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Efficacy of chemical insecticides against fennel aphid, *Hyadaphis coriandri* Das infesting fennel (*Foeniculum vulgare* L.)

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Abstract
Fennel is important seed spices crop cultivated in India. Aphid, *Hyadaphis coriandri* found severely damaging the crop during flowering and fruiting stage which results in to no seed formation or shriveled and of poor quality. Field experiment was conducted to check the efficacy of nine different chemical insecticides against this pest during *rabi* season of two consecutive years (2017-18 and 2018-19) at Entomology farm, B. A. College of Agriculture, Anand Agricultural University, Anand. Among the tested insecticides, flonicamid 50 WG 0.015% and tolfenpyrad 15 EC 0.03% proved effective against aphids on fennel. Dimethoate 30 EC 0.03%, imidacloprid 17.8 SL 0.005% and acephate 75 SP 0.075% were found moderately effective insecticides, whereas thiamethoxam 25 WG 0.0125%, clothianidin 50 WDG 0.02%, diafenthiuron 50 WP 0.05% and dinotefuran 20 SG 0.006% failed to provide satisfactory protection to fennel crop against aphid infestation. The spraying of insecticides belongs to neonicotinoid group *viz*., imidacloprid, thiamethoxam, clothianidin and dinotefuran significantly reduced the activity of bees in fennel, whereas flonicamid and tolfenpyrad recorded higher activity of bees. The higher production of fennel seeds as well as net realization was obtained from flonicamid and tolfenpyrad treated plots. Treatments of dimethoate, imidacloprid and acephate obtained ICBR 1:32.37, 1:26.96 and 1:22.40, respectively. However, the flonicamid and tolfenpyrad recorded 1:14.20 and 1:6.16 ICBR even though they found effective against insect pests on fennel.

Keywords: Fennel, aphid, aphid index, seed yield, incremental cost benefit ration

Introduction
India is known as the 'Land of Spices' as foreign invaders invaded India for spices in ancient times. Vasco De Gama discovered hazardous sea route to India is only for spices trade (Sastry & Sharma, 2001) [14]. Main seed spices of India are coriander, cumin, fennel, fenugreek, dill, ajwain, celery, anise, nigella and caraway. Among all the seed spices, fennel (*Foeniculum vulgare* L.) mainly cultivated in the Surendranagar, Mehsana, Patan, Banaskantha and Morbi districts of Gujarat. In India, estimated area under fennel was 90392 ha with production of 157347 tonne in 2018-19. Gujarat occupies first rank having 38130 ha area with production of 79240 tonne and productivity of 2078 kg ha^{-1} in 2017-18 which was 82 per cent of its total production in India. The estimated area under fennel in Gujarat was 56416 ha with production of 117340 tonne in 2018-19 (Anonymous, 2019) [1].

The number of insect-pests affecting the quality production of fennel *i.e*. aphid: *Hyadaphis coriandri* (Das), thrips: *Thrips flavus* (Schrank); *Thrips tabaci* (Lindeman); *Scirtothrips dorsalis* (Hood), whitefly: *Bemisia tabaci* (Genn.), leaf eating caterpillar/gram pod borer: *Helicoverpa armigera* (Hubner) Hardwick, seed midge: *Systole albipennis* (Walker); *Systole coriandri* (Gussakovsky), cutworm: *Agrotis ipsilon* (Hufnagel) & *Agrotis segetum* (Denis), brown wheat mite: *Pterobia latens* (Muller), pentatomid bugs: *Calcoris noregicus* (Fabricius), lygus bugs: *Lygus spp*., cigarette beetle: *Lasioderma serricorne* (Fabricius), and drug store beetle: *Stegobium paniceum* (Motschulsky) (GOI, 2014) [3].

Among the different insect pests, aphid, *H. coriandri* causes maximum damage to the fennel crop as both nymph and adults suck the cell sap from leaves, stem and umbels, as a result plant becomes weak and stunted. In addition, it exudes copious quantity of honeydew, which favors the growth of sooty mould and results into retarded growth of the plant. In case of severe infestation, the growing points and flower stalks wither and dry up and at flowering and fruiting stage, the seeds are not formed and if they are formed, they are shriveled and of poor quality (Kanjiya *et al*., 2018a) [7].

Mittal and Butani (1989) [10] recorded the losses of fennel seeds caused by aphid up to 903 kg ha^{-1}, which means 50 per cent of the crop losses in Gujarat and it is considered as a major or key pest of fennel which pose as threat to seed spices. According to Ramalho *et al*. (2012) [11], aphids reduced about 80 per cent of the fennel seed yield due to failure of seed setting and seed development. Novel insecticides play a greater role in controlling insect pests because they are target specific in pest, having less toxicity on non-target pest, environment friendly and toxicologically safer, unique mode of action, high efficiency in pest control and resistance management (Gagan *et al*., 2018) [2]. These newer insecticide molecules introduced in the market and their efficacy should be checked for better management of insect pests of fennel.

Materials and Methods

In order to evaluate the efficacy of various insecticides against insect pests in fennel, the experiment was laid out in a Randomized Block Design with three replications having 3.6 m × 5.0 meter plot area during *rabi*, 2017-18 and 2018-19 at Entomology Farm, B. A. College of Agriculture, AAU, Anand. Seeds of fennel *var*. GF-12 were sown in 2nd week of October at a spacing of 90 x 30 cm. Recommended agronomical practices were followed for raising the crop. Details of treatments are given as under.

Table 1: Details of treatments

Sr. No.	Treatments	Conc. (%)	Dose	
			g a.i. / ha	ml or g /10 liter of water
1	Thiamethoxam 25 WG	0.0125	62.5	5 g
2	Diafenthiuron 50 WP	0.05	250	10g
3	Imidacloprid 17.8 SL	0.005	25	2.8 ml
4	Clothianidin 50 WDG	0.02	100	4 g
5	Dinotefuran 20 SG	0.006	30	3 g
6	Acephate 75 SP	0.075	375	10 g
7	Dimethoate 30 EC	0.03	150	10 ml
8	Flonicamid 50 WG	0.015	75	3 g
9	Tolfenpyrad 15 EC	0.03	150	20 ml
10	Untreated Control	-	-	-

Method of application of chemical insecticides

Treatment wise application of insecticide was done on appearance of aphids by using high volume sprayer (knapsack) with required concentration. The second spray was applied after 15 days of first spray.

Method of recording observations

The population of aphid was estimated by adopting zero to four indexes through the observations made on 10 cm terminal twigs of five randomly selected plants from each net plot, one day before (pre-treatment) and 3, 5, 7, 10 and 15 days after treatment. The following indices were suggested by Patel *et al*. (2011) [12] for estimation of aphid population.

Indices Description

0. Plant free from aphids
1. Aphids present but colonies are not building up
2. Small colonies of aphids presents
3. Large colonies of aphids presents on tender parts (counting of the aphid colonies is possible and tender plant parts shows the damage symptoms due to aphids)
4. Entire plants were covered by aphids (counts of aphids in colonies is impossible and plants shows the damage symptoms due to aphids) and finally plant dies

The average aphid index was worked out by the following formula.

$$\text{Average aphid index} = \frac{0N + 1N + 2N + 3N + 4N}{\text{Total number of plants observed}}$$

Where
0, 1, 2, 3 and 4 are aphid index
N = Number of plants showing respective aphid index

Honeybees

To check the impact of insecticide spray on honeybees, activity of bees were recorded by counting the number of bees visiting the plant during peak activity time *i.e.* 12.00 hrs on an area of m^2 plants for two minutes from each net plot, one day before (pre-treatment) and 3, 5, 7, 10 and 15 days after insecticidal application. Numbers of dead bees were also counted from each net plot on next day of spraying.

Yield and Economics

At harvest the seed yield was recorded separately from each net plot. On the basis of yield the economics was calculated. Increase in yield over control was calculated by applying formula given by Khosla (1977) [8].

$$\text{Increase in yield over control (\%)} = \frac{\text{Yield in treatment} - \text{Yield in control}}{\text{Yield in control}} \text{ X } 100$$

In order to know the economics of different treatments evaluated against insect pests infesting fennel, Incremental Cost Benefit Ratio (ICBR) was worked out. For the purpose, total cost of insecticidal treatment per hectare was calculated for each treatment based on the prevailing market price. The net gain (yield) over control was calculated by subtracting the yield obtained in control treatment from the yield obtained in each insecticidal treatment. Then, the realization over control was worked out for each treatment. The net profit (Rs/ha) for each treatment was computed by deducting the cost of insecticidal treatment from the value of realization over control. The ICBR *i.e.* net gain in rupees per rupee cost of insecticidal treatment was calculated by dividing net profit with the cost of treatment. This gives value of gross ICBR.

Results and Discussion

With a view to find out the efficacy of chemical insecticides against insect pests infesting fennel, nine insecticides *viz*., thiamethoxam 25 WG 0.0125%, diafenthiuron 50 WP 0.05%, imidacloprid 17.8 SL 0.005%, clothianidin 50 WDG 0.02%, dinotefuran 20 SG 0.006%, acephate 75 SP 0.075%, dimethoate 30 EC 0.03%, flonicamid 50 WG 0.015% and tolfenpyrad 15 EC 0.03% were evaluated in comparison with control during *rabi*, 2017-18 and 2018-19.

The results of first year (2017-18) indicated that indicated that treatments of flonicamid (0.43 A.I.) and tolfenpyrad (0.54 A.I.) were at par to each other and proved highly effective against *H. coriandri* in fennel (Table 2). Treatments of dimethoate (0.70 A.I.), imidacloprid (0.73 A.I.) and acephate (0.80 A.I.) were equally effective in controlling the aphids and found mediocre in their efficacy. Of the evaluated insecticides, thiamethoxam, diafenthiuron, dinotefuran and clothianidin recorded 0.92 aphid index and found poor in their efficacy against aphids in fennel.

More or less similar trend of efficacy was observed during second year of experimentation (2018-19) as observed in first

year (Table 2). The data indicated the higher effectiveness of flonicamid (0.43 A.I.) and tolfenpyrad (0.49 A.I.). Treatments of dimethoate (0.65 A.I.) and imidacloprid (0.73 A.I.) found at par to each other followed by acephate (0.75 A.I.). These three insecticides found mediocre in their efficacy against aphids in fennel. Treatments of thiamethoxam (0.95 A.I.), clothianidin (0.96 A.I.), diafenthiuron (0.98 A.I.) and dinotefuran (1.03 A.I.) were found less effective against aphids in fennel.

Pooled over years data (Table 2) exposed higher efficacy of flonicamid 50 WG 0.015% (0.43 A.I.) and tolfenpyrad 15 EC 0.03% (0.51 A.I.) against aphids in fennel. Dimethoate 30 EC 0.03% (0.68 A.I.), imidacloprid 17.8 SL 0.005% (0.73 A.I.) and acephate 75 SP 0.075% (0.77 A.I.) were found moderately effective against *H. coriandri* in fennel. In contrast to this, dinotefuran 20 SG 0.006% (0.97 A.I.), diafenthiuron 50 WP 0.05% (0.95 A.I.), clothianidin 50 WDG 0.02% and thiamethoxam 25 WG 0.0125% (0.94 A.I.) failed to provide satisfactory protection to fennel crop against aphid infestation.

In nut-shell aphid, *H. coriandri* can be effectively managed by spray application of flonicamid 50 WG 0.015% and tolfenpyrad 15 EC 0.03%. Kanjiya *et al*. (2018b) [6] reported that aphid, *H. coriandri* on fennel effectively managed by spraying of dimethoate 30 EC 0.03% and flonicamid 50 WG 0.015%. Flonicamid 50 WG 0.015% found best treatment against aphid, *Aphis craccivora* on fenugreek by recording the lowest (3.26 aphids/ 10 cm central shoot) incidence (Sarvaiya, 2017) [13]. Tolfenpyrad 15 EC 0.03% and flonicamid 50 WG 0.015% effectively control the aphid, *Myzus persicae* on cumin with 2.63 and 4.98 aphids per 5 cm shoot (Italiya, 2017) [5]. These reports are in line with the present findings.

Table 2: Bio-efficacy of insecticides against aphids in fennel (Pooled over sprays and years)

Tr. No.	Treatments	Conc. (%)	Aphid index (0-4)		
			2017-18	2018-19	Pooled
T_1	Thiamethoxam 25 WG	0.0125	0.92c	0.95d	0.94d
T_2	Diafenthiuron 50 WP	0.05	0.92c	0.98d	0.95d
T_3	Imidacloprid 17.8 SL	0.005	0.73b	0.73bc	0.73bc
T_4	Clothianidin 50 WDG	0.02	0.92c	0.96d	0.94d
T_5	Dinotefuran 20 SG	0.006	0.92c	1.03d	0.97d
T_6	Acephate 75 SP	0.075	0.80b	0.75c	0.77c
T_7	Dimethoate 30 EC	0.03	0.70b	0.65b	0.68b
T_8	Flonicamid 50 WG	0.015	0.43a	0.43a	0.43a
T_9	Tolfenpyrad 15 EC	0.03	0.54a	0.49a	0.51a
T_{10}	Control	-	2.30d	2.31e	2.30e
S. Em. ±			0.11	0.092	0.080
C.D. at 5%			0.036	0.029	0.021
C. V.%			13.69	13.16	13.43

Treatment means with the letter(s) in common are not significant by DNMRT at 5% level of significance

Effect of chemical insecticides on honeybees

All the evaluated insecticides were found toxic to bees in both the years as well as in pooled over years as all insecticidal treatments significantly reduced the activity of bees in fennel. During the year 2017-18, the lowest (6.67 bees/m^2/2 min) activity of bees were observed in plots treated with thiamethoxam 25 WG 0.0125% and imidacloprid 17.8 SL 0.005% and it was at par with clothianidin 50 WDG 0.02% (7.20 bees/m^2/2 min) and dinotefuran 20 SG 0.006% (7.27 bees/m^2/2 min). The insecticides diafenthiuron 50 WP 0.05%, acephate 75 SP 0.075% and dimethoate 30 EC 0.03% were recorded the bee activity of 8.67, 8.73 and 8.87 bees/m^2/2 min, respectively. The treatments of flonicamid 50 WG 0.015% and tolfenpyrad 15 EC 0.03% were found less toxic to honeybees by recording 10.60 and 10.87 bees/m^2/2 min, respectively. Similarly, during second year of experimentation, the lowest (6.13 bees/m^2/2 min) activity of bees were recorded in the plots treated with imidacloprid and it was at par with thiamethoxam (6.27 bees/m^2/2 min), clothianidin (6.39 bees/m^2/2 min) and dinotefuran (6.60 bees/m^2/2 min). Whereas, the higher activity of bees noticed in plots treated with tolfenpyrad (10.53 bees/m^2/2 min) and flonicamid (10.27 bees/m^2/2 min).

Pooled over years data clearly indicated that the lowest (6.40 bees/m^2/2 min) bees were recorded in plots treated with imidacloprid which was at par with thiamethoxam (6.47 bees/m^2/2 min), clothianidin (6.80 bees/m^2/2 min) and dinotefuran (6.94 bees/m^2/2 min). The activity of bees in treatments of diafenthiuron, acephate and dimethoate were observed between 8.53 and 8.70 bees/m^2/2 min. In contrast to this, flonicamid (10.44 bees/m^2/2 min) and tolfenpyrad (10.70 bees/m^2/2 min) had comparatively higher activity of bees.

The mortality of bees due to spraying of insecticides was observed on the next day of spraying during the year 2018-19. The dead bees were found on the flowering umbels in plots treated with all the evaluated insecticides except flonicamid and tolfenpyrad (Table 3). Maximum (7.33 bees/5 plants) mortality was observed in plots treated with thiamethoxam followed by imidacloprid and clothianidin (7 bees/5 plants). Treatments of dinotefuran, diafenthiuron, acephate and dimethoate registered 2 to 4.67 dead bees/5 plants. Nitro substituted neonicotinoids, such as imidacloprid, clothianidin and thiamethoxam, are more toxic to bees than cyano substituted ones. Some of neonicotinoid metabolites are also neurotoxin and are involved in honeybee mortality (Kiljanek *et al*., 2016). The neonicotinoid insecticides imidacloprid, clothianidin, thiamethoxam and dinotefuran are extremely toxic to honey bees with very low (0.004, 0.004, 0.005 and 0.02 µg/bee) oral LD_{50} values (Umetsu, 2019) [15].

Table 3: Effect of insecticides on activity of honeybees in fennel

Tr. No.	Treatments	Conc. (%)	No. of bees/m²/2 min			Dead bees/5 plant
			2017-18*	2018-19*	Pooled	2018-19
T_1	Thiamethoxam 25 WG	0.0125	6.67a	6.27a	6.47a	7.33
T_2	Diafenthiuron 50 WP	0.05	8.67b	8.60b	8.64b	4.00
T_3	Imidacloprid 17.8 SL	0.005	6.67a	6.13a	6.40a	7.00
T_4	Clothianidin 50 WDG	0.02	7.20ab	6.39a	6.80a	7.00
T_5	Dinotefuran 20 SG	0.006	7.27ab	6.60a	6.94a	4.67
T_6	Acephate 75 SP	0.075	8.73b	8.33b	8.53b	3.00
T_7	Dimethoate 30 EC	0.03	8.87b	8.53b	8.70b	3.00
T_8	Flonicamid 50 WG	0.015	10.60c	10.27c	10.44c	0.00
T_9	Tolfenpyrad 15 EC	0.03	10.87c	10.53c	10.70c	0.00
T_{10}	Control	-	15.93d	14.00d	14.97d	-
S. Em. ±			0.31	0.42	0.43	-
C. D. at 5%			0.94	1.15	1.22	-
C. V.%			11.80	12.31	12.15	-

Treatment means with the letter(s) in common are not significant by DNMRT at 5% level of significance *Pooled over periods

Yield, avoidable losses and economics

During first year (Table 4), the highest (23.12 q/ha) seed yield of fennel was obtained from the plots treated with flonicamid 50 WG 0.015% and it was at par with tolfenpyrad 15 EC 0.03% (22.80 q/ha) followed by dimethoate 30 EC 0.03% (20.50 q/ha). Fennel seed yield was recorded between 18.21 and 19.48 q/ha in the treatments of thiamethoxam 25 WG 0.0125%, clothianidin 50 WDG 0.02%, imidacloprid 17.8 SL0.005% and acephate 75 SP 0.075%. Of the tested insecticides, the lowest (17.05 q/ha) seed yield of fennel was recorded in plots treated with dinotefuran 20 SG 0.006% followed by diafenthiuron 50 WP 0.05% (17.50 q/ha). During the year 2018-19, flonicamid treated plots registered the highest (23.51 q/ha) yield of fennel and it was at par with tolfenpyrad (23.04 q/ha). Clothianidin, acephate and dimethoate treated plots produced 19.02, 19.25 and 20.01q/ha seeds of fennel, respectively. In contrast to this, the lowest (17.05 q/ha) yield of seed was registered in plots treated with dinotefuran followed by diafenthiuron (17.81 q/ha), thiamethoxam (18.51 q/ha) and imidacloprid (18.83 q/ha). Pooled over years data (Table 4) exposed that the highest (23.31 q/ha) seed yield was recorded in plots treated with flonicamid and it was at par with tolfenpyrad (22.92 q/ha) followed by dimethoate (20.26 q/ha). Among the tested insecticides, the lowest (17.05 q/ha) seed yield of fennel was recorded in dinotefuran.

Increase in yield

The increase in yield over control ranged from 34.46 to 83.83 per cent due to application of insecticides (Table 4). Maximum (83.83%) seed yield was increased in the plots treated with flonicamid followed by tolfenpyrad (80.76%). Dimethoate, acephate, clothianidin and imidacloprid treated plots increased yield between 49.21 and 59.78 per cent. The lowest (34.46%) increase in yield recorded in dinotefuran.

Avoidable losses

Avoidable loss in yield of fennel varied from 1.67 to 45.60 per cent in different treatments (Table 4). The avoidable loss was the lowest (1.67%) in the treatment of tolfenpyrad followed by dimethoate (13.08%), acephate (16.90%), clothianidin and imidacloprid (18.83%). The avoidable loss was calculated as 21.24, 24.24 and 26.86 per cent in treatments of thiamethoxam, diafenthiuron and dinotefuran, respectively.

Economics

Economics of various insecticides (Table 4) evaluated against major insect pests infesting fennel indicated that maximum (63780 Rs/ha) net realization was obtained in case of treatment of flonicamid followed by tolfenpyrad (61440 Rs/ha). The net realization was 40140 and 45480 Rs/ha in the treatments of dimethoate and acephate, respectively. Looking to the ICBR, the highest (1:32.37) return was obtained with the treatment of dimethoate followed by imidacloprid (1:26.96) and acephate (1:22.4). The ICBR calculated as 1:14.20, 1:9.02, 1:7.32, 1:7.13 and 1:6.16 in treatments of flonicamid, thiamethoxam, diafenthiuron, dinotefuran and tolfenpyrad, respectively. The lowest (1:5.36) ICBR was recorded with the treatment of clothianidin. Dimethoate, imidacloprid and acephate registered higher ICBR, however these insecticides were fall under moderately effective insecticides against aphids in fennel. Kanjiya *et al*. (2018b) [6] reported that the highest (2880 kg/ha) seed yield of fennel was obtained from plots treated with flonicamid against aphid, *H. coriandri* with maximum (1553 kg/ha) increase in yield over control. The highest (1:70.25) ICBR was calculated from the plots treated with dimethoate followed by acetamiprid (1:54.64), imidacloprid (1:45.68), flonicamid (1:32.82) and thiamethoxam (1:24.59). On the basis of overall rank, the flonicamid found most effective. According to Hirpara (2000) [4], the highest ICBR was obtained from the treatment dimethoate (1:28.29) followed by imidacloprid (1:13.56).

Table 4: Impact of insecticides on seed yield of fennel and economics of insecticides

Tr. No.	Treatments	Conc. (%)	Seed yield (q/ha)			Increase in yield over control (%)	Avoidable losses (%)	Realization (₹/ha)	ICBR
			2017-18	2018-19	Pooled				
T_1	Thiamethoxam 25 WG	0.0125	18.21cde	18.51bc	18.36cde	44.79	21.24	34080	1:9.02
T_2	Diafenthiuron 50 WP	0.05	17.50de	17.81bc	17.66de	39.27	24.24	29880	1:7.32
T_3	Imidacloprid 17.8 SL	0.005	19.01cde	18.83bc	18.92cd	49.21	18.83	37440	1:26.96
T_4	Clothianidin 50 WDG	0.02	18.83cde	19.02bc	18.92cd	49.21	18.83	37440	1:5.36

T_5	Dinotefuran 20 SG	0.006	17.05e	17.05c	17.05e	34.46	26.86	26220	1:7.13
T_6	Acephate 75 SP	0.075	19.48cd	19.25bc	19.37cd	52.76	16.90	40140	1:22.40
T_7	Dimethoate 30 EC	0.03	20.50bc	20.01b	20.26bc	59.78	13.08	45480	1:32.37
T_8	Flonicamid 50 WG	0.015	23.12a	23.51a	23.31a	83.83	00	63780	1:14.20
T_9	Tolfenpyrad 15 EC	0.03	22.80ab	23.04a	22.92ab	80.76	1.67	61440	1:6.16
T_{10}	Control	-	12.81f	12.55d	12.68f	0	45.60	-	-
S. Em. ±	(Treatment) T		0.81	0.79	0.61	-	-	-	-
(Year) Y			-	-	0.35	-	-	-	-
T x Y			-	-	1.12	-	-	-	-
C. D. at 5%	T		2.33	2.28	1.90	-	-	-	-
Y			-	-	1.05	-	-	-	-
T x Y			-	-	NS	-	-	-	-
C. V.%			10.26	10.20	10.23	-	-	-	-

Treatment means with the letter(s) in common are not significant by DNMRT at 5% level of significance

Conclusion

The insecticides flonicamid 50 WG 0.015% and tolfenpyrad 15 EC 0.03% proved effective, whereas dimethoate 30 EC 0.03%, imidacloprid 17.8 SL 0.005% and acephate 75 SP 0.075% found moderately effective against aphids on fennel. In contrast to this, insecticides thiamethoxam 25 WG 0.0125%, clothianidin 50 WDG 0.02%, diafenthiuron 50 WP 0.05% and dinotefuran 20 SG 0.006% failed to provide satisfactory protection to fennel crop against aphid's infestation. The higher (20.26 to 23.51 q/ha) seed yield of fennel was obtained from the treatments of flonicamid, tolfenpyrad and dimethoate. The activity of honeybees was adversely affected by spraying of chemical insecticides. Neonicotinoid insecticides *viz*., imidacloprid, thiamethoxam, clothianidin and dinotefuran treated plots recorded the lowest activities of bees, whereas insecticides flonicamid and tolfenpyrad recorded higher activities and proved safer to honeybees.

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