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RESEARCH PAPER

Evaluation of drone technology in paddy ecosystem against key insect pests

S. NAVEEN[1], ROOPA S. PATIL[1], D. N. KAMBREKAR[1] AND SHRIPAD KULKARNI[2]

[1]Department of Entomology,[2]Department of Plant Pathology, College of Agriculture, Dharwad
University of Agricultural Sciences, Dharwad -580 005, India
*E -mail: naveens761919@gmail.com

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Abstract: This study, conducted at ICAR-Krishi Vigyan Kendra, Malagi farm, Karnataka, during the *kharif* season of 2023-24, evaluated the effectiveness of drone spray technology compared to knapsack sprayers in managing key insect pests in paddy specifically the rice leaf folder (*Cnaphalocrocis medinalis*) and rice ear head bug (*Leptocorisa oratorius*). The insecticides used were fipronil 5% SC and profenophos 50% EC applied during the vegetative and reproductive phases of the crop. Drone spraying demonstrated superior pest control, with higher reductions in pest damage compared to knapsack sprayers. For leaf folder control, fipronil via drone reduced leaf damage by 66.96 per cent in the first application, while profenophos recorded a 53.74 per cent reduction. Similar trends were observed for the ear head bug. Additionally, drone spraying had a lesser impact on natural enemies, such as spiders, coccinellids dragon and damselflies, compared to knapsack methods. The results highlight the advantages of drone technology in providing precise pesticide application ensuring better pest management reduced ecological impact and improved conservation of beneficial insects making it a promising alternative for sustainable agriculture.

Key words: Drone, Knapsack sprayer, Natural enemies, Rice leaf folder, Rice ear head bug

Introduction

Rice (*Oryza sativa* L.), the world's second most consumed cereal crop, is essential for feeding two-thirds of the global population. India, as the second-largest rice producer after China, plays a crucial role in global rice supply (Rai, 2006). However, 52 per cent of global rice production is lost due to biotic agents, with insect pests responsible for 21 per cent of this yield loss. While chemical spraying remains a primary method for pest management, not all spraying techniques are equally effective and efficient in the paddy ecosystem there is a need for innovative spraying method. Dynamic Remotely Operated Navigation Equipment (DRONE) or an Unmanned Aerial Vehicle (UAV), refers to remotely piloted aircraft controlled directly by a human through radio link. The utilization of drones for pesticide spraying provides a significant advantage by replacing labour intensive and hazardous conventional methods, reducing excessive chemical deposition, controlling pests effectively and efficiently and enabling easier application in waterlogged conditions.

Material and methods

The study, titled "Evaluation of drone technology in paddy ecosystem against key insect pests" was conducted at ICAR-Krishi Vigyan Kendra, Sirsi, Malagi farm, Uttara Kannada District, Karnataka, during the *kharif* season of 2023-24, Sirsi. The research focused on evaluating the efficacy of drone spray technology against key paddy pests and its impact on natural enemies. The field was divided into 320 m² plots, with a five-meter buffer zone between treatments. The RNR-15048 variety was sown with 30 x 10 cm spacing. Insecticides Fipronil 5% SC and Profenophos 50% EC were applied using drones and knapsack sprayers during the crops vegetative and reproductive phases. The drone operated at a speed of 2.8 m/s, 2.5 m above the canopy, with a 3.5 m spray width. The accuracy of the flight height and flight velocity will be controlled by the well-trained operator.

Assessment of leaf folder infestation

The damaged leaves and total leaves from 10 randomly selected hills were counted in each treatment. The observations were recorded in all the treatments of insecticides both with drone and knapsack sprayer at one day before spraying (DBS), three, seventh and fourteen days after spraying (DAS).

The per cent leaf damage was calculated as follows,

$$\text{Per cent damaged leaves} = \frac{\text{Number of damaged leaves}}{\text{Total number of leaves}} \times 100$$

Assessment of ear head bug

Observations on the number of adult and nymphs of ear head bugs were recorded on 10 hills and averaged to express on per hill basis. The observations were recorded in all the treatments of insecticides both with drone and knapsack sprayer at one day before spraying (DBS), three, seventh and fourteen days after spraying (DAS).

Natural enemies

The population count for the natural enemies were done simultaneously on the same hills on which insect population were recorded. The common predators such as coccinellids and spiders were collected by hand in the field and visual counts on ten hills and averaged to express per hill basis. Similarly, population of dragonfly and damselfly were collected with ten sweeps and the numbers of adult populations were assessed per square meter area in the same locations.

Result and discussion

This study evaluated the effectiveness of drone and knapsack sprayers in managing key insect pests in paddy specifically focusing on the rice leaf folder (*Cnaphalocrocis medinalis*) and rice ear head bug (*Leptocorisa oratorius)* and their relative impact on the natural enemies like spiders, coccinellids, dragon and damsel flies. The insecticides used were fipronil 5% SC and profenophos 50% EC. The results demonstrated that while both insecticides were effective in reducing pest damage and relatively lower impact on the natural enemies, the method of application significantly influenced the control levels.

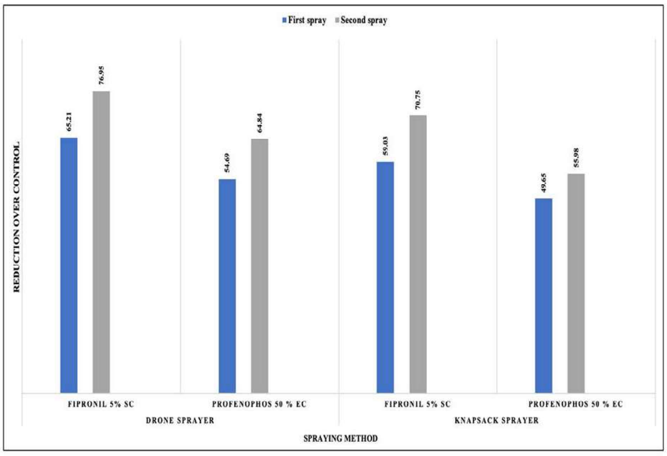
Rice leaf folder (*Cnaphalocrocis medinalis*)

Drone applications of fipronil achieved a mean reduction in leaf damage of 66.96 per cent in the first application and 65.96 per cent in the second. In contrast, fipronil applied via knapsack sprayer resulted in lower reductions of 59.14 per cent and 58.72 per cent, respectively. Profenophos applied with a drone recorded damage reductions of 53.74 per cent in the first application and 53.42 per cent in the second, whereas the knapsack application led to reductions of 46.81 per cent and 49.25 per cent (Table 1). The superior performance of drone spraying is attributed to its ability to deliver a more uniform and precise distribution of insecticide, covering large areas quickly and ensuring consistent application. In comparison, the manually operated knapsack sprayer showed inconsistencies in spray coverage (Fig. 1).

Similar findings were reported by Qin *et al.* (2016), who found that UAV spraying achieved a 91.70 per cent control efficiency, 19.30 per cent higher than knapsack sprayers (72.40%). Wei *et al*. (2020) also observed better pest control with UAVs compared to knapsack sprayers. Nordin *et al.* (2021) reported that UAVs achieved 84.70 per cent efficacy, while knapsack sprayers had only 69.30 per cent. Sambaiah *et al.* (2022) found that UAVs reduced leaf folder damage by 91.80 per cent, while knapsack sprayers achieved a 74.50 per cent reduction.

Fipronil, a phenyl pyrazole, disrupts neurotransmission by inhibiting GABA receptors in insects, leading to higher mortality. Profenophos, an organophosphate that inhibits acetylcholinesterase, was less effective, especially against resistant pests. Fipronil's systemic action allowed it to be absorbed by the plant, providing broader control, while profenophos primarily works on contact, limiting its effectiveness against hidden pests. Vinay (2023) reported that fipronil 5% SC achieved a 64.10 per cent reduction in leaf folder damage, compared to 59.49 per cent with profenophos, reinforcing fipronil's superior efficacy. Firake *et al.* (2010) recorded a 47.36 per cent reduction in leaf folder damage with fipronil 5% SC, and Vinoth (2014) noted over 95 per cent reduction in damage with fipronil applied at 50 g *a.i.*/ha. Hurali *et al*. (2020) found that profenophos 50% EC provided 61.10 per cent control of leaf folder populations.

Overall, this study highlights the advantages of drone sprayers for pest management. Drones provide more precise, consistent insecticide application, ensuring optimal coverage and reducing the variability associated with manual knapsack



Fi g 1. Comparative efficacy of drone vs. knapsack sprayer against leaf folder in paddy

Table 1. Comparative efficacy of drone vs. knapsack sprayer against leaf folder in paddy

Spray equipment	Treatments	Per cent leaf damage											
		First spray						Second spray					
		DBS	3 DAS	7 DAS	14 DAS	Mean	ROC	DBS	3 DAS	7 DAS	14 DAS	Mean	ROC
Drone sprayer	Fipronil 5%	8.34	4.41	3.91	3.98	4.1	66.96	13.58	6.9	5.22	5.79	5.97	65.96
	SC	(16.78)	(12.30)[a]	(11.40)[a]	(11.50)[a]			(21.63)	(15.22)[a]	(13.20)[a]	(13.92)[a]		
	Profenophos	8.53	5.81	4.98	6.44	5.74	53.74	13.75	8.98	7.12	8.42	8.17	53.42
	50% EC	(16.98)	(13.94)[c]	(12.89)[c]	(14.70)[c]			(21.76)	(17.43)[c]	(15.47)[c]	(16.86)[c]		
Knapsacksprayer	Fipronil	7.98	5.12	4.12	5.98	5.07	59.14	12.92	7.89	6.85	6.98	7.24	58.72
	5% SC	(16.40)	(13.07)[b]	(11.71)[b]	(14.15)[b]			(21.06)	(16.31)[b]	(15.17)[b]	(15.31)[b]		
	Profenophos	8.65	5.98	4.98	8.84	6.6	46.81	13.20	9.12	8.60	8.98	8.9	49.25
	50% EC	(17.10)	(14.15)[cd]	(12.89)[c]	(17.29)[d]			(21.29)	(17.57)[cd]	(17.05)[d]	(17.43)[d]		
	Untreated Check	8.84	10.53	11.19	15.53	12.41		14.16	16.2	17.88	18.56	17.54	
		(17.29)	(18.93)[d]	(19.54)[d]	(23.20)[e]			(22.10)	(23.73)[e]	(25.01)[e]	(25.51)[e]		
S.Em(±)		NS	0.26	0.21	0.37			NS	0.45	0.46	0.35		
C.V(%)		9.05	9.10	8.10	10.46			8.67	10.32	11.35	8.21		

DBS – Day before spray, DAS – Days after first spray, NS – Non-Significant, ROC - Reduction over control, Figures in parenthesis are arc sine transformed values. Means showing similar alphabets do not differ significantly by DMRT (p=0.05) sprayers. Their ability to quickly cover large areas improves pest management efficiency, resulting in better overall field outcomes.

Rice ear head bug (*Leptocorisa oratorius*)

Drone applications of fipronil reduced damage by an average of 65.21 per cent in the first application and 76.95 per cent in the second, while knapsack sprayers achieved reductions of 59.03 per cent and 70.75 per cent. Profenophos applied via drone recorded damage reductions of 54.69 per cent in the first application and 64.84 per cent in the second, compared to 49.65 per cent and 55.98 per cent for the knapsack sprayer (Table 2). The drone's superior performance is largely due to its ability to ensure even and precise pesticide application, minimizing the variability common with manual spraying (Fig 2).

The enhanced performance of drone sprayers is attributed to their ability to deliver uniform pesticide distribution and cover larger areas more efficiently. Drone technology ensures optimal pesticide application, while knapsack sprayers, relying on manual operation, often lead to uneven coverage, affecting pest control efficiency.

Supporting these findings, Lee *et al.* (2018) reported a control efficiency of 89.50 per cent with UAV spraying, significantly higher than the 73.20 per cent efficiency of knapsack sprayers. Zhang *et al.* (2019) and Meng *et al.* (2018) similarly noted superior pest control with UAVs, with Meng *et al*. highlighting a 24.70 per cent lower residue level and 19.60 per cent higher control efficacy against wheat aphids compared to knapsack sprayers. Rosedi and Shamsi (2022) observed that UAVs demonstrated 89.90 per cent control efficacy and covered 1.60 times more area than manual sprayers.

Fipronil was found to outperform profenophos in controlling the rice ear head bug due to its specific action on the insect's GABA receptor pathways, causing more severe neurological damage and increased mortality. Profenophos, which affects acetylcholinesterase, can be less effective due to resistance issues and variable pest sensitivities.

These findings are consistent with those of Singh *et al.* (2022), who demonstrated that fipronil 5% SC reduced ear head bug damage by 62.75 per cent, compared to a 58.43 per cent reduction with profenophos 50% EC. Prakash and Kunal (2020) also found fipronil to be more effective, reducing the pest population by 65.30 per cent, while profenophos achieved a 60.80 per cent reduction. Similarly, Patel *et al*. (2018) reported a 45.20 per cent reduction with fipronil, and Sharma *et al*. (2021) recorded a 54.55 per cent reduction with profenophos, further supporting fipronil's superior efficacy.

In conclusion, this study highlights the advantages of drone sprayers in managing rice ear head bugs, offering precise, uniform pesticide application and more effective pest control compared to traditional knapsack sprayers. The superior results observed with drone spraying of both fipronil and profenophos emphasize the potential of drone technology to enhance pest management practices.

Natural enemies

The study assessed the effects of Fipronil and Profenophos applications on natural enemies such as spiders, coccinellids,

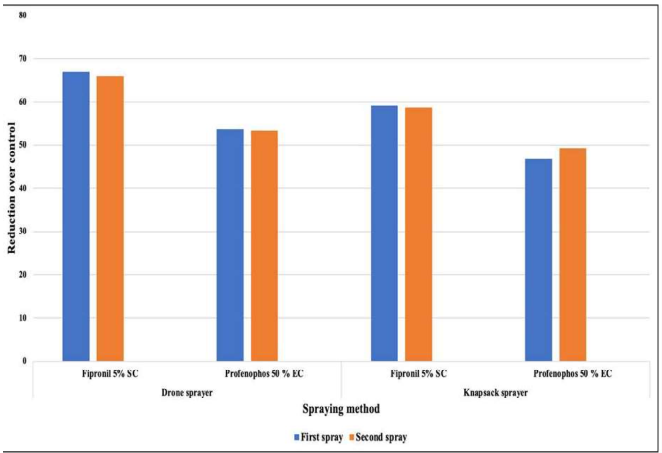


Fig 2. Comparative efficacy of drone vs. knapsack sprayer against ear head bug in paddy

Table 2. Comparative efficacy of drone vs. knapsack sprayer against ear head bug in paddy

Spray equipment	Treatments	Number of nymphs and adults of ear head bug per hill											
		First spray						Second spray					
		DBS	3 DAS	7 DAS	14 DAS	Mean	ROC	DBS	3 DAS	7 DAS	14 DAS	Mean	ROC
Drone Sprayer	Fipronil 5 % SC	3.74 (1.93)	1.42 (1.19)^{a}	1.42 (1.19)^{a}	1.72 (1.31)^{a}	1.52	65.21	4.63 (2.15)	1.48 (1.21)^{a}	1.19 (1.09)^{a}	1.81 (1.34)^{a}	1.56	76.95
	Profenophos 50% EC	3.82 (1.95)	1.94 (1.39)^{b}	1.90 (1.37)^{c}	2.12 (1.46)^{c}	1.98	54.69	4.56 (2.14)	2.41 (1.55)^{b}	2.05 (1.43)^{c}	2.68 (1.64)^{c}	2.38	64.84
Knapsack sprayer	Fipronil 5% SC	3.3 (1.82)	2.26 (1.57)^{c}	1.68 (1.29)^{b}	1.95 (1.40)^{b}	1.79	59.03	4.72 (2.17)	2.26 (1.50)^{c}	1.67 (1.29)^{b}	2.02 (1.42)^{b}	1.98	70.75
	Profenophos 50% EC	3.64 (1.91)	2.28 (1.51)^{d}	1.91 (1.37)^{c}	2.42 (1.56)^{d}	2.20	49.65	4.84 (2.20)	3.10 (1.76)^{d}	2.51 (1.59)^{d}	3.33 (1.82)^{d}	2.98	55.98
	Untreated Check	3.24 (1.87)	3.76 (1.94)^{e}	4.07 (2.01)^{d}	5.28 (2.30)^{e}	4.37		5.13 (2.33)	6.11 (2.47)^{e}	6.84 (2.62)^{e}	7.38 (2.72)^{e}	6.77	
S.Em(±)		NS	0.09	0.10	0.13			NS	0.22	0.13	0.17		
C.V(%)		10.21	8.71	10.98	10.78			8.25	11.64	10.32	11.68		

DBS – Day before spray, DAS – Days after spray, NS – Non-Significant, ROC – Reduction over control. Figures in parenthesis are square root transformed values. Means showing similar alphabets do not differ significantly by DMRT (p=0.05) dragonflies and damselflies using both drone and knapsack sprayers. Across all natural enemy species, the untreated control plots consistently showed the highest populations. Among the treated plots, Fipronil applied via drone demonstrated better conservation of these beneficial organisms compared to both knapsack-applied Fipronil and Profenophos treatments.

Spiders

Initially, spider populations ranged from 1.96 to 2.40 spiders per hill. Three days after treatment the control group had the highest population (2.40 spiders/hill) followed by drone-applied fipronil (1.92 spiders/hill) showing that drones are safer for spiders. Knapsack-applied fipronil reduced the population to 1.73 spiders per hill, while profenophos, applied by drone and knapsack, reduced it further to 1.48 and 1.40 spiders per hill (Table 3). After seven and fourteen days the same trend persisted, with the control group consistently having the highest spider population and fipronil applied via drone maintaining higher populations compared to other methods. These findings highlight that drone-applied fipronil is safer for spiders offering a more sustainable pest management solution in hill ecosystems.

These findings are consistent with the observations of Singh *et al.* (2015), who reported the highest number of predatory spiders in the control plot, with 3.26 spiders per hill, while fipronil 5% SC treatment had the highest population among treatments, at 1.53 spiders per hill. Similarly, Shyamrao *et al.* (2022) confirmed that fipronil was safe for spiders. Additionally, when profenophos 50% EC was applied, drone sprayers again supported higher spider populations, with mean counts of 1.35 and 1.13 spiders per hill during the first and second sprays, compared to 1.20 and 1.11 spiders per hill with knapsack sprayers.

These outcomes support Meng *et al.* (2018), who highlighted that UAV (drone) spraying improves pesticide efficiency and reduces residues, leading to better preservation of beneficial predators like spiders. These findings emphasize the potential of drone spraying to maintain non-target species populations, contributing to a balanced and eco-friendly pest management approach.

Coccinellids

The study evaluated the efficacy of drone and knapsack sprayers for insecticide application on coccinellid populations. Before spraying, the population ranged from 1.73 to 1.95 coccinellids per hill. Three days after the first spray, the control recorded the highest population (1.84 coccinellids per hill), followed by fipronil via drone (1.61 coccinellids per hill), knapsack fipronil (1.47 coccinellids per hill), drone profenofos (1.40 coccinellids per hill), and knapsack profenofos (1.30 coccinellids per hill). By the seventh day, fipronil applied through drone maintained the highest population (2.09 coccinellids per hill), with the control highest overall (2.34 coccinellids per hill). After 14 days, the control remained highest (2.76 coccinellids per hill), and fipronil via drone preserved more coccinellids (2.25 coccinellids per hill) than knapsack application (2.13 coccinellids per hill). After the second spray, drone-applied fipronil resulted in 2.13 coccinellids per hill, while the control recorded the highest population (4.92 coccinellids per hill) (Table 4). Overall, drone sprayers, particularly with fipronil, were more effective and safer for preserving coccinellid populations, making drone technology a more eco-friendly alternative to knapsack sprayers.

These results demonstrate that drones, with their precision and target-specific application, are less harmful to coccinellids. Firake *et al.* (2010) and Chormule *et al.* (2014) also emphasized the importance of reducing pesticide exposure to beneficial insects like coccinellids. Similar findings were supported by Meng *et al.* (2018) and Wei *et al.* (2020), who noted that UAVs (drones) deliver pesticides with minimal impact on beneficial insects, helping to maintain ecological balance by preserving populations of coccinellids. These studies highlight the effectiveness of drone spraying in protecting non-target species while maintaining pest control efficiency.

Table 3. Impact of drone vs. knapsack sprayer on spiders populations in paddy

Spray equipment	Treatments	Number of spiders per hill									
		First spray					Second spray				
		DBS	3 DAS	7 DAS	14 DAS	Mean	DBS	3 DAS	7 DAS	14 DAS	Mean
Drone sprayer	Fipronil 5% SC	2.40 (1.55)	1.92 (1.39)[b]	2.10 (1.45)[b]	2 (1.41)[bc]	2.01	2.56 (1.60)	1.86 (1.36)[b]	2.11 (1.45)	2.34 (1.53)	2.13
	Profenophos 50% EC	2.21 (1.49)	1.48 (1.22)[d]	1.67 (1.29)[e]	2.10 (1.45)[b]	1.75	2.64 (1.62)	1.74 (1.32)[c]	1.88 (1.37)[b]	2.12 (1.46)[c]	1.91
Knapsack sprayer	Fipronil 5% SC	2.27 (1.51)	1.73 (1.32)[c]	1.98 (1.41)[c]	1.91 (1.38)[cd]	1.87	2.79 (1.67)	1.61 (1.27)[d]	1.81 (1.34)[b]	1.92 (1.39)[d]	1.83
	Profenophos 50% EC	2.14 (1.46)	1.40 (1.18)[d]	1.78 (1.33)[d]	1.62 (1.27)[e]	1.60	2.88 (1.70)	1.51 (1.23)[de]	1.65 (1.29)[c]	1.81 (1.35)[e]	1.68
	Untreated Check	1.96 (1.40)	2.40 (1.54)[a]	2.98 (1.73)[a]	3.14 (1.77)[a]	2.84	4.25 (2.17)	4.67 (2.27)[a]	4.92 (2.32)[a]	5.23 (2.39)[a]	4.94
S.Em(±)		NS	0.07	0.09	0.08		0.10	0.11	0.13	0.15	
C.V(%)		8.27	9.98	9.057	8.33		10.92	11.41	9.86	11.34	

DBS – Day before spray, DAS – Day after spray, NS – Non-Significant, Figures in parenthesis are square root transformed values. Means showing similar alphabets do not differ significantly by DMRT (p=0.05

Table 4. Impact of drone vs. knapsack sprayer on coccinellids in paddy

Spray equipment	Treatments	Number of coccinellids per hill									
		Frist Spray					Second Spray				
		DBS	3 DAS	7 DAS	14 DAS	Mean	DBS	3 DAS	7 DAS	14 DAS	Mean
Drone sprayer	Fipronil 5% SC	1.95	1.61	2.09	2.25	1.98	2.73	1.98	2.03	2.39	2.13
		(1.39)	(1.27)^{b}	(1.45)^{b}	(1.52)^{b}		(1.65)	(1.40)^{b}	(1.42)^{b}	(1.54)^{b}	
	Profenophos	1.88	1.40	1.79	1.96	1.73	2.64	1.65	1.80	1.89	1.78
	50% EC	(1.37)	(1.18)^{c}	(1.34)^{d}	(1.40)^{d}		(1.62)	(1.28)^{d}	(1.34)^{c}	(1.37)^{cd}	
Knapsack	Fipronil 5% SC	1.81	1.47	1.95	2.13	1.85	2.58	1.79	1.88	2.01	1.89
sprayer		(1.34)	(1.21)^{c}	(1.39)^{c}	(1.46)^{c}		(1.61)	(1.34)^{c}	(1.37)^{c}	(1.42)^{c}	
	Profenophos	1.73	1.30	1.68	1.82	1.66	2.51	1.25	1.67	1.96	1.63
	50% EC	(1.32)	(1.14)^{d}	(1.29)^{e}	(1.35)^{e}		(1.57)	(1.12)^{e}	(1.29)^{d}	(1.40)^{c}	
	Untreated Check	1.76	1.84	2.34	2.76	2.31	4.21	4.53	4.89	5.34	4.92
		(1.33)	(1.36)^{a}	(1.53)^{a}	(1.66)^{a}		(2.17)	(2.24)^{a}	(2.32)^{a}	(2.41)^{a}	
S.Em(±)		NS	0.06	0.07	0.09		0.10	0.11	0.12	0.15	
C.V(%)		8.63	10.15	8.56	9.99		11.48	9.50	9.80	10.36	

DBS – Day before spray, DAS – Day after spray, NS – Non-Significant, Figures in parenthesis are square root transformed values. Means showing similar alphabets do not differ significantly by DMRT (p=0.05)

Table 5. Impact of drone vs. knapsack sprayer on dragonfly and damselfly in paddy

Spray equipment	Treatments	Number of dragonfly and damselfly per m^2									
		First spray					Second spray				
		DBS	3 DAS	7 DAS	14 DAS	Mean	DBS	3 DAS	7 DAS	14 DAS	Mean
Drone sprayer	Fipronil	3.94	3.34	3.63	3.92	3.63	5.03	4.35	4.73	5.11	4.73
	5% SC	(1.98)	(1.83)^{b}	(1.91)^{b}	(1.98)^{b}		(2.24)	(2.09)b	(2.17)b	(2.26)^{b}	
	Profenophos	3.73	2.96	3.38	3.54	3.29	4.86	3.89	4.28	4.67	4.28
	50% EC	(1.93)	(1.72)^{d}	(1.84)^{c}	(1.88)^{d}		(2.20)	(1.97)d	(2.07)d	(2.16)^{d}	
Knapsack	Fipronil	3.85	3.16	3.44	3.72	3.44	4.95	4.15	4.51	4.87	4.51
sprayer	5% SC										
	(1.96)	(1.78)^{c}	(1.85)^{c}	(1.93)^{c}		(2.22)	(2.04)c	(2.14)c	(2.21)^{c}		
	Profenophos	3.68	2.83	3.02	3.21	3.02	4.75	3.66	3.98	4.30	3.98
	50% EC	(1.92)	(1.68)^{de}	(1.74)^{d}	(1.79)^{e}		(2.18)	(1.91)e	(1.99)e	(2.07)^{e}	
	Untreated	3.89	4.52	4.97	5.42	4.97	6.86	7.25	7.87	8.29	7.81
	Check	(1.97)	(2.13)^{a}	(2.23)^{a}	(2.33)^{a}		(2.71)	(2.78)a	(2.89)a	(2.96)^{a}	
S.Em(±)		NS	0.17	0.15	0.14		0.22	0.24	0.25	0.26	
C.V(%)		8.55	11.40	9.28	8.27		8.30	10.26	11.17	9.60	

DBS – Day before spray, DAS – Day after spray, NS – Non-Significant, Figures in parenthesis are square root transformed values. Means showing similar alphabets do not differ significantly by DMRT (p=0.05)

Dragonflies and damselflies

The study measured dragon and damselfly populations per square meter after applying Fipronil 5% SC and Profenophos 50% EC using drone and knapsack sprayers. For the first spray, Fipronil via drone resulted in a mean of 3.63 dragon and damselflies per square meter, while Profenophos via drone averaged 3.29 per square meter. Using a knapsack sprayer, Fipronil and Profenophos had mean of 3.44 and 3.02 per square meter, respectively. The untreated check had the highest mean of 4.97 per square meter. After the second spray, Fipronil via drone recorded a mean of 4.73 per square meter and Profenophos had a mean of 4.28. Fipronil via knapsack averaged 4.51 and Profenophos 3.98. The untreated check again showed the highest mean at 7.81 per square meter. Drone sprayers proved more consistent reducing pesticide exposure and preserving beneficial insects (Table 5).

These results suggest that drones, with their precision, have a lesser impact on dragonflies and damselflies compared to traditional knapsack methods. This aligns with findings by Meng *et al*. (2018) and Zhang *et al*. (2019), who noted that UAVs reduce non-target impacts by improving pesticide targeting. Similarly, Chormule *et al.* (2014) reported that fipronil 5% SC supported the highest number of natural enemies, reinforcing the idea that drones are more beneficial in preserving non-target species like dragonflies and damselflies.

Conclusions

The findings of this study demonstrate the significant advantages of drone sprayers over traditional knapsack sprayers in managing key insect pests, particularly the rice leaf folder (*Cnaphalocrocis medinalis*) and rice ear head bug (*Leptocorisa oratorius*). Drone applications of fipronil 5 % SC and profenophos 50 % EC consistently outperformed knapsack sprayers, achieving more effective pest control due to their ability to deliver uniform and precise insecticide coverage over large areas. Fipronil was notably more effective than profenophos, owing to its systemic action, which provided enhanced control of both pests.

In terms of natural enemy conservation, drone applications proved to be less disruptive. Populations of spiders, coccinellids, dragonflies, and damselflies were better preserved when insecticides were applied via drones, compared to knapsack sprayers. Fipronil, when applied with drones, maintained higher populations of these beneficial species, further emphasizing the precision and reduced impact of drone technology on non-target organisms.

Overall, the use of drones for insecticide application in paddy fields offers a dual benefit of superior pest control and better preservation of beneficial insects, contributing to a more sustainable and eco-friendly pest management approach. The precision and efficiency of drone sprayers make them a highly effective tool for modern agricultural practices, helping to maintain ecological balance while ensuring optimal pest control outcomes.

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