Original Research Article

Evaluation of the Physical Compatibility of Biopesticides and Chemical Pesticides for Drone Application

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ABSTRACT

Drone spraying technology has demonstrated significant potential in addressing the challenges associated with manual spraying in agriculture. Nevertheless, guaranteeing the physical compatibility of pesticide mixtures for use in drone applications is a vital consideration. The present study assessed the physical compatibility of various insecticide, fungicide, and biopesticide combinations using jar compatibility test at drone and taiwan sprayer doses. Eight insecticide-biopesticide combinations and six fungicide-biopesticide combinations were assessed, revealing no physical incompatibilities such as foaming or sedimentation. Specific combinations, including *Bacillus thuringiensis* var. *kurstaki* with chlorantraniliprole and tetraniliprole, exhibited excellent physical stability without foaming or sedimentation. In contrast, combinations with flubendiamide and cartap hydrochloride showed minor foaming but remained within acceptable limits. pH analysis indicated that most pesticides and their combinations maintained a neutral reaction, except for cartap hydrochloride, which displayed significant acidity, and a few combinations that showed slight pH shifts. These findings confirm the overall physical and chemical compatibility of the tested mixtures, ensuring their suitability for agricultural applications.

Keywords: Drone spraying technology, physical compatibility, Insecticide-biopesticide combinations, jar compatibility test, pH analysis.

1. INTRODUCTION

In the realm of global agriculture, rice stands as a cornerstone, serving as a primary food source for over half of the world's population. However, the cultivation of this vital crop faces relentless threats from pests and diseases despite its 2023 global production of 509 million metric tons, mainly from Asia (FAO, 2023). Pests like rice stem borer and diseases such as sheath blight cause significant yield losses, up to 30%, demanding urgent attention amidst climate change and evolving pest populations [1].

The rise of drone technology is revolutionizing pesticide spraying, heralding a new era in precision agriculture. Pesticide spraying drones, equipped with advanced navigation and application systems, offer unprecedented accuracy and efficiency, reshaping the way farmers protect their crops [2]. With the ability to apply precise amounts of pesticides only where needed, drones minimize waste, reduce environmental impact, and promote sustainable farming practices. As the agricultural sector increasingly adopts these innovative solutions, understanding the intricacies of drone-based pesticide application becomes essential [3-5].

The global market for agricultural drones was valued at USD 1.7 billion in 2022 and is anticipated to reach USD 7.9 billion by 2030, expanding at a CAGR of 21.2% from 2022 to

2030 [6]. The advent of drone technology has transformed modern agriculture, introducing precise, efficient, and cost-effective methods for pesticide application. As farmers and agricultural professionals increasingly adopt drones for crop protection, the integration of biopesticides and chemical pesticides presents both new opportunities and challenges [7]. Biopesticides, derived from natural sources are prized for their environmental benefits and targeted pest control capabilities. In contrast, chemical pesticides are valued for their rapid action and broad-spectrum efficacy.

The concurrent use of biopesticides and chemical pesticides can significantly enhance integrated pest management strategies. However, their physical compatibility, particularly at drone application dosages, is a critical concern. Physical compatibility refers to the ability of different pesticide formulations to be mixed and applied together without adverse reactions such as phase separation, precipitation, or a reduction in efficacy. Ensuring this compatibility is essential to maintaining the effectiveness and safety of pest control measures in drone-based applications.

Insufficient knowledge regarding pesticide compatibility can lead to phytotoxicity or decreased efficacy. Additionally, there is a significant gap in information about the compatibility of newer insecticides and fungicides with biopesticides particularly when applied with drone spraying technology. To address these issues, a study was conducted to assess the physical compatibility of pesticide combinations at drone spraying concentrations compared to traditional taiwan sprayer concentrations. This study aimed to provide valuable insights into the compatibility of pesticide mixtures for drone applications, ensuring their safe and effective use in agricultural settings.

2. MATERIAL AND METHODS

In this experiment four (4) insecticides (flubendiamide 39.35% SC, chlorantraniliprole 18.5% SC, cartap hydrochloride 50% SP and tetraniliprole 200 SC) and one (1) biopesticide (*Bacillus thuringiensis* var. *kurstaki* 0.5% WP) were evaluated for their physical compatibility at drone and taiwan sprayer concentrations. Similarly, three (3) fungicides (propiconazole 10.7% + tricyclazole 34.2% SE, propiconazole 25% EC and tebuconazole 50% + trifloxystrobin 25% WG) and one (1) biopesticide (*Pseudomonas fluorescens* 1.75% WP) were also tested. The experiments were conducted under controlled laboratory conditions at the Institute of Rice Research, Rajendranagar, Hyderabad, during 2022, employing the jar compatibility test outlined in accordance with Indian Standards Specifications (IS, 1973) [8]. pH measurements of both individual pesticides and their combinations were performed using a calibrated pH meter, maintaining a standard reference temperature of 25°C [9].

The study adhered to the pesticide dosage (g or ml a.i. ha^{-1}) recommended for conventional spraying by the Central Insecticides Board and Registration Committee (CIB&RC) for both drone and taiwan sprayer applications. This ensures that the active ingredient (a.i.) dosage per hectare remains consistent across both methods. However, there exists a variance in the volume of spray applied between the two techniques. Specifically, drone spraying employed a spray fluid volume of 36.75 L ha^{-1}, while taiwan spraying utilized a volume of 375 L ha^{-1}. For the formulation of pesticide combinations, the recommended doses of biopesticides, insecticides and fungicides per acre were determined based on CIB&RC guidelines. These doses were then recalculated for taiwan and drone sprayer applications per litre of water, factoring in a spray volume of 375 L ha^{-1} for taiwan spraying and 36.75 L ha^{-1} for drone spraying, as detailed in Table 1 & 2.

Table 1. Details of biopesticides and insecticides tested for physical compatibility

S. No.	Pesticides	Tradename	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	*Bacillus thuringiensis* var. *kurstaki* 0.5% WP	Lipel	1000 g	2.66 g	27.21 g	Agrilife (India) Pvt. Ltd., Hyderabad
2	Flubendiamide39.35%SC	Fame	50ml	0.13 ml	1.36 ml	BayerCropScienceLtd.,Mumbai.
3	Chlorantraniliprole18.5%SC	Coragen	150 ml	0.4ml	4.08 ml	FMCIndiaPvt.Ltd.,Gujarat.
4	Cartaphydrochloride50%SP	Caldan	1000 g	2.66 g	27.21 g	DhanukaAgritechLtd.,Ahmadabad
5	Tetraniliprole200SC	Vayego	250 ml	0.6ml	8.16 ml	BayerCropScienceLtd.,Mumbai.

Table 2. Details of biopesticides and fungicides tested for physical compatibility

S. No.	Pesticides	Tradename	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	*Pseudomonas fluorescens* 1.75% WP	Sheathguard - PF	2500 g	2.66 ml	25ml	Agrilife (India) Pvt. Ltd., Hyderabad
2	Propiconazole 10.7% + Tricyclazole 34.2% SE	Filia	625 ml	1.66 ml	17.01 ml	SyngentaIndiaLtd.,Mumbai
3	Propiconazole 25% EC	Tilt	500 ml	1.33 ml	13.60 g	SyngentaIndiaLtd.,Mumbai
4	Tebuconazole 50% + Trifloxystrobin 25% WG	Nativo	200 g	0.53 g	5.44 g	BayerCropScienceLtd.,Mumbai.

2.1 Evaluation of physical compatibility using jar compatibility test

In this experiment, standard water from an open well, reflective of typical local conditions, was utilized for both the physical compatibility analysis and the actual field application of pesticide mixtures. A precisely measured volume of this water was dispensed into a one-litre container. Biopesticide, insecticide, and fungicide were then sequentially introduced into the container at recommended dosages, following the formulation-specific order prescribed by "WALES" (Suganthy *et al.,* 2010) [10]. This sequence prioritizes the addition of wettable powder (WP) and water-dispersible granules (WDG) first, followed by liquid flowables and suspensions, and finally emulsifiable concentrates (EC) and soluble concentrates (SC). After reaching the one-litre mark, the contents were vigorously agitated by shaking. A 100 ml aliquot of this pesticide solution was then transferred to a calibrated measuring cylinder with a knobbed top and left to stand undisturbed for 60 minutes. Observations regarding foaming and sedimentation were meticulously recorded at intervals of 30 and 60 minutes.

Additionally, pH measurements of both individual biopesticides, insecticides, and fungicides, as well as their combinations were conducted at doses suitable for both Taiwan and drone spraying methods. These pH values were systematically categorized according to the classification system outlined by Bickelhaupt (2012) [11] are as follows

Category	:	**pH**
Extremely acidic	:	< 4.5
Very strongly acidic	:	4.5–5.0
Strongly acidic	:	5.1–5.5
Moderately acidic	:	5.6–6.0
Slightly acidic	:	6.1–6.5
Neutral	:	6.6–7.3
Slightly alkaline	:	7.4–7.8
Moderately alkaline	:	7.9–8.4
Strongly alkaline	:	8.5–9.0
Very strongly alkaline	:	> 9.1

3. RESULTS AND DISCUSSION

3.1 Physical compatibility of insecticide and biopesticide combinations

In the present study, a jar compatibility test was conducted to assess the physical compatibility of insecticide and biopesticide combinations at drone and taiwan sprayer concentrations. The results indicated that most of the combinations were physically compatible, as no signs of incompatibility such as foaming and no sedimentation were observed (refer to Table 3). *B. thuringiensis* var. *kurstaki* 0.5% WP + flubendiamide 39.35% SC combination exhibited 20 ml/l of foaming and no sedimentation at drone dose conditions and showed 10 ml/l of foaming and no sedimentation at taiwan sprayer concentration. *B. thuringiensis* var. *kurstaki* 0.5% WP + chlorantraniliprole 18.50% SC and *B. thuringiensis* var. *kurstaki* 0.5% WP + Tetraniliprole 18.18% SC combinations resulted in no foaming and no sedimentation, at both drone and taiwan dose conditions, indicating excellent physical compatibility. *B. thuringiensis* var. *kurstaki* 0.5% WP + cartap hydrochloride 50% SP combination showed no foaming and no sedimentation at drone dose conditions. Under taiwan dose conditions, it exhibited 10 ml/l of foaming but no sedimentation.

These results suggest that the combinations with chlorantraniliprole and tetraniliprole are physically stable across both the dosages, with no foaming or sedimentation observed. The combinations involving flubendiamide and cartap hydrochloride demonstrated some degree of foaming, particularly under the drone dose. However, no sedimentation was noted, indicating good overall physical stability. Despite this, the mixtures were still considered physically compatible since the foaming volume was less than 2 ml per 100 ml. According to the Indian Standard Specification, the foaming volume more than 2 ml per 100 ml indicates physical incompatibility.

The findings of this study are in line with previous research by Kopparthi [12], who reported that *Bacillus thuringiensis* demonstrated compatibility with insecticides such as emamectin benzoate and flubendiamide. Raju *et al.* [13] reported that chlorantraniliprole was physically compatible with the fungicides tricyclazole, hexaconazole, and propiconazole, as no sedimentation or foaming was observed in the combined mixtures. Visalakshmi*et al*. [14] reported that five insecticides *viz.*, chlorantraniliprole 18.5% SC, chlorpyrifos 20% EC, cartap hydrochloride 50 SP, flubendiamide 480 SC, and profenofos 50 EC were tested with two fungicides, propiconazole and trifloxystrobin 25% + tebuconazole 50% and found that all combinations were physically compatible. Similarly, Sandhya *et al.* [15] demonstrated that lambda-cyhalothrin 4.6% + chlorantraniliprole 9.8% EC, chlorantraniliprole 18.5% SC, flubendiamide 39.35% SC, and azadirachtin 1500 ppm were found physically compatible with azoxystrobin 18.4% + difenoconazole 11.4% SC, and carbendazim 12% + mancozeb 63% WP.

3.2 Physical compatibility of fungicide and biopesticide combinations

In this experiment fungicide and biopesticide combinations were tested for physical compatibility. All the combinationstested, involving *P. fluorescens* + propiconazole 10.7% + tricyclazole 34.2% SE, *P. fluorescens* + propiconazole 25% EC, and *P. fluorescens* + tebuconazole 50% + trifloxystrobin 25% WG, demonstrated no foaming and no sedimentation, indicating excellent physical compatibility under either the drone dose or taiwan dose conditions (table 4). These results suggest that these combinations are physically stable and suitable for application using the specified dosages.

The findings of this study align with previous research by Harsha *et al.* [16] who found that *Bacillus* spp. (BRSN-B2) was compatible with thiophanate methyl + pyraclostrobin and thiamethoxam among seed dressers, thiophanate methyl and copper oxychloride among fungicides, and 2,4-D amine salt, oxyfluorfen. Similarly, Singh *et al*. [17] reported that trifloxystrobin 25% + tebuconazole 50% and propiconazole were found to be comparatively safer for *P. fluorescens*. Georgia [18] confirmed the chemical and physical compatibility of chlorantraniliprole with azoxystrobin and hexaconazole. Goud *et al.* [19] found that propiconazole, when combined with the insecticides indoxacarb and novaluron, resulted in no foaming and sedimentation of 1.8 ml and 0.0 ml, respectively, both within the limits prescribed by the Indian Standards Institution (ISI), which sets the threshold at 2 ml per 100 ml. Additionally, Raju [20] reported that the insecticides rynaxypyr, cartap hydrochloride, buprofezin, profenophos, and flubendiamide were physically compatible with the fungicides tricyclazole, hexaconazole, and propiconazole, as no foaming or sedimentation occurred upon mixing these pesticides.

3.3 pH determination of biopesticides, insecticides, fungicides and their combinations.

The pH of pesticide mixtures significantly impacts their bio-efficacy and can cause phytotoxicity in plants. In this study, the pH values of individual pesticides were analysed at Taiwan sprayer concentrations and drone spraying concentrations, as detailed in table 5 and 7. Furthermore, Table 6 and 8 presents the pH values of pesticide combinations at both Taiwan sprayer and drone spraying concentrations.

Table 3. Physical compatibility of insecticide and biopesticide combinations

S. No.	Pesticide combinations	Drone concentration			Taiwan sprayer concentration		
		Foaming (ml/l)	Sedimentation (ml/l)	Compatibility	Foaming (ml/l)	Sedimentation (ml/l)	Compatibility
1	*Bacillus thuringiensis* var. *kurstaki* 0.5% WP 0.5% WP + Flubendiamide 39.35% SC	20	0	Compatible	10	0	Compatible
2	*B. thuringiensis* var. *kurstaki* 0.5% WP + Chlorantraniliprole 18.50% SC	0	0	Compatible	0	0	Compatible
3	*B. thuringiensis* var. *kurstaki* 0.5% WP + Cartap hydrochloride 50% SP	0	0	Compatible	10	0	Compatible
4	*B. thuringiensis* var. *kurstaki* 0.5% WP + Tetraniliprole 18.18% SC	0	0	Compatible	0	0	Compatible

S. No.	Pesticide combinations	Drone concentration			Taiwan sprayer concentration		
		Foaming (ml/l)	Sedimentation (ml/l)	Compatibility	Foaming (ml/l)	Sedimentation (ml/l)	Compatibility
1	*P. fluorescens* + Propiconazole 10.7% + Tricyclazole 34.2% SE @ 393.75 ml a.i.	0	0	Compatible	0	0	Compatible
2	*P. fluorescens* + Propiconazole 25% EC @	0	0	Compatible	0	0	Compatible

Table 4. Physical compatibility of fungicide and biopesticide combinations

	125 g a.i.						
3	*P. fluorescens* + Tebuconazole 50% + Trifloxystrobin 25% WG @ 100 + 50 g a.i.	0	0	Compatible	0	0	Compatible

3.3.1 pH of insecticide and biopesticides and their combinations

The pH values of insecticides and biopesticide alone exhibited neutral reaction except cartap hydrochloride 50% SP which is moderately acidic (5.60) at drone dose and slightly acidic (6.20) at taiwan dose (table 5). The pH values of the tested pesticide combinations reveal that most combinations exhibit neutral reactions across both drone and taiwan sprayer doses. When biopesticide combined with insecticides all combinations showed neutral reaction except *B. thuringiensis* var. *kurstaki* 0.5% WP + chlorantraniliprole 18.50% SC which was found to be moderately acidic (5.67) (table 6).

Table 5. pH of individual insecticides and biopesticides

S. No.	Pesticide combinations	Drone concentration		Taiwan sprayer concentration	
		pH value	Nature of reaction	pH value	Nature of reaction
1	*B. thuringiensis* var. *kurstaki* 0.5% WP	7.32	Neutral	7.24	Neutral
2	Flubendiamide 39.35% SC	7.00	Neutral	7.30	Neutral
3	Chlorantraniliprole 18.50% SC	6.65	Neutral	7.17	Neutral
4	Cartap hydrochloride 50% SP	5.60	Moderately acidic	6.20	Slightly acidic
5	Tetraniliprole 18.18% SC	6.90	Neutral	7.30	Neutral

Table 6. pH of insecticide and biopesticide combinations

S. No.	Pesticide combinations	Drone concentration		Taiwan sprayer concentration	
		pH value	Nature of reaction	pH value	Nature of reaction
1	*B. thuringiensis* var. *kurstaki* 0.5% WP + Flubendiamide 39.35% SC	7.30	Neutral	7.20	Neutral
2	*B. thuringiensis* var. *kurstaki* 0.5% WP + Chlorantraniliprole 18.50% SC	6.67	Neutral	7.17	Neutral
3	*B. thuringiensis* var. *kurstaki* 0.5% WP + Cartap hydrochloride 50% SP	6.10	Slightly acidic	7.19	Neutral
4	*B. thuringiensis* var. *kurstaki* 0.5% WP + Tetraniliprole 18.18% SC	6.64	Neutral	7.21	Neutral

3.3.2 pH of fungicide and biopesticides and their combinations

The pH of the fungicides alone revealed that almost all fungicides are neutral at both drone and taiwan doses except propiconazole 10.7% + tricyclazole 34.2% SE which was slightly alkaline (7.44) at taiwan sprayer dose (table 7). In case of biopesticide and fungicides mixture, all thetested combinations were found neutral at both drone and taiwan sprayer doses except *P. fluorescens* + propiconazole 10.7% + tricyclazole 34.2% SE which was slightly alkaline (7.40) at taiwan sprayer dose (table 8).

Most insecticides demonstrated neutral pH across different application methods, indicating stability and minimal pH-related risks. Chlorantraniliprole 18.50% SC showed minor pH variation, and cartap hydrochloride 50% SP exhibited significant acidity, especially with drone application, suggesting a need for pH adjustments or buffering. Most combinations retained neutral pH, but *B. thuringiensis* var. *kurstaki* 0.5% WP with cartap hydrochloride 50% SP and *P. fluorescens* with propiconazole 10.7% + tricyclazole 34.2% SE showed slight acidity and alkalinity shifts respectively, particularly with drone and taiwan doses, indicating minor application method impacts.

The pH values of the insecticide and fungicide mixtures showed minimal variation, primarily influenced by the pH of the water used for mixing. The present studies were aligned with Dileepa and Patil [21] who determined the pH of insecticides, including profenophos, chlorantraniliprole, flubendiamide, chlorpyriphos, thiamethoxam, and imidacloprid, along with fungicides hexaconazole, propiconazole, tricyclazole, and carbendazim and demonstrated that majority of the pesticides displayed neutral to moderately acidic pH values. Similar findings were reported by Georgia [18], who found that azoxystrobin, a moderately alkaline substance, retained its moderately alkaline nature when combined with triazophos, chlorantraniliprole, or acetamiprid. Raju *et al.* [13] also observed that mixtures of insecticides and fungicides, including rynaxypyr, cartap hydrochloride, propiconazole, and hexaconazole, exhibited minor pH changes towards alkalinity or acidity. Despite these changes, the bio-efficacy of the individual insecticides, fungicides, and their combinations remained unaffected. Sandhya *et al.* [15] tested pH of various insecticides and fungicides *viz*., lambda cyhalothrin 4.6% + chlorantraniliprole 9.3% ZC, chlorantraniliprole 18.5% SC, flubendiamide 39.35% SC, azadirachtin 1500 ppm, as well as two fungicides: azoxystrobin 18.2% + difenoconazole 11.4% SC, and carbendazim 12% + mancozeb 63% WP and reported that none of them exhibited extreme acidity or alkalinity.

Table 7. pH of individual biopesticide and fungicides

S. No.	Pesticide combinations	Drone concentration		Taiwan sprayer concentration	
		pH value	Nature of reaction	pH value	Nature of reaction
1	*Pseudomonas fluorescens* 1.75% WP	7.2	Neutral	7.3	Neutral
2	Propiconazole 10.7% + Tricyclazole 34.2% SE	7.30	Neutral	7.44	Slightly alkaline
3	Propiconazole 25% EC	7.25	Neutral	7.34	Neutral
4	Tebuconazole 50% + Trifloxystrobin 25% WG	6.51	Neutral	6.64	Neutral

Table 8. pH of biopesticideand fungicide combinations

S. No.	Pesticide combinations	Drone concentration		Taiwan sprayer concentration	
		pH value	Nature of reaction	pH value	Nature of reaction
1	*P. fluorescens* + Propiconazole 10.7% + Tricyclazole 34.2% SE	7.1	Neutral	7.4	Slightly alkaline
2	*P. fluorescens* + Propiconazole 25% EC	7.2	Neutral	7.3	Neutral
3	*P. fluorescens* + Tebuconazole 50% + Trifloxystrobin 25% WG	6.68	Neutral	6.81	Neutral

4. CONCLUSION

The jar compatibility test results reveal that, all combinations at taiwan sprayer and drone spraying concentration exhibited no sedimentation. Conversely, one combination at drone concentration and two combinations at taiwan sprayer concentration produced 20 ml and 10 ml foaming and remaining combinations produced no foaming at both drone and taiwan sprayer concentrations, respectively. Most of the pesticide combinations maintained neutral pH across varied application methods, ensuring stability. However, careful pH adjustment may be necessary for specific formulations, especially when combined or applied using unconventional methods, to optimize efficacy and minimize potential risks.

COMPETING INTERESTS

The authors declare that they have no competing interests to disclose.

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