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Development of eco-friendly pest management module for the management of aphids, *Hyadaphis coriandri* (Das) infesting coriander, *Coriandrum sativum* L.

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Abstract
Coriandrum sativum is an important green leafy vegetable as well as seed spice crop. Among the various insect pests infesting coriander, the coriander aphid, *Hyadaphis coriandri* is a regular and major pest of coriander and responsible for reduction in crop yield. Development of eco-friendly pest management practices is essential in the production of high quality and pesticide residue free produces. Field experiment was conducted at Pappampatti, Coimbatore district, Tamil Nadu from January 2021 to April 2021 to develop IPM module for the management of aphids, *Hyadaphis coriandri* infesting coriander. Results of the field experiment revealed that among the treatments, IPM module (T_5) comprising of designer seed treatment [Polymer (3g) - thiamethoxam 5 FS (5g) - azospirillum (120g) - *Trichoderma viride* 4 g per kg of seed] - border cropping with cowpea - erecting yellow sticky traps at 12/ha - need based application of spinosad 45 SC @ 75 ml per acre recorded the lowest mean population of aphids (5.72 aphids per three umbels plant^{-1}) followed by another IPM module with azadirachtin 10,000 ppm (T_4) (7.07 aphids per three umbels plant^{-1}) and farmer's practice (7.77 aphids per three umbels plant^{-1}). The IPM modules (T_4 and T_5) were designed in such a way that they are safe to the natural enemies, which recorded the highest population of coccinellids *viz.*, 1.59 and 1.57 coccinellids per plant, respectively. Maximum harvestable seed yield of 960 kg/ha was recorded in T_5, the IPM module with spinosad 45 SC followed by farmer's practice (857 kg/ha). Hence, the IPM module with spinosad 45 SC (T_5) is adjudged as the best treatment for the management of coriander aphids, *H. coriandri*.

Keywords: *Coriandrum sativum, Hyadaphis coriandri,* designer seed, azadirachtin, spinosad, IPM

1. Introduction

Coriander (*Coriandrum sativum* L.), belongs to the family Apiaceae, is an important seed spice crop grown mainly in Madhya Pradesh, Rajasthan, Andhra Pradesh and other states of India. It is commonly called as dhania and cultivated for both green leafy vegetables and seed purposes. Among all the seed spices, coriander occupies first place in India in terms of area, production and productivity. Coriander is also grown as intercrop in various crops since it attracts large number of predators, parasitoids and pollinators due to the presence of huge quantity of nectar and volatile oil emitted from the plant.

A number of insect pests *viz.*, thrips, *Thrips tabaci*, jassids, *Empoasca kerri*, aphids, *Myzus persicae* [1], *Hyadaphis coriandri* [2], *Aphis gossypii*, *Aphis craccivora*, pod borer, *Heliothis armigera*, whitefly, *Bemisia tabaci*, seed wasp, *Systole albipennis* [3], bugs, termites and few lepidopteran caterpillar inflict damage to this crop [4]. Among the insect pests, aphids are the most important pests of coriander causing maximum crop losses at field conditions. Aphids are also responsible for loss of seed health and quality. Initial population establishment starts during vegetative stage, whereas, the peak population reaches during flowering and fruiting stages of crop [5]. Thus, aphids cause more damage to the harvestable produce of the crop resulting in yield loss up to 50 per cent and reduce the quality of seeds [6].

In the present day agriculture, farmers are solely relying upon variety of insecticides for pest management and such indiscriminate use of pesticides results in accumulation of pesticides on the harvestable produces in the form of residues, development of resistance to insecticides, resurgence of minor pests and mortality of non-target organisms such as natural enemies and pollinators particularly honeybees. Pesticide residue in seed spice is becoming a major concern particularly in coriander due to which the country faces a huge loss in national economy [7]. Considering the significance of this pest, the present study was undertaken to develop Integrated Pest Management (IPM) module for the management of aphids, *H. coriandri* infesting coriander.

2. Materials and methods

Field experiment was conducted in the farmer's holdings at Pappampatti, Coimbatore district, Tamil Nadu from January 2021 to April 2021 to develop IPM module against aphids infesting *C. sativum*. The experiment was laid out using randomized block design (RBD) with seven treatments replicated thrice. The treatments details are as follows,

T_1 - Designer seed treatment [Polymer (3g) - thiamethoxam 5 FS (5g) - azospirillum (120g) - *Trichoderma viridie* 4 g per kg of seed]

T_2 - T_1 + Foliar application of azadirachtin 10,000 ppm at 1 ml/litre

T_3 - T_1 + Foliar application of spinosad 45 SC @ 75 ml per acre

T_4 - Eco-friendly pest management module comprising of designer seed treatment [Polymer (3g) - thiamethoxam 5 FS (5g) - azospirillum (120g) - *Trichoderma viridie* 4 g per kg of seed] - border cropping with coriander for amaranthus and cowpea for coriander - erecting yellow sticky traps at 12/ha - need based application of azadirachtin 10,000 ppm at 200 ml/acre

T_5 - Eco-friendly pest management module comprising of designer seed treatment [Polymer (3g) - thiamethoxam 5 FS (5g) - azospirillum (120g) - *Trichoderma viridie* 4 g per kg of seed] - border cropping with coriander for amaranthus and cowpea for coriander - erecting yellow sticky traps at 12/ha - need based application of spinosad 45 SC @ 75 ml per acre

T_6 - Farmer's practice (Chemical control)

T_7 - Untreated control

First spray of respective insecticides was given at 45 days after sowing (DAS) when the pest population crossed the economic threshold level of 1.5 aphid index/plant and second spray was given 30 days after the first spray *i.e.* at 75 DAS, when the pest population crossed the ETL once again. Ten plants were randomly selected from each plot and the population of aphids and natural enemies were recorded at weekly intervals and the population of aphids and natural enemies were expressed as number/plant.

Population of *H. coriandri* was count on three leaves per plant during the vegetative sage and three umbels per plant during reproductive stage on ten randomly selected plants in each plot starting from 21 DAS till 105 DAS. Average aphid index was worked out by adopting the following formula [8].

$$\text{Average aphid index} = \frac{{}_0N + {}_1N + {}_2N + {}_3N + {}_4N + {}_5N}{\text{Total number of plants observed}}$$

Where, 0, 1, 2, 3, 4, 5 are the aphid index

N = Number of plants showing respective aphid index

Aphid index	Degree of infestation
0	Plant free from aphid
1	Aphid present but colonies not built up. No injury due to pest appearance on plant
2	Small colonies of aphid present on leaves of plant. Such leaves exhibit slight curling due to aphid feeding
3	Large colonies of aphid present on leaves and other parts, damage symptoms visible due to aphid feeding
4	Most of the leaves covered with aphid colonies. Counts are not possible and the plant shows more damage symptoms due to aphid feeding
5	The plant completely covered with aphid colonies, plant growth hindered due to pest feeding

Observations were recorded at weekly intervals and average aphid index was worked out. Population of predatory coccinellids was recorded on ten randomly selected plants at weekly intervals and the mean value was worked out. Seed yield of coriander was recorded from each plot at harvest.

2.1 Statistical analysis

The data obtained from the field experiment were analyzed using AGRES ver. (7.01), Pascal international solutions. Wherever necessary, the pest load in number was transformed into square root of x + 0.5 values before carrying out statistical analysis. Least Significant Difference (LSD) was used to compare the treatment means at 5 per cent level of significance.

3. Results and Discussion

3.1 Efficacy of different pest management options on coriander aphid, *H. coriandri*

Results of the field experiment to evaluate the efficacy of different pest management options on coriander aphid, *H. coriandri* revealed that the initial infestation of aphids on coriander was noticed at 35 DAS with the population range of 1.02 to 4.75 aphids per three leaves per plant.

In T_1, where designer seed treatment is the sole component, the population of aphids increased gradually and reached its peak of 238.08 aphids per three umbels per plant at 70 DAS. Thereafter, the population gradually declined to 1.06 aphids per three umbels per plant at 98 DAS towards crop maturity stage.

In all the treatments, the population of aphids increased gradually from 35 DAS. After 1st spray at 45 DAS, the population of aphids decreased for two weeks and started increasing and attained the peak infestation at 70 DAS. After 2nd spray at 75 DAS, the population of aphids decreased gradually and disappeared towards maturity *i.e.* at 105 DAS. The mean number of aphids throughout the cropping period in different treatments was worked out and the results revealed that among the treatments, the IPM module with spinosad 45 SC (T_5) was adjudged as the best treatment which recorded the lowest number of aphids (5.72 aphids per plant) with 92.12 per cent reduction over untreated control followed by the IPM module with azadirachtin 10,000 ppm (T_4) with the mean number of 7.01 aphids per plant and 90.34 per cent reduction over control. Farmer's practice of spraying chemical pesticides (T_6) was recorded to be statistically on par with the IPM module (T_4) with the mean number of 7.77 aphids per plant and with the population reduction of 89.29 per cent over untreated control. Module T_2 and T_3 were next in the order of efficacy and were recorded to be statistically on par with each other with the mean population of 14.96 and 13.52 aphids per plant with the reduction of 79.39 and 81.38 per cent, respectively. Among the treatments, T_1 recorded the maximum number of 54.17 aphids per plant with the mean reduction of only 25.39 per cent only as against 72.61 aphids per plant in untreated control (Table 1).

Results on aphid index revealed that the mean aphid index was recorded to be the lowest (0.21) in the IPM module with spinosad 45 SC (T_5) followed by the IPM module with azadirachtin 10,000 ppm (T_4) (0.29) and farmer's practice (T_6) (0.31). Among the treatments, the maximum aphid index of 1.08 was recorded in T_1 which had the option of only designer seed treatment as against the maximum aphid index of 1.19 in untreated control (Table 2).

3.2 Efficacy of different pest management options on the population of predatory coccinellids

Predatory coccinellids appeared at 14 DAS and recorded up to 98 DAS. At 14 DAS, population of coccinellid beetles was recorded to be in the range of 0.03 to 0.06 beetles per plant. The population of coccinellid beetles increased gradually and reached the peak at 70 DAS coinciding with the population build-up of aphids and the number ranged from 2.12 to 5.43 beetles per plant. Later, the predator population declined gradually towards the crop maturity as the population of aphids decreased.

The mean number of predatory coccinellids per plant was found to be the maximum in the IPM module with azadirachtin 10,000 ppm (T_4) (1.59 beetles/plant) with 3.69 per cent increase over untreated control and was found to be statistically on par with the IPM module with spinosad 45 SC (T_5) (1.57 beetles/plant) and untreated control (T_7) (1.54 beetles/plant). The population of predatory coccinellids was enhanced in the IPM modules (T_4 and T_5) as they had cowpea as a border crop. Among the treatments, farmer's practice registered the lowest number of 0.12 coccinellids per plant with 92.1 per cent reduction over untreated control due to insecticidal sprays. Among the pest management modules, T_3 and T_2 also registered minimum number of 0.53 and 0.61 beetles per plant with 65.36 and 60.11 per cent reduction over untreated control, respectively (Table 3).

3.3 Efficacy of different pest management options on seed yield of coriander

Seed yield of coriander in different treatments was in the range of 456 to 960 kg per ha. Among the treatments, the IPM module with spinosad 45 SC (T_5) registered the maximum seed yield of 960 kg/ha, followed by the farmer's practice with chemical pesticides (857 kg/ha) and the IPM module with azadirachtin 10,000 ppm (T_4) (838 kg/ha). Among the pest management modules, T_3 and T_2 registered the seed yield of 686 and 621 kg/ha, respectively, as against the minimum seed yield of 456 kg/ha in the untreated control. (Figure 1).

The results are in agreement with the findings of Suganthy and co-workers [9], who reported that IPM module comprising of designer seed treatment [Polymer (3 g) - carbendazim (2 g) - Gaucho (5 g) - *Azospirillum* (120 g) kg^{-1} of seed] - cowpea as border crop - erecting yellow sticky traps at 12 per ha - need based spraying of azadirachtin 10,000 ppm at 1 ml per litre recorded the lowest incidence of sucking pests *viz*., aphids, thrips and whiteflies followed by farmer's practice (chemical control) in *Solanum nigrum*. Chaudhary and co-workers [10] tested six different neem-based insecticide formulations against coriander aphid, *H. coriandri* and reported that azadirachtin 1,500 ppm at 5 ml/litre was the most effective in reducing the population of aphids with the increased coriander seed yield of 1043 kg/ha.

Table 1: Efficacy of different pest management options on coriander aphid, *Hyadaphis coriandri*

Treatments	Number of aphids/plant*													
	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS	70 DAS	77 DAS	84 DAS	91 DAS	98 DAS	105 DAS	Mean	PROC
T1	0.00 (0.71)^{a}	0.00 (0.71)^{a}	1.95 (1.57)^{b}	36.04 (6.04)^{cd}	52.23 (7.26)^{f}	116.04 (10.80)^{d}	188.32 (13.74)^{d}	238.08 (15.45)^{d}	115.80 (10.78)^{e}	46.75 (6.87)^{f}	16.34 (4.10)^{f}	1.06 (1.25)^{c}	0.0 (0.71)^{a}	54.17 (7.39)^{d}	25.39
T2	0.00 (0.71)^{a}	0.00 (0.71)^{a}	2.80 (1.82)^{d}	35.16 (5.97)^{c}	16.83 (4.16)^{e}	28.02 (5.34)^{c}	36.45 (6.08)^{c}	58.56 (7.69)^{c}	30.85 (5.60)^{d}	12.97 (3.67)^{e}	2.72 (1.79)^{e}	0.08 (0.76)^{b}	0.0 (0.71)^{a}	14.96 (3.93)^{c}	79.39
T3	0.00 (0.71)^{a}	0.00 (0.71)^{a}	2.15 (1.63)^{c}	34.87 (5.95)^{c}	13.04 (3.68)^{d}	25.43 (5.09)^{c}	34.10 (5.88)^{c}	53.78 (7.37)^{c}	26.52 (5.20)^{c}	10.56 (3.33)^{d}	2.32 (1.68)^{d}	0.05 (0.74)^{b}	0.0 (0.71)^{a}	13.52 (3.74)^{c}	81.38
T4	0.00 (0.71)^{a}	0.00 (0.71)^{a}	1.02 (1.23)^{a}	18.52 (4.36)^{a}	3.75 (2.06)^{c}	8.62 (3.02)^{b}	22.82 (4.83)^{a}	30.32 (5.55)^{ab}	12.34 (3.58)^{b}	6.25 (2.60)^{c}	1.56 (1.44)^{c}	0.00 (0.71)^{a}	0.0 (0.71)^{a}	7.01 (2.74)^{b}	90.34
T5	0.00 (0.71)^{a}	0.00 (0.71)^{a}	1.08 (1.26)^{a}	20.36 (4.57)^{a}	1.13 (1.28)^{b}	5.13 (2.37)^{a}	20.43 (4.57)^{a}	28.26 (5.36)^{a}	8.05 (2.92)^{a}	1.32 (1.35)^{a}	0.06 (0.75)^{a}	0.00 (0.71)^{a}	0.0 (0.71)^{a}	5.72 (2.49)^{a}	92.12
T6	0.00 (0.71)^{a}	0.00 (0.71)^{a}	2.82 (1.82)^{d}	26.28 (5.17)^{b}	0.62 (1.06)^{a}	8.58 (3.01)^{b}	28.06 (5.34)^{b}	35.58 (6.01)^{b}	10.42 (3.30)^{b}	3.76 (2.06)^{b}	0.50 (1.00)^{b}	0.00 (0.71)^{a}	0.0 (0.71)^{a}	7.77 (2.88)^{b}	89.29
T7	0.00 (0.71)^{a}	0.00 (0.71)^{a}	4.75 (2.29)^{e}	38.65 (6.26)^{d}	86.30 (9.32)^{g}	154.65 (12.46)^{e}	269.40 (16.43)^{e}	306.14 (17.51)^{e}	126.62 (11.27)^{f}	72.46 (8.54)^{g}	28.02 (5.34)^{g}	2.09 (1.61)^{d}	0.0 (0.71)^{a}	72.61 (8.55)^{e}	–
S. Ed	-	-	0.016	0.114	0.104	0.147	0.189	0.217	0.145	0.095	0.053	0.010	-	0.104	-
CD (P=0.05)	-	-	0.034	0.252	0.229	0.325	0.415	0.479	0.320	0.209	0.117	0.022	-	0.229	-

DAS - Days after sowing; *Mean three replications; PROC - Percent reduction over control;
In a column, means followed by common letter(s) are not significantly different by LSD; Figures in parenthesis are square root transformed values

Table 2: Efficacy of different pest management options on aphid index in coriander

Treatments	Aphid index*													
	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS	70 DAS	77 DAS	84 DAS	91 DAS	98 DAS	105 DAS	Mean
T1	0.00	0.00	0.26	1.12	1.26	2.18	2.54	3.16	2.56	1.92	1.21	0.05	0.00	1.08
T2	0.00	0.00	0.38	1.08	0.47	1.22	1.48	1.94	1.53	0.32	0.15	0.00	0.00	0.57
T3	0.00	0.00	0.36	1.02	0.45	1.17	1.34	1.83	1.45	0.28	0.12	0.00	0.00	0.53
T4	0.00	0.00	0.12	0.93	0.25	0.28	1.06	1.27	0.31	0.12	0.06	0.00	0.00	0.29
T5	0.00	0.00	0.35	1.06	0.05	0.32	0.75	0.42	0.13	0.08	0	0.00	0.00	0.21
T6	0.00	0.00	0.2	0.98	0.39	0.3	1.03	1.29	0.33	0.14	0.05	0.00	0.00	0.31
T7	0.00	0.00	0.52	1.18	1.42	2.23	2.56	3.24	2.68	2.13	1.75	0.08	0.00	1.19

DAS - Days after sowing; *Mean three replications

Table 3: Efficacy of different pest management options on the population of predatory coccinellids

Treatments	Number of coccinellids/plant*														PROC/PIOC
	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS	70 DAS	77 DAS	84 DAS	91 DAS	98 DAS	105 DAS	Mean	
T_1	0.00 (0.71)^{a}	0.06 (0.75)^{b}	0.15 (0.81)^{d}	0.18 (0.82)^{b}	0.56 (1.03)^{b}	1.54 (1.43)^{g}	2.52 (1.74)^{d}	3.86 (2.09)^{c}	4.81 (2.30)^{d}	4.62 (2.26)^{e}	1.53 (1.42)^{c}	1.28 (1.33)^{d}	0.36 (0.93)^{b}	0.00 (0.71)^{a}	1.43 (1.39)^{d}	- 6.81
T_2	0.00 (0.71)^{a}	0.03 (0.73)^{a}	0.10 (0.77)^{c}	0.23 (0.85)^{c}	0.45 (0.97)^{a}	0.18 (0.82)^{b}	0.56 (1.03)^{c}	1.45 (1.40)^{b}	2.53 (1.74)^{c}	2.24 (1.66)^{c}	0.84 (1.16)^{b}	0.32 (0.91)^{c}	0.26 (0.87)^{c}	0.00 (0.71)^{a}	0.61 (1.05)^{c}	- 60.11
T_3	0.00 (0.71)^{a}	0.03 (0.73)^{a}	0.06 (0.75)^{b}	0.15 (0.81)^{a}	0.68 (1.09)^{c}	0.26 (0.87)^{c}	0.45 (0.97)^{b}	1.38 (1.37)^{b}	2.12 (1.62)^{b}	1.96 (1.57)^{b}	0.75 (1.12)^{b}	0.14 (0.80)^{b}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	0.53 (1.01)^{b}	- 65.36
T_4	0.06 (0.75)^{c}	0.10 (0.77)^{c}	0.23 (0.85)^{f}	0.38 (0.94)^{f}	0.96 (1.21)^{d}	0.86 (1.17)^{d}	2.34 (1.69)^{d}	3.94 (2.11)^{d}	5.36 (2.42)^{e}	4.56 (2.25)^{ef}	2.72 (1.79)^{e}	1.85 (1.53)^{e}	0.53 (1.01)^{f}	0.00 (0.71)^{a}	1.59 (1.45)^{e}	+ 3.69
T_5	0.03 (0.73)^{b}	0.06 (0.75)^{b}	0.20 (0.84)^{e}	0.32 (0.91)^{e}	1.12 (1.27)^{e}	0.98 (1.22)^{e}	2.26 (1.66)^{d}	3.98 (2.12)^{d}	5.37 (2.42)^{e}	4.43 (2.22)^{d}	2.52 (1.74)^{d}	1.78 (1.51)^{e}	0.46 (0.98)^{e}	0.00 (0.71)^{a}	1.57 (1.44)^{e}	+ 2.04
T_6	0.00 (0.71)^{a}	0.03 (0.73)^{a}	0.03 (0.73)^{a}	0.28 (0.88)^{d}	0.54 (1.02)^{b}	0.12 (0.79)^{a}	0.34 (0.92)^{a}	0.35 (0.92)^{a}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	0.13 (0.79)^{a}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	0.12 (0.79)^{a}	- 92.10
T_7	0.03 (0.73)^{b}	0.10 (0.77)^{c}	0.16 (0.81)^{d}	0.24 (0.86)^{c}	0.66 (1.08)^{c}	1.24 (1.32)^{f}	2.63 (1.77)^{e}	4.36 (2.20)^{e}	5.43 (2.44)^{e}	4.82 (2.31)^{f}	1.62 (1.46)^{c}	1.32 (1.35)^{d}	0.43 (0.96)^{d}	0.00 (0.71)^{a}	1.54 (1.43)^{e}	-
S. Ed	0.0094	0.0230	0.0031	0.0054	0.0127	0.0133	0.0209	0.0297	0.0352	0.0330	0.0203	0.0133	0.0055	-	0.0168	-
CD (P=0.05)	0.0204	0.0502	0.0068	0.0118	0.0276	0.0290	0.0456	0.0648	0.0766	0.0719	0.0441	0.0291	0.0121	-	0.0367	-

DAS - Days after sowing; *Mean three replications; PROC - Percent reduction over control; PIOC - Percent increase over control;
(-) Percentage reduction over control; (+) Percentage increase over control
In a column, means followed by common letter(s) are not significantly different by LSD; Figures in parenthesis are square root transformed values

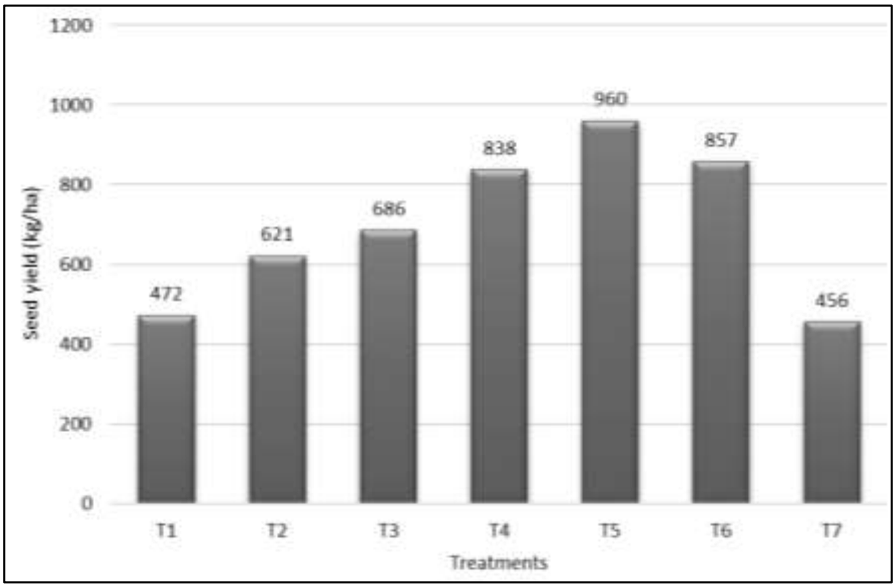

Fig 1: Efficacy of different pest management options on seed yield of coriander

5. Conclusion

As coriander is used both as green leafy vegetable and seed spice, use of chemical pesticides for pest management is to be restricted. To combat the problem of aphids infesting coriander without the pesticide residues in the end product, development of eco-friendly pest management strategy is need of the hour. Keeping this in mind, an eco-friendly integrated pest management module comprising of designer seed treatment [Polymer (3g) - thiamethoxam 5 FS (5g) - azospirillum (120g) - *Trichoderma viridie* 4 g per kg of seed] - border cropping with coriander for amaranthus and cowpea for coriander - erecting yellow sticky traps at 12/ha - need based application of spinosad 45 SC @ 75 ml per acre was developed and adjudged as the best treatment which recorded the lowest number of aphids (5.72 aphids per plant) with 92.12 per cent reduction over untreated control followed by another IPM module with azadirachtin 10,000 ppm with the mean number of 7.01 aphids per plant and 90.34 per cent reduction over control. IPM module with azadirachtin 10,000 ppm (1.59 beetles/plant) and another IPM module with spinosad 45 SC (1.57 beetles/plant) conserved more number of natural enemies *viz.*, predatory coccinellid beetles. IPM module with spinosad 45 SC not only reduced the population of aphids by conserving the predator population, but also registered the maximum seed yield of 960 kg/ha.

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Conflict of Interests

The authors declare that there is no conflict of interest in the publication of this content.

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