3 and Table 2, teejet11001vs (1#) results in more droplet density than teejet110015vs (1.5#) and teejet11002vs (2#). The number of spray deposits of teejet11002vs treatment in different wheat locations was 6.9, 4.7 3.6 points/cm^2 respectively, which were quite lower than the other two nozzles. For wheat aphids controlling, two fan nozzles (teejet110015vs and teejet11002vs) were not a optimal selection. Between teejet11001vs and teejet110015vs, as was shown in Figure 2, the number of three locations of teejet11001vs was more than teejet110015vs 1.6, 12.7. 8.5 points/cm^2 respectively, which indicated two nozzles performed approximately the same on wheat head. While for flag leaf and 3rd top leaf, droplet numbers of teejet11002vs suddenly reduced. There was the impartible connection between droplet and control efficacy. A smaller model of nozzle means smaller droplet size [15]. Theoretically among these three tests nozzle, the droplet size condition was 1#<1.5#<2#. Therefore, a larger model would get less density of droplet with the same volume pesticide, and the density of droplet was gradually reduced from top to bottom of wheat canopy.

3.2 Droplet Deposition

The droplet deposition was measured by filter papers at each sample site. The droplet deposition of four kinds of imidacloprid were not significantly difference (Figure 4). Among the four formulation, 20% imidacloprid SL and 70% imidacloprid WDG achieved 0.18 μg/cm^2 on wheat head, 0.02 μg/cm^2 higher than 25% imidacloprid WP and 5% imidacloprid EC. But on wheat flag leaf and 3rd top leaf of wheat, four formulation performed approximately. The deposition of wheat head was higher than other location. For nozzles treatments, it was similar with the tendency of droplet density. Namely, 1# nozzle reached to the highest deposition which was 0.18, 0.13, 0.12 μg/cm^2 in three parts of wheat canopy.

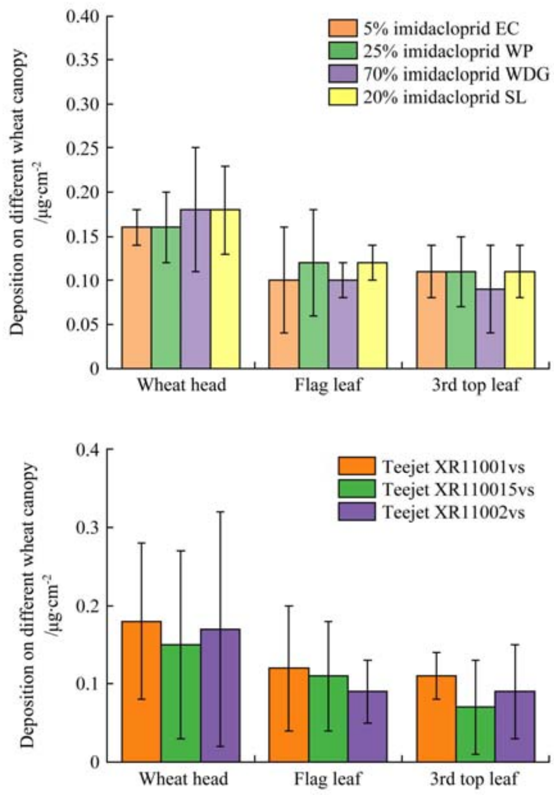

Figure 4 Droplet deposition of spraying four imidacloprid formulations on different location canopies of wheat

In addition to the droplet density and deposition, the uniformity and penetrability of droplet is also fairly vital for controlling pests. The uniformity of the deposition distribution of UAV was influenced by many factors[16]. For instance, the types, the flight accuracy, the flight parameters, the spraying system, the biased downwash wind and the meteorological condition[17]. By calculating the droplet density coefficient of variation of the wheat head, the flag leaf and the 3rd top leaf of three model nozzles, the penetration performance and the uniformity of the spray can be evaluated[18]. The greater the coefficient of variation means the less uniform the spraying, and the less penetrable the droplets in the wheat canopy. The uniformity of teejet11001vs nozzle was highest, and the CV of its droplet density was only 22.8% (Table 2). Then teejet110012vs came to the second, teejet110015vs performed the worst uniformity and penetrability with the CV of 57.4%, among the three nozzles.

Table 2 The droplet density and coefficient variation (CV) on wheat canopy of three nozzles

Nozzle	Droplet density on wheat canopy/points·cm^{-2}			SD	CV/%
	Wheat head	Flag leaf	3rd top leaf		
Teejet11001vs	27.9	23.1	15.6	5.1	22.8
Teejet110015vs	26.3	10.4	7.1	8.4	57.4
Teejet11002vs	6.9	4.7	3.6	1.4	27.1

3.3 Control efficacy of wheat aphids

The control efficacy of MG-1P UAV sprayer applying four imidacloprid formulation on wheat aphids were indicated in Table 3. The control efficacy on Day 7 after applying were all beyond 85%, among them 5% imidacloprid EC and 20% imidacloprid SL were even beyond 95%, and the EC formulation assumed highest control efficacy. From the comparison of different formulation of imidacloprid, it was found that after applying for 1 day, the control efficacy of 5% imidacloprid EC, 20% imidacloprid SL and 70% imidacloprid WDG achieved to over 80%, while 25% imidacloprid WP performed non-ideally. On the 3rd day, basically performed the same tendency, 5% imidacloprid EC could control approximately 90% wheat aphids. Then the formulation of SL came second. Deposition parameters played a vital role in the process of controlling targets. In this study we used tracer method to determine the deposition of Allura Red on filter paper to represent the deposition of pesticide droplet. Theoretically, higher deposition signified that more pesticide effectively absorbed and used by wheat plants to control the aphids. The above datas of deposition were well verified this connection between droplet deposition and control efficacy. We could see formulation of EC and SL achieved better deposition rate than the formulation of WP and WDG. The deposition rate of 5% imidacloprid EC reached to 62.1%.

Table 3 Control efficacy and deposition of four imidacloprid formulation and three model of fan-nozzle

Treatment number	Nozzle type	Formulation	Deposition Rate/%	Control efficacy/%		
				1DAT	3DAT	7DAT
1	teejet11001vs	EC	62.1	89.4 a	94.7 a	97.7 a
2	teejet11001vs	WP	54.9	71.1b	82.9 b	85.1 ab
3	teejet11001vs	WDG	55.3	80.4ab	82.4 b	93.2 a
4	teejet11001vs	SL	58.7	86.1 a	90.5 a	95.7 a
5	teejet110015vs	SL	56.6	61.2c	78.1c	85.0ab
6	teejet11002vs	SL	54.8	71.9 b	82.5 b	85.8 ab

Note: DAT is days after treatment.

For three nozzles, results demonstrated from 1DAT teejet11001vs (1#) performed higher control efficacy than teejet110015vs (1.5#) and teejet11002vs (2#). And unsurprisingly, after treatment 7 days, 1# nozzle control efficacy reached to 95.7% which was higher than 1.5# and 2# 10.7% and 9.9% respectively. Similar to control efficacy results, the deposition rate results showed same tendency. The deposition rate of 1# nozzle was higher than 1.5# and 2# 2.1% and 3.9%. There was a biological optimal particle size relationship between droplet size and pesticide efficacy. Yuan et al. [15] verified that spray same volume, small droplet have widely biocide radius and performed better control efficacy than big droplet.

4 Conclusions

In this study, four kinds of imidacloprid (EC, SL, WP, WDG) formulation were applied by MG-1P UAV in the field. In addition, three fan-nozzles (teejet11001vs, teejet110015vs, teejet11002vs) were selected to spray 20% imidacloprid SL in the field. The droplet density, the droplet deposition on wheat canopy, deposition rate and the control efficacy on wheat aphids were evaluated in the research. The conclusions are shown as follows:

(1) The droplet density and deposition of four imidacloprid formulation was not significantly different. 25% imidacloprid WP showed the worst both on droplet density and deposition.

(2) The deposition uniformity on wheat plants from top to bottom of three nozzles was teejet11001vs (CV=22.8%) > teejet11002vs (CV=27.1%) > teejet110015vs (CV=57.4%), which the tendency was same with droplet density and deposition results.

(3) The control efficacy of different formulation was 5% imidacloprid EC (7DAT=97.7%) > 20% imidacloprid SL (7DAT= 95.7%) > 70% imidacloprid WDG (7DAT=93.2%) > 25% imidacloprid WP (7DAT=85.1%).

(4) Under the same operation parameters with 20% imidacloprid SL, the control efficacy of three nozzles was teejet11001vs (7DAT=95.7%) > teejet11002vs (7DAT=85.8%) > teejet110015vs (7DAT=85%), and the tendency was same with deposition results.

This study demonstrated excellent control efficacy and deposition of EC, SL to control wheat aphids and good deposition uniformity on wheat plants with teejet11001vs. At the same time, formulation of WP and nozzles of teejet110015vs were not recommended when using UAV sprayer to apply imidacloprid against wheat aphids according to our study results. It can be concluded that the appropriate pesticide formulation and spraying components can lead to good control efficacy and utilization rate of pesticide.

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