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Research Article

Improving control efficacy of pesticide sprayed by unmanned aerial vehicle using a compound

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Abstract

In this work, a synergist used for unmanned aerial vehicle (UAV) was fabricated by a compound including isooctyl alcohol (IA), xanthan gum (XG), methyl oleate (MO), etc. The optimum proportion of compound was obtained through measuring the surface tension, critical micelle concent (CMC) and other performances. Besides, the experiment of control efficiency on rice suggested synergist could improve utilization efficiency (UE) of pesticide effectively. Schematic illustration of the mechanism of synergist and digital photograph of water-dispersed paper was shown in Figure 1.

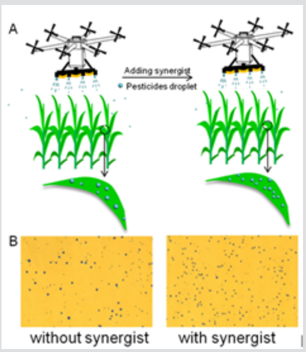

Figure 1: Schematic illustration of the mechanism of synergist and digital photograph of water-dispersed paper.

Keywords: Compound; Synergistic; Surfactant; Uav; Utilization Efficiency

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Introduction

In recent years, improving UE of pesticides has become more and more important in agricultural. UAV is one of the most advanced machine in modern plant protection field.[1-4] UAV does not need special landing site and will not be influenced by the air traffic control.[5] Thus, UAV is usually used for high-stalk crops field such as corn field compared with ground spraying equipment. Meanwhile, UVA is suitable for complex terrains like hilly regions and it can also reduce pesticides poisoning rate effectively because it separates staff from pesticides when it works[6,7].

However, there are also some disadvantages in UVA which limit its application. In the process of using UAV, droplets would drift and evaporate which cause drug damage to the non-target crops and environmental pollution.[8] Besides, droplets sizes of traditional pesticides from UVA is usually uneven. According to previous studies, the pesticides droplets of particle size between 60-90 μm has higher UE.[9] Smaller droplets are easy to drift under the action of propellers and wind,[10, 11] meanwhile, larger droplets tend to bounce on leaves surface will reduce pesticide deposition on the target plants.[12, 13] Besides, the lager surface tension of traditional pesticides can reduce the wetting permeability and shorten the time of staying on the leaves surface [14, 15].

Some studies suggested suitable surfactant could increase coverage of the droplets on the leaves and increase absorption rate effectively.[16-18] Thus, some researchers used viscous polymers to reduce the size and increase the rate of collision of droplets which could improve the UE of pesticide.[19-22] For the lacking of researches about reasonably adding surfactants in pesticides, this work fabricated a synergist suitable for UAV which could improve wettability, dispersibility, and permeability of pesticides. Meanwhile, this synergist could reduce the drift of droplets and surface tension effectively.

Methods

Materials: XG brought from Hua'en chemical Co. Ltd (Nanjing, China). Magnesium aluminum silicate (MAS) was brought from national pharmaceutical group corporation (Shanghai, China) Condensations of fatty alcohol with ethylene oxide, sodium diethylhexyl sulfosuccinate, poloxamer, fatty alcohol-polyoxyethylene ether, polyoxyethylene fatt, polyoxyethylene castor oil, polyoxyethylene sorbitan fatty acid ester, alkylphenol ethoxylates, styrylphenol polyoxyethylene ether (AE No.600), calcium dodecylbenzene sulfonate (AE No.500) were brought provided by Hai'an Petrochemical Plant (Jiangsu, China). Benzoyl propiconazole suspending agent (30%) was provided by Hulian Biological Pharmaceutical Co. Ltd (Shanghai, China). Imidacloprid emulsion (450g/L) was brought from Zhengye Zhongnong Hi-tech Co. Ltd. Information of 28 kinds of different surfactants and other material were shown in supporting imformation.

Instrument: The interfacial tension of droplets were observed on an automatic tension apparatus (BCZ-800, Benchuang instrument Co. Ltd). The size distribution of droplets were measured and analyzed by laser granularity instrument (319, Jinan winner particle instrument

Co. Ltd). Electricity heat drum wind drying oven brought by Yiheng Scientific Instrument Co. Ltd (Shanghai, China). And Multi-rotor UAV (P20) provided by Jifei technology Co. Ltd (Guangzhou, China). Thermal sprayer (TS-60S) brought by Longray tech Co. Ltd (Shenzhen, China).

Investigating surface tension and CMC of surfactant: 28 types (Table 1) of different surfactants were diluted 1000 times and the surface tension were measured according to the ring method.22 The surface tension was set as y-axis and the logarithm of concentration was set as x-axis. Then, the curve was plotted through origin data processing software and the inflection point was the CMC of surfactants.

Type	Code name
The condensation offatty alcohols andethylene oxide	JFC、JFC-1、JFC-2、JFC-M、JFC-S、JFC-E
Sodium diethylhexyl sulfosuccinate	T
Poloxamer	L64
Primary Alcobol Ethoxylate	MOA-7、O-20
Polyoxyethylene sorbitan monolaurate	T-20
Polyoxyethylene sorbitan monopalmate	T-40
Polyoxyethylene fatty acid	LAE-9、A-105、A-110、SG-9
Polyoxyethylene castor oil	EL-10、EL-12、EL-20、EL-40、EL-60、EL-80、EL90
Alkylphenol ethoxylates	OP-9、OP-10、TX-4、TX-5、TX-7、TX-9、TX-10、TX-13、TX-15

Table 1: Information of surfactant.

Ps: All the above were provided by Jiangsu Hai ‘an Petrochemical Plant

Determination size and distribution of droplet: For above 28 types of different surfactants, the volumetric weighted average diameter (VAD), dispersion coefficient (R.S), and the proportion of 60-90 μm of droplets were determine by Winner 319 spray laser. Therein, the droplets were obtained through a siphon conical nozzle (diameter of 1.0 mm, air pressure was 0.14 mPa, and liquid flow was 160 mL/min).

Permeability of surfactant investigated: The selected surfactants (0.4 mL) with deionized water (399.6 mL) were added in beaker respectively to obtain 400 mL solution (0.1%). Then, canvas sheets were placed in the top of the solution and the time of sinking to the bottom was record by stopwatch. The shorter infiltration time suggested permeability was better. After that, the top three surfactants with the shortest infiltration time and five commercial surfactants (Table 2) with good permeability were selected to prepare solution with different concentrations of 0.1%, 0.2%, 0.4%, 0.8% and 1% respectively. The penetration time was also record according to the above method.

Name	Proposed dosage	Manufacturer
A	40-80 mL/667m^2	Mingdelida Crop Technology Co. Ltd
B	15 g/667 m^2	Shufeng Crop Science Co. Ltd
C	5000 times diluent	NELESCO882(Pty)Ltd
D	3000-5000 times diluent	Nippon Kayaku Co. Ltd
E	50 mL/667 m^2	Anhui Huifuqiang Agricultural Science and Technology Co. Ltd

Table 2: Five commercial agent.

Investigating of anti-evaporation performance: The top three surfactants (0.1%, 200 mL) were added into a beaker (500 mL), and the same amount of deionized water was set as control cheak (CK) group. Then, those beakers were placed in a thermostatic water bath at 40°C for 24h. The weight was recorded and the ratio of water evaporation inhibition was calculated using the following equation (1)

$$R=(Wf - Wd)\div Wf\times 100\% \quad (1)$$

Wherein R was ratio of water evaporation inhibition, Wf and Wd were evaporation weight of blank control and experimental group respectively.

Orthogonal experiments (Table 3) were carried out to select suitable surfactant combinations according to ratio of water evaporation inhibition. Then, the optimal combinations was selected according to the results and XG (0.02%), MAS (0.025%), film forming agent (0.02%), and sedimentation agent (0.1% and 0.2%) were added to system to obtain synergist. Optimal combinations was only added in CK group and the water evaporation inhibitor of all group were calculated according to the above method.

Groups	Additive proportion(%)		
	IA	JFC	A-110
1	0.8	0.4	0.8
2	0.8	0.5	1
3	0.8	0.6	1.2
4	1	0.4	1
5	1	0.5	1.2
6	1	0.6	0.8
7	1.2	0.4	1.2
8	1.2	0.5	0.8
9	1.2	0.6	1

Table 3: Information of orthogonal design.

Investigating of effect of synergist on pesticide: Synergist was added into benzylpropiconazole suspension concentrates (SC) and emulsifiable concentrates (EC) respectively. Next, adding tap water into system until the volume was 1L. Then, the surface tension, time of wetting permeability, ratio of water evaporation inhibition, and droplet size and distribution of each treatment were measured through above method.

Control effect of synergist on rice investigated: The 30% prothioconazole (P) and rice (nanjing 9108) were selected as pesticide and target crop for control. Therein, the experiment were divided into five groups which were synergistic, agent A, B, E, and CK. Besides, every group included usual dose, 10% reduction dose, 20% reduction dose and 30% reduction dose. What's more, the CK was only water and each treatment zone covers 280 m2 was sprayed with 3 L of pesticides solution. Importantly, and the pesticides solution was applied at the rupturing stage.

There were three test points at the middle flight line of the UAV and the distance between two test points was 10 meters. At each test point, droplets test glasses were placed both on the left and right sides in parallel (height was 80 cm). Then, those glasses were retrieved after the UAV stopping spraying for 10min. Significantly, the tank on UAV was cleaned thoroughly before applying another pesticides solution. The retrieved glasses were observed through microscope

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and every glass was checked 100 areas. Afterwards, the number of droplets in unit area were recorded and the diameter of droplets was also measured.

After using pesticides solution, the control efficiency of synergistic on rice was investigated through five-point sampling method at milk stage period. 30 clusters of rice were investigated continuously at each point. Then, the level of infected plants and severity of disease were recorded. And the disease index (the standards of index judgment was shown in Tables 4 and 5 and control efficiency were calculated using the following equation (2 and 3).

$$\text{Disease index} = \sum (a \times b) \div (c \times d) \times 100 \quad (2)$$

Control efficiency (%) = (Disease index of control group-Disease index of study group) ÷Disease index of control group×100 (3)

Wherein a was number of diseased leaves at each grade, b was representative value of each grade, c was total number of leaves and d was representative value of highest.

The illness level	The number of false smut
0	0
1	1
2	2
3	3-5
4	6-9
5	≥10

Table 4: The grading standard of the disease of false smut.

The illness level	Sites of disease part	Area of disease
0	none	0
1	lower	10%-25%
2	lower middle	25%-50% 10%-25%
3	lower middle upper	≥50% 25%-50% 25%-25%
4	lower middle upper	≥90% ≥50% 25%-50%
5	all plant body	100%

Table 5: The grading standard of the disease of southern leaf blight of maize.

Results

Investigating of surfactant surface tension, CMC, droplet size and distribution: Spray tests of 28 surfactants solutions were carried out and the results were shown in Figure 2. The VAD and proportion of 60-90 μm of droplets were increased but R.S was decreased after adding surfactant (Figures 2A and C). What's more, all surfactants could increase the proportion of droplets of 60-90 μm except TX-7 (21.127%) compared with CK (21.383%). The TX-7 and TX-9 had higher R.S (1.89 and 1.871) compared with CK (1.852) suggested these two surfactants could disperse the droplets. According to Figure 2B, the CMC of MOA-7 and SG-9 were the lowest (0.0015%) and highest (0.3439%) respectively. And the data indicated there was no significant correlationship between the surface tension and the CMC.

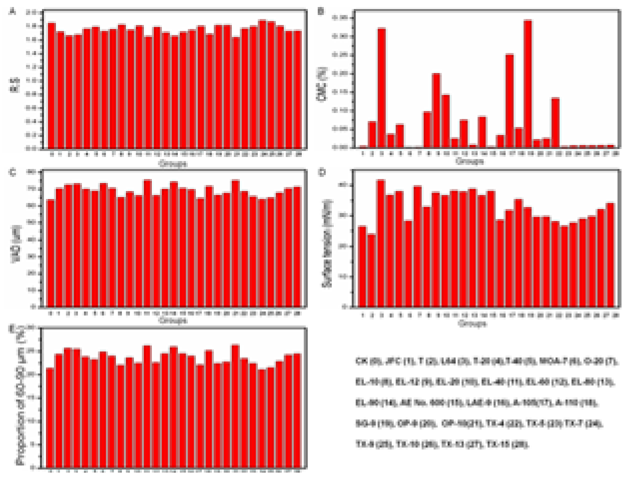

Figure 2: (A) R.S, (B) CMC, (C) VAD, (D) surface tension, and (E) proportion of 60-90 μm of different surfactants.

In Figures 3A and B, VAD was inversely proportional to R.S but proportional to the proportion of droplets (60-90μm). R.S and the dispersion of droplets decreased indicated the distribution of droplets became concentrate. There was a linear proportion by inversion between R.S and the droplet proportion of 60-90 μm. And the proportion of droplets (60-90 μm) decreased suggested the distribution of droplets became dispersed (Figure 3C).

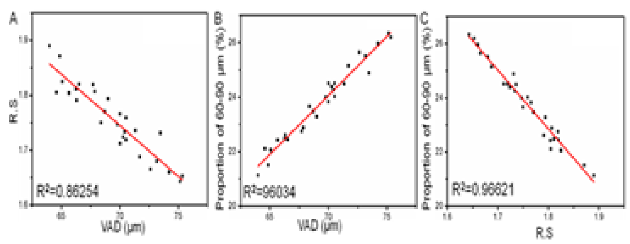

Figure 3: The linear relationship between R.S and VAD (A), proportion of 60-90 μm and VAD (B), proportion of 60-90 μm and R.S (C).

Preliminary screening of surfactant: In order to reduce the surface tension and dosage of surfactant meanwhile increase the adhesive on plant effectively. Preliminary screening criteria were as follows: surface tension was about 30-40 mN·M-1, smaller CMC and R.S, larger proportion of droplets (60-90 μm). Thus, JFC, T, MOA-7, LAE-9, OP-9, OP-10, A-110, EL-40, O-20, T-20, AE No. 600, TX-5, TX-7, TX-9, TX-10, and TX-13 were selected from 28 surfactants.

Permeability of surfactant investigated: The permeability time of the above 16 surfactants were tested and the results were shown in Figure 4C. According to Figure 4, the permeability time was related to surface tension. The surfactants with smaller surface tension had the shorter permeability time. However, the canvas sheet could not be infiltrated (OP-9, OP-10, TX-13, TX-15, A-110, T-20, AE No.600, and EL-40) when the surface tension was more than 30 mN/m. Thus, the surfactants JFC, T and TX-10 were selected from 16 surfactants.

According to Figure 5A, the permeability time of JFC was 25.17s while the canvas sheets did not sink in JFC-2 solution with surfactant proportion of additions of 0.1%. And in solution with surfactant

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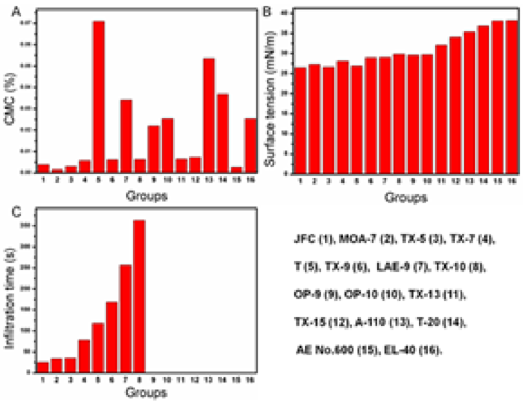

Figure 4: (A) CMC, (B) surface tension, and (E) infiltration time of different surfactants.

proportion of additions of 0.2%, the permeability time of JFC-E was 10.41s while the canvas did not sink for JFC-2. When surfactant proportion of additions was 0.4%, the longest and shortest permeability time were 4.19s (JFC-E) and 24.38s (JFC-2) respectively. And when surfactant proportion of additions was 0.8%, the longest and shortest permeability time were 3.11s (JFC-E) and 8.49s (JFC-M) respectively. Last, the longest and shortest permeability time were 2.94s (JFC-E) and 7.88s (JFC-M) respectively when surfactant proportion of additions was 1%.

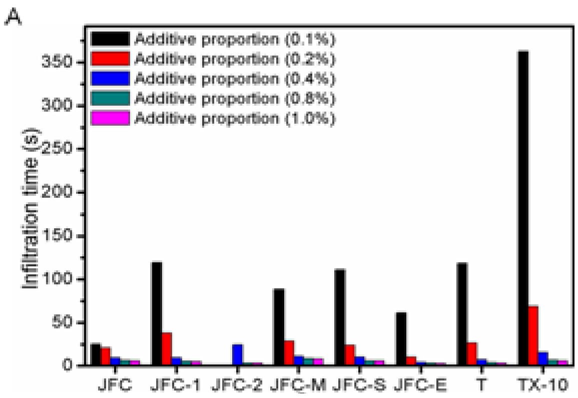

Figure 5(A): The infiltration time of surfactants with different proportion of additions.

Those results showed the permeability time was significantly shortened and tended to be stable with the increase of the concentration of the surfactant. Besides, the permeability time of JFC and JFC-M decreased by about 90% and the permeability time Tx-10 decreased by about 95% with the concentration increased from 0.1% to 1%. The permeation time of JFC-2 in solution with surfactant proportion of additions of 1% was only 3.14s. For all surfactants, the permeation time of solution tended to be stable in solution with surfactant proportion of additions of 0.8%-1%. Thus, the surfactants including JFC, JFC-2, JFC-E and T had better permeability.

Investigating of anti-evaporation performance: As shown in Figure 5B , A-110 and T-20 with addition amount of 1% had higher evaporation inhibition rates which were 10.8% and 11.5% respectively. And, TX-7 with addition amount of 0.5% had the highest moisture evaporation inhibition rate (7.5%), followed by JFC, LAE-9 and T-20 (5.9%, 5.6% and 5.1%). What's more, the evaporation inhibition rate of T-20 with addition amount of 0.1% was the highest (6.9%), followed by OP-9, TX-7 and A-110 (5.7%, 5.1% and 5%). JFC-E and OP-9 had the highest water evaporation inhibition rate with addition amount of 0.1% and AE No.600 and TX-13 had the highest water evaporation inhibition rate with the addition amount of 0.5%. TX-10, A-110, O-20, T-20 and OP-10 with addition amount of 1% had the highest water evaporation inhibition rate. The results suggested the relation between water evaporation inhibition rate and addition amount was different for different surfactants.

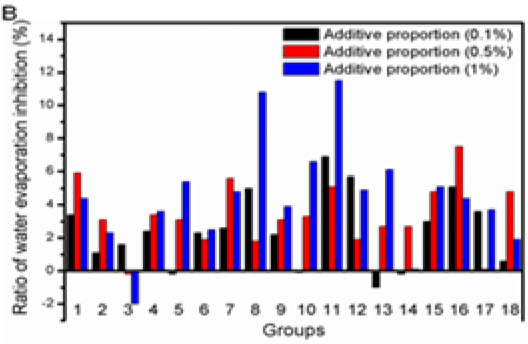

Figure 5 (B): The ratio of water evaporation inhibition of different surfactants.

Furthermore, the water evaporation inhibition rates of 10 organic compounds were also tested, and the results were shown in Figure 5C. IA with different addition amount both had better inhibitory effect of evaporation and the highest evaporation inhibition rate was reached 1%. And, isopropyl alcohol (0.1% and 1%), glycerol (0.1%), ethyl formate (1%), ethyl acetate (0.1% and 1%) could promote the evaporation of water. Besides, the evaporation inhibition rate was inversely proportional to addition amount of N-octanol but proportional to IA.

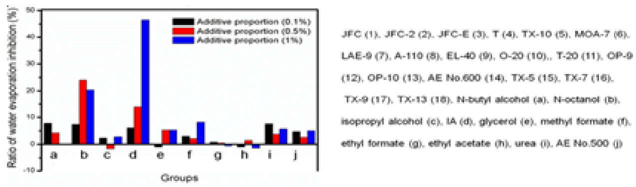

Figure 5 (C): different organic compounds in different proportions.

To consider the wet permeability of surfactants and the inhibition effect of evaporation, JFC, A-110, and IA were selected as compound surfactants. The orthogonal design was used to measure the water evaporation inhibition rates of three substances and the experiment contents were shown in Table 5. According to Figure 6, the water evaporation inhibition rate of the top three groups reached 68.0%, 67.2%, and 66.1% respectively.

Based on above data, the influence of common pesticide additives including XG, MAS, film agent and condensation nucleus with optimum WER on the water evaporation inhibition was tested. As shown in Figure 5B, after adding XG (0.02%), MAS (0.02%), film agent (0.02%) and condensation nuclear (0.1%) respectively, the water evaporation inhibition rate both remained above 60%. However, after adding 0.2% of condensed nuclear, the water evaporation inhibition rate decreased to 30.3% which suggested water evaporation inhibition rate was affected more by condensation nucleus.

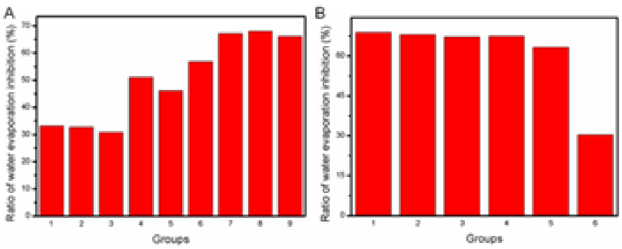

Figure 6: The ratio of water evaporation inhibition of orthogonal and different groups (WER (1), WER&0.02%XG (2) , WER&0.025%MAS (3), WER&0.02% film agent (4), WER&0.1% coagulant nucleus (5), and WER&0.2% coagulant nucleus (6)).

Investigating of effect of synergist on pesticide: JFC, A-110, and IA were selected as moisture evaporating inhibitor through analyzing evaporation inhibition and compatibility of surfactant. And for further improving pesticides adhesion on the targets and product stability, the final components of synergetic included IA (24%), JFC (12%), A-110 (16%), film formers (0.4%), XG (0.4%), condensation nucleus (2%), MAS (0.5%), MO (22.35%), and paraffin oil (22.35%).

The benzoylpropiconazole SC and EC were selected to test the effect of synergizing and other agents on the parameters including surface tension, infiltration time, and ratio of water evaporation inhibition. As shown in Figure 7, the surface tension of benzoyl propiconazole were between 27.4 and 28.8 mN/M which reduced significantly after adding synergist. And the infiltration time was also shortened which was between 4.07 and 4.81 s, indicating the synergist could improve wetting permeability effectively. Besides, the ratio of water evaporation inhibition was increased obviously after adding synergist.

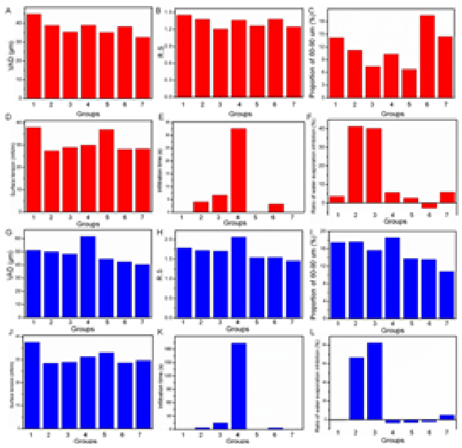

Figure 7: The effects of different additives (CK (1), synergist (2), agent A (3), agent B (4) agent C (5) agent D (6), agent E (7)) on the surface tension, infiltration time, ratio of water evaporation inhibition rate, VAD, R.S. and droplet distribution of benzoyl propiconazole SC (A-F) and (G-L) EC.

Furthermore, according to Figure 7, VAD and R.S of benzoyl propiconazole SC and EC were both lower after the addition of different additives expect agent B suggested the distribution of fog drops became more concentrated. However, those additives had only a minimal effect on proportion of 60-90 µm. According to the results, the surface tension of benzoylpropiconazole SC and EC could be reduced significantly meanwhile the wetting permeability performance could be enhanced by synergizers.

Control effect on rice investigated: The field experiment was shown in Figure 8. And results of the control effect (Figure 8) were showed a downward trend with the decrease of pesticide dosage. Therein, the control effect of four additives groups were slightly reduced with pesticide dosage decreased. Obviously, P with synergist had better control effect. Besides, the control effect of synergistic and agent A groups could maintain above 60% when pesticide dosage reduced by 20%. The control effect was not change significantly when pesticide dosage reduced by 10% and 20%. However, the control effect was reduced obviously when pesticide dosage reduced by 30%. Therefore, the pesticide dosage can only reduced by 20% for ensuring control effect.

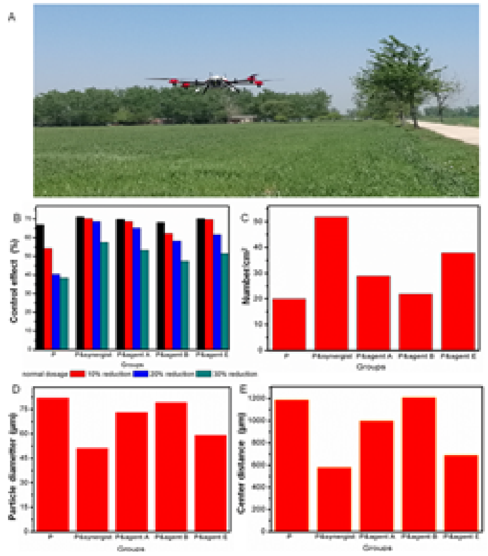

Figure 8: Digital photograph of UVA in filed (A) and the effect of reducing pesticide on rice by using UVA (B), and distribution and size of droplets on rice (C-E).

What's more, the distribution and size of droplets were different in every groups. For P group, droplets had the minimum quantity (20/cm2), the biggest particle size (82µm), and the longest center distance (1190 µm). For group of P&synergist, the droplets had the maximum quantity (52/cm2), and the shortest center distance (51 µm) which suggested the distribution of droplets was the most densely.

Conclusion

In this work, a synergist for pesticide sprayed by unmanned aerial vehicle which could increase adhesion and reduce drift of pesticides effectively. The optimum components of synergist was obtain through investigating the surfactant surface tension, CMC, droplet size and distribution of droplets. The formulation of synergist was IA (24%), JFC (12%), A-110 (16%), film forming agent (0.4%), XG (0.4%), coagulated nuclear material (2%), MAS (0.5%), MO (22.35%), and paraffin oil (22.35%).What's more, the results of field experiment on rice suggested the control effect of pesticide could achieve 60% when the dosage of pesticide is reduced by 10% to 20% after adding synergist. Thus, this synergist could improve the UE effectively and reduce environmental pollution which has great application prospects in agriculture.

Authorship contribution statement

Yu Chi: Designing experiments, Data acquisition and Analysis, Writing–review & editing, Xianyan Su: Data acquisition and Analysis, Writing–review & editing, Fei Hu: Formal analysis, Writing–review & editing. Zhao Li: Formal analysis, Writing–review & editing. Zhenghe Ye: Writing–review & editing. Xuexiang Ren:Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Graphical Abstract

In this work, a synergist used for unmanned aerial vehicle (UAV) was fabricated by a compound including isooctyl alcohol (IA), xanthan gum (XG), methyl oleate (MO), etc. This synergist could increase adhesion and reduce drift of pesticides, besides, it also could improve the UE effectively and reduce environmental pollution which has great application prospects in agriculture.

Highlights

- A synergist for pesticide sprayed by unmanned aerial vehicle is developed.
- The synergist can efficiently improve the utilization efficiency of pesticide.
- The synergist has the advantages of simple process and low cost.

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