INTEGRATED MANAGEMENT OF THRIPS ON CHILLI PLANTATIONS THROUGH INTERCROPPING WITH CLUSTER BEAN

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Abstract. Chilli (*Capsicum annuum* L.), a key tropical and subtropical crop in India, is valued as a versatile spice and vegetable. Thrips, a major pest of chilli, can cause severe damage, resulting in yield losses of 50–90%. This study aimed to evaluate the best integrated pest management (IPM) practices to identify the most effective strategy for controlling thrips in chilli crops. Field experiments were conducted in Thondamanatham village, Cuddalore district, using a randomized block design with four treatment modules, including an untreated check, each replicated seven times with the TNAU hybrid chilli CO 1. Results showed that intercropping chilli with cluster bean (*Cyamopsis tetragonoloba* (L.). Taub.) (IPM Module 1) resulted in the lowest thrips population and the highest green chilli yield, with a benefit-cost (BC) ratio of 2.51. This module also maintained a well-distributed population of natural predators, including spiders, coccinellids, and chrysopids, ensuring ecological balance. These findings demonstrate that IPM Module 1 effectively combines pest suppression with ecological sustainability, making it a practical and eco-friendly approach for chilli farmers.
Keywords: *IPM, Capsicum annuum, Scirtothrips dorsalis, Thrips parvispinus, trap cropping*

Introduction

Capsicum annuum L. (chilli) is a vital spice and popular vegetable crop widely cultivated in India, integral to Indian cuisine. Its vibrant color and unique pungency offer significant commercial, dietary, and therapeutic benefits, and it is cultivated year-round (Reddy and Puttaswamy, 1984). Native to tropical America, it was the Portuguese who brought chili to India in the 1800s. Today, India is the second-largest producer of chillies worldwide, contributing about one-fourth of world's total production. Chilli is recognized as a commercial spice crop in both tropical and sub-tropical regions of India. It holds economic value and is rich in nutrients, serving as a great source of antioxidant substances and natural colors (Navarro et al., 2006). The attractive color is due to a pigment called "Capsanthin," while the pungency comes from an alkaloid known as "capsaicin."

Although chilli has significant export potential and meets a large domestic demand, several factors limit its productivity. More than 293 insects and mite species damage chillies in the field and during storage, rendering the pest spectrum affecting the crop

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complex (Anonymous, 1987; Butani, 1976). Key pests encompass yellow mite (*Polyphagotarsonemus latus* Banks), fruit borer (*Helicoverpa armigera* Hubner), aphids (*Myzus persicae* Sulzer, *Aphis gossypii* Glover), and thrips (*Scirtothrips dorsalis* Hood) (Berke and Shieh, 2000). These pests can cause yield losses of 75% or more in the Indian subcontinent (Sarkar et al., 2015), making them critical production challenges (Puttarudraiah, 1959; Solanki and Rai, 2006). Thrips complex are major pests of chilli crops, particularly *S. dorsalis* and recently the invasive species *Thrips parvispinus* (Karny) and in light of its potential to attain pest status, systematic monitoring of this pest was conducted in different regions of India following its initial documentation (Anonymous, 2022). Thrips complexes are recognized for causing substantial yield losses, varying from 12% to 90% at the national scale. Nymphs and adults feed on plant sap, causing upward leaf curling, silvering and distortion. They infest the chilli crop from seedling stage to reproductive stage. Severe infestations can lead to flower and fruit drop, reduced yield, and poor quality (Reddy and Puttaswamy,1984; Ahamd et al., 1987; Rai et al., 2014). Effective thrips management is crucial for safe guarding crop yield and quality.

Over the past two decades, the reliance on insecticides for managing these pests, especially in irrigated crops, has increased. Excessive pesticide use has led to problems including resistance to pesticides, pest resurgence, destruction of natural enemies, and outbreaks of leaf curl in chilli. Additionally, pesticide residues in chilli are a growing concern for exports to developed countries (Pradeep and Korat, 2018; Joia et al., 2001; Dhotre et al., 2001). Consequently, it is imperative to devise efficient non-chemical pest management solutions and use of new-generation insecticides which are more tissue specific and activate in unique ways within target insect cells without affecting the natural enemies, to guarantee sustainable crop management and yield nutritious food (Jeyarani et al., 2010; Gundannavar et al., 2007).

These approaches can help manage pest populations with minimal disruption to the agro-ecosystem. One of the promising sustainable component is trap crops which helps to protect the main crop by attracting pests away or concentrating them in specific areas where they can be managed easily. These crops are often more appealing to pests than the main crop, while also benefiting natural enemies. Intercropping and strip cropping can diminish pest load by employing push (repelling pests) or pull (attracting pests) tactics. Studies indicate that perimeter trap cropping, within the framework of IPM (Integrated Pest Management), may improve crop quality along with profitability, decrease pesticide application and mitigate likelihood of secondary pest infestations (Boucher et al., 2003). Trap cropping, which involves planting a more attractive crop to guard main cash crop, can be from the same or different plant families (Vaiyapuri et al., 2007). This method reduces pesticide use and costs, preserves natural enemies, enhances crop quality, and supports soil and environmental health. Various spatial patterns can be employed for trap crops, depending on the target pest and farm size (Majumdar, 2010). Using trap crops can effectively reduce insect pests on chillies, particularly in alternate rows (Maharjan et al., 2013).

Intercropping refers to the simultaneous cultivation of two or more crops within the same field which can be done in various ways (Andrews and Kassam, 1976; Kass, 1978; Andow, 1991a; Perrin and Phillips, 1978; Perrin, 1977). Successful intercropping systems often use solar energy, nutrients, and soil moisture more efficiently than single-crop systems (Vandermeer, 1989; Andow, 1991b; Adler and Hazzard, 2009; Devi et al., 2020; Panwar et al., 2021). Intercropping may reduce pest damage as follows (Aiyer, 1949): (1) the spread of plants makes them harder for pests to locate; (2) certain plants can act as

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trap crops, diverting pests away; and (3) some crops can repel herbivores. Despite the potential of IPM strategies, there is limited research on their effectiveness in managing thrips on chilli under Indian conditions. Existing studies have primarily focused on chemical control, often overlooking the ecological and practical benefits of integrated approaches. Additionally, the role of intercropping and trap cropping in conserving natural predators and their impact on pest suppression remains underexplored. This study was undertaken to address these gaps and evaluate sustainable IPM strategies for thrips management in chilli cultivation. The specific objectives are:

1. To assess the efficacy of IPM modules, including intercropping, trap cropping, and economic threshold level (ETL)-based insecticide applications, in reducing thrips populations
2. To evaluate the impact of these strategies on natural predator populations, such as spiders, coccinellids, and chrysopids
3. To analyze the effects of these IPM practices on green chilli yield and economic returns

It is hypothesized that IPM strategies integrating intercropping, trap cropping, and ETL-based insecticide applications will significantly reduce thrips populations, conserve natural predators, and improve chilli yield and profitability compared to conventional or chemical control methods. This study seeks to provide a sustainable framework for chilli pest management, emphasizing ecological benefits, economic viability, and the production of high-quality, pesticide-free chillies for domestic and export markets.

Materials and methods

Field experiments were performed at Thondamanatham village, Kullanchavadi block, Cuddalore district, Tamil Nadu, India to study the impact of intercropping systems on chilli thrips and to identify effective integrated management practices for thrips on chillies. Experiments were set up in a randomized block design comprising four treatment modules including untreated check, each replicated seven times, using the TNAU hybrid chilli CO 1.

T1–Module1: Seed treatment with thiamethoxam 30 FS at 7.0 ml/kg; border crop with three closely spaced rows of maize (*Zea mays* L.); intercropping with cluster bean (*Cyamopsis tetragonoloba* (L.) Taub.) at a 6:1 ratio; blue sticky traps at 50/ha, placed 30 to 60 cm above ground level to catch adult thrips; and ETL-based application (5 thrips/leaf) of fipronil 5 SC at 800 ml/ha for first spraying and thiacloprid 21.70 SC at 300 ml/ha for second spraying.

T2–Module2: Seed treatment with thiamethoxam 30 FS at 7.0 ml/kg; border crop with three closely spaced rows of maize; intercropping with Agathi (*Sesbania grandiflora* Pers.) at a 10:1 ratio; blue sticky traps at 50/ha, placed 30 to 60 cm above ground level; and ETL-based application (5 thrips/leaf) of fipronil 5 SC at 800 ml/ha for first spraying and thiacloprid 21.70 SC at 300 ml/ha for second spraying.

T3–Module3: Farmers’ practice using acephate 70 SP at 2 g/l of water.

T4–Module4: Untreated check.

Chili seeds were subjected to Thiamethoxam 30 FS treatment and cultivated in a raised nursery. Experimental plot was organized by conducting four ploughings as cross ploughings to fragment clods to achieve soil leveling. The plot has been cleared of weeds and left overs from earlier crops. 35-day-old chilli seedlings had been carted into main

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field, which was 5 × 4 m and spaced 60 × 60 cm apart. Seeds for the border crop of maize and intercrops like cluster beans were sown, along with fifteen-day-old Agathi seedlings during chilli transplanting, following specific row proportions between main crop and intercrops. Management practices had been carried out according to the recommended guidelines from Tamil Nadu Agricultural University Horticultural Crops Production Guide (Coimbatore and Department of Agriculture, 2020), except for the plant protection measures against the target pest, thrips complexes. In Modules 1 and 2, blue sticky traps were set at 50/ha, which are placed 30-60 cm above ground level to catch adult thrips.

Thrips complex of chilli crops found are, *Scirtothrips dorsalis* and *Thrips parvispinus*. The populations of adults and nymphs of thrips complex, had been recorded. For this, 5 chilli plants were randomly chosen and tagged in each plot. Thrips counts were taken from top, middle, along bottom leaves and expressed as a number of thrips per leaf until the population exceeded ETL of 5 thrips per leaf at 30 and 60 Days After Transplanting (DAT). In all treatments, insecticide spraying was based on this ETL. The first spray of fipronil 5 SC at 800 ml/ha was done at 30 DAT, followed by a second spray of thiacloprid 21.70 SC at 55 DAT, with a 25-day interval for Modules 1 and 2. For Module3, acephate 75 SP at 2 g/l of water was used for two sprays. Insecticides were sprayed employing a knapsack sprayer fitted with a hollow cone nozzle, at a volume of 500 l/ha. The target pest was chilli thrips complex. To evaluate the effectiveness of the different agro-chemicals, thrips populations were recorded one day before each spraying as a pre-treatment count (PTC), and again 3, 7, and 14 days after spraying. These data were examined and analyzed using ANOVA after necessary transformations for comparison of treatment means (Gomez and Gomez, 1984). Ten plants were chosen randomly in each plot and scored visually for Leaf Curl Index (LCI) at 70 and 100 DAT following a 0-4 scale (Niles,1980), 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/plants showing curling, heavy damage, malformation of growing points, reduction in plant height; and 4 = more than 75% leaves/plant showing curling severe to complete destruction of growing point, drastic reduction in plant height, defoliation, severe malformation.

Population distribution of natural enemies included both nymphs and adults of chrysopids, coccinellid beetles, as well as spiders. Five randomly chosen plants from each treatment were visually observed to document these predators. Population densities of natural enemies had been noted based on the counts of coccinellids, spiders, and chrysopids per plant. For this, 5 plants were randomly tagged in each plot and observed at 60 and 90 DAT. In this field experiment, the percentage reduction compared to the control, green chilli yield, and BC ratio was also calculated. The following formula was used to determine the decrease in thrips population compared to untreated control (Henderson and Tilton, 1955):

$$\text{Per cent reduction of abundance over control} = \frac{\text{Abundance in control plot} - \text{Abundance in treated plot}}{\text{Abundance of control plot}} \times 100$$

The first harvesting was done at 90 DAT, with subsequent plucking occurring every 5-7 days. The fruit yield from each plot was recorded separately, and the total yield for each treatment was calculated by adding the yields from successive plucking. This total yield per plot was then converted to kilograms per hectare. Percentage increase in yield for each treatment relative to control was determined using a specified formula. Increase in yield over control in various treatments had been evaluated by employing following formula:

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$$\text{Increase of Yield (per cent)} = \frac{\text{Yield of the treated plot} - \text{Yield of Control plot}}{\text{Yield of Control plot}} \times 100$$

To compare yield performance of chilli across different treatments, ANOVA was conducted using STAR IRRI package developed by International Rice Research Institute in Philippines. Critical Difference (CD) at a 5% level of significance and P-values had been utilized to assess variations among treatment means.

The information collected was economically analyzed using conventional methodologies established by CIMMYT, Mexico. Partial budgeting was conducted for each therapy to ascertain the incurred expenses and net returns. The analysis utilized current market pricing of inputs to compute the partial budget for various treatment combinations. An analysis of BC ratios was conducted to identify the most cost-effective treatment. The investigation involved assessing various cultivation expenses and returns from fruit output for each treatment, standardized to one hectare of land.

Results and discussion

Population of thrips and leaf curl index in chilli plantations

Intercropping cluster beans with the chilli crop resulted in the lowest thrips population (7.43 thrips per leaf), followed by intercropping with Agathi (9.46 thrips per leaf) (*Table 1*). Seven days after spraying, IPM Module 1 recorded 3.37 thrips per leaf, while IPM Module 2 showed 4.29 thrips per leaf. In contrast, the farmer's practice had a higher count of 8.44 thrips per leaf, whereas, untreated check recorded 9.32 thrips per leaf. On day 14 after spraying, IPM Module 1 recorded 4.03 thrips per leaf, and Module 2 had 4.87 thrips per leaf (*Fig. 1*). The average of these observations indicated that IPM Module 1 had 3.704 thrips per leaf, followed by Module 2 with 4.585 thrips per leaf. IPM Module 1 demonstrated a 60.61% reduction in thrips compared to farmer practices (*Fig. 2*). After the second spraying, all treatments showed significantly lower thrips populations than the control.

Table 1. *Impact of IPM modules on thrips population*

IPM modules	I Spraying-thrips population (numbers/leaf)				Per cent reduction over farmers practices	II Spraying-thrips population (numbers/leaf)				Per cent reduction over farmers practices
	PTC	7 DAS	14 DAS	Mean		PTC	7 DAS	14 DAS	Mean	
Module:1	7.434 (2.904)	3.379 (2.092)	4.030 (2.243)	3.704 (2.168)	60.61	9.434 (3.230)	2.329 (1.824)	3.466 (2.113)	2.898 (3.937)	67.46
Module:2	9.462 (3.234)	4.297 (2.302)	4.873 (2.423)	4.585 (2.363)	51.24	11.462 (3.530)	3.301 (2.074)	4.873 (2.423)	4.087 (4.497)	54.10
Module:3	12.506 (3.675)	8.447 (3.074)	10.360 (3.370)	9.404 (3.222)	-	15.506 (4.063)	8.447 (3.074)	9.363 (3.219)	8.905 (3.147)	-
Module:4	13.179 (3.765)	9.320 (3.212)	11.484 (3.533)	10.402 (3.373)	-	16.521 (4.186)	9.450 (3.232)	12.450 (3.667)	10.95 (3.449)	-
SE (d)	0.005	0.025	0.026	0.0255	-	0.015	0.03	0.021	0.0255	-
CD (0.05)	0.002	0.008	0.009	0.0085	-	0.005	0.01	0.007	0.0085	-
SE (m)	0.002	0.012	0.012	0.0120	-	0.007	0.014	0.01	0.0120	-
C.V.	0.132	0.813	0.788	0.8005	-	0.355	1.023	0.643	0.8330	-

Figures in parenthesis are square root transformation; PTC- Pre-treatment count; DAS-days after spraying

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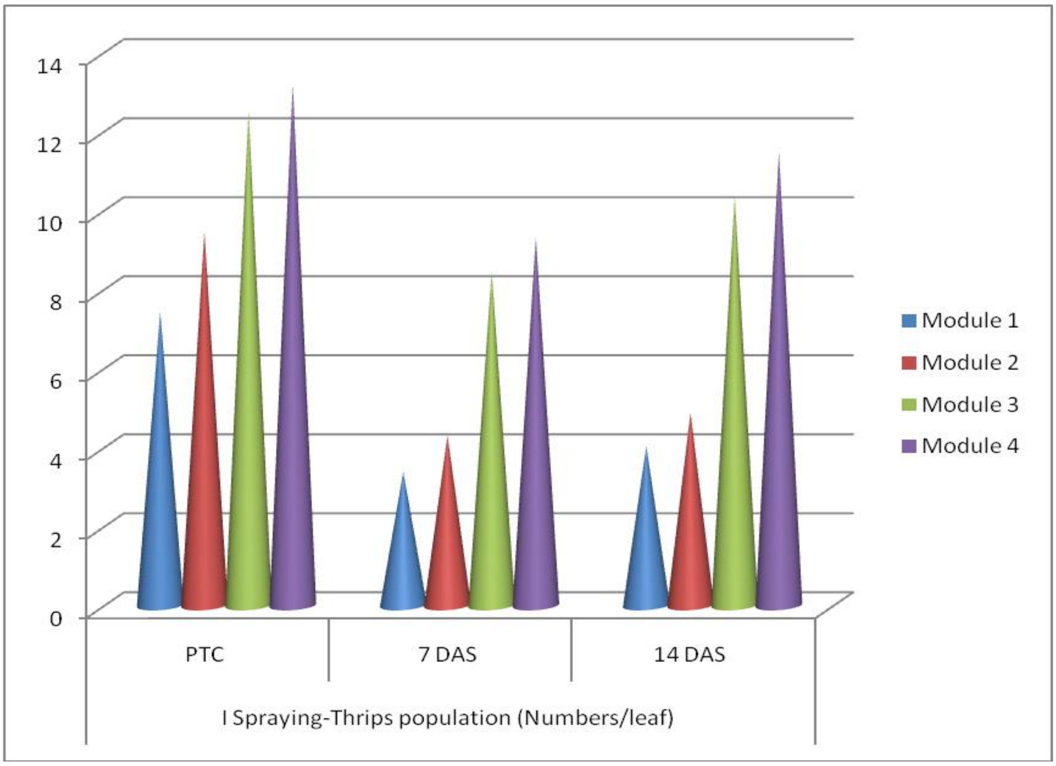

***Figure 1.** Impact of IPM modules on thrips population. I Spraying - thrips population (numbers/leaf)*

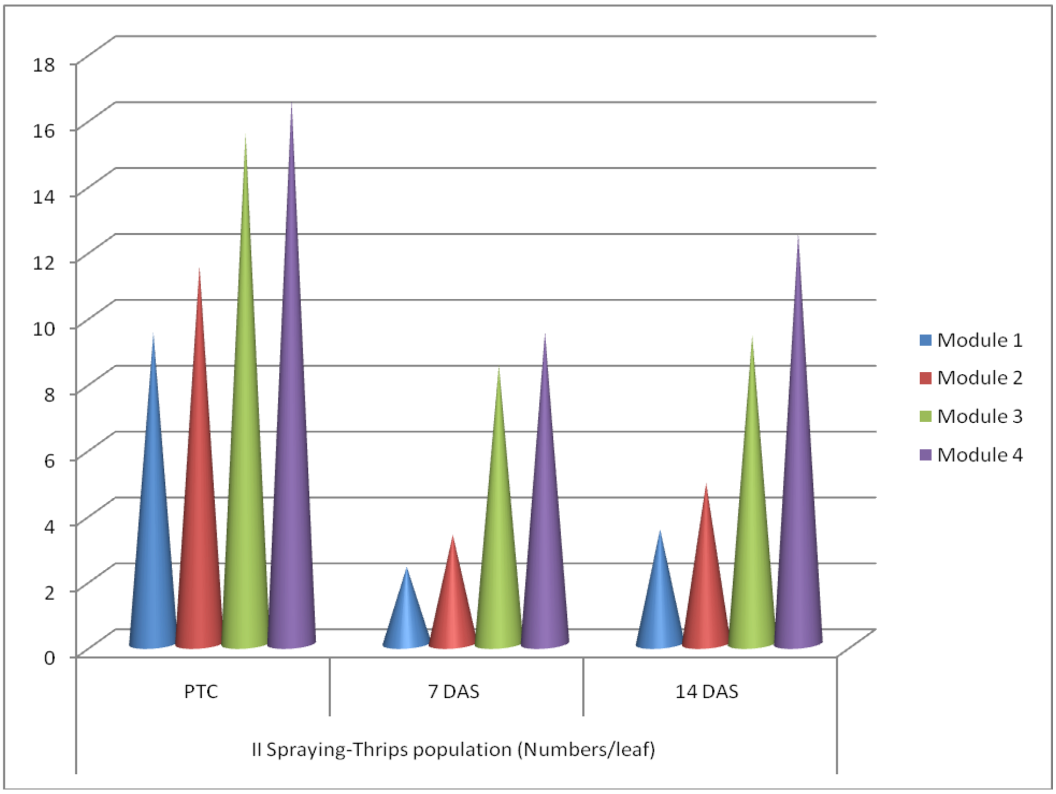

***Figure 2.** Impact of IPM modules on thrips population. II Spraying - thrips population (numbers/leaf)*

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Results also indicated in *Table 2*, that lowest LCI (1.15) was observed in Module 1, which included closely spaced rows of maize and intercropping cluster beans at a 6:1 ratio, resulting in a reduction of leaf curl by 59.75%. This was statistically aligned with Module2, which had a LCI of 1.85 with maize and Agathi intercropped at a 10:1 ratio. All treatments performed significantly better than Module3 (farmer's practice), and Module4 (untreated check), which had the highest LCI of 2.86 and 3.19. Based on LCI, the treatments were ranked in the following order: Module 1, Module 2, Module 3, and Module 4 (untreated check) (*Fig. 3*).

Table 2. *Leaf curl index and economics of different IPM modules in chilli*

IPM modules	Leaf curl index	Per cent reduction of leaf curl index over farmers practice	Yield (kg/ha)	Increase of yield over farmer's practice	BC ratio
Module:1	1.15 (1.466)	59.75	14395.714 (119.986)	53.15	2.51
Module:2	1.85 (1.688)	35.25	12361.429 (111.186)	31.50	2.15
Module:3	2.86 (1.964)	-	9400.000 (96.958)	-	1.65
Module: 4	3.19 (2.048)	-	8858.571 (94.125)	-	1.26
C.D.	0.009	-	0.342	-	-
SE (m)	0.003	-	0.114	-	-
SE (d)	0.004	-	0.162	-	-
C.V.	0.435	-	0.287	-	-

Figures in parenthesis are square root transformation

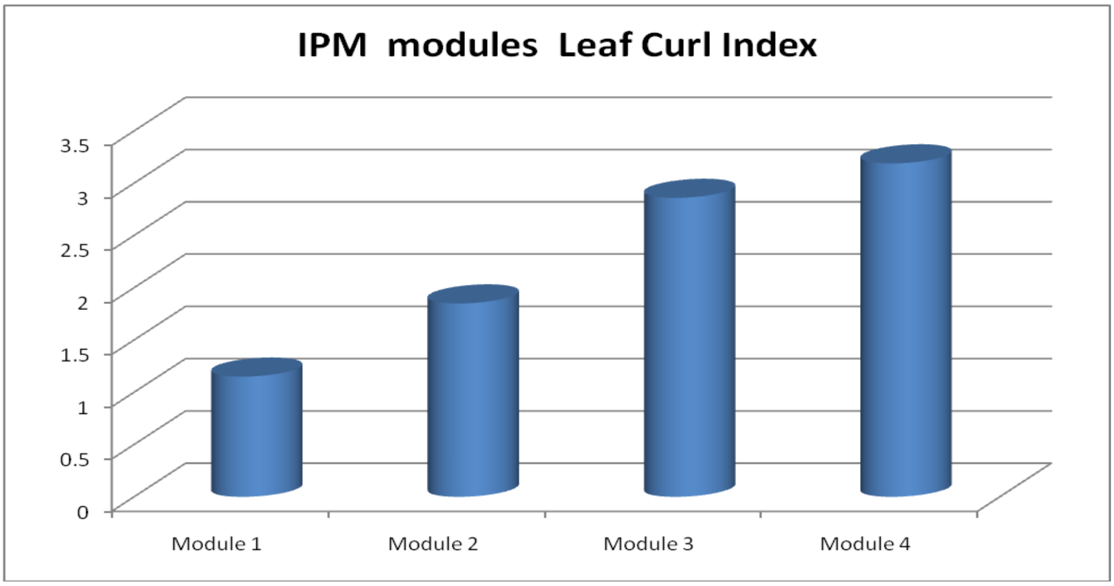

Figure 3. *Leaf curl index of different IPM modules in chilli*

Population of natural enemies in chilli plantations

Concepts of border cropping and intercropping align well with the ecological approach to habitat manipulation in agroecosystems for pest management. Diverse techniques can modify habitat within an IPM framework. This study involved

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cultivating several intercrops to attract beneficial insects and shield target crops from pests. This approach helps prevent pests from reaching main crop or concentrates them in specific areas where they can be effectively managed (Dutta et al., 2014). Among the intercrops, cluster beans showed a significantly lower thrips population compared to other crops alongside the border crop of maize. This may be due to the pests preferring cluster beans as a food source or oviposition site, reducing their presence in main crop and concentrating them in intercrop.

Similar trends were also reported in tomatoes with marigold as a trap crop which reduced larval population of tomato fruit borer by 81–89% (Hussain and Bilal, 2007). Grain sorghum has proven effective as a trap crop for corn earworm in cotton (Tillman and Mullinix, 2004). Push-pull strategy in cotton demonstrated that *H. armigera* developed resistance to insecticides but was reduced under trap cropping systems, preferring other minor crops (Duraimurugan and Regupathy, 2005). Trap cropping can significantly lower losses in the primary crop from pests, as seen with corn, beans, sunflowers, pigeon peas, and cowpeas (Clifton and Duphily, 2006). Coccinellid population varied from 2.63-3.74 coccinellids per plant. The highest count of 3.74 coccinellids/plant was found in Module 1, followed by Module 2 with 3.14 coccinellids/plant, while the lowest was 2.85 coccinellids/plant in the farmer's practice and 2.64 coccinellids/plant in the untreated check (*Table 3*). The increase in coccinellid population over the farmer's practice was highest in Module 1, which included closely spaced rows of maize and intercropping with cluster beans at a 6:1 ratio, showing an increase of 31.17%. Module 2, with maize and intercropping of agathi at a 10:1 ratio, showed a 10.21% increase. These results indicate that intercropping with various crops plays an important function in preserving and augmenting the number of coccinellids in chilli cultivation.

Table 3. *Natural enemies of different IPM modules against thrips damage in chilli*

IPM modules	Population (numbers/plant)			Per cent increase of natural enemies population over farmer's practice		
	Coccinellids	Spiders	Chrysopids	Coccinellids	Spiders	Chrysopids
Module: 1	3.74 (2.176)	5.25 (2.499)	2.47 (1.862)	31.17	66.59	106.79
Module: 2	3.14 (2.035)	4.34 (2.312)	1.99 (1.728)	10.21	37.95	66.55
Module: 3	2.85 (1.962)	3.15 (2.037)	1.19 (1.481)	-	-	-
Module: 4	2.64 (1.907)	2.95 (1.987)	1.04 (1.428)	-	-	-
C.D.	0.014	0.006	0.011	-	-	-
SE (m)	0.005	0.002	0.004	-	-	-
SE (d)	0.007	0.003	0.005	-	-	-
C.V.	0.631	0.259	0.59	-	-	-

Figures in parenthesis are square root transformation

Spider population varied between 2.95 and 5.25 spiders per plant. The highest count of 5.25 spiders/plant was found in treatment Module 1, followed by Module 2 with 4.34 spiders/plant. Lowest number of spiders (3.15 spiders/plant) was observed in the

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farmer’s practice and was 2.95 spiders/plant in the untreated check. The increase in spider population over the farmer’s practice was greatest in Module 1, which included a border crop of closely spaced three rows of maize and intercropping with cluster beans at a 6:1 ratio, showing an increase of 66.59%. Module 2, which also had maize as the border crop and intercropped with agathi at a 10:1 ratio, showed a 37.95% increase. These results indicate that intercropping with different crops significantly helps conserve and enhance the population of spiders in chilli cultivation.

A similar trend was observed for chrysopids. The chrysopid population varied between 1.04 and 2.47 chrysopids per plant. The highest count of 2.47 chrysopids/plant was seen in Module 1, followed by Module 2 with 1.99 chrysopids/plant. The minimum count of chrysopids (1.19 chrysopids per plant) was seen in the farmer’s practice, whereas the untreated control exhibited 1.04 chrysopids per plant. The increase in chrysopid population over the farmer’s practice was highest in Module 1, with a 106.79% increase, and in Module 2, which showed a 66.55% increase. Overall, these results demonstrate that intercropping with various crops and the border cropping of maize play an essential function in preserving and augmenting coccinellid populations and other beneficial insects, thus contributing to ecological pest management.

Effect of different intercrops on yield and economics of Chilli

Table 2 illustrates impact of various intercrops on the production and economic viability of chilli. The maximum production of green chillies was recorded in IPM module 1, yielding 14,395.714 kg/ha, succeeded by IPM module 2 with 12,361.429 kg/ha. In contrast, the farmer’s practice yielded only 9,400.00 kg/ha followed by 8858.571 kg/ha in untreated check. Highest BC ratio of 2.51 was observed in IPM module 1, while IPM module 2 had a BC ratio of 2.15, compared to 1.65 in the farmer’s practice and 1.26 in the untreated check. Based on these results, IPM module 1 is recommended for effectively managing chilli thrips. Studies (Blaser et al., 2007; Hossain et al., 2021; Singh et al., 2023) have shown that trap cropping systems provide benefits such as erosion control, reduced nutrient leaching, better labor distribution, and higher economic returns, making them a more eco-friendly pest management option than sole cropping.

This study tackles key challenges like pesticide resistance, residue contamination, and environmental harm by minimizing reliance on chemical pesticides. The IPM strategy integrates ecological methods such as intercropping, trap cropping, and selective pesticide use, reducing chemical dependency while ensuring compliance with export standards and safeguarding human health and the environment.

Ecological mechanisms in IPM strategies

Intercropping with cluster beans and border cropping with maize reduce thrips populations through:

1. Host disruption: Mixed cropping confuses pests, making it harder to locate chillies.
2. Trap cropping: Cluster beans and maize attract thrips away from chillies.
3. Enhanced predator habitat: Diversified cropping supports predators like spiders and coccinellids.
4. Push-pull effect: Repellent and attractive crops work together to control pests naturally.

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Potential limitations of IPM strategies

1. Scalability: Labor-intensive practices may challenge large-scale adoption.
2. Regional applicability: Effectiveness may vary across agro-climatic zones.
3. Economic viability: Initial investments may deter resource-poor farmers.
4. Pest spillover: Trap crops could unintentionally spread pests if not managed carefully.
5. Crop compatibility: The approach requires further testing for other crops.

These strategies balance ecological benefits and practicality, offering a sustainable solution to chilli pest management.

Conclusion

The findings of this study underscore the ecological and economic advantages of adopting integrated pest management (IPM) strategies for chilli cultivation. IPM module 1, which included intercropping with cluster beans and border cropping with maize, proved to be the most effective in managing thrips populations, enhancing natural predator abundance, and achieving the highest green chilli yield and benefit-cost ratio (2.51). These results validate the hypothesis that incorporating ecological strategies such as intercropping and trap cropping into pest management can reduce pest pressure, promote predator conservation, and improve crop productivity and profitability. The study highlights the potential of cluster beans as a viable intercrop, offering agronomic benefits such as nitrogen fixation and improved soil health, while simultaneously reducing thrips populations. This approach also supports biodiversity by creating a favorable environment for natural predators like spiders, coccinellids and chrysopids, reducing the need for chemical insecticides. From a practical perspective, adopting IPM module 1 offers farmers a sustainable and cost-effective alternative to pesticide-dependent practices, addressing key concerns such as pesticide residues, pest resistance, and environmental degradation. The integration of ecological pest management strategies into chilli cultivation not only ensures higher yields and economic returns but also contributes to long-term sustainability and export-quality production. Future research should focus on refining these IPM modules for broader applicability across different agro-climatic regions, exploring additional intercrop combinations, and assessing their long-term impacts on agroecosystem health. By promoting such ecologically sound pest management practices, this study lays the foundation for a more resilient and sustainable chilli production system.

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