



Field evaluation of pollination efficiency of Asiatic hive bee, *Apis cerana* under cyantraniliprole and tolfenpyrad treatments in watermelon ecosystem

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Abstract

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) is a highly pollinator-dependent crop in which honey bees play a vital role in ensuring successful fruit set and yield. However, insecticide applications during the flowering period may adversely affect honey bee foraging and pollination efficiency. The present study evaluated the pollination efficiency of *Apis cerana* under cyantraniliprole and tolfenpyrad treatments in the watermelon ecosystem. Pollen and nectar foraging activity declined markedly in insecticide-treated plots on the 1st, 3rd and 5th days after spraying, with the greatest reduction observed on the first day. From the 7th day onward, foraging activity showed an increasing trend, while outgoing forager activity appeared similar across treatments. Tolfenpyrad (3.92 ± 0.17 fruits vine⁻¹; 41.65 t ha⁻¹) and cyantraniliprole (3.85 ± 0.26 fruits vine⁻¹; 41.44 t ha⁻¹) under bee-colony conditions produced significantly higher fruit set and yield than their corresponding treatments without bee colonies ($p < 0.001$), whereas the water spray control without bee colony recorded the lowest yield (20.37 t ha⁻¹) highlighting the critical role of managed bee pollination in enhancing watermelon productivity. These findings indicate that, under the conditions of this study, the integration of managed *A. cerana* colonies with the judicious use of cyantraniliprole (90 g a.i. ha⁻¹) and tolfenpyrad (150 g a.i. ha⁻¹) can sustain pollination services and improve watermelon productivity.

Keywords: crop productivity; foraging behaviour; honey bee; insecticides; pollination services; pollinator conservation

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1. Introduction

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) is an economically important cucurbit cultivated throughout the world under varied environmental conditions (1, 2). The monoecious nature of watermelon, characterised by distinct male and female flowers on the same plant, makes effective pollination essential. The crop produces relatively large, heavy and sticky pollen grains that are not efficiently dispersed by wind. Therefore, successful fertilisation, fruit set and fruit quality depend largely on timely insect-mediated pollen transfer (3). With a global production of more than 101.62 million tonnes, watermelon ranks among the most widely cultivated horticultural crops. China dominates world production, whereas India, Turkey, Algeria and Iran also contribute substantially to global output (4).

Despite the expansion in cultivated area and production, successful watermelon cultivation is strongly dependent on effective pollination, as the crop is

predominantly cross-pollinated. Pollination is a fundamental ecological process that sustains ecosystem stability and enables the reproduction of both cultivated and wild plant species, thereby supporting biodiversity and agricultural productivity (5). Animal-mediated pollination provides immense economic and agricultural benefits, contributing more than US \$800 billion annually to global agricultural production, with over 75 % of the world's leading food crop types benefiting from animal pollination (6, 7).

Among the various insect pollinators visiting watermelon flowers, honey bees are considered the most efficient owing to their abundance, floral constancy and effective pollen-carrying ability. Honey bees visit watermelon flowers for both pollen and nectar and facilitate pollen transfer from staminate to pistillate flowers during foraging (8). Since watermelon flowers remain open and receptive for only a few hours during the morning, timely bee visitation is critical for achieving

maximum pollination efficiency and crop productivity (9). Inadequate pollination during this limited flowering period can result in poor fruit set, misshapen fruits, reduced fruit size and weight, poor seed development and ultimately lower marketable yield (10).

Although thousands of bee species contribute to pollination services, honey bees, especially *Apis mellifera* Linnaeus and *Apis cerana* Fabricius, dominate commercial pollination systems worldwide (11). Among the honey bee species involved in watermelon pollination, *A. cerana*, the indigenous honey bee of Asia, is one of the most important managed pollinators of agricultural and horticultural crops. Compared with *A. mellifera*, *A. cerana* is better adapted to Asian agro-climatic conditions and is widely managed for crop pollination across the region. It is characterised by efficient foraging behaviour, rapid colony development and effective pollination efficiency. Its synchronised foraging activity during the flowering period makes it an ideal pollinator for watermelon cultivation (12).

Although honey bees are highly efficient pollinators of watermelon, their pollination services may be influenced by crop protection practices adopted during the flowering period. Watermelon cultivation is frequently challenged by economically important insect pests, necessitating the application of insecticides to minimise yield losses (13). In commercial watermelon production systems, insecticide applications are frequently carried out during the flowering period to manage key insect pests, often coinciding with peak honey bee foraging activity (14). Exposure to insecticide residues on flowers may alter the foraging behaviour, visitation frequency and pollen transfer efficiency of honey bees, thereby affecting fruit set and yield (15). However, limited information is available on the field-level effects of cyantraniliprole and tolfenpyrad on the foraging behaviour of *A. cerana* and the resulting pollination efficiency and watermelon productivity under managed pollination conditions. This knowledge gap limits the development of pollinator-friendly pest management strategies that effectively balance crop protection with pollination services. Therefore, the objectives of the present study were:

- To evaluate the effects of cyantraniliprole and tolfenpyrad insecticide treatments on the foraging behaviour of *A. cerana* in watermelon ecosystem
- To assess the influence of *A. cerana* pollination under cyantraniliprole and tolfenpyrad insecticide treatments on fruit set and yield in watermelon ecosystem

2. Materials and Methods

Experimental design

The experiment was carried out during 2025 in six separate one-hectare watermelon fields planted with the hybrid NS 295, located in Kurumparam R. F. village in the Tindivanam block of Viluppuram district. The fields

were selected based on their uniform crop growth, similar agronomic management practices and adequate isolation distance to minimise cross-foraging of honey bees and insecticide drift between treatments. Each field represented one treatment and the crop was planted at a spacing of 200 × 60 cm following standard agronomic practices. All intercultural operations, including irrigation, fertiliser application, weeding and other recommended crop management practices, were carried out uniformly across all treatments throughout the experimental period. Each treatment plot contained approximately 8333 watermelon plants. Each one-hectare treatment field was divided into seven equal plots, each containing approximately 1190 watermelon plants. Each treatment consisted of seven managed *A. cerana* colonies ($n = 7$). The one-hectare treatment field was divided into seven equal plots, with one managed *A. cerana* colony placed in each plot. Each bee colony was considered one replication for honey bee foraging observations, whereas the corresponding field plot associated with each colony was considered one replication for fruit set and fruit yield assessments. The bee hives were placed at different locations within each field to ensure uniform pollination activity throughout the experimental area. The study included 6 treatments: T_1 - Tolfenpyrad spray (Keefun®) + bee colony, T_2 - Cyantraniliprole spray (Benevia®) + bee colony, T_3 - Control (water spray + bee colony), T_4 - Tolfenpyrad spray + without bee colony, T_5 - Cyantraniliprole spray + without bee colony and T_6 - Control (water spray + without bee colony). The insecticide applications were carried out at approximately 10 % flowering during periods of minimal honey bee activity, after daily foraging had ceased, to minimise bee exposure while enabling assessment of their effects on pollination under field conditions. The insecticides were applied using a knapsack sprayer at a spray volume of 500 L ha⁻¹. The insecticides were applied at their recommended field doses (Table 1). For each treatment, the required quantity of the commercial formulation was measured and diluted with clean water to obtain the recommended spray concentration immediately before application. The treatment plots were separated by an isolation distance of more than 1 km from each other to prevent overlapping of foraging areas and to avoid insecticide drift. This distance was selected based on the typical foraging range of *A. cerana*, as most foraging activity occurs within 500–900 m of the hive under normal field conditions (16). Hives were installed 48 hr before anthesis and maintained throughout the flowering and fruiting periods. Routine checks ensured colony health and queen activity. Foraging behaviour observations were recorded only in treatments involving bee colonies (T_1 , T_2 and T_3), because bee foraging activity can be assessed only in the presence of managed pollinators. Fruit set and yield per hectare were recorded in all 6 treatments, both with and without bee colonies, in order to distinguish the individual and combined effects of insecticide application and bee pollination on crop productivity.



Table 1. Details of insecticides used in the field study

Sl. No.	Insecticide	Chemical group	Mode of action	Dose mL L ⁻¹	Manufacturer
1	Tolfenpyrad 15 % EC	Pyrazole insecticide	Inhibits mitochondrial electron transport (Complex I inhibitor)	2	Nichino India Pvt. Ltd.
2	Cyantraniliprole 10.26 % OD	Anthranilic diamide	Ryanodine receptor modulator	1.8	FMC India Pvt. Ltd.

Foraging observation and yield attributes

The foraging behaviour of *A. cerana* was assessed by recording the number of bees entering and exiting the hive for 5 min every hour during the observation period. Foraging activity of *A. cerana* was recorded at 1st, 3rd, 5th, 7th, 10th and 15th days after insecticide application to assess the immediate and longer-term effects of the insecticides on honey bee foraging behaviour and to monitor the temporal pattern of foraging recovery. The numbers of outgoing foragers, pollen foragers and nectar foragers were recorded for 5 min hr⁻¹ at the hive entrance from 07:00 to 12:00 hr each day. Fruit set per vine and yield per hectare were recorded from each treatment plot to evaluate the pollination efficiency of *A. cerana*. Total fruit yield (tonnes/hectare) was measured using a digital platform weighing scale (SWISSER Instruments Pvt. Ltd., India; capacity: 300 kg; precision: 0.01 kg).

Statistical analysis

The foraging activity data of pollen foragers, nectar foragers and outgoing foragers were analysed using descriptive statistics. Results were expressed as means accompanied by standard error (SE) to represent variability in observations. To compare differences among treatments, the non-parametric Kruskal-Wallis test was applied for fruit set and fruit yield, followed by pairwise Dunn's post-hoc tests for multiple comparisons ($p < 0.05$).

3. Results

Effect of insecticide treatments on hourly foraging activity of *Apis cerana* in watermelon

The assessment of honey bee foraging behaviour was conducted only for treatments containing managed *A. cerana* colonies (T₁–T₃), as these treatments were specifically designed to assess the effects of insecticide applications on pollen and nectar foraging activity under field conditions. On the first day, during 07:00–08:00 hr, the mean number of pollen foragers was recorded as (140.78 ± 26.73), followed by cyantraniliprole (115.78 ± 1.72) and tolfenpyrad (104.11 ± 0.92) and the similar trend was observed at 08:00–09:00 hr, 09:00–10:00 hr, 10:00–11:00 hr and 11:00–12:00 hr. Nectar foragers during 07:00–08:00 hr were 58.41 ± 2.23 in the control followed by 48.41 ± 3.55 in cyantraniliprole and 43.08 ± 0.69 in tolfenpyrad and this treatment-wise pattern was maintained at 08:00–09:00 hr, 09:00–10:00 hr, 10:00–11:00 hr and 11:00–12:00 hr. Maximum nectar foraging occurred during 09:00–10:00 hr and 10:00–11:00 hr, with higher values in the control (116.92 ± 7.95 and 129.74 ± 3.52) compared to cyantraniliprole (106.59 ± 2.25 and 116.74 ± 2.88) and tolfenpyrad (99.92 ± 1.42 and 109.74 ± 3.52) (Table 2).

Table 2. Effect of insecticide treatments on hourly foraging activity of *Apis cerana indica* on the first day

Hours	No. of foragers entering / exiting hive / 5 min								
	Control (1 st day)			Tolfenpyrad (1 st day)			Cyantraniliprole (1 st day)		
	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers
	Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers	
07.00–08.00	140.78 ± 26.73	58.41 ± 2.23	235.63 ± 5.47	104.11 ± 0.92	43.08 ± 0.69	228.96 ± 8.77	115.78 ± 1.72	48.41 ± 3.55	229.96 ± 8.77
08.00–09.00	102.36 ± 6.23	79.69 ± 3.47	231.52 ± 11.65	68.96 ± 1.85	66.36 ± 1.01	217.85 ± 3.74	74.69 ± 2.39	70.03 ± 0.37	219.52 ± 3.63
09.00–10.00	76.31 ± 2.05	116.92 ± 7.95	244.80 ± 6.88	59.64 ± 4.63	99.92 ± 1.42	217.47 ± 3.84	64.97 ± 1.72	106.59 ± 2.25	234.80 ± 2.79
10.00–11.00	65.11 ± 7.22	129.74 ± 3.52	168.93 ± 19.18	48.44 ± 3.78	109.74 ± 3.52	142.93 ± 16.74	55.11 ± 1.45	116.74 ± 2.88	152.93 ± 8.80
11.00–12.00	33.32 ± 0.41	54.66 ± 4.80	59.00 ± 19.36	21.99 ± 6.31	47.99 ± 2.29	48.66 ± 16.04	23.66 ± 6.20	50.32 ± 0.83	55.53 ± 13.33

On the third day after spraying, the observed treatment-wise pattern in pollen and nectar forager activity was like that recorded on the first day, with the control showing higher mean pollen and nectar forager activity than the cyantraniliprole and tolfenpyrad treatments throughout the observation period (07:00–12:00 hr). Mean nectar foraging activity was most pronounced during 09:00–11:00 hr (Table 3). A similar temporal pattern was observed on the fifth day after spraying (Table 4).

On the 7th day after spray, during 07:00–08:00 hr, the mean number of pollen foragers was 176.75 ± 4.36 in the control, 174.08 ± 0.66 in the cyantraniliprole treatment and 170.75 ± 0.58 in the tolfenpyrad treatment. The same treatment-wise pattern was observed during the remaining observation periods. Nectar forager activity during the early- and mid-morning observation periods followed the same temporal pattern,

with the highest mean values recorded between 09:00 and 11:00 hr (Table 5). A similar temporal pattern was observed on the tenth and 15th days after spray (Tables 6 and 7). Outgoing forager activity remained largely uniform among treatments across all observation hours (07:00–12:00 hr) on the 1st, 3rd, 5th, 7th, 10th and 15th days after spray.

Overall, from the 1st to 15th day after spray, pollen and nectar forager activity in the insecticide-treated plots was lower than the control, with the greatest treatment-wise difference observed on the 1st day and a less pronounced pattern on the 3rd and 5th days. From the 7th to the 15th day after spray, the mean pollen and nectar forager activity in the insecticide-treated plots showed a treatment-wise pattern similar to that of the control, reflecting the observed temporal changes in foraging activity over the study period.

Table 3. Effect of insecticide treatments on hourly foraging activity of *Apis cerana* on the third day

No. of foragers entering / exiting hive / 5 min									
Hours	Control (3 rd day)			Tolfenpyrad (3 rd day)			Cyantraniliprole (3 rd day)		
	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers
	Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers	
07.00–08.00	157.02 ± 1.24	61.95 ± 2.87	241.92 ± 35.1	117.02 ± 1.24	55.29 ± 2.06	235.63 ± 5.47	127.02 ± 1.24	58.62 ± 0.68	237.63 ± 5.10
08.00–09.00	106.13 ± 4.96	80.65 ± 3.28	239.17 ± 9.28	83.80 ± 4.29	72.32 ± 1.13	224.52 ± 3.97	95.46 ± 1.83	76.99 ± 1.59	229.52 ± 1.67
09.00–10.00	77.44 ± 2.84	119.12 ± 0.87	242.26 ± 0.96	70.78 ± 3.14	105.79 ± 2.73	231.47 ± 4.14	74.11 ± 0.50	112.46 ± 2.01	231.47 ± 4.14
10.00–11.00	58.54 ± 4.62	136.02 ± 6.73	175.29 ± 16.32	50.87 ± 0.56	117.35 ± 3.90	150.26 ± 16.41	55.21 ± 1.31	127.68 ± 1.68	160.26 ± 9.66
11.00–12.00	35.08 ± 3.67	62.23 ± 2.22	79.06 ± 2.13	25.08 ± 2.96	55.57 ± 2.23	66.00 ± 2.15	27.42 ± 0.64	59.90 ± 0.32	72.66 ± 5.28

Table 4. Effect of insecticide treatments on hourly foraging activity of *Apis cerana* on the fifth day

No. of foragers entering / exiting hive / 5 min									
Hours	Control (5 th day)			Tolfenpyrad (5 th day)			Cyantraniliprole (5 th day)		
	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers
	Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers	
07.00–08.00	162.90 ± 3.96	69.63 ± 0.83	243.07 ± 16.73	126.23 ± 1.07	62.96 ± 5.87	239.74 ± 13.62	142.90 ± 2.26	66.29 ± 2.54	239.74 ± 13.62
08.00–09.00	113.46 ± 2.25	86.95 ± 2.17	231.06 ± 11.23	93.46 ± 2.25	76.95 ± 2.17	234.39 ± 8.54	105.46 ± 1.78	81.95 ± 0.53	231.06 ± 9.80
09.00–10.00	79.30 ± 1.50	121.63 ± 4.10	242.06 ± 30.85	75.30 ± 1.78	114.96 ± 1.30	238.72 ± 31.42	77.63 ± 0.93	118.29 ± 2.97	238.72 ± 27.82
10.00–11.00	57.06 ± 1.37	161.92 ± 2.50	166.17 ± 16.70	54.39 ± 1.32	141.92 ± 3.46	162.83 ± 15.54	56.39 ± 2.42	145.26 ± 3.53	164.50 ± 16.04
11.00–12.00	30.03 ± 4.90	66.27 ± 4.67	78.26 ± 1.05	26.70 ± 4.84	58.27 ± 4.27	71.59 ± 4.33	28.03 ± 4.58	62.93 ± 1.80	75.26 ± 3.86

Table 5. Effect of insecticide treatments on hourly foraging activity of *Apis cerana* on the seventh day

Hours	No. of foragers entering / exiting hive / 5 min								
	Control (7 th day)			Tolfenpyrad (7 th day)			Cyantraniliprole (7 th day)		
	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers
	Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers	
07.00–08.00	176.75 ± 4.36	69.99 ± 1.74	230.50 ± 24.17	170.75 ± 0.58	67.66 ± 1.11	229.50 ± 23.77	174.08 ± 0.66	66.99 ± 1.74	229.50 ± 23.47
08.00–09.00	119.00 ± 3.99	89.32 ± 0.34	247.09 ± 28.67	115.00 ± 2.29	86.99 ± 2.25	245.43 ± 29.22	117.66 ± 1.66	88.32 ± 1.28	246.76 ± 25.49
09.00–10.00	78.33 ± 2.15	133.95 ± 3.01	250.78 ± 32.94	75.33 ± 1.32	127.95 ± 2.28	247.78 ± 31.35	77.00 ± 1.23	131.95 ± 2.45	248.78 ± 31.85
10.00–11.00	61.77 ± 3.78	167.76 ± 1.07	160.66 ± 2.47	59.44 ± 1.13	161.33 ± 2.01	159.33 ± 4.37	60.11 ± 0.87	164.66 ± 2.37	160.33 ± 2.32
11.00–12.00	31.39 ± 0.60	65.84 ± 3.27	84.62 ± 0.69	30.39 ± 1.54	63.50 ± 3.14	79.29 ± 0.93	31.39 ± 2.00	65.03 ± 3.06	82.62 ± 1.75

Table 6. Effect of insecticide treatments on hourly foraging activity of *Apis cerana* on the tenth day

Hours	No. of foragers entering / exiting hive / 5 min								
	Control (10 th day)			Tolfenpyrad (10 th day)			Cyantraniliprole (10 th day)		
	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers
	Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers	
07.00–08.00	179.36 ± 1.48	72.06 ± 2.06	220.57 ± 14.78	174.69 ± 0.13	70.73 ± 1.04	217.91 ± 17.10	177.03 ± 3.03	71.06 ± 1.24	218.91 ± 13.33
08.00–09.00	120.60 ± 2.61	104.25 ± 3.63	236.66 ± 12.89	117.26 ± 1.18	101.58 ± 1.70	233.32 ± 12.41	119.26 ± 0.30	103.92 ± 3.67	233.99 ± 15.49
09.00–10.00	85.89 ± 1.96	143.81 ± 2.39	259.99 ± 30.70	82.55 ± 0.59	139.48 ± 4.68	254.99 ± 33.32	84.89 ± 2.50	142.15 ± 0.97	258.32 ± 30.01
10.00–11.00	56.26 ± 0.65	169.96 ± 4.59	180.69 ± 2.31	54.26 ± 1.36	165.29 ± 3.17	179.02 ± 3.83	55.59 ± 0.10	168.63 ± 3.92	180.02 ± 2.43
11.00–12.00	30.81 ± 0.91	72.71 ± 3.83	89.37 ± 2.02	30.14 ± 0.89	70.38 ± 2.89	84.70 ± 3.17	30.14 ± 4.25	72.38 ± 3.78	87.37 ± 1.14

Table 7. Effect of insecticide treatments on hourly foraging activity of *Apis cerana* on the fifteenth day

Hours	No. of foragers entering / exiting hive / 5 min								
	Control (15 th day)			Tolfenpyrad (15 th day)			Cyantraniliprole (15 th day)		
	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers	Incoming foragers		Outgoing foragers
	Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers		Pollen foragers	Nectar foragers	
07.00–08.00	182.69 ± 5.47	73.40 ± 1.23	213.91 ± 9.88	180.69 ± 1.97	71.40 ± 1.49	212.91 ± 10.11	181.23 ± 5.26	72.06 ± 2.06	213.91 ± 9.88
08.00–09.00	125.60 ± 2.31	105.58 ± 2.64	233.32 ± 12.41	122.60 ± 1.56	103.58 ± 3.60	232.32 ± 12.14	124.60 ± 1.56	104.25 ± 3.63	233.32 ± 12.41
09.00–10.00	103.89 ± 5.32	147.15 ± 7.51	236.66 ± 4.56	102.89 ± 4.33	144.15 ± 5.64	234.99 ± 4.86	102.22 ± 3.26	147.15 ± 7.51	235.66 ± 4.67
10.00–11.00	62.93 ± 3.78	189.96 ± 2.32	180.69 ± 2.31	60.59 ± 2.70	187.63 ± 3.54	179.02 ± 1.46	61.26 ± 3.93	188.63 ± 3.61	179.02 ± 3.18
11.00–12.00	31.48 ± 4.33	69.38 ± 4.55	91.70 ± 2.03	30.48 ± 0.61	67.38 ± 4.54	90.03 ± 3.90	30.48 ± 1.56	68.34 ± 0.91	91.03 ± 2.45

Influence of insecticide application on fruit set and yield in watermelon

Fruit set and yield were evaluated across all 6 treatments (T_1 – T_6), including treatments with and without managed bee colonies, to assess the contribution of *A. cerana* pollination under different insecticide treatments. Fruit set and fruit yield of watermelon differed significantly among treatments (fruit set: $\chi^2 = 26.35$, $df = 5$, $p < 0.001$; fruit yield: $\chi^2 = 30.591$, $df = 5$, $p < 0.001$). Bee-included treatments recorded higher mean fruit set than treatments without bee colonies. The tolfenpyrad spray + bee colony treatment (3.92 ± 0.17 fruits vine⁻¹) had a significantly higher fruit set than the tolfenpyrad spray + without bee colony treatment (2.57 ± 0.20 ; adjusted $p = 0.008$). Similarly, the cyantraniliprole spray + bee colony treatment (3.85 ± 0.26) had a significantly higher fruit set than the cyantraniliprole spray + without bee colony treatment (2.71 ± 0.18 ; adjusted $p = 0.017$). The water spray + bee colony treatment (3.71 ± 0.18) recorded a significantly higher fruit set than the water spray + without bee colony treatment (2.50 ± 0.18 ; adjusted $p = 0.01$). Tolfenpyrad spray with bee colony (41.65 t ha⁻¹) recorded significantly higher fruit yield than the water spray control with bee colony (29.40 t ha⁻¹; adjusted $p = 0.0363$), cyantraniliprole spray without bee colony (29.96 t ha⁻¹; adjusted $p = 0.0468$) and the water spray control without bee colony (20.37 t ha⁻¹; adjusted $p = 0.00007$). Similarly, cyantraniliprole spray with bee colony (41.44 t ha⁻¹) recorded significantly higher fruit yield than the water spray control with bee colony (adjusted $p = 0.0274$), cyantraniliprole spray without bee colony (adjusted $p = 0.0319$) and the water spray control without bee colony (adjusted $p = 0.00004$). The water spray control without bee colony recorded the lowest fruit yield (Table 8).

Table 8. Fruit set and yield of watermelon under different insecticide treatments

Treatments	Fruit set (vine ⁻¹)	Fruit yield (t ha ⁻¹)
Tolfenpyrad spray + bee colony (T_1)	3.92 ± 0.17^a	41.65^a
Cyantraniliprole spray + bee colony (T_2)	3.85 ± 0.26^a	41.44^a
Control (water spray + bee colony) (T_3)	3.71 ± 0.18^a	29.40^{bc}
Tolfenpyrad spray + without bee colony	2.57 ± 0.20^b	30.94^b
Cyantraniliprole spray + without bee colony	2.71 ± 0.18^b	29.96^{bc}
Control (water spray + without bee colony)	2.50 ± 0.18^b	20.37^c
p value	0.001	0.001

Means of seven replications. Means followed by different letters differ significantly according to Dunn's post hoc test ($p < 0.05$).

4. Discussion

Honey bee foraging in agricultural fields is essential for colony survival and effective pollination, as bees depend on nectar and pollen collected from flowering plants. Proper foraging supports food storage, brood development and colony strength (8). Beekeepers usually place hives in areas assumed to have low pesticide exposure to protect hive health and productivity (17). However, the present findings show that even these areas are contaminated with insecticides, indicating the widespread presence of pesticides in agricultural landscapes. Such contamination disrupts normal foraging behaviour and negatively affects colony performance (18).

The temporal pattern of pollen and nectar foraging activity observed in the present study suggests that insecticide application influenced the foraging behaviour of *A. cerana* during the initial period after spraying. The lower pollen and nectar foraging activity observed during the first 5 days after insecticide application may be associated with the reported behavioural effects of insecticide exposure, including temporary repellency, impaired orientation and reduced foraging motivation in honey bees (19, 20). From the 7th day onwards, pollen and nectar foraging activity in the insecticide-treated plots gradually increased. This temporal pattern coincided with the reported dissipation of cyantraniliprole and tolfenpyrad residues under field conditions (21, 22). As insecticide residues decline over time through environmental processes such as sunlight exposure, temperature, rainfall and plant growth dilution, the toxicity and repellency of treated plant surfaces are expected to decrease (23, 24). Therefore, the temporal increase in foraging activity observed in the present study may reflect reduced exposure of foraging bees as insecticide residues dissipated over time.

Cyantraniliprole and tolfenpyrad caused a temporary reduction in pollen and nectar foraging during the first five days after application, with the lowest activity observed on the first day after spraying, followed by a gradual temporal increase throughout the observation period. In contrast, neonicotinoids caused more severe and prolonged impairment of foraging efficiency in *A. cerana indica*, with clothianidin and thiamethoxam markedly reducing nectar foraging and outgoing forager activity for up to 15 days after application (25). The contrasting temporal patterns may be associated with differences in the modes of action of these insecticides. Neonicotinoids act as agonists of nicotinic acetylcholine receptors, whereas cyantraniliprole (an anthranilic diamide) targets ryanodine receptors and tolfenpyrad (a pyrazole insecticide) inhibits mitochondrial complex I (25). These differences in target sites may contribute to the comparatively less persistent effects of cyantraniliprole and tolfenpyrad on honey bee foraging activity observed in the present study. The temporary reduction in foraging activity is unlikely to have impaired pollination services under the recommended field conditions; however, repeated or prolonged exposure during flowering may adversely affect colony performance and pollination efficiency (26, 27).



Cyantraniliprole posed a low risk to pollinators, with negligible acute oral and contact toxicity to honeybees and minimal risk from pollen and nectar residues. Furthermore, semi-field and field studies further demonstrated the safety of cyantraniliprole to honeybees and its compatibility with pollination by *Bombus terrestris* under practical agricultural conditions (28). In contrast, the present study revealed a significant reduction in pollen and nectar foraging activity during the 1st, 3rd and 5th days following the application of cyantraniliprole and tolfenpyrad. However, this adverse effect was temporary, as foraging activity gradually recovered from the 7th day onwards and became comparable to the untreated control.

The gradual recovery of foraging activity from the 7th day onwards may be attributed to the progressive dissipation of insecticide residues from floral resources, resulting in reduced exposure of foraging bees over time. In addition, the reversible nature of the behavioural effects at the recommended field doses may have enabled honey bees to resume normal foraging activity as residue levels declined (18). This recovery pattern suggests that the observed reductions in foraging were primarily transient behavioural responses rather than persistent impairments under field conditions.

Similarly, the foraging activity of *A. cerana* and *A. mellifera* remained unaffected after the application of acetamiprid and endosulfan, indicating the absence of any repellent effect (29). The discrepancy between the findings of previous and present studies may be explained by differences in the insecticides evaluated, their physicochemical properties and mode of action, persistence and residue dynamics on floral resources (29). While previous researchers primarily assessed acute toxicity and overall pollinator safety, the present study focused on behavioural responses, which may be more sensitive indicators of sublethal effects (28). Therefore, although cyantraniliprole appears to pose a low risk in terms of pollinator survival, the temporary reduction in foraging activity observed in the current study suggests that short-term behavioural disturbances can occur following application.

Tolfenpyrad and cyantraniliprole treatments with managed *A. cerana* colonies recorded higher fruit yields (41.65 and 41.44 t ha⁻¹, respectively), demonstrating enhanced productivity under the combined influence of effective pollination and pest management. In contrast, another study reported the highest fruit yield of 35.63 t ha⁻¹ in plots treated with cyantraniliprole 10.26 OD at 90 g a.i. ha⁻¹ (4). The higher fruit yield observed in the present study may be attributed to the combined effect of effective pest management and enhanced pollination by *A. cerana*. However, differences between the present and previous studies may also be influenced by variations in experimental conditions, including the use of managed bee colonies in the present study, as well as differences in watermelon cultivar, soil characteristics, regional agro climatic conditions and crop management practices, all of which can affect fruit yield (30).

5. Conclusion

Cyantraniliprole and tolfenpyrad were associated with a temporary reduction in the pollen and nectar foraging activity of *Apis cerana* during the initial period after application, followed by a gradual temporal increase in foraging activity from the seventh day onwards. The integration of managed *A. cerana* colonies with effective insecticide-based pest management significantly enhanced fruit set and yield compared with treatments without bee colonies. These findings indicate that the judicious application of cyantraniliprole (90 g a.i. ha⁻¹) and tolfenpyrad (150 g a.i. ha⁻¹) at the recommended field doses, applied at approximately 10 % flowering during periods of minimal honey bee activity after daily foraging has ceased, can effectively balance crop protection and pollination services, thereby improving watermelon productivity while minimising adverse effects on pollinator activity. Furthermore, behavioural responses should be considered alongside conventional acute toxicity endpoints to provide a more comprehensive assessment of pesticide risks to pollinators. From a practical perspective, insecticide applications should be scheduled during periods of minimal bee activity, preferably after daily foraging has ceased. Effective communication between growers and beekeepers should also be encouraged to minimise pollinator exposure while maintaining pest management and pollination services. Future research should investigate the long-term effects of repeated insecticide applications on honey bee colony health, brood development and pollination services under diverse agroecosystems.

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Authors' contributions

MI, SMR and SA contributed to literature collection, conceptualisation, writing the original draft, review and editing, while SVR, AJ, JM, RAR, BKS and BM contributed to literature collection and figure design. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interest to declare.

Ethical issues

None



Declaration of generative AI and AI assisted technologies in the writing process

During the preparation of this work, the authors used QuillBot as a supportive aid during the language polishing, grammar correction and rephrasing phases of manuscript preparation. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

- Zafar S, Amjad A, Waseem M, Sultan MT, Israr M, Manzoor MF, et al. Watermelon (*Citrullus lanatus* L.): A functional food with potential therapeutic by-products. *Cogent Food Agric.* 2026;12(1):2673601. <https://doi.org/10.1080/23311932.2026.2673601>
- Ikram M, Srinivasan MR, Suganthi A, Saminathan VR, Auxilia J, Jayakanthan M, et al. Pollinators of cucurbit crops: Diversity, efficiency and conservation challenges. *Plant Sci Today.* 2025;12:11521. <https://doi.org/10.14719/pst.11521>
- Delaplane KS, Mayer DF. Crop pollination by bees. Wallingford, United Kingdom: CABI Publishing; 2000:1–344. <https://doi.org/10.1079/9780851994482.0000>
- Food and Agriculture Organization of the United Nations. FAOSTAT [Internet].
- Breeze TD, Bailey AP, Balcombe KG, Potts SG. Pollination services in the UK: How important are honeybees? *Agric Ecosyst Environ.* 2011;142(3–4):137–43. <https://doi.org/10.1016/j.agee.2011.03.020>
- Rader R, Cunningham SA, Howlett BG, Inouye DW. Non-bee insects as visitors and pollinators of crops: Biology, ecology and management. *Annu Rev Entomol.* 2020;65:391–407. <https://doi.org/10.1146/annurev-ento-011019-025055>
- Porto RG, De Almeida RF, Cruz-Neto O, Tabarelli M, Viana BF, Peres CA, et al. Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. *Food Secur.* 2020;12(6):1425–42. <https://doi.org/10.1007/s12571-020-01043-w>
- Chaand D, Sharma D, Ganai SA, Norboo T, Sharma S. Effect of colony strength on colony build up and foraging activity of *Apis mellifera* L. *J Entomol Zool Stud.* 2017;5(6):1369–73.
- Njoroge N, Gemmill B, Bussmann R, Newton LE, Ngumi VW. Diversity and efficiency of wild pollinators of watermelon (*Citrullus lanatus* (Thunb.) Mansf.) at Yatta, Kenya. *J Appl Hortic.* 2010;12(1):35–41. <https://doi.org/10.37855/jah.2010.v12i01.07>
- Khalifa SA, Elshafiey EH, Shetaia AA, El-Wahed AAA, Algethami AF, Musharraf SG, et al. Overview of bee pollination and its economic value for crop production. *Insects.* 2021;12(8):688. <https://doi.org/10.3390/insects12080688>
- Su XL, Hua QY, Chen YF, Jiang XS, Xi WJ, Zhao DX, et al. Behavior of *Apis cerana cerana* and *Apis mellifera ligustica* as pollinator for long-season cultivated watermelon in tunnel greenhouse under summer high temperature condition. 2017:104–10.
- Theisen-Jones H, Bienefeld K. The Asian honey bee (*Apis cerana*) is significantly in decline. *Bee World.* 2016;93(4):90–7. <https://doi.org/10.1080/0005772X.2017.1284973>
- Edelson JV, Duthie J, Roberts W. Watermelon seedling growth and mortality as affected by *Anasa tristis* (Heteroptera: Coreidae). *J Econ Entomol.* 2002;95(3):595–7. <https://doi.org/10.1603/0022-0493-95.3.595>
- Archana BR, Pujar K, Chethan T, Hiremath KM, Arpitha KC, Varma H. Influence of insecticide application on pollinators and predatory arthropods in watermelon agroecosystem. *Arch Curr Res Int.* 2024;24(9):161–6. <https://doi.org/10.9734/acri/2024/v24i9878>
- Srivani G, Kumar GS, Djanaguiraman M, Priya RS, Sharmila R, Arthanari PM, et al. Unraveling pesticide impacts on pollinators: A global challenge for sustainable crop protection. *Sci Nat.* 2026;113(2):38. <https://doi.org/10.1007/s00114-026-02086-3>
- Sparks TC, Nauen R. IRAC: Mode of action classification and insecticide resistance management. *Pestic Biochem Physiol.* 2015;121:122–8. <https://doi.org/10.1016/j.pestbp.2014.11.014>
- El Agrebi N, Steinhauer N, Tosi S, Leinartz L, de Graaf DC, Saegerman C. Risk and protective indicators of beekeeping management practices. *Sci Total Environ.* 2021;799:149381. <https://doi.org/10.1016/j.scitotenv.2021.149381>
- Gill RJ, Ramos-Rodriguez O, Raine NE. Combined pesticide exposure severely affects individual- and colony-level traits in bees. *Nature.* 2012;491(7422):105–8. <https://doi.org/10.1038/nature11585>
- Desneux N, Decourtye A, Delpuech JM. The sublethal effects of pesticides on beneficial arthropods. *Annu Rev Entomol.* 2007;52(1):81–106. <https://doi.org/10.1146/annurev.ento.52.110405.091440>
- El-Din HS, Helmy WS, Al Naggar Y, Ahmed FS. Chronic exposure to a field-realistic concentration of Closer® SC (24% sulfoxaflor) insecticide impacted the growth and foraging activity of honey bee colonies. *Apidologie.* 2022;53(2):22. <https://doi.org/10.1007/s13592-022-00937-2>
- Malhat F, Kasiotis KM, Shalaby S. Magnitude of cyantraniliprole residues in tomato following open field application: Pre-harvest interval determination and risk assessment. *Environ Monit Assess.* 2018;190(3):116. <https://doi.org/10.1007/s10661-018-6496-7>
- Wang W, Chen H, Gao D, Long J, Long H, Zhang Y. Dissipation and dietary risk assessment of thiacloprid and tolfenpyrad in tea in China. *Agronomy.* 2022;12(12):3166. <https://doi.org/10.3390/agronomy12123166>
- Fantke P, Gillespie BW, Juraske R, Jolliet O. Estimating half-lives for pesticide dissipation from plants. *Environ Sci Technol.* 2014;48(15):8588–602. <https://doi.org/10.1021/es500434p>
- Fantke P, Juraske R. Variability of pesticide dissipation half-lives in plants. *Environ Sci Technol.* 2013;47(8):3548–62. <https://doi.org/10.1021/es303525x>
- Chandrasekar S, Marimuthu M, Angappan S, Pernamallur SA, Kaithamalai B, Pagalahalli SS. Effects of neonicotinoid residues in *Apis cerana indica* bees and bee products: LC-MS/MS analysis and dietary risk assessment in a sunflower field study. *Ecotoxicol.* 2025;1–16. <https://doi.org/10.1007/s10646-025-02857-0>
- Henry M, Beguin M, Requier F, Rollin O, Odoux JF, Aupinel P, et al. A common pesticide decreases foraging success and survival in honey bees. *Science.* 2012;336(6079):348–50. <https://doi.org/10.1126/science.1215039>
- Tsvetkov N, Samson-Robert O, Sood K, Patel HS, Malena DA, Gajiwala PH, et al. Chronic exposure to neonicotinoids reduces honey bee health near corn crops. *Science.* 2017;356(6345):1395–7. <https://doi.org/10.1126/science.aam7470>



28. Dinter A, Samel A. Cyantraniliprole: Pollinator profile of the novel insecticides under laboratory, semi-field and field conditions. 2015:28–49.
29. Stanley J, Sah K, Jain SK, Bhatt JC, Sushil SN. Evaluation of pesticide toxicity at their field recommended doses to honeybees, *Apis cerana* and *A. mellifera*, through laboratory, semi-field and field studies. Chemosphere. 2015;119:668–74. <https://doi.org/10.1016/j.chemosphere.2014.07.039>
30. Chandana TP, Muthuswami M, Krishnamoorthy SV, Suganthi A. Evaluation of insecticides against major pests of watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai]. Biochem Cell Arch. 2021;21(2).

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