ASSESSMENT OF PESTICIDE MIXTURES FOR UNMANNED AERIAL SPRAYING IN RICE: A PHYSICAL COMPATIBILITY PERSPECTIVE

Abstract

The use of drone spraying technology has shown great promise in overcoming the limitations of manual spraying in agriculture. However, ensuring the physical compatibility of pesticide mixtures for drone applications remains a crucial aspect. In this study, we conducted an experiment to investigate the physical compatibility of five insecticides *viz,* chlorantraniliprole 18.5% SC, tetraniliprole 200 SC, cartap hydrochloride 50% SP, flubendiamide 39.35% SC, and acephate 50% + imidacloprid 1.8% SP with five fungicides*viz*, picoxystrobin 7.5% + tricyclazole 22.5% SC, azoxystrobin 18.2% + difenoconazole 11.4% SC, tebuconazole 50% + trifloxystrobin 25% WG, picoxystrobin 7% + propiconazole 12% SC, and prochloraz 23.5% + tricyclazole 20% SE at drone and taiwan spraying concentrationsby jar compatibility test. Among the 25 combinations tested only seven combinations at drone spraying concentration showed foaming ranging from 15-20ml/l. Furthermore, none of the pesticides or their combinations shown alkaline pH. Thus, all the pesticide combinations demonstrated resistance to alkaline degradation, potentially leading to the formation of sedimentation when these pesticides are combined.

Keywords: Pesticide compatibility, drone spraying, taiwan sprayer, jar compatibility test, Compatibility issues, alkaline degradation, pesticide combinations.

Introduction

In the field of agriculture, the application of pesticides has traditionally been carried out through two methods: ground spraying and aerial spraying (Faical *et al.*, 2017). However, ground spraying poses significant challenges, including increased pesticide exposure for operators and potential issues with spray dispersal, leading to ineffective chemical application. Operators using manual backpack sprayers are exposed to highly toxic pesticides, resulting in acute poisoning cases reported by the World Health Organization (WHO) affecting approximately 1,000,000 individuals annually. The fatality rate ranges between 0.4 to 1.9 percent due to exposure to these toxic substances (Tudi *et al*., 2021). Moreover, spraying pesticides in rice fields presents additional difficulties due to water, low-lying patches, and salinity resulting from monocropping practices.

On the other hand, aerial application systems, such as Unmanned Aerial Vehicles (UAVs), have emerged as a solution to mitigate the risks associated with ground spraying.

UAVs, operated remotely or in autonomous mode, offer enhanced safety for operators by spraying pesticides from above the plants without entering the crop, thereby minimizing the risk of crop damage. Utilizing UAVs provides several advantages, including improved manoeuvrability, light weight, increased efficiency, timely coverage of larger areas, and the ability to spray in complex terrains. As a result, the adoption of UAVs in agriculture is expected to experience significant growth over the next decade.According to global marketintelligence and advisory firm BIS research, the global drone market, which is currently dominatedbyUS,China,andIsrael,willtouch$28.47billion[Rs209,692crore]thisyear,outofwhichIndiawillcontribute about 4.25 per cent. The drone market in India is expected to reach $1.21 billion (Rs 8,911crore) in CY 2021. It is likely to touch $1.81 billion (Rs 13,330 crore) by FY 2026 growing at acompound annual growth rate (CAGR) of 14.61 percent. Therefore, Govt. of India is focusing onbringing drone-based technologies in agriculture and implementing pro-drone policies as one of themusthavetechnology.

However, despite the numerous benefits offered by drone spraying, there are compatibility issues that need to be addressed. Farmers often need to manage multiple insect pests and diseases simultaneously, requiring either multiple applications of pesticides or the use of pesticide mixtures. The inadequate knowledge of pesticide compatibility can lead to phytotoxicity or reduced efficacy. Furthermore, information regarding the compatibility of newer combinations of insecticides and fungicides is scarce and insufficient, particularly when applied using drone spraying equipment. Incompatibility between pesticides can result in phytotoxicity, reduced efficacy, or even contribute to pesticide resistance (Peshney, 1990).

To address these concerns, an experiment was conducted to test the physical compatibility of pesticide combinations at drone spraying concentrations in comparison with taiwan sprayer concentrations. This experiment was aimed to provide insights into the compatibility of pesticide mixtures for drone spraying and to ensure their safe and effective use in the field.

Materials and Methods

The physical compatibility of 10 individual pesticides as represented in Table1. (5 insecticides and 5fungicides) and their combinations (25) with drone (UAV)and manual spraying (taiwan sprayer) concentrations wereevaluated under laboratory conditions by conducting jar compatibility test. The selection of pesticides was done based on their cost, broad-spectrum nature, and availability in the market.

Pesticides used in the study:

The twenty-five pesticide combinations involving five insecticides *viz.*, chlorantraniliprole18.5%SC, tetraniliprole200SC, cartap hydrochloride 50% SP, flubendiamide39.35%SC and acephate50% + imidacloprid1.8%SP and five fungicides *viz.*,picoxystrobin 7.5% + tricyclazole 22.5% SC, azoxystrobin18.2% + difenoconazole11.4%SC, tebuconazole50% + trifloxystrobin25% WG, picoxystrobin7% + propiconazole12%SC and prochloraz 23.5% + tricyclazole 20% SE at both taiwan and drone spraying dose were tested for physical compatibility through jar compatibility test.

In the study, the pesticide dosage (*a.i.* dose ha^{-1}) used for conventional spray, as recommended by the Central Insecticides Board and Registration Committee (CIB&RC), was followed for both drone spraying and taiwan sprayer application. This means that, the active ingredient (*a.i.*) dose per hectare remains the same for both drone and taiwan sprayer application. However, there was a difference in the spray volume applied between the two methods. For drone spraying, a spray fluid of 40 l ha^{-1} was used, while for taiwan spraying, a spray volume of 375 l ha^{-1} was considered. For preparing pesticide combinations, the recommended dose of insecticide and fungicide per acre was taken as per CIB&RC recommendations. The doses were then calculated for taiwan sprayer and drone sprayer per liter of water, considering a spray volume of 375 l ha^{-1} for taiwan sprayer and 40 l ha^{-1} for drone spraying. For instance, the recommended dose of azoxystrobin 18.2% SC + difenconazole 11.4% SC is 1 ml l^{-1} for conventional spray, 1.33 ml l^{-1} for taiwan sprayer, and 12.5 ml l^{-1} for drone spraying.

Jar Compatibility test:

The experiment was conducted at Institute of Rice Research, ARI, PJTSAU, Rajendranagar, Hyderabad during 2022.The physical compatibility of 10 individual pesticides (5 insecticides and 5fungicides) and their combinations (25) with droneand manual spraying (taiwan sprayer) concentrations wereevaluated under laboratory conditionsby conducting jar compatibility test as prescribed by Indian Standards Specifications (IS, 1973) andpH of all pesticides individually and in combinations was measured by using pH meter under laboratory conditions. The standard reference temperature used for calibration was 25 ^{0}C (Rajasekar and Mallapur, 2017).For jar compatibility test, the water was taken from the same water source that was used for tank mixes. Measured quantity of water was taken in a one-litre jar to which one insecticide and fungicide were added at recommended doses in the following order as per "WALES" (Suganthy *et al*.,2010) wettable powder (WP) and water dispersible granules (WDG), liquid flowables and suspensions, emulsifiable concentrates (EC) and soluble concentrates (SC).Then, the volume was made up to one liter with hard water, agitated by shaking the jar and transferred 100 ml of this pesticide solution to 100 ml knobbed and calibrated measuring cylinder and left undisturbed for 60 minutes. Observations were recorded after 30 and 60 minutes with respect to foaming and sedimentation.

Measurement of pH of pesticide solutions:

The pH of insecticides and fungicides alone and in combinations both at taiwan and drone spraying dose was recorded. While measuring pH, first thepH meter was calibrated by using buffer tablets withthe standard reference temperature of 25^0C.For taking observations, electrodes were submerged in the sample of pesticide solutions and stirred for a few seconds, further allowed the values to stabilize and finally recorded readings.

Results and Discussion:

Jarcompatibilitytest:

From the results of jar compatibility test as represented in Table 2, outofthe25combinationstested, foaming and sedimentation was not observed in any of the combinations at taiwan sprayer concentrations.However, at the drone spraying concentrations foamingof20ml/l wasobservedwithcartap hydrochlorideincombinationwithpicoxystrobin + tricyclazole and cartap hydrochlorideincombinationwithtebuconazole+trifloxystrobin.Similarly, tetraniliprole in combination with prochloraz + tricyclazole, cartaphydrochloride in combination with prochloraz + tricyclazole, flubendiamide in combination with picoxystrobin+ propiconazole, flubendiamide in combination with prochloraz + tricyclazoleand acephate + imidacloprid incombination with prochloraz + tricyclazoleshown foaming of 15ml/l.The rest of the combinations showed no foaming or sedimentation and blended properly. The results of the present study are in line with reports of Visalakshmi *et al.* (2016) conducted lab and field experiments in rice to evaluate the compatibility and efficacy of five insecticides *viz.*, chlorantraniliprole 18.5 % SC. chlorpyriphos 20 % EC, cartap hydrochloride 50 SP, flubendiamide 480 SC, profenofos 50 EC with two fungicides propiconazole and trifloxystrobin 25 % + tebuconazole 50 % and concluded that all the combinations are physically compatible. Sandhya *et al.* (2021) conducted a laboratory experiment to study the physical compatibility of four insecticides lambda cyhalothrin 4.6 % + chlorantraniliprole 9.8 % EC, chlorantraniliprole 18.5 % SC, flubendiamide 39.35 % SC, azadirachtin 1500 ppm and two fungicides azoxystrobin 18.4 % + difenoconazole 11.4 % SC, carbendazim 12 % + mancozeb 63 % WP and the results shown that all the combinations are physically compatible. Prajapati *et al.* (2005) studied the physical compatibility of insecticides *viz.*, cartap hydrochloride 50 WP (0.05 %) and triazophos 20 EC (0.02 %) with fungicides *viz.*, carbendazim 50 WP (0.05 %), tricyclazole 75 WP (0.04 %), propiconazole 25 EC (0.025 %) and hexaconazole 5 EC (0.01 %) in rice and stated that cartap hydrochloride can be mixed with all the fungicides tested but triazophos is compatible with only carbendazim and tricyclazole. Bhatnagar (2004) evaluated the compatibility of pesticides against rice leaf folder and blast. Insecticides *viz.*, triazophos 20 EC, cartap hydrochloride 50 WP and fungicides *viz.*, tricyclazole 75 WP, carbendazim 50 WP were evaluated by jar compatibility test and reported that all the combinations are physically compatible.

pHdeterminationofpesticidesaloneand in combinations at 25^0 C:

The pH ofpesticide mixtures will have profound influence on the bio-efficacy of the pesticides andalso affect the plants by resulting in phytotoxicity. In this study, the pH of individual pesticides was examined at taiwan sprayer concentrations and drone spraying concentrations, as shown in Table 3. Additionally, Table 4 presents the pH values of pesticide combinations at both taiwan sprayer concentrations and drone spraying concentrations. Comparing the pH of pesticide combinations at drone spraying concentrations to that of taiwan sprayer concentrations, slight variations were observed. The pH of pesticide combinations at drone spraying concentrations tended to decrease, resulting in more acidic pesticide solutions compared to taiwan sprayer concentrations. Certain combinations involving the pesticide cartap hydrochloride 50% SP, when applied with both sprayer types, resulted in moderately to very strongly acidic conditions. These combinations may require additional pH adjustment measures for effective application. However, none of the pesticide combinations, at either taiwan sprayer concentrations or drone spraying concentrations, exhibited an alkaline pH. This suggests that the pesticide combinations remained resistant to alkaline degradation. Consequently, none of the pesticide combinations exhibited sedimentation in the jar compatibility test, further supporting their stability. The outcome of the present study is in line with the findings of Seaman and Riedl (1976) who revealed that azadiractin (Azatin XL) should be maintained at pH 5-7 and applied soon after mixing which otherwise will rapidly hydrolyzes in more acidic or alkaline conditions.

The pH stability of pesticide combinations is crucial for maintaining their efficacy and minimizing the potential adverse effects on plants. However, it is important to note that physical compatibility and pH alone does not provide a complete assessment of compatibility. Other factors, such as chemical interactions and physical properties, should be considered to ensure optimal pesticide performance.

Table 1Details of insecticides and fungicides tested for physical compatibility

S.no	Pesticides	Trade name	Recommended dose (g or ml ha^{-1})	Taiwan sprayer dose (g or ml lit^{-1} of water)	Drone spraying dose (g or ml lit^{-1} of water)	Source of supply
1	Chlorantraniliprole18.5%SC	Coragen	@ 150 ml	0.4 ml	3.75 ml	FMC India Pvt.Ltd., Gujarat.
2	Tetraniliprole200SC	Vayego	@ 200 ml	0.6 ml	6.25 ml	Bayer Crop Science Ltd., Mumbai.
3	Cartaphydrochloride50%SP	Caldan	@ 1000 g	2.66 g	25 g	Dhanuka Agritech Ltd., Ahmadabad
4	Flubendiamide39.35%SC	Fame	@ 50 ml	0.13 ml	1.25 ml	Bayer Crop Science Ltd., Mumbai.
5	Acephate50% + Imidacloprid1.8%SP	Starthene Power	@ 1250 g	3.33 g	18.75 g	SWAL Corporation Ltd. New Delhi.
6	Picoxystrobin7.5% + Tricyclazole22.5%SC	Galileo Sensa	@ 1000 ml	2.66 ml	25 ml	Dupont India Pvt.Ltd., Gujarat.
7	Azoxystrobin18.2% + Difenoconozole11.4%SC	Amistar Top	@ 500 ml	1.33 ml	12.5 ml	Syngenta India Ltd., Mumbai
8	Tebuconazole50% + Trifloxystrobin25% WG	Nativo	@ 200 g	0.5 g	4.68 g	Bayer Crop Science Ltd., Mumbai.
9	Picoxystrobin7% + Propiconazole12%SC	Galileo Way	@ 1000 ml	2.66 ml	25 ml	Dupont India Pvt.Ltd., Gujarat.
10	Prochloraz 23.5% + Tricyclazole 20% SE	Blacil	@ 1000 ml	2.66 ml	25 ml	Adama India Pvt.Ltd. Gujarat.

Table 2 Physical compatibility of insecticides and fungicides

S. No	Pesticide combinations	Taiwan sprayer concentration			Drone concentration		
		Foaming (ml/l)	Sedimentation (ml/l)	Compatibility Reaction	Foaming (ml/l)	Sedimentation (ml/l)	Compatibility Reaction
1	Chlorantraniliprole 18.5% SC + Picoxystrobin 7.5%+Tricyclazole 22.5% SC	0	0	Compatible	0	0	Compatible
2	Chlorantraniliprole 18.5% SC + Azoxystrobin 18.2%+Difenoconozole 11.4% SC	0	0	Compatible	0	0	Compatible
3	Chlorantraniliprole 18.5% SC + Tebuconazole 50%+Trifloxystrobin 25% WG	0	0	Compatible	0	0	Compatible
4	Chlorantraniliprole 18.5% SC + Picoxystrobin 7%+Propiconazole 12% SC	0	0	Compatible	0	0	Compatible
5	Chlorantraniliprole 18.5% + Prochloraz 23.5% + Tricyclazole 20% SE	0	0	Compatible	0	0	Compatible
6	Tetraniliprole 200 SC + Picoxystrobin 7.5%+Tricyclazole 22.5% SC	0	0	Compatible	0	0	Compatible
7	Tetraniliprole 200 SC + Azoxystrobin 18.2% + Difenoconozole 11.4% SC	0	0	Compatible	0	0	Compatible
8	Tetraniliprole 200 SC + Tebuconazole 50%+Trifloxystrobin 25% WG	0	0	Compatible	0	0	Compatible
9	Tetraniliprole 200 SC + Picoxystrobin 7%+Propiconazole 12% SC	0	0	Compatible	0	0	Compatible
10	Tetraniliprole 200 SC + Prochloraz 23.5% + Tricyclazole 20% SE	0	0	Compatible	15	0	Incompatible
11	Cartap hydrochloride 50% SP + Picoxystrobin 7.5%+Tricyclazole 22.5% SC	0	0	Compatible	20	0	Incompatible
12	Cartap hydrochloride 50% SP + Azoxystrobin 18.2%+Difenoconozole 11.4% SC	0	0	Compatible	0	0	Compatible

13	Cartap hydrochloride 50% SP + Tebuconazole 50%+Trifloxystrobin 25% WG	0	0	Compatible	20	0	Incompatible
14	Cartap hydrochloride 50% SP + Picoxystrobin 7%+Propiconazole 12% SC	0	0	Compatible	0	0	Compatible
15	Cartap hydrochloride 50% SP + Prochloraz 23.5% + Tricyclazole 20% SE	0	0	Compatible	15	0	Incompatible
16	Flubendiamide 39.35% SC + Picoxystrobin 7.5%+Tricyclazole 22.5% SC	0	0	Compatible	0	0	Compatible
17	Flubendiamide 39.35% SC + Azoxystrobin 18.2%+Difenoconozole 11.4% SC	0	0	Compatible	0	0	Compatible
18	Flubendiamide 39.35% SC + Tebuconazole 50%+Trifloxystrobin 25% WG	0	0	Compatible	0	0	Compatible
19	Flubendiamide 39.35% SC + Picoxystrobin 7%+Propiconazole 12% SC	0	0	Compatible	15	0	Incompatible
20	Flubendiamide 39.35% SC + Prochloraz 23.5% + Tricyclazole 20% SE	0	0	Compatible	15	0	Incompatible
21	Acephate 50%+Imidacloprid 1.8% SP + Picoxystrobin 7.5%+Tricyclazole 22.5% SC	0	0	Compatible	0	0	Compatible
22	Acephate 50%+Imidacloprid 1.8% SP + Azoxystrobin 18.2%+Difenoconozole 11.4% SC	0	0	Compatible	0	0	Compatible
23	Acephate 50%+Imidacloprid 1.8% SP + Tebuconazole 50%+Trifloxystrobin 25% WG	0	0	Compatible	0	0	Compatible
24	Acephate 50%+Imidacloprid 1.8% SP + Picoxystrobin 7%+Propiconazole 12% SC	0	0	Compatible	0	0	Compatible
25	Acephate 50%+Imidacloprid 1.8% SP + Prochloraz 23.5% + Tricyclazole 20% SE	0	0	Compatible	15	0	Incompatible

Table 3pH of individual pesticides at taiwan and drone sprayer concentrations

S. No	Pesticides	Taiwan sprayer concentration		Drone concentration	
		pH	Nature	pH	Nature
1	Chlorantraniliprole18.5%SC	6.32	Slightly acidic	6.28	Slightly acidic
2	Tetraniliprole200SC	6.50	Slightly acidic	6.32	Slightly acidic
3	Cartaphydrochloride50%SP	5.68	Moderately acidic	4.97	Very strongly acidic
4	Flubendiamide39.35%SC	6.27	Slightly acidic	6.24	Slightly acidic
5	Acephate50% + Imidacloprid1.8%SP	6.23	Slightly acidic	5.93	Moderately acidic
6	Picoxystrobin7.5% + Tricyclazole22.5%SC	6.44	Slightly acidic	6.42	Slightly acidic
7	Azoxystrobin18.2% + Difenoconozole11.4%SC	6.40	Slightly acidic	6.38	Slightly acidic
8	Tebuconazole50% + Trifloxystrobin25% WG	6.58	Neutral	6.68	Neutral
9	Picoxystrobin7% + Propiconazole12%SC	6.32	Slightly acidic	6.28	Slightly acidic
10	Prochloraz 23.5% + Tricyclazole 20% SE	6.60	Neutral	6.38	Slightly acidic

Table 4 pH of insecticide and fungicide combinations at taiwan and drone sprayer concentrations

S. No	Pesticide combinations	Taiwan sprayer concentration		Drone concentration	
		pH	Nature	pH	Nature
1	Chlorantraniliprole 18.5% SC + Picoxystrobin 7.5%+Tricyclazole 22.5% SC	6.59	Neutral	6.42	Slightly acidic
2	Chlorantraniliprole 18.5% SC + Azoxystrobin 18.2%+Difenoconozole 11.4% SC	6.71	Neutral	6.32	Slightly acidic
3	Chlorantraniliprole 18.5% SC + Tebuconazole 50%+Trifloxystrobin 25% WG	6.70	Neutral	6.64	Neutral
4	Chlorantraniliprole 18.5% SC + Picoxystrobin 7%+Propiconazole 12% SC	6.59	Neutral	6.40	Slightly acidic
5	Chlorantraniliprole 18.5% + Prochloraz 23.5% + Tricyclazole 20% SE	6.63	Neutral	6.40	Slightly acidic
6	Tetraniliprole 200 SC + Picoxystrobin 7.5%+Tricyclazole 22.5% SC	6.60	Neutral	6.49	Slightly acidic
7	Tetraniliprole 200 SC + Azoxystrobin 18.2%SC + Difenoconozole 11.4% SC	6.62	Neutral	6.63	Neutral
8	Tetraniliprole 200 SC + Tebuconazole 50%+Trifloxystrobin 25% WG	6.88	Neutral	6.70	Neutral
9	Tetraniliprole 200 SC + Picoxystrobin 7%+Propiconazole 12% SC	6.66	Neutral	6.50	Slightly acidic
10	Tetraniliprole 200 SC + Prochloraz 23.5% + Tricyclazole 20% SE	6.70	Neutral	6.45	Slightly acidic
11	Cartap hydrochloride 50% SP + Picoxystrobin 7.5%+Tricyclazole 22.5% SC	5.63	Moderately acidic	4.83	Very Strongly acidic
12	Cartap hydrochloride 50% SP + Azoxystrobin 18.2%SC+Difenoconozole 11.4% SC	5.62	Moderately acidic	4.87	Very Strongly acidic

13	Cartap hydrochloride 50% SP + Tebuconazole 50%+Trifloxystrobin 25% WG	5.63	Moderately acidic	4.97	Very Strongly acidic
14	Cartap hydrochloride 50% SP + Picoxystrobin 7%+Propiconazole 12% SC	5.63	Moderately acidic	4.90	Very Strongly acidic
15	Cartap hydrochloride 50% SP + Prochloraz 23.5% + Tricyclazole 20% SE	5.61	Moderately acidic	5.00	Very Strongly acidic
16	Flubendiamide 39.35% SC + Picoxystrobin 7.5%+Tricyclazole 22.5% SC	6.62	Neutral	6.56	Neutral
17	Flubendiamide 39.35% SC + Azoxystrobin 18.2%SC+Difenoconozole 11.4% SC	6.60	Neutral	6.52	Neutral
18	Flubendiamide 39.35% SC + Tebuconazole 50%+Trifloxystrobin 25% WG	6.77	Neutral	6.64	Neutral
19	Flubendiamide 39.35% SC + Picoxystrobin 7%+Propiconazole 12% SC	6.61	Neutral	6.52	Neutral
20	Flubendiamide 39.35% SC + Prochloraz 23.5% + Tricyclazole 20% SE	6.64	Neutral	6.60	Neutral
21	Acephate 50%+Imidacloprid 1.8% SP + Picoxystrobin 7.5%+Tricyclazole 22.5% SC	6.40	Slightly acidic	5.90	Moderately acidic
22	Acephate 50%+Imidacloprid 1.8% SP + Azoxystrobin 18.2%+Difenoconozole 11.4% SC	6.42	Slightly acidic	5.90	Moderately acidic
23	Acephate 50%+Imidacloprid 1.8% SP + Tebuconazole 50% +Trifloxystrobin 25% WG	6.50	Slightly acidic	5.83	Moderately acidic
24	Acephate 50%+Imidacloprid 1.8% SP + Picoxystrobin 7% +Propiconazole 12% SC	6.35	Slightly acidic	5.82	Moderately acidic
25	Acephate 50% + Imidacloprid 1.8% SP + Prochloraz 23.5% + Tricyclazole 20% SE	6.41	Slightly acidic	5.83	Moderately acidic

Conclusion

Itisevidentfromthejarcompatibilitytest results thatoutof25pesticidecombinations at taiwan sprayer concentrations and at drone spraying concentration evaluated,25 combinations of taiwan sprayer concentration and 18 combinations of drone spraying concentration showedneitherfoamingnorsedimentation,whiletheremaining seven combinations at drone spraying concentrations showed foaming ranging from 15-20 ml/l. These seven combinationsweretreated as physicallyincompatible and rest of the combinations can be takeover to semi-field and field conditions for further tests like bio-efficacy and phytotoxicity studies.

Future Scope

The compatible pesticide combinations for drone spraying should be evaluated for their efficacy in real world field conditions along with their potentialimpact on environment.Integrating the compatible pesticide combinations with other pest management approaches, such as biological control, cultural practices, and resistant crop varieties, to develop holistic and sustainable IPM strategies for rice cultivation. Future research avenues would contribute to a deeper understanding of the identified pesticide combinations, their practical applicationsin drone spraying, and their potential benefits in terms of pest control, crop protection, and environmental sustainability.

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