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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Chilli is a crop cultivated in tropical and subtropical regions of India, and the crop is attacked by a multitude of pests at different crop stages. The present study revealed that field experiments were laid out with three treatments, viz., IPM module, farmer practice, and untreated control, at Kuttiyagoundanur village of Kolathur block of Salem District, Tamil Nadu. The results of the IPM capsule for the management practices of major pests and diseases, including viral diseases in chillies. The pre-treatment count on thrips/leaf was non-significant in all treatments, and it ranged from 7.20 to 8.40 thrips/leaf. Among the three treatments, farmers practice of chemical control recorded less infestation of 2.93 thrips/leaf, followed by the IPM module recording 3.60 thrips/leaf. Before adoption of treatment, the mite/leaf count was between 17.09 and 19.23 mite/leaf. The IPM module recorded less infestation of 5.32 mites/leaf, followed by farmers practice recording 12.90 mites/leaf. The pre-treatment count of *Helicoverpa armigera* larvae was between 3.20 and 3.72 larvae/plant. Among the treatments, chemical control recorded less infestation of fruit borer and fruit damage (0.17 larvae/plant) and 1.40 percent, followed by the IPM module, which is 1.17 larvae/plant and 4.91 percent. The leaf curl infection was low in farmers practices. 10.82 percent, followed by the IPM module recorded 15.26 percent. Maximum fruit yield of 11200 kg/ha with a comfortable B:C ratio of 2.96 was obtained in the IPM module, followed by farmer practice with a B:C ratio of 2.91.

Keywords: Chilli; thrips; insecticides; mite.

1. INTRODUCTION

Chilli (*Capsicum annuum* L.) remains a main economical spice in addition to the prevalent vegetable crop grown all over India (Reddy,1988). At present, India is the highest producer, purchaser, and exporter of chilli in the world and contributes 31% of the total spice export from India with an economic share of Rs. 8429.92 crore (Spice Board, 2021). In India, chilli is the most horticultural crop, not only because of its financial position but also for the dietary value of its fruits, such as total fat 0.4 g/100 g, sodium 9 mg/100 g, potassium 322 mg/100 g, dietary fiber 1.5 g/100 g, sugar 5 g/100 g, and protein 1.9 g/100 g, which are excellent sources of natural colors and antioxidant compounds (Navarro et al., 2006). The eye-catching color is attributable to the presence of a pigment identified as ‘Capsanthin’ and the pungency because of an alkaloid called "capsaicin".

“Although the crop has turned into an enormous export prospect in addition to vast domestic requirements, a number of restrictive reasons have been characterized for low productivity. The pest range of chilli crop is multidimensional, with more than 293 insect and mite species devastating the crop in the field as well as in post-harvest” (Anonymous et al., 1987),(Butani, 1976). “The important key pests such as fruit borer, *Helicoverpa armigera* Hubner, *Myzus persicae* Sulzer., *Aphis gossypii* Glover., thrips, *Scirtothrips dorsalis* Hood., and yellow mite, *Polyphagotarsonemus latus* Banks (Berke and Shieh, 2000), of which *S. dorsalis*, *A. gossypii*, *P. latus,* and *H. armigera* are mostly accountable for causing yield loss up to 75% or more in the Indian subcontinent” (Sarkar et al., 2015) and these are the utmost vital production limitations (Puttarudraiah, 1959), (Solanki and Rai,2006). “In the course of the last two decades, insecticidal management of chilli pests has been common, particularly in irrigated crops categorized by high pesticide usage. Indiscriminate usage of pesticides has recurrently led to the development of unwanted problems like the annihilation of natural enemies, pest resurgence, and failure of control strategies that result in the outbreak of leaf curl in chilli” (Joia et al.,2001). “The harvest losses due to aphid and whitefly are roughly 50 percent” (Hosamani, 207). The loss produced by the thrips is reported fluctuating from 50–90 percent and fruit borers to an amount of 90 percent (Reddy and Reddy, 1999). “In this background, it is therefore essential to formulate effective non-chemical pest management tactics against key pests for sustained crop management and production of healthy food. The new insecticides are more tissue-specific, activated in unique ways inside the target cells of insects, resulting in reduced threat to other organisms. Selective toxicity to insects and safety to natural enemies have made the new class of insecticides more user and eco-friendly. In order to prevent the infestation of the insect pests and to produce a quality crop, it is essential to manage the pest population at an appropriate time with suitable measures" (Gundannavar et al., 2007). "The practice of insecticides for the management of these pests is greatly disparaged for several reasons, and hence swapping from insecticides to trap cropping might be an ecologically safe control measure, which delivers protection by hampering the pests from entering the main crop and checking or concentrating the movements in certain pockets of the field where they are easily controlled. Trap crops have vital characteristics that are noticeably more attractive to the pests than the main crop and have added utility for natural enemies. Intercropping and strip cropping decrease pest burden on the cash crop through either a push (deterrent from the cash crop) or pull (attraction to other species) tactic. Researchers established that the usage of the perimeter trap crop method as part of Integrated Pest Management (IPM) or organic programs can help improve crop quality and total farm profitability while decreasing pesticide usage and the possibility of secondary pest outbreaks" (Boucher et al., 2013) "In tomato fields, adoption of marigold (3:1 combination) as a trap crop decreased 81–89% in the larval population of tomato fruit borer" (Hussain et al., 2007). Grain sorghum could serve as an effective trap crop for corn earworm in cotton (Tillman and Mullinix, 2004) Insect pests exhibited disruption with the cultivation of trap crops such as corn, beans, sunflower, pigeon pea, and cowpea (Clifton and Duphily, 2006); "whereas it was found that the damages in the main crop due to insect pest infestation decreased significantly due to trap cropping as compared to control. The insect pests on chilli may be reduced by using trap crops on the borers or at the alternate rows" (Maharjan et al., 2013).

Intercropping is the agronomic practice of cultivating two or more crops in the same field (Andrews and Kassam, 1976) or combining crops, weeds deliberately used as cover crops (Andow, 1991a) and relay intercropping is planting of one intercrop species before another life cycle partially overlaps (Kass, 1978). Mixture of crop cultivars having benefits related to conventional intercropping (Perrin and Phillips, 1978). In agriculture, polyculture systems provide a higher secure yield (Perrin, 1977) "Moreover, successful interculture systems have superior effectiveness in harnessing solar energy, nutrients, and soil moisture compared to monocropping under similar conditions" (Vandermeer, 1989),(Andow, 1991b). "In India, intercropping decreases pest damage due to the reduced number of individual plants, and intercropping serves as a trap crop by distracting pests along with a repellent effect" (Aiyer, 1949). "Conventional agricultural practices have deleterious effects on the environment, human health, food security, and alternative management strategies like intercropping for insect pest management that thwart pesticide contamination of food, insecticide resistance, and no harmful result on beneficial organisms" (Adler and Hazzard, 2009), (Devi et al., 2020), (Panwar et al., 2021). Considering the above facts, the study was undertaken to evaluate the integrated pest management module for the management of key insect pests in chillies.

2. MATERIALS AND METHODS

Field trials were carried out at Kuttiyagoundanur village of Kolathur block of Salem District, Tamil Nadu, to study the effect of the Integrated Pest Management Module against key insect pests of chillies and to find out the efficacy of the IPM module for key insect pests in chillies in a randomized block design with the following three modules as treatments and replicated seven times with Lalima Chilli variety.

T1-Module 1: Seed treatment with Bacillus @ 2 g/lit; Barricade crop with two rows of maize; intercropping of cluster beans @ 6:1 ratio; mulching with silver plastic mulch; Yellow sticky traps @ 50/ha placed at 30 cm to 60 cm above ground level to trap adult thrips; Basal soil application of micronutrient mixture @ 2.5 kg// ha each ferrous sulphate, zinc sulphate, copper sulphate, manganese sulphate, and borax along with the foliar application of micronutrient mixture (0.2 percent of each ferrous sulphate, zinc sulphate, copper sulphate, manganese sulphate, and 0.1 percent borax) @ 30 and 45 DAS ; Traps for fruit flies – 12 Nos/ha;; application of flubendiamide @ 0.2 ml/l (12 WAT); ETL-based (5 thrips/leaf) application of Imidacloprid 17.8 SL @ 3.0 ml/10 lit followed by pyriproxifen @ 0.1% at 10 days interval

T2: Farmers practice (FP): Five sprays of thiodicarb 75 WP @ 0.5 g/lit at 3 WAT, 5 WAT, 7 WAT, 9 WAT, and 11 WAT

T3: Module 3: Untreated control: The research plot was prepared with four ploughings and cross ploughings were executed to pulverize the clods as well as level the soil. The weeds and left over crop residues of earlier crops were gathered and displaced from the soil of the research plot. Thirty-five-day-old seedlings of chilli were transplanted in main field experimental plots of size 5 x 4 m with a spacing of 60 x 60 cm. The seeds of the border crop of maize and intercrops such as cluster beans were sown, and fifteen-day-old agathi seedlings were transplanted at different row proportions between the main crop, chilli.

All the management practices were followed as per the recommended package of practices of the Tamil Nadu Agricultural University Horticultural Crops Production Guide, except the plant protection measures against target pests like thrips. Yellow sticky traps @ 50/ha placed at 30 cm to 60 cm above ground level to trap adult thrips in the treatment Module 1.

2.1 Observation on Thrips

The population of two stages of thrips, *viz.,* adults and nymphs of thrips, *Scirtothrips dorsalis* (Hood), were totaled. For calculating the population, five chilli plants were carefully selected randomly in each plot and tagged. The population count of thrips was taken from top, middle, and bottom leaves and stated as the number of thrips per leaf until the population crosses the ETL of 5 thrips per leaf at 30, 60 days after transplanting (DAT). ETL based (5 thrips/lleaf) spraying of insecticides was done in all the treatments. First spraying of Imidacloprid 17.8 SL @ 3.0 ml/10 lit followed by pyriproxifen @ 0.1% at 10 days interval for the treatment module 1. For the treatment module 2, thiodicarb 75 WP @ 0.5 g/liter of water was used for five sprayings at 3 WAT, 5 WAT, 7 WAT, 9 WAT, and 11 WAT. The plant protection chemicals were sprayed with the assistance of a knapsack sprayer fixed with a hollow cone nozzle. The insecticides were sprayed with a volume of water at the rate of 500 l/ha. The marked insect was chilli thrips, *S. dorsalis*. To evaluate the efficacy of different plant protection chemicals, observation on population thrips was documented one day before each spraying as pre-treatment count (PTC) in addition to 3, 7, and 14 days after spraying. These recordings were subjected to analysis of variance after making the necessary transformation (Gomez and Gomez, 1984) for comparison of treatment means.

2.2 Observation on Mites

The mite population, along with the damaged leaf, was collected from topmost, center, and lowermost and preserved in the punctured polythene bag of size 16 x 18 cm, and the samples were taken to the laboratory and observed under 20x amplification under a binocular microscope. The complete number of mites from every single leaf was totaled and reported in terms of the number of mites per leaf.

2.3 Observation on Fruit Borer

The examination of the larval population of chilli fruit borer, *H. armigera* was executed on five randomly chosen plants from each treatment at 16 and 18 WAT. Three different treatments were executed.

2.4 Observation on Leaf Curl Index

Ten plants were chosen randomly in every plot and recorded visually for leaf curling index (LCI) at 70 and 100 DAT following the 0–4 scale (Blaser et al., 2007).

Where 0 = absence of symptoms,

1 = 1–25% leaves/plant showing curling.

2 = 26–50% leaves/plant showing curling moderately damaged,

3 = 51–75% leaves/plant showing curling, heavily damaged, malformation of growing points, reduction in plant height, and

4 = more than 75% of leaves/plant showing curling, severe to complete destruction of the growing point, drastic reduction in plant height, defoliation, and severe malformation.

The population distribution of natural enemies includes both nymphs and adults of coccinellid beetles, chrysopids, and spiders. These predators were documented by visual observation on five randomly selected plants in each treatment. Later, the population densities of natural enemies were recorded based on the observations on the number of Coccinellids, Spiders, and *Chrysopa* per plant. For enumerating the population, five plants were chosen randomly in each plot and tagged and observed at 60 and 90 DAT.

In this field experiment, percent reduction over control, green chilli yield, and BC ratio were also calculated. The reduction of the thrips population over untreated control was calculated using the following formula (Henderson and Tilton, 1955).

Percent reduction of abundance over control = Abundance in control plot; abundance in treated plot / Abundance in the control plot * 100

First harvesting was carried out at 90 DAT, and consecutive plucking was finished at an interval of 5-7 days. Fruit yield of each plot was obtained from the whole population distinctly, and the total yield of every treatment was calculated by cumulating the consecutive plucking from respective plots. Afterward, yield per plot was calculated in kilograms per hectare. To relate the yield accomplishment of chilli in different treatments, an analysis of variance was executed in a randomized block design. The percent increase in yield in treatment over control was determined from the following formula (Dutta, 2014).

The increase in yield over control in different treatments was calculated by using the following formula,

Increase of Yield (%) = Yield of treated plot - Yield of control plot / Yield of control plot * 100

2.5 Dry Chilli Fruit Yield

Totally two pickings of red chilli were completed during the 2020 *kharif* season. The total fruit yield from the respective plot was recorded and indicated in terms of dry chilli fruit yield per hectare and submitted for statistical analysis.

2.6 Cost Economics

The fruit yield per plot was documented and calculated to quintals per hectare. The data were thus arranged, pooled, and categorized on the basis of their yield performance. The benefit cost ratio (B:C ratio) of various treatments was computed by estimating different costs of cultivation and returns from fruit yield after transforming them to one hectare of land. The average market price of dry chilli (Cv. Byadgi dabbi) was Rs 140 per kg during the experimentation.

The following formulas were used for the calculation of the B:C ratio.

1. Gross return = Yield x Market price of Byadgi dabbi (Rs. 14000/q)
2. Net Returns = Gross Return - Total Cost
3. B:C ratio = Gross Return / Total Cost

The figures on mean population of sucking pests, natural enemies, and fruit borer were transformed to $\sqrt{x+1}$ and percent damage was transformed to arcsine transformation and then subjected to ANOVA using the M-STATC® software package. The treatment effect was compared by following Duncan's Multiple Range Test (DMRT).

An analysis of benefit-cost ratios (BCR) was carried out to find out the cost effective treatment. The analysis was done by estimating different costs of cultivation and returns from fruit yield in each treatment after converting them to one hectare of land.

3. RESULTS AND DISCUSSION

3.1 Thrips

The pre-treatment count on thrips/leaf was non-significant in all treatments, including the untreated control, and it ranged from 7.20 to 8.40 thrips/leaf. The thrips infestation in leaf ranged from 3.20 to 9.46, 2.60 to 11.58, 3.82 to 16.42, and 2.10 to 13.46 in 5, 7, 9, and 11 WAT, respectively. During the vegetative stage (5 WAT) IPM module: {Seed treatment with Bacillus @ 2 g/lit; barrier crop with two rows of maize; intercropping of cluster bean @ 6:1 ratio; mulching with silver plastic mulch; yellow sticky traps @ 50/ha placed at 30 cm to 60 cm above ground level to trap adult thrips; Basal soil application of micronutrient mixture @ 2.5kg / ha each ferrous sulphate, zinc sulphate, copper sulphate, manganese sulphate and borax along with the foliar application of micronutrient mixture (0.2 per cent of each ferrous sulphate, zinc sulphate, copper sulphate, manganese sulphate and 0.1 per cent borax) @ 30 and 45 DAS; Traps for fruit flies – 12 Nos/ ha; ETL based (5 thrips/leaf) application of Imidacloprid 17.8 SL @ 3.0 ml/10 lit followed by pyriproxifen @ 0.1% at 10 days interval was effective in reducing the thrips population (3.20/leaf) followed by farmers practice {Five sprays of thiodicarb 75 WP @ 0.5 g/lit at 3 WAT, 5 WAT, 7 WAT, 9 WAT and 11 WAT} (4.60/leaf) and highest population of thrips (9.46/leaf) was observed in untreated control. Similarly, 7 WAT data indicated that the IPM module was found to be effective in reducing the thrips population (2.60/leaf), followed by farmers practice (3.22/leaf), and the highest population of thrips (11.58/leaf) was observed in untreated control. Results after 9 WAT showed that the IPM module was found to be superior over farmers practices and untreated control.

Table 1. Population dynamics of thrips under different treatments

Treatments	PTC No. of Thrips/leaf	No. of Thrips/leaf				Mean	Per cent reduction over control
		5WAT	7 WAT	9WAT	11WAT		
T1 *IPDM module*	7.90 (2.98)	3.20 (2.04)	2.60 (1.89)	2.10 (1.75)	3.82 (2.18)	2.93 (1.96)	76.98
T2 *Farmers practice*	7.20 (2.86)	4.60 (2.35)	3.22 (2.04)	2.30 (1.81)	4.26 (2.28)	3.60 (2.12)	71.72
T3 Untreated control	8.40 (3.06)	9.46 (3.22)	11.58 (3.53)	13.46 (3.78)	16.42 (4.15)	12.73 (3.67)	-
CD (5%)	**0.005**	**0.078**	**0.115**	**0.14**	**0.13**	**0.11**	
SE(m)	**0.002**	**0.025**	**0.038**	**0.04**	**0.04**	**0.03**	
SE(d)	**0.003**	**0.036**	**0.053**	**0.06**	**0.06**	**0.05**	
CV%	**0.17**	**2.82**	**4.26**	**5.55**	**4.37**	**4.25**	

WAT: Weeks After Transplanting, Figures in the parenthesis are $\sqrt{x+0.5}$ transformed values

Table 2. Population dynamics of mites under different treatments

Treatments	PTC mite/leaf	Chilli mite/leaf			Per cent reduction over control	Leafcurl Index %	Per cent reduction over control
		13WAT	15WAT	Mean			
T1 *IPDM module*	19.23 (4.47)	7.01 (2.82)	3.64 (2.14)	5.32 (2.48)	73.80	10.82 (19.11)	69.86
T2 *Farmers practice*	18.99 (4.45)	14.60 (3.93)	11.21 (3.48)	12.90 (3.70)	36.48	15.26 (22.89)	57.49
T3 Untreated control	17.09 (4.23)	19.21 (4.47)	21.42 (4.71)	20.31 (4.59)	-	35.90 (36.70)	
CD (5%)	**0.016**	**0.10**	**0.15**	**0.12**	**-**	**1.34**	
SE(m)	**0.005**	**0.03**	**0.05**	**0.04**	**-**	**0.43**	
SE(d)	**0.007**	**0.04**	**0.07**	**0.05**	**-**	**0.61**	
CV%	**0.32**	**2.50**	**4.19**	**3.34**	**-**	**4.71**	

WAT: Weeks After Transplanting, Figures in the parenthesis are $\sqrt{x+0.5}$ transformed values

Table 3. Population dynamics of fruit borer larvae and its damage under different treatments

Treatments	PTC Fruit borer larvae/plant	Fruit borer larvae/plant				
		13WAT	15WAT	Mean	Per cent reduction over control	Fruit damage %
T1 *IPDM module*	3.72 (2.16)	0.21 (1.10)	0.13 (1.06)	0.17 (1.08)	95.98	1.40 (6.76)
T2 *Farmers practice*	3.20 (2.04)	1.60 (1.61)	0.74 (1.31)	1.17 (1.46)	72.34	4.91 (12.74)
T3 Untreated control	3.40 (2.09)	3.92 (2.21)	4.54 (2.34)	4.23 (2.27)		13.60 (21.54)
CD (5%)	**0.008**	**0.08**	**0.10**	**0.09**		**0.88**
SE(m)	**0.003**	**0.02**	**0.03**	**0.02**		**0.28**
SE(d)	**0.004**	**0.04**	**0.04**	**0.04**		**0.40**
CV%	**0.37**	**4.91**	**6.05**	**5.48**		**5.96**

WAT: Weeks After Transplanting, Figures in the parenthesis are $\sqrt{x+0.5}$ transformed values

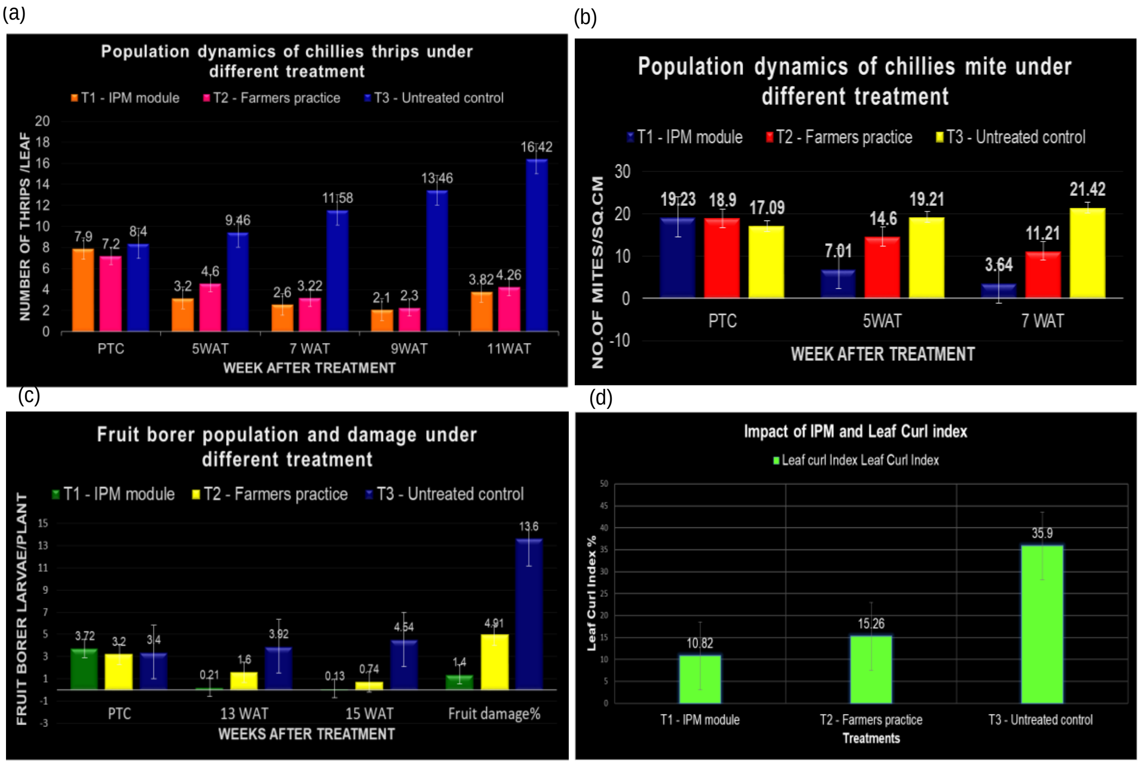

Fig. 1. Population dynamics of key insect pest of chillies under different treatments (a) Chillies thrips (b) Chillies mite (c) Fruit borer (d) Leaf Curl Index

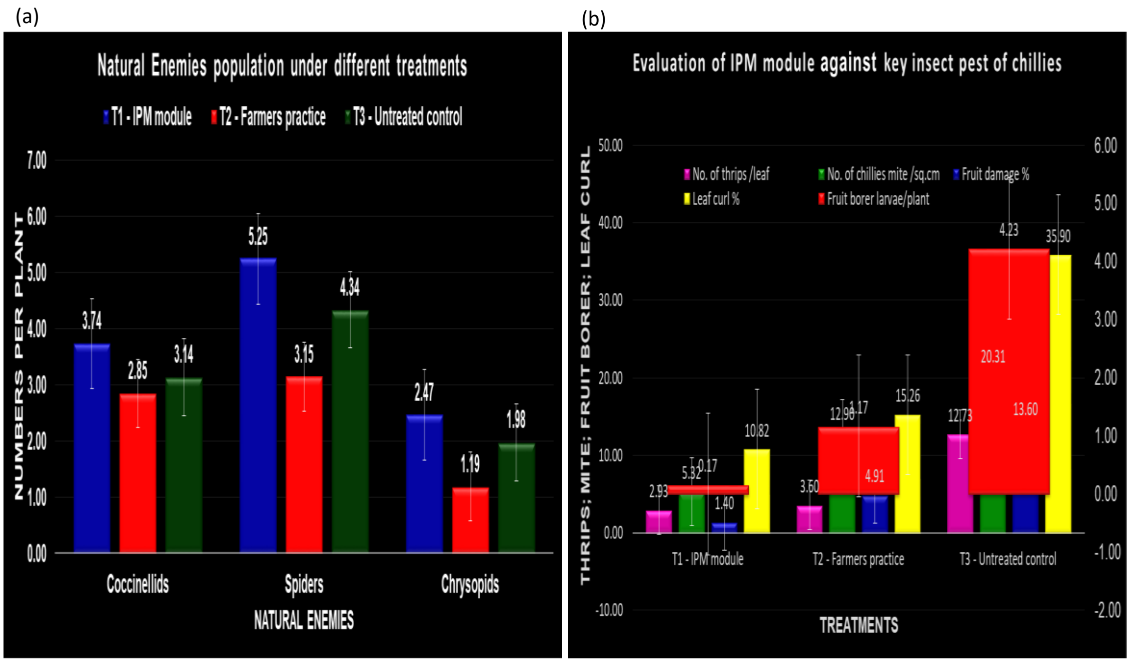

Fig. 2. Scenario of natural enemies and key insect pest of chillies (a) Natural enemies (b) Key insect pests of chillies

After 11 WAT IPM modules indicated to be effective in bringing down the thrips population (3.82/leaf), which was followed by farmers practice (4.26/leaf) and untreated control (16.42/leaf). The mean of four observations recorded that the IPM module recorded 2.93/leaf, followed by farmers practice (3.60/leaf). The highest thrips population (12.73/leaf) was observed in untreated control. Similar observations were recorded by (Kardinan and Maris, 2021) who reported the ability of biopesticides to reduce the intensity of pest attack and also observed the inability of biological pesticides to reduce the pest population of thrips. (halder et al., 2016) reported that minimum thrips population in variety Kashi Anmol was noted in both the years, viz. 2011-12 (2.77 / terminal leaves) and 2012-13 (1.17) with an average of 1.97 thrips/terminal leaves in case of integrated module, and the same trend was also observed in variety Kashi Gaurav. The lowest thrips population was recorded by the integrated module, and the corresponding values were 3.79 (2011-12) and 2.12 (2012-13), with an average of 2.96. M-2 was an effective IPM module because of the reduced incidence of duo sucking pests, which might be due to the effectiveness of its individual components.

3.2 Mite

The pre-treatment count of mite/leaf ranged from 17.09 to 19.23 mite/leaf. The mite infestation in leaves ranged from 7.01 to 19.21 and 3.64 to 21.42 in 13 and 15 WAT, respectively. During the vegetative stage (5 WAT) IPM module – {Seed treatment with Bacillus @ 2 g/lit; Barrier crop with two rows of maize; Intercropping of cluster bean @ 6:1 ratio; mulching with silver plastic mulch; Yellow sticky traps @ 50/ha placed at 30cm to 60cm above ground level to trap adult thrips; Basal soil application of micronutrient mixture @ 2.5kg / ha each ferrous sulphate, zinc sulphate, copper sulphate, manganese sulphate and borax along with the foliar application of micronutrient mixture (0.2 per cent of each ferrous sulphate, zinc sulphate, copper sulphate, manganese sulphate and 0.1 per cent borax) @ 30 and 45 DAS; Traps for fruit flies – 12 Nos/ ha; ETL based (5 thrips/leaf) application of Imidacloprid 17.8 SL @ 3.0 ml/10 lit followed by pyriproxifen @ 0.1% at 10 days interval was effective in reducing the mite population (7.01/leaf) followed by farmers practice {Five sprays of thiodicarb 75 WP @ 0.5 g/lit at 3 WAT, 5 WAT, 7 WAT, 9 WAT and 11 WAT} (14.60/leaf) and highest population of mite (19.21/leaf) was observed in untreated control. After 15 WAT, the IPM module was found to be successful in bringing down the mite population (3.64/leaf), which was followed by farmers practice (11.21/leaf) and untreated control (21.42/leaf). The mean of two observations recorded that IPM module recorded 5.32/leaf followed by farmers practice (12.90/leaf).The above findings were in conformity with the findings of the (halder et al., 2016) mite population (21.42/leaf) observed in untreated control. The above findings were in conformity with the findings of (halder et al., 2016) reported that the integrated module registered the lowest mite population of 2.18 and 1.98 per terminal leaf during 2011-12 and 2012-13, respectively, with an average of 2.08 mites/terminal leaves, which is the lowest than any other pest management modules.

3.3 Leaf Curl Index

The results (Table 2) informed that the lowest leaf curl index (10.82%) was recorded from the IPM module {Seed treatment with Bacillus @ 2 g/lit; Barrier crop with two rows of maize; Intercropping of cluster bean @ 6:1 ratio; Mulching with silver plastic mulch; Yellow sticky traps @ 50/ha placed at 30 cm to 60 cm above ground level to trap adult thrips; Basal soil application of micronutrient mixture @ 2.5 kg// ha each ferrous sulphate, zinc sulphate, copper sulphate, manganese sulphate, and borax along with the foliar application of micronutrient mixture (0.2 percent of each ferrous sulphate, zinc sulphate, copper sulphate, manganese sulphate, and 0.1 percent borax) @ 30 and 45 DAS; traps for fruit flies – 12 Nos/ha;; ETL-based (5 thrips/leaf) application of Imidacloprid 17.8 SL @ 3.0 ml/10 lit followed by pyriproxifen @ 0.1% at 10 days wherein the farmers practice the leaf curl reduction of 15.26. However, the maximum leaf curl index (35.90%) was recorded in the untreated control. Based on the degree of leaf curl index, the treatments could be assembled in the order of IPM module, farmer practice, and untreated control. Similar findings were reported by (Kurbett et al.,2018), Observed mean data on LCI per plant where both M3 Chemi-intensive module (0.40/plant) and M2-Adaptable module (0.45/plant) were found equally superior in reducing the mite population. Whereas, the M1-Biointensive module recorded 0.85 LCI per plant, indicating moderate efficacy against the mite population.

3.4 Fruit Borer Larvae and Fruit Damage%

The mean data relating to fruit borer infestation showed a significantly lower number of larvae noticed in the IPM module (0.17/plant), which was followed by farmers practice (1.17/plant). However, farmers practice recorded a relatively higher larval population (1.17/plant), but superior to untreated control (4.23/plant). Further results on fruit damage indicated that the IPM module recorded the comparatively lowest fruit damage of 1.40%. Whereas, farmers practice was next best in reducing the fruit damage (4.91%). Unquestionably, the untreated control recorded the highest fruit damage (13.60%). The results on fruit yield showed that the IPM module registered the significantly highest yield of 11200 kg/ha. Further, farmers practice recording the yield of 10300 kg/ha superior to the untreated control (6100 kg/ha) from Table 3. Similar findings were reported by (Sarkar *et al.,* 2015) observed that the population density of fruit borer, *H. armigera* at different intervals 70, 85, 100 and 115 DAT was significantly less in M-I which comprises of Marigold trap crop, vermicompost -1-1 2.5 t ha + Neem cake 250 kg ha (devoid of application of recommended dose of fertilizers, i.e RDF) superimposed with sprays of Neemazal TS @ 2 ml l at 5 -1 week after transplanting (WAT), diafenthiuron @ 1gl -1-1 (8 WAT), flubendiamide @ 0.2 ml l (11 WAT) and -1 Neemazal@2ml l (14 WAT) (0.08, 0.10, 0.12 and 0.12 respectively) and was on par -1 with M-II which comprises of Marigold trap crop, neemcake -1-1 500 kg h a + vermicompost 1.25 t ha + without application of RDF superimposed with sprays of NSKE -1 @ 5% (5 WAT), abamectin @ 0.75 ml l (8 WAT), -1 spinosyn @ 0.3 ml l (11 WAT) (0.12, 0.20, 0.20 and 0.24 larvae plant). More larval density (0.32, 0.44, 0.40, and 0.48) was recorded in M-IV. Fluctuation of larval density might be influenced due to IPM strategies and was in the decreasing order of intensity as M-I < M-II < M-III < M-IV. Similarly, M-I registered significantly less fruit damage (2.77%), which was on par with M-II (2.93). Significantly higher percent fruit damage was noticed in M-IV (4.27). Mean data indicating extent of fruit damage was in the order M-I < M-II < M-III < M-IV.

3.5 Population of Natural Enemies

It looks like the idea of border cropping and intercropping fits into the ecological outline of habitat manipulation in an agroecosystem for pest management. Many other approaches alter the environment as part of the IPM strategy. Though, in the current study, diverse intercrops were grown up to attract insects or other organisms to safeguard target crops from pest attack, averting the pests from reaching the crop or accumulating them in a specified part of the field, where they can be economically destroyed. Among intercrops, clusterbeans reported significantly less thrips population compared to other crops with the border crop of maize. It might be because of preference by the pest to clusterbeans as either a food source or oviposition site than the main crop, thus preventing or making less likely the arrival of the pest to the main crop and/or concentrating it in the intercrop where it can be economically destroyed. The population of coccinellids ranged from 2.85 to 3.74 coccinellids/plant. A significantly higher number of coccinellids of 3.74 coccinellids/plant was observed in the treatment IPM module, which was followed by the untreated control (3.14 coccinellids/plant), whereas the lowest number of coccinellids (2.85 coccinellids/plant) was recorded from the farmers practice. The increase of the coccinellid population over farmers practice was high in the treatment IPM module, wherein the border crop closely spaced three rows of maize; intercropping of cluster beans at a 6:1 ratio; and border crop closely spaced three rows of maize**;** intercropping of Agathi at a 10:1 ratio, with observations of 31.23% and 10.18%, respectively. These results revealed that chilli safeguarded by intercropping with different crops played a significant role in preserving and augmenting the population of coccinellids.

The population of spiders ranged from 3.15 to 5.25 spiders per plant. A remarkable higher number of spiders of 5.25 spiders per plant was observed in the treatment IPM module, which was followed by the treatment untreated control (4.34 spiders per plant), whereas the lowest number of spiders (3.15 spiders per plant) was recorded from the Farmers practice. The increase of the spider population over Farmers practice was high in the treatment IPM module, wherein the border crop closely spaced three rows of maize; intercropping of cluster bean at a 6:1 ratio; and border crop closely spaced three rows of maize**;** intercropping of Agathi at a 10:1 ratio, with observations of 66.67% and 37.78%, respectively. These results informed that chilli safeguarded by intercropping with divergent crops played an important role in preserving and augmenting the population of spiders.

A similar trend was observed in Chrysopids also. The population of Chrysopids ranged from 1.19 to 2.47 Chrysopids/plant. A significantly higher number of Chrysopids of 2.47 Chrysopids/plant was observed in the treatment IPM module, which was followed by the treatment untreated control (1.98 Chrysopids/plant), whereas the lowest number of Chrysopids (1.19 Chrysopids/plant) was recorded from the Farmers practice. The increase of the

Table 4. Natural enemies' population and yield

IPM modules	Population (Numbers/Plant)			Per cent increase of Natural enemies population over Farmer's Practice			Yield (Kg/ha)	B:C Ratio
	Coccinellids	**Spiders**	**Chrysopids**	**Coccinellids**	**Spiders**	**Chrysopids**		
T1 *IPDM module*	3.74 (2.176)	5.25 (2.499)	2.47 (1.862)	31.23	66.67	107.56	11200	2.96
T2 *Farmers practice*	2.85 (1.962)	3.15 (2.037)	1.19 (1.481)	-	-	-	10300	2.61
T3 Untreated control	3.14 (2.035)	4.34 (2.312)	1.98 (1.728)	10.18	37.78	66.39	6100	1.60
C.D.	**0.005**	**0.007**	**0.006**	**-**	**-**	**-**	**594.73**	
SE(m)	**0.002**	**0.002**	**0.002**	**-**	**-**	**-**	**194.19**	
SE(d)	**0.002**	**0.003**	**0.003**	**-**	**-**	**-**	**274.63**	
C.V.	**0.212**	**0.249**	**0.294**	**-**	**-**	**-**	**5.97**	

Chrysopids population over Farmers practice was high in the treatment IPM module, wherein the border crop closely spaced three rows of maize; intercropping of cluster bean at a 6:1 ratio; and border crop closely spaced three rows of maize**;** intercropping of Agathi at a 10:1 ratio with observations of 107.56% and 66.39%, respectively. These outcomes informed that chilli safeguarded by intercropping with divergent crops accorded an important role in preserving and augmenting the population of Chrysopids. These results revealed that chilli protected by intercropping with various different crops and border cropping of maize contributed a significant role in conserving and enhancing the population of coccinellids and thus served as an ecological pest management attribute. Similar findings were observed by (Akshata Kurbett *et al.,* 2018) reported that the mean data indicated that the M1-Biointensive module recorded a higher number of coccinellids, which is almost on par with the M4-untreated control, indicating the bio-intensive module is ecofriendly and encouraged the coccinellid population. The next best module was M2-Adaptable Module. Least coccinellids were observed in the M3-Chemi-intensive module (0.16/plant), indicating an adverse effect of insecticides. The mean data also indicated that the chrysopid population was more in the M1-Biointensive module (0.92/plant), which is followed by the M2-Adaptable module (0.59/plant). However, the M3-Chemi-intensive module registered the lowest coccinellids, indicating the toxicity of insecticides on the coccinellid population. A similar trend was observed in mean data on spider population, where the M1-Biointensive module (0.84/plant) encouraged the spider population, followed by the M2-Adaptable module (0.56/plant), and M3-Chemi-intensive module adversely affected the spider population (0.07/plant). The studies on the efficacy of modules on natural enemies concluded that the M1-Biointensive module recorded a higher number of natural enemies such as coccinellids, chrysopids, and spiders as compared to the M2-adoptable module and the M3-chemintensive module. (Tatagar *et al.,* 2011) revealed that chilli plots surrounded by two rows of maize all along the border (untreated) recorded significantly more number of coccinellids (2.56 no/pl.) at 15 WAT, which also supports the present findings.

3.6 Effect of IPM Module on Yield and Economics of Chillies

The effect of different intercrops on yield and economics of chilli is presented in Table 2. Green chilli yield was higher in the IPM module to the tune of 11,200 kg per hectare, followed by farmers practice (10,300 kg), while in untreated control it was 6,100 kg. The highest BC ratio (2.96) was recorded in the IPM module followed by farmers practice (2.91), while in the untreated control it was 2.50. From the results of this experiment, the IPM module can be recommended for the effective management of key insect pests of chillies [38, 39]. They reported that advantages of trap crop systems include erosion control, lessened percolation of nutrients, stabilized disposition of labor, and higher economic returns, and it serves as an eco-friendly pest management attribute than sole cropping.

4. CONCLUSION

From the current findings, it may be inferred that an IPM module incorporating environmentally companionable tools is highly needed. In the public interest of these studies, IPM module-based pest management is considered to be a novel tool in chilli cultivation. This IPM module contains ecologically safe components, and there is a wonderful opportunity for their manipulation of bio-agents, intercrops, and botanicals. It may be concluded that the IPM module can be recommended for the effective management of key pests of chilli. Moreover, chilli protected by intercropping with clusterbeans and border cropping of maize contributed a significant role in conserving and enhancing the population of predators and thus served as an ecological pest management attribute.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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