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RESEARCH ARTICLE

Evaluation of selected biopesticides and chemical insecticides against natural enemies in the pigeon pea ecosystem

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Abstract

The safety evaluation of biopesticides and chemical insecticides against natural enemies in the pigeon pea ecosystem was carried out at Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Kalyani, West Bengal, India. Pigeon pea (Var. UPAS-120) seeds were planted in 20 m^2 plots during the *kharif* seasons of 2013- 2014 with a spacing of 60 cm x 20 cm and eleven treatments were arranged in a randomized block design (RBD). Two sprays of chemical insecticides and bio-pesticides were applied at 15 days intervals. Fourteen days before and after each spray, the number of coccinellid complexes (adult and grub) was counted. The experimental findings revealed that fenvalerate was most toxic treatment to the coccinellids. The next most toxic insecticides were spinosad, indoxacarb and flubendiamide whereas biopesticides were comparatively less toxic to the natural enemies. However, *M. anisopliae* was recorded as the least toxic biopesticide in the present study. The mortality of adult *Bracon brevicornis* W. in the laboratory was highest with spinosad followed by fenvalerate, indoxacarb, annonin and karanjin. The impact of insecticidal treatments on the emergence of adult of *Trichogramma chilonis* I. from pupae of *Corcyra cephalonica* Stainton showed that fenvalerate was the most toxic, with the lowest emergence of adults from the pupae, followed by spinosad, karanjin and indoxacarb.

Keywords: biopesticides; coccinellids; safety assessment; *Trichogramma chilonis*

Introduction

Natural enemies play a vital role in any agro ecosystem through reducing the need for chemical pesticides, supports sustainable agricultural practices by controlling populations of harmful pests. The over reliance on chemical pesticides decreases as the pest population decreases naturally thus preventing contamination of soil and water from pesticides. Natural enemies contribute to the balance of the ecosystem by maintaining biodiversity and promoting the health of the entire agro ecosystem. By promoting biological control, agro-ecosystems become more resilient and sustainable. The presence of natural enemies helps maintain the long-term health of the ecosystem. In some cases, like hoverflies in an apple orchard, natural enemies also interact with pollinators, indirectly supporting crop production through improved pollination services (1). Natural enemies help to maintain an ecological balance within agro ecosystems, ensuring that no single species dominates the system and preventing pest outbreaks. Their role in agro ecosystems is crucial for integrated pest management (IPM), enhancing crop productivity and ensuring environmental sustainability. Numerous insecticides that are frequently used to manage different pests also reduce the efficacy of other beneficial insects. Across the globe, loss of beneficial agents due to use of non-selective chemicals may induce serious problem for crops grown. As natural enemies decline, some pests shift from secondary to key status, increasing their potential for economic damage (2). One method of preventing the resurgence of pests is to use selective insecticides that successfully control the pest while having little effect on the natural enemy population (3). Survival of predators in cotton ecosystem was greater on dried residues treated with selective insecticides like pymetrozine, chlorantraniliprole, pyriproxyfen and cyantraniliprole (4). Predators and parasitoids may come into contact with insecticides through their host after they have been applied, either by direct contact with the treated surface or by consuming nectar and pollen from flowers. Therefore, pesticides may have an effect on an organism's ability to survive, grow, develop, reproduce and their behaviour (5-7). Additionally, determining the precise impact of pesticides in field conditions within the crop environment is quite challenging. Hence, the present experiments were undertaken to evaluate the toxicity of insecticides on artificially cultured natural enemies under laboratory condition besides in the field.

Materials and Methods

Field experiments

The field trials were carried out at University Research Farm, Kalyani, W.B., Bidhan Chandra Krishi Viswavidyalaya to study the safety assessment of some biopesticides and insecticides on natural enemies occurred in pigeon pea field. Pigeon pea (variety: UPAS 120) seeds were planted in 20 m^2 plots with 60 cm x 20 cm (row-to-row x plant-to-plant) spacing during the *kharif* seasons of 2013 and 2014. To raise the crop, standard agronomical management techniques were employed. RBD was used to set up the studies, with eleven treatments replicated thrice. Treatments viz. flubendiamide 480 SC (60 g a.i./ha), indoxacarb 14.5 SC (75 g a.i./ha), spinosad 45 SC (75 g a.i./ha), *Metarhizium anisopliae* (1x10^8 CFU/gm., WP), *Beauveria bassiana* (1x10^8 CFU/gm., WP), *Bacillus thuringiensis* (18000 IU/mg, WP), annonin 1 % EC (100 g a.i/ha), azadirachtin 1 % EC (100 g a.i/ha), karanjin 2 % EC (50 g a.i./ha), fenvalerate 20 EC (100 g a.i./ha) and untreated control. All treatments were applied twice using a pneumatic sprayer at 15 day intervals and volume of spray solution was used at the rate of 500 litres/ha. The number of coccinellid complexes (adults and grubs) was counted from five plants for each replication both prior to and 14 days following each spray.

Laboratory experiments

Rearing of Corcyra cephalonica Stainton in laboratory

The culture of C. *cephalonica* Stainton for mass production was carried out under laboratory conditions using a slightly modified method described previously (8, 9). In each rearing jar, about 1000 Corcyra eggs were kept. To facilitate the emergence of Corcyra adults, the opening of each jar was covered with muslin cloth and maintained at 30±1 °C without regulating relative humidity. After emergence of the adult, they were kept in a double mouthed black colour glass cage which measured as 12 cm in diameter and 15 cm in length for egg laying. One side of the egg laying cage was covered with a 30 mesh wire net to permit Corcyra eggs to collect on the petridish (10 cm in diameter) kept underneath and the other mouth was closed with a muslin cloth that had a hole in it to allow Corcyra moths to be released. At various intervals of time, the eggs were collected from the egg laying cages, which were maintained at the temperature of 30±1 °C and humidity of 75±5 %. For the mass rearing of *T. chilonis*, collected eggs were utilized, whilst *B. brevicornis* was reared using fully formed larvae (fifth instars).

Rearing of *Trichogramma chilonis* Ishii

For mass rearing of *T. chilonis,* a slightly modified version of the methods described in previous studies (8, 9). Less than 12-hour-old Corcyra eggs were deep-frozen (below 0 °C) for 24 hours in order to destroy the growing embryo. A uniform thin layer of a 2 % aqueous solution of pure gum Arabic was applied to a card (15.5 cm length and 8 cm width). The eggs were then uniformly sprinkled on top of the card using a camel hairbrush to create a uniform layer. Each card had about 20,000 (1 cc) eggs adhered to it. Then, single egg card was kept in every rearing container of *T. chilonis*. The parasitoids and egg card were kept in a chamber maintaining 26 ± 2 °C temperature and 70 ± 5 % relative humidity. A 1:1 mixture of distilled water and honey was used to feed the adult parasites. The parasitoids were given the ideal quantity of host eggs in order to prevent super parasitism. After a day, the egg card was removed from the rearing unit and replaced with a fresh card for parasitisation. The procedure was carried out until 50 % of the parasites, mostly males were killed. Each card of parasitised eggs was cut into tiny pieces once they had darkened and each piece was stored in a different rearing unit until the adult parasite emerged.

Rearing of *B. brevicornis* Wesmael

The parasitoid rearing technique was carried out with slight modifications to the method reported previously (7-9). Ten pairs of recently emerged adults of *B. brevicornis* were placed in a glass jar with a muslin-covered mouth that was 15 cm long and 12.5 cm wide. An aqueous solution with 10 % sugar that had been soaked in cotton was given to the adult parasites. Thirty fully developed *C. cephalonica* larvae were placed on the cloth cover after being taken from the lab culture. The parasitized larvae were taken out after a day and put in a petridish (10 cm in diameter) lined with filter paper and kept in a control chamber maintaining temperature at 26±2 °C and humidity at 70±5 %.The parasites were given a fresh batch of larvae and the process was repeated until half of the parasites, mostly males were dead. After the parasite larvae pupated, a fine pair of forceps was used to remove the unfed body part of the *Corcyra* larvae. In order to facilitate the emergence of adult parasites, the pupae were stored in a glass jar (20.5 cm in length and 10 cm in diameter).

Preparation of solution of chemical insecticides and bio-pesticides

For applying of treatments on natural enemies, each formulation is dissolved in 500 mL of water in the recommended doses considering the field spray volume of 500 L/ha and sprayed using hand sprayer.

Application of treatments on T. chilonis pupae

The parasitized egg cards with *T. chilonis* pupal stage (4 days post-parasite) were dipped into pesticide solutions containing the required field dosages. Then, the egg cards were taken out and allowed to dry under a fan. After that, the egg cards were stored individually in glass vials to enable the adult parasitoid to emerge from the host eggs treated with pesticide. Eggs were submerged in water as part of the control treatment. When adult parasitoids emerged, the pupae's mortality was calculated by counting parasitized eggs that did not exhibit adult emergence. Thirty parasitized eggs were observed in each of the three replications of each treatment (8, 10).

Application of treatments on the adults of B. brevicornis

Castor leaf circles (4.2 cm in diameter) and strips (14 cm x 5.5 cm) were immersed in insecticidal solutions with specified field dosages and then dried with a fan. The leaf strips were soaked in water for the control treatment. The interior surface of a plastic container (6.0 cm length × 4.5 cm diameter) was fully lined with treated leaf strips. A leaf circle was placed at the bottom. Within the container, ten recently emerging adult female *B. brevicornis* were released with three replications. The tubes were stored at 26 ± 2 °C and 70 ± 5 % relative humidity, with the bottom side facing upward to ensure continuous contact of the parasitoids with the insecticide-treated leaf strips. The opening of the plastic container was covered with a cloth that was secured with a rubber band. After 1 hr, 24 hr and 48 hr of release, mortality was noted and the moribund adults were deemed dead (8, 11).

Analysis

The mortality data of natural enemies were converted into arc sine transformed values before analysis of variance (ANOVA) using completely randomized design (12). The critical difference (CD) was estimated at the 5 % level of significance.

Results and Discussion

Impact of treatments on coccinellids population on pigeon pea during 2013-2015

The effect of treatments on the coccinellids complex during the first season is presented in Table 1. There was no significant difference between the treatments before application of spray. After two sprays, the mean data (coccinellids/plant) revealed that fenvalerate was the most toxic to coccinellids having highest percent reduction over control (45.87 %) followed by spinosad (41.87 %) and indoxacarb (36.80 %). The safest treatment was *M. anisopliae* with maximum population (3.25 coccinellids/plant) and minimum reduction over control (13.33 %) followed by annonin (16.27 %), azadirachtin (20.27 %) and *Bt* (21.33 %). The population in untreated control plot gradually increased with an average of 3.75 coccinellids/plant. The effect of insecticides on coccinellids populations during the second season are shown in Table 2. As in the first season, no significant differences were observed before spraying. After two sprays, populations were recorded at 45 DAS. The mean coccinellid population revealed the same trend as found in first season. Among the treatments, the safest treatment was *M. anisopliae* where the percent reduction of coccinellid population recorded to be minimum (11.58 %). The most toxic the treatment was fenvalerate (2.19 coccinellids/plant) showing highest reduction of coccinellids (48.23 %) followed by spinosad (42.08 %), indoxacarb (35.46 %), flubendiamide (32.62 %), karanjin (24.82 %), *B. Bassiana* (23.88 %), *Bt.* (22.46 %), azadirachtin (21.51 %), annonin (14.18 %). Annonin and *M. anisopliae* were statistically at par with each other. Mean effect (pooled of two years) of insecticides on coccinellids population is illustrated in Table 3. The pooled data also showed the similar pattern as found in two consecutive years. The safest treatment was *M. anisopliae* with lowest reduction of 12.46 % and highest coccinellid population of 3.50/plant. The most toxic treatment was fenvalerate (2.11 coccinellids/plant) with 47.05 % reduction over control. The next orders of toxicity in term of reduction over control of different treatments were spinosad (41.97 %), indoxacarb (36.13 %), flubendiamide (32.18 %), karanjin (25.61 %), *Beauveria bassiana* (24.21 %), *Bt* (21.90 %), azadirachtin (20.89 %). In untreated control plots, population of coccinellids was maximum (3.99 adult/plants). These results indicate that fenvalerate insecticide showed extremely toxic to the coccinellids followed by spinosad. The indoxacarb and flubendiamide were moderate toxic whereas the safest treatment was *M. anisopliae*. These findings of indoxacarb and flubendiamide can be correlated with the previous studies, who revealed low to moderate toxicity of these insecticides (13-16). The present findings are in partial agreement, who found that there was significant effect of azadirachtin on the coccinellids (17). The present results studied the toxicity of *B. bassiana* (Botani Gard) and azaditachtin on *C. montrouzieri* and *C. maculate* (18).

Impact of treatments on mortality of adult of *Bracon brevicornis W.* under laboratory condition

The results revealed that a significant difference was observed in adult mortality among the treatments with varying exposure times to the target natural enemy. As showing Table 4, spinosad was the most toxic across all exposure times from 1 hour to 48 hour (36.7 %, 63.3 % and 73.3 % mortality respectively). Next to spinosad, fenvalerate and indoxacarb were toxic to adults of *Bracon brevicornis* with mean mortality of 45.56 % and 32.22 %. Comparatively, flubendiamide and the microbial and botanical insecticides were safer towards the adults of *Bracon* that exhibited very less mortality over different exposures of time. During the first hour, no mortality was observed in most treatments except in karanjin (3.3 %). After 24 hour, karanjin and flubendiamide treatments showed mortality of 6.7 % which were statistically at par. After 48 hour, the safest treatment

Table 1. Impact of treatments on coccinellid population in pigeon pea ecosystem during 2013-14

Treatments	Dose (mL/L)	Adult/plant before spray	Coccinellids population/plant after 14 days of spraying			Reduction of coccinellid population over untreated control (%)
			Spray I	Spray II	Mean	
Flubendiamide 480 SC	0.25	3.66 (1.98)	2.66 (1.75)	2.46 (1.70)	2.56 (1.73)	31.73
Indoxacarb 14.5 SC	1.00	3.01 (1.83)	2.50 (1.71)	2.24 (1.63)	2.37 (1.67)	36.80
Spinosad 45 SC	0.30	2.94 (1.80)	2.27 (1.64)	2.09 (1.59)	2.18 (1.62)	41.87
M. anisopliae	5.00	2.06 (1.50)	3.11 (1.87)	3.39 (1.94)	3.25 (1.91)	13.33
B. bassiana	5.00	2.17 (1.49)	1.69 (1.46)	3.97 (2.08)	2.83 (1.80)	24.53
Bt.	5.00	3.16 (1.91)	2.35 (1.67)	3.55 (1.98)	2.95 (1.83)	21.33
Annonin 1 % EC	2.00	3.18 (1.85)	2.39 (1.68)	3.89 (2.06)	3.14 (1.88)	16.27
Azadirachtin 1 % EC	2.00	2.46 (1.62)	3.14 (1.88)	2.84 (1.80)	2.99 (1.84)	20.27
Karanjin 2 % EC	2.00	3.42 (1.95)	3.07 (1.86)	2.45 (1.70)	2.76 (1.78)	26.40
Fenvalerate 20 EC	1.00	2.46 (1.64)	2.39 (1.68)	1.67 (1.46)	2.03 (1.57)	45.87
Control	-	2.12 (1.50)	2.56 (1.73)	4.94 (2.30)	3.75 (2.03)	-
SEm(±)	-	0.33	0.02	0.04	0.02	-
CD at 5 %	-	NS	0.06	0.12	0.07	-

Parenthesis data are transformed in to square root values √ (x+0.5)

Table 2. Impact of treatments on coccinellid population in pigeon pea ecosystem during 2014-15

Treatments	Dose (mL/L)	Adult/plant before spray	Coccinellids population/plant after 14 days of spraying			Reduction of coccinellid population over untreated control (%)
			Spray I	Spray II	Mean	
Flubendiamide 480 SC	0.25	3.64 (1.99)	3.14 (1.88)	2.56 (1.73)	2.85 (1.81)	32.62
Indoxacarb 14.5 SC	1.00	3.46 (1.88)	2.68 (1.76)	2.78 (1.79)	2.73 (1.77)	35.46
Spinosad 45 SC	0.30	3.19 (1.89)	2.86 (1.81)	2.04 (1.57)	2.45 (1.70)	42.08
M. anisopliae	5.00	2.16 (1.52)	3.29 (1.92)	4.19 (2.13)	3.74 (2.03)	11.58
B. bassiana	5.00	2.47 (1.67)	1.65 (1.45)	4.79 (2.26)	3.22 (1.90)	23.88
Bt.	5.00	3.16 (1.90)	3.10 (1.87)	3.46 (1.96)	3.28 (1.92)	22.46
Annonin 1 % EC	2.00	2.98 (1.83)	3.14 (1.88)	4.12 (2.12)	3.63 (2.00)	14.18
Azadirachtin 1 % EC	2.00	3.24 (1.90)	2.18 (1.62)	4.46 (2.19)	3.32 (1.93)	21.51
Karanjin 2 % EC	2.00	3.17 (1.85)	3.19 (1.89)	3.17 (1.89)	3.18 (1.89)	24.82
Fenvalerate 20 EC	1.00	3.12 (1.81)	2.56 (1.73)	1.82 (1.51)	2.19 (1.62)	48.23
Control	-	3.34 (1.93)	3.42 (1.95)	5.04 (2.32)	4.23 (2.14)	-
SEm(±)	-	0.33	0.03	0.04	0.03	-
CD at 5 %	-	NS	0.07	0.13	0.07	-

Parenthesis data are transformed in to square root values √ (x+0.5)

Table 3. Mean impact of treatments on coccinellid population in pigeon pea ecosystem (Pooled of two seasons)

Treatments	Dose (mL/L)	Adult/plant before spray	Coccinellids population/plant after 14 days of spraying			Reduction of coccinellid population over untreated
			Spray I	Spray II	Mean	
Flubendiamide 480 SC	0.25	3.65 (1.98)	2.90 (1.82)	2.51 (1.71)	2.71 (1.77)	32.18
Indoxacarb 14.5 SC	1.00	3.24 (1.85)	2.59 (1.73)	2.51 (1.71)	2.55 (1.72)	36.13
Spinosad 45 SC	0.30	3.07 (1.85)	2.57 (1.73)	2.07 (1.58)	2.32 (1.66)	41.97
M. anisopliae	5.00	2.11 (1.51)	3.20 (1.90)	3.79 (2.04)	3.50 (1.97)	12.46
B. bassiana	5.00	2.32 (1.58)	1.67 (1.46)	4.38 (2.17)	3.03 (1.85)	24.21
Bt.	5.00	3.16 (1.91)	2.73 (1.77)	3.51 (1.97)	3.12 (1.87)	21.90
Annonin 1 % EC	2.00	3.08 (1.84)	2.77 (1.78)	4.01 (2.09)	3.39 (1.94)	15.23
Azadirachtin 1 % EC	2.00	2.85 (1.76)	2.66 (1.75)	3.65 (2.00)	3.16 (1.88)	20.89
Karanjin 2 % EC	2.00	3.30 (1.90)	3.13 (1.88)	2.81 (1.79)	2.97 (1.84)	25.61
Fenvalerate 20 EC	1.00	2.79 (1.72)	2.48 (1.70)	1.75 (1.48)	2.11 (1.60)	47.05
Control	-	2.73 (1.72)	2.99 (1.84)	4.99 (2.31)	3.99 (2.09)	-
SEm(±)	-	0.23	0.02	0.03	0.02	-
CD at 5 %	-	NS	0.05	0.09	0.05	-

Parenthesis data are transformed in to square root values √ (x+0.5)

proved to be *M. anisopliae* with only 7.8 % mortality. The mean effect showed that spinosad was most toxic followed by fenvalerate, indoxacarb, annonin, karanjin and flubendiamide, azadirachtin, *Bt.*, *B. bassiana* and *M. anisopliae* with 57.78 %, 45.56 %, 32.22 %, 18.89 %, 10.00 %, 4.67 %, 2.97 % and 2.77 %. Among the treatments annonin though has not shown any mortality in 1st hour after 24 hour and 48 hour showed significantly higher mortality among the biopesticides with 23.3 % and 33.3 % mortality. In control the mortality of insects were significantly less at 2.56 %. Spinosad was the least harmful to *B. hebetor* in the vial and the leaf technique, based on the LC50 at 24 hours of exposure as mentioned in previous studies and here as Spinosad was less effective on *B. hebetor*'s searching efficiency (19, 20). The findings of present study who showed that spinosad was toxic to hymenopteran parasitoid, *Dinarmus basalis*. Moderate toxicity of indoxacarb toward *B. brevicornis* was reported earlier (21, 22).

Table 4. Effect of insecticides on the mortality of adult *Bracon brevicornis* W. over different time exposure

Treatments	Dose (mL/L)	Percent mortality of *Bracon* Adult			
		1 hr	24 hr	48 hr	Average
Flubendiamide 480 SC	0.25	0.0 (4.05)	6.7 (15.53)	23.3 (29.22)	10.00 (18.91)
Indoxacarb 14.5 SC	1.00	10.0 (18.91)	30.0 (33.52)	56.7 (49.12)	32.22 (34.89)
Spinosad 45 SC	0.30	36.7 (37.56)	63.3 (53.03)	73.3 (59.23)	57.78 (49.76)
M. anisopliae	5.00	0.0 (4.05)	0.5 (5.74)	7.8 (16.74)	2.77 (10.41)
B. bassiana	5.00	0.0 (4.05)	0.7 (6.29)	8.2 (17.15)	2.97 (10.73)
Bt.	5.00	0.0 (4.05)	0.0 (4.05)	9.6 (18.53)	3.20 (11.09)
Annonin 1 % EC	2.00	0.0 (4.05)	23.3 (29.22)	33.3 (35.57)	18.89 (26.12)
Azadirachtin 1 % EC	2.00	0.0 (4.05)	0.0 (4.05)	14.0 (22.38)	4.67 (13.14)
Karanjin 2 % EC	2.00	3.3 (11.29)	6.7 (15.52)	20.0 (26.92)	10.00 (18.91)
Fenvalerate 20 EC	1.00	26.7 (31.41)	70.0 (57.10)	40.0 (39.52)	45.56 (42.74)
Control	-	0.0 (4.05)	3.3 (11.29)	4.3 (12.71)	2.56 (10.07)
SEm±	-	0.91	1.93	2.17	1.59
CD (P≤0.05)	-	13.68	15.60	12.56	12.20

Parenthesis data are transformed in to arc sine transformed values

Table 5. Impact of insecticides on the emergence of adult of *Trichogramma chilonis* from treated pupae

Treatments	Dose (mL/L)	Percent emergence of *T. chilonis* adult
Flubendiamide 480 SC	0.25	55.12 (48.23)
Indoxacarb 14.5 SC	1.00	32.87 (35.29)
Spinosad 45 SC	0.30	7.39 (16.31)
M. anisopliae	5.00	61.73 (52.08)
B. bassiana	5.00	61.62 (52.01)
Bt.	5.00	67.75 (55.70)
Annonin 1 % EC	2.00	56.74 (49.16)
Azadirachtin 1 % EC	2.00	62.43 (52.49)
Karanjin 2 % EC	2.00	23.92 (29.61)
Fenvalerate 20 EC	1.00	2.77 (10.41)
Control	-	80.28 (64.00)
SEm±	-	3.11
CD (P≤0.05)	-	12.74

Parenthesis data are transformed in to arc sine transformed values

Impact of treatments on emergence of adult of *Trichogramma chilonis* I. from treated pupae

The impact of treatments on the emergence of adults from treated pupae of *T. chilonis* Ishii is presented in Table 5. Among the insecticides, fenvalerate was found to be most toxic with least emergence of adult from the pupae (2.77 %) followed by spinosad (7.39 %), karanjin (23.92 %), indoxacarb (32.87 %), flubendiamide (55.12 %), annonin (56.74 %), *B.bassiana* (61.62 %) and *M. anisopliae* (61.73 %), azadiractin (62.43 %) and *Bt.* (67.75 %). The emergence of adult was very high in control with 80.28 %. The present findings revealed that indoxacarb was moderately safer than fenvalerate and spinosad, which may be in agreement with earlier reports stating that indoxacarb was harmless to *T. pretiosum* and that indoxacarb and *B. thuringiensis* were harmless to *T. chilonis* up to the first six hours of exposure (23, 24). The findings of the present investigation are in line with earlier reports showing that *B. thuringiensis*, spinosad, thiodicarb and indoxacarb were the only four out of nine pesticides that were relatively safer to beneficial insects (25).

Conclusion

The present study evaluated the safety of chemical as well as bio-pesticides on natural enemies in the pigeon pea ecosystem. The study revealed that bio-pesticides were safe for all the natural enemies compared to chemical insecticides. Among the biopesticides, *M. anisoplae* was the safest for the natural enemies. Among the chemical pesticides, flubendiamide was comparatively less toxic to the natural enemies. Therefore, all the tested bio-pesticides and flubendiamide may be incorporated into IPM programme for ecofriendly pest management as well as conservation of natural enemies in crop ecosystems.

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Authors' contributions

BCD, PPD and AS conceptualized the study and conducted the research work. SP[1] and SS contributed to manuscript writing. CS conducted the statistical tests. SP[1] and SP[2] edited the manuscript. NKA conducted the plagiarism check and final editing of manuscript. All authors read and approved the final manuscript. [SP[1] - Sandip Patra and SP[2] - Shubham Pramanik].

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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