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EVALUATION OF DIFFERENT IPM MODULES AGAINST MAJOR INSECT PESTS OF CHILLI

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ABSTRACT

A field experiment was conducted during rabi seasons of 2024–25 and 2025–26 at Acharya N.G. Ranga Agricultural University (ANGRAU) - Agricultural Research Station, Rekulakunta, Ananthapuramu, Andhra Pradesh, to evaluate the efficacy of different Integrated Pest Management (IPM) modules against major insect pests of chilli (*Capsicum annuum* L.). The experiment was laid out in Randomized Block Design (RBD) with four IPM modules *viz.*, M1 (IIVR module), M2 (Dr. YSRHU module), M3 (IIHR module) and M4 (Farmers' practice) replicated five times. Observations were recorded on thrips population, incidence of *Spodoptera litura*, *Helicoverpa armigera*, gall midge damage, viral diseases (leaf curl and bud necrosis) and yield.

The results revealed that M3 (IIHR module) was most effective in reducing pest incidence and improving yield during both seasons. The lowest mean thrips population was recorded in M3 with 12.77 and 15.24 thrips/terminal leaves during 2024–25 and 2025–26, respectively, compared to farmers' practice (24.73 and 26.64 thrips/terminal leaves). The lowest mean larval population of *Spodoptera litura* was recorded in M3 (0.132 and 0.266 larvae/plant) and *Helicoverpa armigera* (0.502 and 0.76 larvae/plant) during both seasons. Gall midge damage was minimum in M3 with 2.33 and 1.66 deformed fruits/plant. Viral disease incidence was also lower in IPM modules, with minimum leaf curl incidence in M3 (7.74 and 2.53%) and bud necrosis incidence (0.66 and 0.23%) compared to farmers' practice.

Yield data indicated that M3 recorded the highest total yield of 6138 kg ha^{-1} (2024–25) and 9716 kg ha^{-1} (2025–26), whereas farmers' practice recorded the lowest yield (5137 and 7199 kg ha^{-1}). Among the evaluated IPM modules, M3 (IIHR module) recorded the highest gross returns, net returns and C:B ratio during both rabi seasons. It recorded a C:B ratio of 1:1.06 and 1:1.75 during 2024–25 and 2025–26, respectively. Overall, the IIHR module proved superior by effectively managing major insect pests and viral diseases and enhancing yield of chilli under Ananthapuramu conditions.

Key words : Chilli, IPM modules, Thrips, *Spodoptera litura*, *Helicoverpa armigera*, Gall midge, Viral diseases, Yield.

Introduction

Among the major insect pests infesting chilli, thrips (*Scirtothrips dorsalis*), whiteflies (*Bemisia tabaci*), mites, *Spodoptera litura* and *Helicoverpa armigera* are of significant importance as they cause direct damage by feeding and indirect damage by transmitting viral diseases such as leaf curl and bud necrosis (Reddy and Puttaswamy, 1985; Seal *et al*., 2006). Thrips damage the crop by rasping and sucking plant sap, resulting in leaf curling, distortion and reduced photosynthetic activity (Kumar *et al*., 2011). Similarly, *Spodoptera litura* and *Helicoverpa armigera* cause severe defoliation and fruit

damage, leading to considerable yield losses (Fand *et al*., 2015). In addition, whiteflies act as vectors for leaf curl virus, which is one of the most devastating diseases in chilli, drastically reducing both yield and quality (Varma and Malathi, 2003).

Farmers predominantly rely on indiscriminate and repeated application of chemical insecticides for pest management. Although chemical control provides quick results, its continuous and unscientific use has led to several problems such as development of insecticide resistance, pest resurgence, destruction of natural enemies, pesticide residues in produce and environmental contamination (Kranthi, 2015). These challenges necessitate the adoption of eco-friendly and sustainable pest management strategies.

Integrated Pest Management (IPM) has emerged as a viable approach that combines cultural, biological, mechanical and chemical methods in a compatible manner to manage pest populations below economic threshold levels while minimizing environmental hazards (Pedigo and Rice, 2009). The use of bio-control agents such as *Lecanicillium lecanii* and *Metarhizium anisopliae*, botanicals like neem-based products, trap crops, barrier crops and need-based application of selective insecticides plays a crucial role in reducing pest incidence and preserving natural enemies (Saxena, 1989; IIHR, 2020).

Several research institutes such as IIVR, IIHR and State Agricultural Universities, including Dr. YSR Horticultural University, have developed various IPM modules for chilli cultivation. These IPM modules under field conditions is essential to identify the most efficient, sustainable and economically viable strategy for managing major insect pests of chilli (Anonymous, 2023).

Keeping this in view, the present investigation was undertaken to evaluate different IPM modules against major insect pests of chilli during rabi seasons of 2024–25 and 2025–26, with the objective to evaluate the IPM module that can reduce pest incidence, minimize viral diseases and enhance yield under field conditions.

Materials and Methods

Experimental details

A field experiment was conducted on chilli (*Capsicum annuum* L.) variety LCA 643 during the *rabi* season of 2024–25 and 2025–26 at the Acharya N.G. Ranga Agricultural University (ANGRAU), Agricultural Research Station, Rekulakunta, Ananthapuramu. The experiment was laid out in a Randomized Block Design (RBD) with four treatments (IPM modules) and five replications. Each experimental plot measured 100 m².

Treatment details (IPM modules)

Module 1 (M1: IIVR module)

The module consisted of seedling dip with imidacloprid 17.8% SL @ 1 ml L^{-1} of water followed by sequential sprays of buprofezin 25% SC @ 1 ml L^{-1} at 25 days after transplanting (DAT), fipronil 5% SC @ 2 ml L^{-1} at 35 DAT, *Lecanicillium lecanii* (1×10^8 CFU g^{-1}) @ 5 g L^{-1} at 45 DAT, chlorfenapyr 10% SC @ 1.5 ml L^{-1} at 55 DAT and neem oil (10000 ppm) @ 2 ml L^{-1} at 65 DAT, followed by subsequent rotation of insecticides.

Module 2 (M2: Dr. YSRHU module)

This module included application of neem cake @ 200 kg $acre^{-1}$ during final land preparation and seedling root dip with imidacloprid 600 FS @ 0.3 ml L^{-1} at transplanting. Soil application of fipronil 0.3% granules @ 20 kg ha^{-1} was done at 15 and 45 days after planting. Barrier crops (2–3 rows of sorghum/maize) were raised around the main crop, and trap crops such as castor and marigold were grown within the field. Neem-based formulations (azadirachtin 10000 ppm @ 3 ml L^{-1} or NSKE 5%) were sprayed as deterrents. Yellow, blue and white sticky traps @ 20 $acre^{-1}$ and pheromone traps @ 4 $acre^{-1}$ were installed. Need-based application of recommended insecticides (fipronil, diafenthiuron, chlorfenapyr and spiromesifen) was followed for sucking pests, while chlorantraniliprole or emamectin benzoate was applied against lepidopteran pests.

Module 3 (M3: IIHR module)

The module involved drip irrigation and mulching with 25–30-micron polyethylene film. Soil drenching with *Lecanicillium lecanii* (1×10^8 CFU g^{-1}) was carried out. Sticky traps (yellow, blue and white) @ 20 $acre^{-1}$ were installed. Foliar application of *Metarhizium anisopliae* (1×10^8 CFU g^{-1}) @ 5 g L^{-1} and initial sprays of NSKE 5% and pongamia oil 1% were undertaken. This was followed by need-based sprays of spinosad 45% SC @ 0.3 ml L^{-1}, imidacloprid 17.8% SL @ 0.5 ml L^{-1}, fipronil 5% SC @ 2 ml L^{-1}, fluxametamide 10% EC @ 0.8 ml L^{-1} and broflanilide 20% SC @ 0.25 ml L^{-1}, along with pongamia oil (3–4 ml L^{-1}) as a synergist.

Module 4 (M4: Farmers' practice)

The farmer's practice consisted of indiscriminate application of insecticide mixtures such as chlorpyrifos + cypermethrin, ethion + cypermethrin, fipronil, diafenthiuron and synthetic pyrethroids etc., at different crop stages based on farmer preference.

Recording of observations

For recording pest incidence, five spots of 1 m² area were selected randomly in each plot. From each plot,

five plants were randomly selected for detailed observations.

Thrips and mites populations were recorded from three leaves (top, middle and bottom canopy) per plant, and the number of insects per cm² leaf area was counted. The observations were taken at regular intervals (30, 60, 90, 120 and 150 DAT).

The larval population of *Spodoptera litura* and *Helicoverpa armigera* was recorded as number of larvae per plant from the selected plants.

The incidence of gall midge was assessed based on the number of deformed fruits per plant at 120 DAT.

For viral diseases, the number of infected plants showing symptoms of leaf curl and bud necrosis was recorded at the end of the crop season and expressed as percentage.

Thrips glued to sticky traps were counted from 25 square grids using a hand-held magnifying lens of 10× magnification. Observations were taken every fifteen days, weekly intervals after installation (DAI) upto 35 DAI. Coccinellids glued to sticky traps were counted from 25 square grids.

Yield and economic analysis

Yield data were recorded from each plot at different harvests and expressed as kg ha^{-1}. Total yield was computed by summing the yields of all harvests. The cost of cultivation and returns obtained from each treatment were used to calculate the benefit–cost ratio.

Statistical analysis

The data obtained from the experiment were subjected to statistical analysis appropriate for Randomized Block Design (RBD). Treatment means were compared using standard error of mean (SEm) and critical difference (CD) at 5 per cent level of significance.

Results and Discussion

Thrips population under different IPM modules

The population of thrips varied significantly among the IPM modules during both rabi seasons of 2024–25 and 2025–26 (Table 1). During 2024–25, the lowest mean thrips population was recorded in M3 (IIHR module) (12.77 thrips/terminal leaves), followed by M2 (Dr. YSRHU module) (15.32 thrips/terminal leaves) and M1 (IIVR module) (17.01 thrips/terminal leaves). The highest mean thrips population was observed in M4 (Farmers' practice) (24.73 thrips/terminal leaves). Peak thrips incidence was noticed during January and February, where farmers' practice recorded maximum population (41.36 and 38.66 thrips/terminal leaves, respectively). Similarly,

Table 1 : Incidence of Black thrips on chilli under different IPM modules during *rabi* season, 2024–25 and 2025–26.

Modules	Thrips population per terminal leaves											
	2024-25						2025-26					
	November 30 DAT)	December (60 DAT)	January (90 DAT)	February (120 DAT)	March (150 DAT)	Mean	November 30 DAT)	December (60 DAT)	January (90 DAT)	February (120 DAT)	March (150 DAT)	Mean
M1 (IIVR module)	12.33	12.25	24.33	22.66	13.45	17.01	10.6	11.33	27	25.66	14.25	17.76
M2 (Dr. YSRHU module)	6.66	14.33	23.66	25.33	6.65	15.32	5.33	11.66	26.33	28.66	6.35	15.66
M3 (IIHR module)	5.0	12.23	22.66	18.66	5.33	12.77	7	13.66	28	21.33	6.23	15.24
M4 (Farmers practice)	7.89	17.33	41.36	38.66	18.45	24.73	6.66	18	45.66	42.66	20.22	26.64
SEm ±	0.12	0.14	0.18	0.17	0.13		0.10	0.12	0.16	0.17	0.14	
CD (P=0.05)	0.37	0.44	0.56	0.52	0.41		0.32	0.38	0.50	0.52	0.42	
CV%	2.64	1.89	1.21	1.16	2.18		2.81	1.92	0.89	0.96	1.84	
F test	Sig	Sig	Sig	Sig	Sig		Sig	Sig	Sig	Sig	Sig	

Values are mean of five replications.

during 2025–26, the overall mean thrips population was lowest in M3 (IIHR module) (15.24 thrips/terminal leaves), closely followed by M2 (Dr. YSRHU module) (15.66 thrips/terminal leaves) and M1 (IIVR module) (17.76 thrips/terminal leaves). Farmers' practice recorded the highest thrips population (26.64 thrips/terminal leaves). The highest thrips incidence was observed during January and February, with farmers' practice recording 45.66 and 42.66 thrips/terminal leaves, respectively. The reduced thrips incidence in IIHR and Dr. YSRHU modules might be due to integration of sticky traps, botanicals, bioagents and need-based selective insecticides, which effectively suppressed pest multiplication and maintained population below economic threshold levels. Similar findings were reported by Kumar *et al*. (2011) and Seal *et al*. (2006), who observed significant reduction in thrips population under IPM modules in chilli.

Incidence of *Spodoptera litura* under different IPM modules

The larval population of *Spodoptera litura* differed among modules during both seasons (Table 2). During 2024–25, the lowest mean larval population was recorded in M3 (IIHR module) (0.132 larvae/plant), followed by M2 (Dr. YSRHU module) (0.198 larvae/plant) and M1 (IIVR module) (0.264 larvae/plant). Farmers' practice recorded the highest larval population (1.128 larvae/plant). Higher infestation was noticed during November and December, which gradually declined during later crop stages. During 2025–26, the lowest mean larval population was recorded in M3 (IIHR module) (0.266 larvae/plant), followed by M2 (Dr. YSRHU module) (0.332 larvae/plant) and M1 (IIVR module) (0.398 larvae/plant). Farmers' practice recorded maximum larval population (1.328 larvae/plant). The effective suppression of *Spodoptera litura* in IIHR module might be attributed to the combined effect of entomopathogenic fungi, botanicals and need-based application of selective insecticides such as spinosad and broflanilide. These results are in accordance with Fand *et al*. (2015), who reported that integrated approaches significantly reduced *Spodoptera* infestation in chilli.

Incidence of *Helicoverpa armigera* under different IPM modules

The larval population of *Helicoverpa armigera* showed clear variation among modules during both seasons (Table 3). During 2024–25, the lowest mean larval population was recorded in M3 (IIHR module) (0.502 larvae/plant), followed by M1 (IIVR module) (0.834 larvae/plant) and M2 (Dr. YSRHU module) (0.932 larvae/plant). Farmers' practice recorded the highest larval

Table 2 : Incidence of *Spodoptera litura* larvae on chilli under different IPM modules during *rabi* season, 2024–25 and 2025–26.

Modules	*Spodoptera litura* larvae per plant											
	2024-25						2025-26					
	November 30 DAT)	December (60 DAT)	January (90 DAT)	February (120 DAT)	March (150 DAT)	Mean	November 30 DAT)	December (60 DAT)	January (90 DAT)	February (120 DAT)	March (150 DAT)	Mean
M1 (IIVR module)	0.66	0.33	0.33	0.00	0.00	0.264	1	0.66	0.33	0	0	0.398
M2 (Dr. YSRHU module)	0.33	0.66	0.00	0.00	0.00	0.198	0.33	1.0	0.33	0	0	0.332
M3 (IIHR module)	0.00	0.66	0.00	0.00	0.00	0.132	0	1.33	0	0	0	0.266
M4 (Farmers practice)	1.33	2.65	1.00	0.33	0.33	1.128	1.66	2.66	1.33	0.66	0.33	1.328
SEm ±	0.03	0.05	0.03	0.02	0.02		0.04	0.05	0.03	0.04	0.02	
CD (P=0.05)	0.10	0.15	0.09	0.06	0.06		0.12	0.16	0.09	0.12	0.06	
CV%	6.84	4.21	6.12	7.33	7.33		5.62	3.94	6.21	5.85	7.10	
F test	Sig	Sig	Sig	Sig	Sig		Sig	Sig	Sig	Sig	Sig	

Values are mean of five replications.

Table 3 : Incidence of *Helicoverpa armigera* larvae on chilli under different IPM modules during *rabi* season, 2024–25 and 2025–26.

Modules	*Helicoverpa armigera* larvae per plant										
	2024-25						2025-26				
	November 30 DAT)	December (60 DAT)	January (90 DAT)	February (120 DAT)	March (150 DAT)	Mean	November 30 DAT)	December (60 DAT)	January (90 DAT)	February (120 DAT)	March (150 DAT)	Mean
M1 (IIVR module)	0.33	1.00	1.66	0.65	0.53	0.834	0.33	1.33	2.00	1.00	0.33	1.00
M2 (Dr. YSRHU module)	0.00	1.33	2.00	1.00	0.33	0.932	0.33	1.66	2.33	1.33	0.66	0.26
M3 (IIHR module)	0.00	0.23	1.33	0.62	0.33	0.502	0.00	1.00	1.66	0.66	0.33	0.76
M4 (Farmers practice)	0.66	2.00	3.00	1.72	0.66	1.608	0.66	2.33	3.66	2.00	1.00	1.93
SEm ±	0.02	0.04	0.05	0.04	0.03		0.02	0.04	0.05	0.04	0.03	
CD (P=0.05)	0.06	0.13	0.16	0.12	0.09		0.06	0.13	0.16	0.12	0.09	
CV%	8.40	4.92	3.85	5.21	6.18		8.18	4.61	3.56	4.84	5.94	
F test	Sig	Sig	Sig	Sig	Sig		Sig	Sig	Sig	Sig	Sig	

Values are mean of fivereplications.

population (1.608 larvae/plant). The peak infestation was observed during January and February, where farmers' practice recorded maximum larval population (3.00 and 1.72 larvae/plant, respectively). During 2025–26, the lowest mean larval population was recorded in M3 (IIHR module) (0.76 larvae/plant), followed by M1 (IIVR module) (1.00 larvae/plant). Farmers' practice recorded the highest mean population (1.93 larvae/plant). The reduction in larval population under IIHR module might be due to integration of botanicals and timely application of selective insecticides such as spinosad, fluxametamide and broflanilide, which act as feeding deterrents and effectively suppress fruit borer establishment. Similar results were reported by Pedigo and Rice (2009) and Fand *et al*. (2015), emphasizing the importance of IPM practices in reducing *Helicoverpa* incidence.

Gall midge incidence (Deformed fruits per plant)

Gall midge infestation expressed as percent fruit damage at 120 DAT showed significant variation among the IPM modules (Table 4). During 2024–25, the lowest fruit damage was recorded in M3 (IIHR module) (3.52%), followed by M2 (Dr. YSRHU module) (8.53%) and M1 (IIVR module) (9.56%). The highest gall midge damage was observed in M4 (Farmers' practice) (10.23%). During 2025–26, M3 again recorded the lowest damage (4.86%), followed by M2 (6.95%) and M1 (7.30%), while maximum damage was recorded in farmers' practice (8.37%). The lower gall midge incidence under IIHR module might be due to the combined effect of cultural practices, bioagents and botanicals, which helped in reducing pest buildup. Similar findings were reported by Kiran Ghatage *et al*. (2022), who observed that adoption of an IPM module comprising organic amendments and botanical applications followed by need-based chemical spray significantly reduced gall midge incidence by 46.46 per cent over untreated control. The same module also resulted in higher dry chilli yield (7.19 q ha^{-1}) compared to untreated control (4.20 q ha^{-1}), indicating the effectiveness of integrated approaches in minimizing gall midge damage and improving productivity.

Leaf curl viral disease incidence

The incidence of leaf curl viral disease differed among modules in both seasons (Table 5). During 2024–25, the lowest leaf curl incidence was recorded in M3 (IIHR module) (7.74%), followed by M2 (Dr. YSRHU module) (11.69%) and M1 (IIVR module) (14.15%). Farmers' practice recorded the highest leaf curl incidence (18.66%). During 2025–26, the lowest leaf curl incidence was recorded in M3 (2.53%), followed by M2 (2.78%) and M1 (2.83%), while farmers' practice recorded the

Table 4 : Effect of different IPM modules on gall midge infestation in chilli during rabi season, 2024–25 and 2025–26.

Modules	Percent fruit damage due to gall midge in chilli (120 DAT)	
	2024-25	2025-26
M1 (IIVR module)	9.56	7.30
M2 (Dr. YSRHU module)	8.53	6.95
M3 (IIHR module)	3.52	4.86
M4 (Farmers practice)	10.23	8.37

Values are mean of five replication.

Table 5 : Effect of different IPM modules on incidence of leaf curl viral disease in chilli during *rabi* 2024–25 and 2025–26.

Modules	Per cent of Leaf curl viral disease infested plants (100 sq.mts plot)	Per cent of Leaf curl viral disease infested plants (100 sq.mts plot)
	2024-25	2025-26
M1 (IIVR module)	14.15	2.83
M2 (Dr. YSRHU module)	11.69	2.78
M3 (IIHR module)	7.74	2.53
M4 (Farmers practice)	18.66	4.146

Values are mean of three replications.

Table 6 : Effect of different IPM modules on incidence of bud necrosis viral disease in chilli during rabi 2024–25 and 2025–26.

Modules	Per cent of bud necrosis viral disease infested plants	
	2024-25	2025-26
M1 (IIVR module)	2.53	0.66
M2 (Dr. YSRHU module)	1.33	0.66
M3 (IIHR module)	0.66	0.23
M4 (Farmers practice)	3.23	1.52

Values are mean of five replications.

highest incidence (4.146%). The reduced incidence of leaf curl viral disease in IPM modules could be attributed to better management of whitefly vector populations through use of sticky traps, botanicals and need-based selective insecticide applications. These findings are in line with Varma and Malathi (2003), who reported that effective vector control plays a crucial role in reducing leaf curl disease in chilli.

Bud necrosis viral disease incidence

Bud necrosis viral disease incidence was comparatively lower in IPM modules compared to farmers' practice during both seasons (Table 6). During 2024–25, the lowest incidence was recorded in M3 (IIHR module) (0.66%), followed by M2 (1.33%) and M1 (2.53%). Farmers' practice recorded the highest bud necrosis incidence (3.23%). During 2025–26, the lowest bud necrosis incidence was recorded in M3 (0.23%), followed by M1 (0.66%) and M2 (0.66%), while farmers' practice recorded the highest incidence (1.52%). The reduced bud necrosis incidence under IPM modules might be due to effective suppression of thrips vector population through integration of botanicals, bioagents and selective insecticides. Similar findings were reported by Seal et al. (2006), who observed that IPM modules significantly reduced thrips-transmitted viral diseases in chilli.

Thrips population attracted to different coloured sticky traps

The pooled data on the number of thrips attracted to different coloured sticky traps during rabi 2024–25 and 2025–26 are presented in Table 7. Significant differences were observed among the different coloured sticky traps in attracting thrips at all the observations from 7 to 35 days after installation (DAI).

The yellow sticky traps recorded the lowest mean number of thrips throughout the observation period, with 2.34, 2.84, 2.92, 3.02 and 3.52 thrips per square inch at 7, 14, 21, 28 and 35 DAI, respectively, with an overall mean of 2.93 thrips per square inch. The white sticky traps recorded intermediate thrips catches of 3.22, 4.48, 5.32, 5.64 and 6.26 thrips per square inch, with a mean of 4.98 thrips per square inch.

In contrast, the blue sticky traps recorded the highest thrips catches at all observation intervals, with 4.25, 6.80, 5.42, 6.48 and 7.01 thrips per square inch at 7, 14, 21, 28 and 35 DAI, respectively, with an overall mean of 5.99 thrips per square inch. Thus, among the three colours tested, blue traps attracted the maximum number of thrips, followed by white, whereas yellow traps recorded the lowest thrips population.

Coccinellid population attracted to different coloured sticky traps

The pooled data on the number of coccinellids attracted to different coloured sticky traps in the IPM module plots during *rabi* 2024–25 and 2025–26 are presented in Table 8. The number of coccinellids captured on the sticky traps showed a gradual increasing trend from 7 to 35 days after installation (DAI).

The white sticky traps recorded the highest mean coccinellid population, with 0.95, 1.11, 1.23, 1.36 and 1.48 coccinellids per square inch at 7, 14, 21, 28 and 35 DAI,

Table 7 : Pooled data of Thrips population glued on sticky traps in IPM module plots during *rabi* 2024–25 and 2025–26.

Sticky traps	Mean no. of thrips per square inch area of trap					
	7 DAI	14 DAI	21 DAI	28 DAI	35 DAI	Mean
Blue	4.25	6.80	5.42	6.48	7.01	**5.992**
White	3.22	4.48	5.32	5.64	6.26	**4.984**
Yellow	2.34	2.84	2.92	3.02	3.52	**2.928**
CV %	8.12	9.24	8.76	8.94	9.48	
F- test	Sig	Sig	Sig	Sig	Sig	

Values are mean of five replications.

Table 8 : Pooled data of coccinellids population glued on sticky traps in IPM module plots during *rabi* 2024–25 and 2025–26.

Sticky traps	Mean no.of coccinellids per square inch area of trap					
	7 DAI	14 DAI	21 DAI	28 DAI	35 DAI	Mean
Blue	0.68	0.79	0.87	0.96	1.04	**0.868**
White	0.95	1.11	1.23	1.36	1.48	**1.226**
Yellow	0.73	0.81	0.89	0.97	1.01	**0.882**
CV %	14.82	16.95	18.24	13.76	11.58	
F- test	NS	NS	Sig	Sig	Sig	

Values are mean of five replications.

respectively, with an overall mean of 1.226 coccinellids per square inch. The yellow sticky traps recorded 0.73, 0.81, 0.89, 0.97 and 1.01 coccinellids per square inch, with a mean of 0.882, while blue traps recorded the lowest values of 0.68, 0.79, 0.87, 0.96 and 1.04, with an overall mean of 0.868 coccinellids per square inch.

The differences among trap colours were non-significant at 7 and 14 DAI, whereas significant differences were observed at 21, 28 and 35 DAI. Overall, white sticky traps attracted comparatively more coccinellids than blue and yellow traps, indicating greater attraction of coccinellids towards white traps under the experimental conditions. The coefficient of variation ranged from 11.58 to 18.24 per cent across the observation periods.

Yield performance of chilli under different IPM modules

The yield data recorded during both rabi seasons showed considerable variation among the evaluated IPM modules (Table 7). During 2024–25, the highest total yield was recorded in M3 (IIHR module) (6138 kg ha^{-1}), followed by M2 (Dr. YSRHU module) (5986 kg ha^{-1}) and M1 (IIVR module) (5929 kg ha^{-1}) and. The lowest yield was recorded in M4 (Farmers' practice) (5137 kg ha^{-1}).

Similarly, during 2025–26, the highest total yield was again recorded in M3 (IIHR module) (9716 kg ha^{-1}), followed by M2 (8121 kg ha^{-1}) and M1 (7579 kg ha^{-1}). Farmers' practice recorded the lowest yield (7199 kg ha^{-1}).

The higher yield obtained under IIHR module might be attributed to effective suppression of sucking pests and fruit borers, along with reduced viral disease incidence. Further, the use of mulching and drip irrigation might have contributed to improved crop growth and yield.

The findings of the present study are also in accordance with the report of Md. Jewel Alam *et al*. (2022), who observed that an IPM module integrating botanical sprays (neem leaf extract), continuous use of pheromone traps, yellow sticky traps, removal of infested plant parts and need-based application of imidacloprid resulted in effective reduction of pest population and produced higher yield (8.42 t ha^{-1}) along with improved growth parameters. Their study further emphasized that IPM modules are not only effective in pest reduction but also contribute to improved yield attributes and profitability through reduced pest damage.

Cost economics of different IPM modules against major insect pests of chilli

The cost economics of the different IPM modules evaluated against major insect pests of chilli during rabi 2024–25 and 2025–26 are presented in Table 10. Considerable variation was observed among the modules with respect to cost of cultivation, gross returns, net returns and C ratio.

During 2024–25, the cost of cultivation ranged from ` 2,76,519 ha$^{-1}$ in M1 (IIVR module) to ` 2,80,100 ha^{-1} in M4 (farmer's practice). The highest gross returns of ` 2,94,624 ha$^{-1}$ were recorded in M3 (IIHR module), followed by M2 (Dr. YSRHU module) with ` 2,87,328 ha^{-1} and M1 (IIVR module) with ` 2,84,592 ha$^{-1}$. The lowest gross returns were recorded in M4 (farmer's practice) at ` 2,46,576 ha^{-1}. Similarly, the highest net returns were obtained in M3 (` 17,145 ha$^{-1}$), followed by M2 (` 8,978 ha^{-1}) and M1 (` 8,073 ha$^{-1}$), whereas M4 recorded a negative net return of ` 33,524 ha^{-1}. The C ratio was highest in M3 (1:1.06), followed by M2 (1:1.03) and M1 (1:1.02), while M4 recorded the lowest C ratio (1:0.88).

During 2025–26, the cost of cultivation ranged from ` 2,77,479 ha$^{-1}$ in M3 (IIHR module) to ` 2,80,100 ha^{-1} in M4 (farmer's practice). The highest gross returns were recorded in M3 (` 5,05,232 ha$^{-1}$), followed by M2 (`

Table 9 : Yield performance of chilli under different IPM modules during *rabi* 2024–25 and 2025–26.

Modules	First Harvest - Yield (Kgs/ha)		Second Harvest - Yield (Kgs/ha)		Third Harvest - Yield (Kgs/ha)		Total Yield (Kgs/ha)	
	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26	2024-25	2025-26
M1 (IIVR module)	1906	2598	2093	2751	1930	2230	5929	7579
M2 (Dr. YSRHU module)	2087	2565	1903	3291	1996	2265	5986	8121
M3 (IIHR module)	2033	3573	2063	3523	2042	2620	6138	9716
M4 (Farmers practice)	1812	2335	1713	2744	1612	2120	5137	7199

Values are mean of five replications.

Table 10 : Cost economics particulars.

Modules	Yield (kg ha^{-1}) 2024–25	Yield (kg ha^{-1}) 2025–26	Cost of cultivation (` ha^{-1}) 2024-25	Cost of cultivation (` ha^{-1}) 2025-26	Gross returns (` ha^{-1}) 2024–25	Gross returns (` ha^{-1}) 2025–26	Net returns (` ha^{-1}) 2024–25	Net returns (` ha^{-1}) 2025–26	C:B ratio 2024–25	C:B ratio 2025–26
M1	5929	7579	276519	285479	284592	394108	8073	108629	1:1.02	1:1.38
M2	5986	8121	278350	287045	287328	422292	8978	135247	1:1.03	1:1.47
M3	6138	9716	277479	287469	294624	505232	17145	217763	1:1.06	1:1.75
M4	5137	7199	280100	302548	246576	374348	-33524	71800	1:0.88	1:1.23

4,22,292 ha^{-1}), M1 (` 3,94,108 ha$^{-1}$) and M4 (` 3,74,348 ha^{-1}). Correspondingly, the highest net returns were obtained in M3 (` 2,17,763 ha$^{-1}$), followed by M2 (` 1,35,247 ha^{-1}), M1 (` 1,08,629 ha$^{-1}$) and M4 (` 71,800 ha^{-1}). The C ratio was also highest in M3 (1:1.75), followed by M2 (1:1.47), M1 (1:1.38) and M4 (1:1.23).

Overall, M3 (IIHR module) consistently recorded the highest gross returns, net returns and C ratio during both seasons, indicating its superior economic performance. The economic advantage of M3 was particularly pronounced during 2025–26, when it recorded a yield of 9716 kg ha^{-1}, gross returns of ` 5,05,232 ha$^{-1}$ and net returns of ` 2,17,763 ha^{-1}. Thus, among the evaluated IPM modules, M3 (IIHR module) was found to be the most economically viable module, followed by M2 (Dr. YSRHU module) and M1 (IIVR module), whereas farmer's practice (M4) recorded the lowest economic performance, particularly during 2024–25.

Overall performance of IPM modules

Among all the evaluated modules, M3 (IIHR module) was found to be superior by recording minimum thrips population, lowest incidence of *Spodoptera litura* and *Helicoverpa armigera*, reduced gall midge damage, minimum viral disease incidence and highest yield during both seasons. This was followed by M2 (Dr. YSRHU module) and M1 (IIVR module). Farmers' practice consistently recorded higher pest population, disease incidence and lower yield, indicating the disadvantages of indiscriminate pesticide use such as pest resurgence and resistance development. Similar observations were reported by Kranthi (2015).

Thus, the IIHR module proved to be the most effective and sustainable IPM strategy for chilli cultivation under field conditions of Ananthapuramu district.

Conclusion

The present investigation conducted during the *Rabi* seasons of 2024–25 and 2025–26 at ANGRAU–Agricultural Research Station, Rekulakunta, Ananthapuramu, revealed that the tested IPM modules significantly influenced pest incidence, viral disease occurrence and yield of chilli. Among the four evaluated modules, M3 (IIHR module) was found to be the most effective and superior module in managing major insect pests. It recorded the lowest thrips population (12.77 and 15.24 thrips/terminal leaves during 2024–25 and 2025–26, respectively), minimum infestation of *Spodoptera litura* (0.132 and 0.266 larvae/plant) and *Helicoverpa armigera* (0.502 and 0.76 larvae/plant), along with reduced gall midge damage.

Further, the IIHR module also registered the lowest incidence of leaf curl viral disease (7.74% and 2.53%) and bud necrosis viral disease (0.66% and 0.23%) compared to farmers' practice. Yield performance was also highest in the IIHR module, with 6138 kg ha^{-1} during 2024–25 and 9716 kg ha^{-1} during 2025–26, indicating the effectiveness of integrating mulching, drip irrigation,

bioagents, botanicals, sticky traps and need-based selective insecticides.

The IIHR module (M3) also recorded the highest gross returns, net returns and C ratio in both seasons, demonstrating its superior economic viability. Farmers' practice (M4) consistently recorded higher pest population, greater disease incidence and comparatively lower yield and economic returns, highlighting the limitations of conventional indiscriminate pesticide-based pest management.

Thus, the study concludes that the IIHR IPM module (M3) is an effective, economically viable, eco-friendly and sustainable pest management strategy for chilli cultivation under the agro-climatic conditions of Ananthapuramu district. Its adoption can help farmers achieve effective pest and viral disease suppression, higher productivity and improved economic returns, while promoting safer and more sustainable chilli production.

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