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STANDARDIZATION OF DOSAGE FOR DRONE BASED FOLIAR APPLICATION OF FUNGICIDES IN THE MANAGEMENT OF FOLIAR DISEASE OF CHILLI

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ABSTRACT

The use of agricultural spray drones for pesticide application is an innovative and rapidly growing technology in agriculture, offering farmers greater precision and efficiency in managing their crops. However, unlike traditional knapsack sprayers, spray drones currently face a significant challenge: the absence of standardized pesticide dosages for foliar applications. This gap highlights the need for further research and development to optimize drone-based spraying systems for practical and sustainable use. The present study is aimed to establish standardize fungicidal dosages to be used drone-based applications for effective management of anthracnose and powdery mildew in chilli. Field experiments were conducted at HREC, Hidkal and HREC, Devihosur, during the *Kharif* season of 2023 using a randomized complete block design (RCBD). Treatments included various dosages of fungicides sprayed through drones, at a height of 2 meters and a speed of 5 m/s, with a spray solution of 25 l/ha were compared to knapsack spray of recommended dosage and an untreated control. For anthracnose, the lowest PDI (21.48) was achieved with Hexaconazole 5 EC at 500 ml/ha applied by drone as well as knapsack, which was on par with the 300 ml/ha drone application (PDI 22.96). For powdery mildew, the lowest PDI (14.81) was seen in knapsack, 500 ml/ha, which was on par with drone at 500 ml/ha (15.55) and drone at 250 ml/ha (17.78). Control treatments showed the highest PDI values (55.55 for anthracnose; 61.48 for powdery mildew). No phytotoxicity symptoms were observed with any drone-applied dose and residue analysis of fungicides confirmed that all drone-sprayed chilli samples remained within FSSAI's MRL limits, with no adverse impact on soil health. Additionally, drone applications demonstrated a slightly higher B:C ratio than knapsack sprayer, supporting their economic viability for adoption.
***Keywords* :** Drone, Drone based spraying, Disease management, Phytotoxicity, Residue.

Introduction

Agriculture forms the foundation of human society, providing sustenance and livelihoods for millions worldwide. With the global population steadily increasing, the demand for enhanced food production has grown significantly, making mechanization and technological integration essential. Advances in agricultural technology, particularly through the use of unmanned aerial vehicles (UAVs) or drones, have transformed traditional farming practices. Drones offer numerous advantages, including real-time data collection, precision in resource management, and efficient crop monitoring. Equipped with advanced sensors, they enable farmers to reduce inputs such as water and pesticides while improving productivity and ensuring environmentally sustainable practices (Sharma *et al.*, 2022; Khan *et al.*, 2021).

Chilli is an important commercial crop in India, widely cultivated for its economic value. However, it is highly susceptible to several diseases, which can severely impact productivity and quality. Major diseases affecting chilli include anthracnose, caused by *Colletotrichum* spp., and powdery mildew, caused by *Leveillula taurica*. Anthracnose results in lesions on fruits, stems, and leaves, while powdery mildew causes whitish powdery growth on foliage, reducing photosynthetic activity. These diseases spread rapidly under conducive environmental conditions, necessitating timely and effective management interventions to prevent significant crop losses (Thangjam *et al*., 2020).

The application of drones in the management of chilli diseases presents a transformative solution. Traditional pesticide application methods, such as knapsack sprayers, are limited by labor shortages, slower application rates, and uneven coverage. In contrast, drones enable faster, more precise, and efficient spraying, ensuring comprehensive treatment of large areas in a shorter time. Additionally, drones reduce human exposure to hazardous chemicals and minimize pesticide wastage. Despite these advantages, the lack of standardized dosage guidelines for drone spraying remains a challenge. This necessitates research to determine the appropriate concentrations and techniques for effective disease management in chilli crops, paving the way for improved efficiency in plant protection strategies.

Materials and Methods

Experimental field

The research was conducted at the fields of the Horticulture Research and Extension Center (HREC), Hidkal, for the management of anthracnose, and at the HREC, Devihosur, for the management of powdery mildew.

Technical specification of drone used in the experiment

The drone used in the experiment is of Multiplex Pvt. Ltd., India company with following specification

Drone	MD 10H (Hexacopter)
Dimension	1496 x 1308 x 568 mm (L x W x H)
Maximum takeoff weight	24.90 kg
Endurance	10 min (with full payload)
Maximum flying speed	6 m/s
Pump discharge rate	5 L/min
Tank volume	10 L
Spray swath	2.5 - 5 m
Maximum transmission range	500 m

Standardization of foliar application of Hexaconazole 5 EC for the management of anthracnose and powdery mildew of chilli

Experimental Design : Randomized block design
No. of treatments : 9
No. of replication : 3
Variety : Byadagi Dabbi
Disease focused : Anthracnose and Powdery mildew
Spacing : 60 x 45 cm^2
Season : *Kharif* 2023
No of sprays : 3
Stage of crop : Flowering and fruiting
Flight height of drone : 2 m
Flying speed : 5 m/s
Mode of drone operation: Autonomous

Treatment details:

Sl No	Treatment	Sprayer	Dosage (ml/ha)	Total spray volume (l/ha)	Dosage (ml/l)
1	Hexaconazole 5 EC	Drone	500	25	20.00
2*	Hexaconazole 5 EC	Drone	300	25	12.00
3	Hexaconazole 5 EC	Drone	200	25	8.00
4	Hexaconazole 5 EC	Drone	100	25	4.00
5	Hexaconazole 5 EC	Drone	50	25	2.00
6	Hexaconazole 5 EC	Drone	25	25	1.00
7	Hexaconazole 5 EC	Knapsack	500	500	1.00
8	Water spray	Drone	-	25	-
9	Control	-	-	-	-

*T_2 treatment was imposed only at HREC Hidkal for the management of chilli anthracnose

Observations recorded

Assessment of anthracnose and powdery mildew disease severity in chilli

To assess disease severity, ten plants were selected from each plot. These plants were evaluated for anthracnose and powdery mildew 10 days after each spray application. The evaluations were performed using the standard scoring chart established by Mayee and Datar (1986).

Disease scale (0-9) for scoring anthracnose in chilli.

Scale	Description
0	No symptoms on leaf or branch or fruit.
1	Small, irregular spots covering 1 per cent or less area of leaf or branch or fruit.
3	Brown, dirty, pin headed spots covering 1-10 per cent area on leaf area on leaf or branch or fruit.
5	Dark brown, dirty black spots with blackish margin covering 11-25 per cent of area of leaf or branch or fruit
7	Dark brown, circular or irregular spots with blackish covering 26-50 per cent area of leaf or branch or fruit.
9	Dark brown, circular or irregular spots with blackish covering 51 per cent and above area of leaf or branch or fruit.

Disease scale (0-9) for scoring powdery mildew in chilli.

Scale	Description
0	No symptom of powdery mildew
1	Small scattered powdery mildew specks covering 1 % or less leaf area.
3	Small powdery lesions covering 1-10 % of leaf area.
5	Powdery lesions enlarged covering 11-25 % of leaf area
7	Powdery lesions coalesce to form big patches covering 26-50 % of leaf area.
9	Big powdery patches covering 51 % or more of leaf area and defoliation occurs.

The per cent disease index (PDI) was calculated using the formula provided by Wheeler (1969).

$$\text{Per cent disease index} = \frac{\text{Sum of total numerical rating}}{\text{Total number of samples observed} \times \text{maximum grade used}} \times 100$$

Analysis of spray droplet size and distribution

Water sensitive papers

The water-sensitive papers (WSPs) are made of a rigid material with a specially coated yellow surface that turns dark blue upon contact with aqueous droplets. After the spray application, the WSPs can be immediately inspected to preliminarily assess spray quality. Droplet size and spray distribution from drone applications were assessed using water-sensitive papers (WSPs), a standard method for evaluating spray coverage in agricultural practices. These papers were handled with gloves and positioned at various levels within the canopy using clips.

Analysis of water sensitive paper using ImageJ software

The droplet size and spread of the drone application were meticulously analyzed utilizing ImageJ software. This powerful tool enabled precise measurements and detailed assessments of droplet size distribution and coverage across the experimental plots. By analyzing images captured before and after the drone application, ImageJ facilitated the quantification of droplet sizes and their spatial distribution, providing crucial data on the effectiveness and uniformity of the spray application.

WSP are placed at various level within the canopy using clips. Following the spray application, the WSPs were collected and allowed to dry completely. Once dried, they were stored in appropriately sized zip covers and transported to the laboratory. The papers were then scanned at 600 dpi using an HP scanner and the resulting images were analyzed using ImageJ software. This software provides the detailed classification of size and density.

Droplets are measured in terms DV0.1, DV0.5 and DV0.9 parameters. DV0.5, also known as the Volume Median Diameter (VMD), represents the median droplet size, where half of the spray volume is in droplets smaller and half in droplets larger than this size. The ImageJ software provides detailed classifications of droplet size into DV0.1, DV0.5 and DV0.9, along with droplet density measurements. Droplet sizes are measured in microns (µm).

Flower, leaf and fruit drop.

Observations for flower, leaf and fruit drop were recorded following the drone spraying.

Phytotoxicity of fungicide on drone application

Phytotoxicity analysis was conducted based on visual phytotoxicity grades recorded on the 0th, 1st, 3rd, 5th and 7th days following each spray application. Observations for chlorosis, leaf tip burning, necrosis, epinasty, hyponasty, vein clearing, scorching and wilting were documented at 0, 1, 3, 5, 7 and 10 days post-spray (Sambaiah *et al,* 2023).

These symptoms were graded using a 0–10-point phytotoxicity scale.

Scale	Range	Scale	Range
0	00	6	51-60%
1	1-10%	7	61-70%
2	11-20%	8	71-80%
3	21-30%	9	81-90%
4	31-40%	10	91-100%
5	41-50%		

Economic analysis of drone application of fungicide

The economics of drone-based spraying compared to conventional spraying were as well as anthracnose and powdery mildew of chilli. The economic evaluation was conducted by calculating the benefit-cost ratio (B:C) and net returns for chilli.

Residue level due to drone application of fungicide

After fungicide application, samples for residue analysis in chilli were collected on the 5th, 10th and 15th days post-application in autoclaved polythene bags with soil samples also collected on the 15th day. These samples were then sent to K2VR Analytical Research Private Limited, Bangalore, for detailed residue analysis.

Statistical analysis

The experimental data recorded were analyzed statistically for their significance of difference by the statistical procedure adopted for randomized block design (RBD) and interpretation of data was carried out following Walter (1997). The level of significance used in analysis was at P=0.05. Critical differences were calculated wherever the F test was significant. The values of the percent disease index were subjected to arc sign transformation.

Results

Standardizing the foliar application of Hexaconazole 5 EC using drones for effective management of anthracnose in chilli.

The efficacy of different concentrations of Hexaconazole 5 EC applied using UAV (drone) sprayers was compared to a knapsack sprayer and untreated control for the incidence chilli anthracnose. The Per cent Disease Index (PDI) was recorded and 10 days after each spray and data was analyzed as mentioned in material and methods. The results are presented in Table 01.

Table 1 showed that there was no significant differences between treatments before the first spray. However, 10 days after the first spray least PDI was observed in the T_1 (Hexaconazole 5 EC at 500 ml/ha applied through drone) 12.59, this was on par with the T_7 (Hexaconazole 5 EC at 500 ml/ha applied through knapsack sprayer), T_2 (Hexaconazole 5 EC at 300 ml/ha applied through drone) and T_3 (Hexaconazole 5 EC at 200 ml/ha applied through drone) with PDI of 14.07, 14.81 and 15.55 respectively. The highest PDI was noticed in the untreated control T_9 (32.59).

10 days after the second spray, the lowest PDI 20.00 was observed in both T_1 (Hexaconazole 5 EC at 500 ml/ha applied through drone) and T_7 (Hexaconazole 5 EC at 500 ml/ha applied through knapsack sprayer). This was on par with T_2 (Hexaconazole 5 EC at 300 ml/ha applied through drone) and T_3 (Hexaconazole 5 EC at 200 ml/ha applied through drone) which recorded a PDI of 21.48 and 22.96 respectively. The highest PDI (42.21) was observed in the untreated control (T_9).

Similarly, 10 days after the third spray, T_1 (Hexaconazole 5 EC at 500 ml/ha applied through drone) and T_7 (Hexaconazole 5 EC at 500 ml/ha applied through knapsack sprayer) recorded the lowest PDI (21.48), which were on par with the T_2 (Hexaconazole 5 EC at 300 ml/ha applied through drone) with a PDI 22.96. This was followed by T_3 (Hexaconazole 5 EC at 200 ml/ha applied through drone) recorded a PDI (25.92), which was on par with T_2. The control treatment (T_9) had the highest PDI (55.55).

The data concerning yield revealed that Hexaconazole 5 EC at 500 ml/ha applied through drone recorded a yield of 7.02 q/ha, followed by same dose applied using knapsack recorded yield of 6.97 q/ha, followed by Hexaconazole 5 EC at the 300 ml/ha applied through drone recorded a yield 6.89 q/ha which is significantly superior to untreated control 5.25 q/ha.

Standardizing the foliar application of Hexaconazole 5 EC through drones for effective management of powdery mildew in chilli.

The effectiveness of different doses of Hexaconazole 5 EC sprayed using a drone for managing chilli powdery mildew was evaluated. The results are presented in Table 2.

Table 2 shows that there was no significant difference between the treatments before spraying. 10 days after the first spray, the lowest Per cent Disease Index (PDI) was noticed in the T_6 (Hexaconazole 5 EC at 500 ml/ha applied through knapsack sprayer) with 17.02. Which is on par with T_1 (Hexaconazole 5 EC at 500 ml/ha applied through drone) and T_2 (Hexaconazole 5 EC at 200 ml/ha applied through drone) which recorded PDI of 18.51 and 18.50 respectively. The highest PDI (37.70) was recorded in T_8 (control)10 days after the second spray, T_6 (Hexaconazole 5 EC at 500 ml/ha applied through knapsack sprayer) recorded the lowest PDI of (14.81), which is on par with T_1 (Hexaconazole 5 EC at 500 ml/ha applied through drone) and T_2 (Hexaconazole 5 EC at 200 ml/ha through drone) which recorded PDI of 15.55 and 17.78 respectively. The highest PDI (61.48) was observed in the control treatment (T_8).

The data concerning yield revealed that Hexaconazole 5 EC at 500 ml/ha applied through drone recorded a yield of 6.03 q/ha, followed by same dose applied using knapsack recorded yield of 5.98 q/ha, followed by Hexaconazole 5 EC at the 200 ml/ha applied through drone recorded a yield 5.88 q/ha which is significantly superior to untreated control 4.25 q/ha.

Studies on droplet size and spread on drone spray in chilli

The droplets produced by the drone sprayer were more uniform in size with smaller droplets overall. The droplet size analysis is summarized in Table 3. The drone produced a Volume Median Diameter (VMD) of 288 µm, 253 µm and 270 µm in the upper, middle and lower regions respectively. The droplet density was 60.25 droplets/cm² in the upper region, 51.77 droplets/cm² in the middle region and 48.83 droplets/cm² in the lower region.

Flower, leaf and fruit drop

Spraying was conducted during the flowering and fruiting stages, with no observed drop of flowers, fruits, or leaves

Phytotoxicity of drone spray of Hexaconazole on drone application in chilli plant

The data collected on phytotoxicity following the application of fungicidal treatments are presented in the Table 4. After each spray, it was noted that the various treatments applied through drone did not result in any phytotoxic symptoms, including chlorosis, epinasty, hyponasty, stunting, leaf injury, vein clearing, necrosis, scorching or wilting. Observations were conducted on days 1, 3, 5, 7, 10 and 15 post-applications. A similar trend was observed after the second spray with no signs of phytotoxicity detected across any treatments, regardless of the application method or dosage.

Residue level due to drone application of Hexaconazole 5 EC in chilli

Table 5 presents the residue levels from drone applications. On the 5th day, T_1 (Hexaconazole 5 EC at a dose of 500 ml/ha applied through drone) had the highest chemical residue, measuring 0.227 mg/kg. This was followed by T_2 (Hexaconazole 5 EC at a dose of 300 ml/ha applied through drone) with a residue of 0.164 mg/kg and T_3 (Hexaconazole 5 EC at a dose of 200 ml/ha applied through drone) with a residue of 0.098 mg/kg. T_7 (Hexaconazole 5 EC at a dose of 500 ml/ha applied through knapsack) recorded the lowest residue level, at 0.042 mg/kg.

After 10 days post-application, the highest residue was observed in T_1 (Hexaconazole 5 EC at a dose of 300 ml/ha applied through drone) at 0.182 mg/kg. This was followed by T_2 (Hexaconazole 5 EC at a dose of 500 ml/ha applied through drone) and T_3 (Hexaconazole 5 EC at a dose of 200 ml/ha applied through drone) with residue of 0.149 mg/kg and 0.089 mg/kg respectively. The lowest residue was found in T_7 (Hexaconazole 5 EC at a dose of 500 ml/ha applied through knapsack) at 0.033 mg/kg.

The chilli fruit and soil samples were collected on the 15th day post-application. In all treatments, the fungicide residue in the soil was below the level of quantification. However, in the chilli fruits, the highest residue was observed in T_1 (Hexaconazole 5 EC at a dose of 500 ml/ha applied through drone) at 0.109 mg/kg, followed by T_2 (Hexaconazole 5 EC at a dose of 300 ml/ha applied through drone) at 0.10 mg/kg and T_3 (Hexaconazole 5 EC at a dose of 200 ml/ha applied through drone) at 0.061 mg/kg. The lowest residue was recorded in T_7 (Hexaconazole 5 EC at a dose of 500 ml/ha applied through knapsack) at 0.024 mg/kg.

Economic analysis of drone application of fungicide in chilli at HREC, Hidkal

Table 6 presents the economic returns of different treatments. T_1 (Hexaconazole 5 EC at 500 ml/ha applied through drone) produced a highest net return of Rs 147,246 and a Benefit-Cost (B:C) ratio of 2.10 followed by T_7 (Hexaconazole 5 EC at 500 ml/ha applied through knapsack) resulting in net returns of Rs 145,396 and a B:C ratio of 2.09, T_2 (Hexaconazole 5 EC at 300 ml/ha applied through drone) with a net returns of Rs 142442 and a B:C ratio of 2.07 and T_3 (Hexaconazole 5 EC at 200 ml/ha applied through drone) produced net returns of Rs135440 and a B:C ratio of 2.02. The control treatment (T_9), where no fungicide was used, showed significantly lower returns of Rs 81,186 and a B:C ratio of 1.63.

Table 1 : Standardization of different dosage of Hexaconazole 5 EC for the management of anthracnose on chilli for drone based foliar spray

Treatments	Chemical	Dose (ml/ha)	Sprayer	Per cent Disease Index				Yield (q/ha)
				Before I spray	10 days after I spray	10 days after II spray	10 days after III spray	
T_1	Hexaconazole 5 EC	500	Drone	14.81 (27.59) *	12.59 (26.47)	20.00 (27.59)	21.48 (27.59)	7.02
T_2	Hexaconazole 5 EC	300	Drone	16.29 (28.61)	14.81 (27.59)	21.48 (28.61)	22.96 (28.60)	6.89
T_3	Hexaconazole 5 EC	200	Drone	16.29 (29.57)	15.55 (28.61)	22.96 (30.59)	25.92 (30.58)	6.71
T_4	Hexaconazole 5 EC	100	Drone	17.03 (32.51)	18.52 (34.34)	31.85 (35.26)	33.33 (35.26)	6.50
T_5	Hexaconazole 5 EC	50	Drone	14.81 (34.34)	24.44 (37.04)	36.29 (41.38)	43.70 (41.37)	6.00
T_6	Hexaconazole 5 EC	25	Drone	14.07 (36.6)	28.88 (38.79)	39.25 (42.22)	45.16 (42.22)	5.65
T_7	Hexaconazole 5 EC	500	Knapsack	15.55 (28.55)	14.07 (26.57)	20.00 (27.59)	21.48 (27.58)	6.97
T_8	Water Spray	-	Drone	14.07 (37.48)	31.85 (39.66)	40.74 (44.79)	49.62 (44.78)	5.12
T_9	Control (No spray)	-	-	14.81 (38.35)	32.59 (40.51)	42.21 (48.2)	55.55 (48.19)	5.25
S. Em ±				**1.03**	**0.92**	**0.99**	**0.94**	**0.11**
CD at 5 %				**NS**	**2.76**	**2.98**	**2.83**	**0.32**

* Figures in parenthesis are in Arc sin transformation

Table 2 : Standardization of different dosage of Hexaconazole 5 EC for the management of powdery mildew on chilli for drone based foliar spray

Treatments	Chemical	Dose (ml/ha)	Sprayer	Per cent Disease Index			Yield (q/ha)
				Before I spray	10 days after I spray	10 days after II spray	
T_1	Hexaconazole 5 EC	500	Drone	24.44 (29.57) *	18.51 (25.36)	15.55 (23.09)	6.03
T_2	Hexaconazole 5 EC	200	Drone	22.96 (28.61)	18.50 (25.44)	17.78 (24.85)	5.88
T_3	Hexaconazole 5 EC	100	Drone	24.44 (29.57)	27.39 (31.50)	39.26 (38.77)	5.32
T_4	Hexaconazole 5 EC	50	Drone	22.96 (28.45)	30.36 (33.43)	43.70 (41.38)	5.19
T_5	Hexaconazole 5 EC	25	Drone	24.44 (29.37)	31.11 (33.83)	49.63 (44.78)	4.88
T_6	Hexaconazole 5 EC	500	Knapsack	25.92 (30.49)	17.02 (24.09)	14.81 (22.62)	5.98
T_7	Water Spray	-	Drone	25.92 (30.59)	37.01 (37.47)	57.03 (49.07)	4.40
T_8	Control (No spray)	-	-	25.92 (30.59)	37.70 (37.86)	61.48 (51.66)	4.25
S. Em ±				**2.17**	**1.32**	**1.72**	**0.08**
CD at 5 %				**NS**	**3.99**	**5.22**	**0.25**

* Figures in parenthesis are in Arc sin transformed value

Table 3 : Size and spread of spray droplet of Drone sprayer in chilli

	Drone			
	DV 0.1 (µm)	DV 0.5 (µm)	DV 0.9 (µm)	Deposits/cm²
Upper	157	288	483	60.25
Middle	148	253	389	51.77
Lower	152	270	436	48.83

Table 4 : The phytotoxicity effect of drone application of Hexaconazole 5 EC on chilli

Treatments	Chemical	Doses (ml/ha)	Sprayer	Observations Chlorosis, leaf tip burning, necrosis, epinasty, hyponasty, vein clearing, scorching, wilting						
				Beforespray	1 DAS	3 DAS	5 DAS	7 DAS	10 DAS	15 DAS
T_1	Hexaconazole 5 EC	500	Drone	0	0	0	0	0	0	0
T_2	Hexaconazole 5 EC	300	Drone	0	0	0	0	0	0	0
T_3	Hexaconazole 5 EC	200	Drone	0	0	0	0	0	0	0
T_4	Hexaconazole 5 EC	100	Drone	0	0	0	0	0	0	0
T_5	Hexaconazole 5 EC	50	Drone	0	0	0	0	0	0	0
T_6	Hexaconazole 5 EC	25	Drone	0	0	0	0	0	0	0
T_7	Hexaconazole 5 EC	500	Knapsack	0	0	0	0	0	0	0
T_8	Water Spray	-	Drone	0	0	0	0	0	0	0
T_9	Control	-	-	0	0	0	0	0	0	0

Table 5 : The residue level of different doses of Hexaconazole 5 EC on chilli fruits sprayed through drone

Sl. No	Treatments	Spray Volume (l/ha)	Dose (ml/ha)	Sprayer	5^{th} DAS (mg/kg)	10^{th} DAS (mg/kg)	15^{th} DAS (mg/kg)	Soil 15^{th} DAS (mg/kg)	MRL As per FSSAI in chilli
T_1	Hexaconazole 5 EC	25	500	Drone	0.227	0.182	0.109	BLQ of 0.008	0.5
T_2	Hexaconazole 5 EC	25	300	Drone	0.164	0.149	0.100	BLQ of 0.008	0.5
T_3	Hexaconazole 5 EC	25	200	Drone	0.098	0.089	0.061	BLQ of 0.008	0.5
T_7	Hexaconazole 5 EC	500	500	Knapsack	0.042	0.033	0.024	BLQ of 0.008	0.5

Table 6 : Economic analysis of chilli with drone application of fungicide at HREC Hidkal

Sl. No	Treatments	Dose (ml/ha)	Yield (q/ha)	Cost of fungicide (Rs/ha)	Cost of spraying (Rs/ha)	Cost of cultivation (Rs/ha)	Total cost (Rs/ha)	Returns (Rs/ha)	B:C	Net returns (Rs/ha)
			1	2	3	4	5=2+3+4	6	7=6/5	8=6-5
1	Hexaconazole 5 EC	500	7.02	990	3750	128814	133554	280800	2.10	147246
2	Hexaconazole 5 EC	300	6.89	594	3750	128814	133158	275600	2.07	142442
3	Hexaconazole 5 EC	200	6.71	396	3750	128814	132960	268400	2.02	135440
4	Hexaconazole 5 EC	100	6.5	198	3750	128814	132762	260000	1.96	127238
5	Hexaconazole 5 EC	50	6.00	99	3750	128814	132663	240000	1.81	107337
6	Hexaconazole 5 EC	25	5.65	49.5	3750	128814	132614	226000	1.70	93386.5
7	Hexaconazole 5 EC Knapsack sprayer	500	6.97	990	3600	128814	133404	278800	2.09	145396
8	Water spray	Water	5.12	0	3750	128814	132564	205000	1.55	72436
9	Control (No spray)	-	5.25	0	0	128814	128814	210000	1.63	81186

Avg Price: 400 Rs/ kg, Labour charge for knapsack spraying 1 ha is considered as Rs1200 (700+500), Drone charge for per hectare is Rs 1250 (Rs 500 /acre)
No of spray: 3

Discussion

Hexaconazole 5 EC for the management of anthracnose of chilli

The present experiment, conducted during the *kharif* season of 2023-2024, aimed to standardize fungicide application for managing chilli anthracnose using drones with a different dose. The results revealed that Hexaconazole 5 EC applied @ 500 ml/ha through drone and knapsack recorded the lowest PDI (21.48), followed by the treatment @ 300 ml/ha, which resulted in a PDI of (22.96), which was on par with both drone and knapsack sprayed at the dose of 500 ml/ha. The control treatment, in comparison, had a PDI of 55.55 per cent.

It is evident from the present investigation that even with a reduced dosage of Hexaconazole 5 EC @ 300 ml/ha, applied through drone effectively controlled chilli anthracnose without compromising efficacy. These findings suggest that lower rates of fungicide can be employed without significant loss of disease control. Therefore, the application of 300 ml/ha using drones can successfully manage chilli anthracnose while maintaining optimal performance

The data concerning yield revealed that Hexaconazole 5 EC at 500 ml/ha applied through drone recorded a yield of 7.02 q/ha, followed by same dose applied using knapsack recorded yield of 6.97q/ha, followed by Hexaconazole 5 EC at the 300 ml/ha applied through drone recorded a yield 6.89 q/ha which is significantly superior to untreated control 5.25 q/ha.

The results of this experiment were similar to those of the study conducted by Sambaiah *et al.* (2023), who evaluated the use of UAV for managing late leaf spot in groundnut. In their study, they recommended the use of Hexaconazole 5 EC for UAV spraying at a dose of 300 ml/acre, which is 50 percent of the dose recommended for traditional spray.

Hexaconazole 5 EC for the management of powdery mildew in chilli

An experiment conducted during the *kharif* season of 2023-2024 focused on optimizing fungicide dosages for managing powdery mildew on chilli through drone application. The results showed that applying Hexaconazole 5 EC at 500 ml/ha using a knapsack sprayer resulted in the lowest PDI (14.81). This was on par with the drone applications at both the 500 ml/ha dose and a reduced 200 ml/ha dose, which achieved PDI of 15.55 and 17.78 respectively. These findings demonstrate that even with a lower dosage of 200 ml/ha through, drone effectively controlled the disease without compromising efficacy.

The present investigation demonstrated that, through drone application, Hexaconazole 5 EC at a reduced dosage of 200 ml/ha can effectively manage chilli powdery mildew without compromising efficacy.

Hexaconazole 5 EC is a systemic triazole fungicide. Triazole antifungal agents target the ergosterol biosynthesis pathway by inhibiting 14-α-demethylase, an enzyme responsible for removing the methyl group at the C-14 position of sterol precursors. This inhibition causes the buildup of abnormal sterol intermediates (14-α-methylsterols) on the fungal cell surface, ultimately leading to the cessation of fungal growth.

Present results contribute to the effort of standardizing drone application doses for effective disease management. Similar findings were reported by Xiao *et al.* (2020), who compared the control efficacy of drones and knapsack sprayers in managing *Phytophthora capsica* in processing pepper fields. They found that applying only one-third of the recommended field dosage using Cymoxanil 8% + Mancozeb 72% WP yielded the best control results. This aligns with our findings, suggesting that drone applications can achieve optimal efficacy even with reduced pesticide volumes while maintaining high levels of bio-efficacy, supporting effective disease control and promoting resource efficiency in agricultural practices.

Size and spread of droplets of drone

The use of drones in agriculture has revolutionized the way crop spraying is conducted, providing a more efficient and precise method of pesticide and fertilizer application. One of the critical factors determining the effectiveness of drone-based spraying is the size and spread of the droplets produced. Smaller droplets can cover more area but may drift away, while larger droplets have less drift but might not cover as much area. The type of nozzle, the pressure of the spray and the height of the drone all affect droplet size and spread. By understanding these factors, we aim to optimize drone spraying techniques to ensure uniform coverage, minimize wastage and reduce environmental impact

The Volume Median Diameter (VMD), also known as DV 0.5, represents the median droplet size, where half of the total spray volume is made up of droplets smaller than the VMD and half is larger. This droplet size is crucial in determining the efficacy of drone applications for disease management. According to Syngenta Crop Protection AG (Basel, Switzerland), optimal results are achieved when there are at least 20–30 droplets/cm² for insecticide or pre-emergence herbicide applications, 30–40 droplets/cm² for post-emergence herbicides and 50–70 droplets/cm² for fungicide applications.

In this study, the average VMD for drone-applied droplets in chilli crop was measured across different canopy levels. In chilli, the VMD was recorded at 288 µm in the upper canopy, 253 µm in the middle canopy and 270 µm in the lower canopy, with corresponding droplet densities of 60.25 droplets/cm², 51.77 droplets/cm² and 48.83 droplets/cm². These values indicate a uniform droplet distribution, which is essential for effective disease management across all canopy layers.

Phytotoxicity of drone application

The application of fungicide through drones may pose a risk of phytotoxicity due to the use of low spray volumes and high concentrations compared to traditional methods of fungicide application. The present study evaluated the phytotoxicity effects of fungicide applied through drone to assess the potential impact on plant health.

Hexaconazole 5 EC

The fungicide dose plays a critical role in disease management. When Hexaconazole 5 EC was applied through drones to manage chilli anthracnose and powdery mildew at the recommended dose with a lower spray volume of 25 l/ha, no phytotoxicity symptoms were observed across all treatments.

Economics of drone application of fungicides in managing the disease.

This study conducted an economic analysis of drone application for managing foliar diseases in chilli using chemical fungicide. The objective was to evaluate the cost-effectiveness and potential financial benefits of using drone technology in crop protection

Chilli anthracnose

The economics of drone application for fungicide Hexaconazole 5 EC at various doses revealed that the highest B:C ratio of 2.10 was recorded in T_1, which was comparable to the treatment with the same dose applied using a knapsack sprayer (T_7, B:C ratio of 2.09). The second highest treatment with drone application achieved a B:C ratio of 2.07. while the control treatment showed a B:C ratio of 1.63. These results demonstrate that drone applications are equally effective as knapsack sprayers in disease management, showing nearly identical B:C ratios. Additionally, by reducing pesticide use by 40 per cent of the recommended field dose, the T_2 treatment, with the second-highest B:C ratio, offers a viable option without compromising yield. This indicates that drones can provide cost-effective solutions in disease management while promoting more efficient pesticide use.

Residue level due to drone application of fungicide

The present study investigated the residue levels of the fungicide Hexaconazole 5 EC in chilli. The fungicide was applied through drone using low volumes and high concentrations at various doses. Chilli samples from treatments sprayed by drone with higher doses of Hexaconazole 5 EC at rates of 500 ml/ha, 300 ml/ha and 200 ml/ha, as well as the treatment applied using a knapsack sprayer at the recommended dose, were collected for residual analysis on the 5th, 10th and 15th days after spraying.

On the 5th day post-application, the residues detected in the samples were 0.227 mg/kg, 0.164 mg/kg, 0.098 mg/kg and 0.042 mg/kg (knapsack), respectively. All samples were found to be below the Maximum Residue Limit (MRL) set by the Food Safety and Standards Authority of India (FSSAI), which is 0.5 mg/kg (Anonymous, 2024).

On the 15th day, residue analysis in the soil from these plots showed levels below the limit of quantification, indicating no adverse impact on soil health, even with the higher doses applied through drone

Conclusion

The study highlights the potential of drones as a transformative tool in the agricultural sector, particularly for managing diseases in chilli crops. Drone-based applications provide significant advantages, including precision in fungicide delivery, reduced labor dependency, and efficient coverage. For chilli, Hexaconazole 5 EC was effective in managing anthracnose and powdery mildew, with reduced doses of 300 ml/ha and 200 ml/ha, respectively, achieving comparable results to the recommended dose. These findings emphasize the potential for optimizing fungicide usage, reducing costs, and minimizing environmental impact. Drone spraying demonstrated safe application, with no observed phytotoxic effects or adverse impacts on crop health. Residue analysis indicated acceptable levels well within safety limits, supporting the suitability of drones for sustainable disease management in chilli cultivation. Economic analysis further confirmed the cost-effectiveness of drone applications, with high benefit-cost ratios for both anthracnose and powdery mildew management. Overall, the study underscores the efficiency, safety and economic viability of drone-based fungicide applications, paving the way for broader adoption in chilli farming to enhance productivity and sustainability.

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