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RESEARCH ARTICLE

Field evaluation of bio-rational and integrated pest management strategies against *Helicoverpa armigera* Hübner in tomato

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Abstract

A field experiment was conducted at Krishi Vigyan Kendra, Moga, Punjab to evaluate the efficacy of biorational and integrated pest management strategies against *Helicoverpa armigera* Hübner infesting tomato (*Solanum lycopersicum* L.). The experiment was laid out in a randomized block design (RBD) with seven treatments and three replications. The treatments included chemical insecticides chlorantraniliprole 18.5 SC (Coragen), flubendiamide 39.35 SC (Fame), and spinosad 48 SC (Tracer), biological agents *Bacillus thuringiensis* (Delfin WG), a homemade neem extract and an integrated approach comprising sequential applications of spinosad and *B. thuringiensis* along with pheromone mass trapping. Larval populations were recorded before treatment and at 3, 7, 10 and 14 days after each spray. Among all treatments, chlorantraniliprole 18.5 SC @ 0.5 mL L^{-1} proved most effective, recording 96.26% reduction in larval population at 14 days after the second spray. Spinosad 48 SC @ 0.3 mL L^{-1} and flubendiamide 39.35 SC @ 0.3 mL L^{-1} were the next most effective treatments, achieving 93.05 and 89.30% reduction, respectively. *B. thuringiensis* and homemade neem extract provided moderate suppression, whereas the integrated approach resulted in 76.99% reduction at 14 days after the second spray. The results indicate that chlorantraniliprole and spinosad offer effective management of *H. armigera* and can be integrated with biological and mechanical tactics as part of a sustainable pest management strategy for tomato cultivation.

Keywords: Chlorantraniliprole, integrated pest management, biopesticides, larval suppression, sustainable pest management

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Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops cultivated worldwide owing to its high nutritional value, commercial importance and year-round demand. It is a rich source of vitamins, minerals, organic acids and antioxidants, particularly lycopene, which contributes significantly to human health (Arora et al., 2012). In India, tomato is cultivated over approximately 8.4 lakh hectares with an annual production of about 213 lakh tonnes, making it one of the leading vegetable crops in the country (NHB, 2023-24). Punjab possesses favorable agro-climatic conditions for tomato cultivation under both open-field and protected cultivation systems. However, the productivity and quality of tomato are severely constrained by several insect pests, among which the tomato fruit borer, *Helicoverpa armigera* (Hübner), is considered one of the most destructive. *H. armigera* causes substantial economic losses by feeding on flowers and boring into developing fruits, rendering them unmarketable. Yield losses ranging from 22 to 38% have been reported depending on crop stage, pest pressure and environmental conditions (Dhandapani et al., 2003). The pest exhibits a wide host range, high reproductive potential, facultative diapause and remarkable migratory ability, making its management particularly challenging (Fitt, 1989). Besides *H. armigera*, other economically important insect pests affecting tomato include *Bemisia tabaci* (whitefly), *Amrasca devastans* (jassid), *Myzus persicae* (aphid), *Liriomyza trifolii* (leaf miner) and *Epilachna vigintioctopunctata* (hadda beetle) (Cohic, 1958; Pandey et al., 2015).

Management of *H. armigera* has traditionally relied on repeated applications of chemical insecticides. Although chemical control provides rapid suppression of pest populations, indiscriminate and prolonged use has led to several concerns, including pesticide residues in fruits, environmental contamination, destruction of natural enemies and development of insecticide resistance (Kumari et al., 2010). *H. armigera* has developed resistance to numerous insecticide groups worldwide, highlighting the need for alternative and sustainable management strategies (IRAC, 2023). Among the newer insecticides, chlorantraniliprole and flubendiamide have gained importance because of their high efficacy against lepidopteran larvae through activation of insect ryanodine receptors, resulting in feeding cessation and mortality. Spinosad, a fermentation-derived insecticide, has been widely adopted in integrated pest management (IPM) programs due to its effectiveness against caterpillar pests and comparatively lower impact on beneficial arthropods. In contrast, microbial insecticides such as *Bacillus thuringiensis* (Bt) and botanical products derived from neem (*Azadirachta indica*) are considered environmentally safer alternatives because of their selective toxicity, biodegradability and compatibility with biological control agents. Neem-based products possess antifeedant, repellent, growth-regulating, and oviposition-deterrent properties, whereas Bt acts through ingestion and is particularly effective against early larval instars (Isman, 2006; Wink, 1993). Recent field studies have also reported strong performance of diamide insecticides and spinosyns in reducing *H. armigera* incidence under vegetable production systems (Sarkar et al., 2024; Devi et al., 2024).

Although several studies have independently evaluated chemical insecticides, microbial biopesticides and botanical products against *H. armigera*, comparative field-based assessments integrating these management options under the agro-climatic conditions of Punjab remain limited. Furthermore, information on the relative performance of newer diamide insecticides, biopesticides and their integration with pheromone-based management approaches is inadequate under local production systems. Therefore, the present investigation was undertaken to evaluate and compare selected chemical, biological, botanical and integrated management approaches for the suppression of *H. armigera* in tomato under field conditions. The study aims to generate location-specific information that can contribute to the development of effective, environmentally sound and resistance-management-based strategies for sustainable tomato production.

Materials and Methods

The present field investigation was conducted at the Krishi Vigyan Kendra, Moga, Punjab during the Rabi season of 2021-22 to evaluate the efficacy of biorational insecticides against *H. armigera* infesting tomato. The experimental site is located in the trans-gangetic plains region and experiences a semi-arid climate characterized by hot summers and cool winters. The soil of the experimental field was sandy loam in texture, neutral in reaction, and well-drained, providing favorable conditions for tomato cultivation. The tomato variety Punjab Ratta, known for its susceptibility to *H. armigera*, was selected for the study. Seeds were sown in a nursery during October 2021, and 30-day-old healthy seedlings were transplanted on 15 November 2021 at a spacing of 60 × 45 cm between rows and plants, respectively. Standard agronomic practices recommended for tomato cultivation by Punjab Agricultural University were followed throughout the crop season, except for plant protection measures, which were imposed according to the experimental treatments. The experiment was laid out in a randomized block design (RBD) comprising seven treatments with three replications. Each experimental plot measured 3 × 3 m and accommodated 25 plants. The treatments evaluated are presented in Table 1.

The insecticidal sprays were initiated at the onset of flowering and repeated at 14-day intervals using a manually operated knapsack sprayer. A spray volume of approximately 250 L ha^{-1} was maintained to ensure uniform coverage. For recording observations, ten plants were randomly selected from each plot and tagged. These plants were observed throughout the experiment and larval counts of *H. armigera* were recorded by examining all plant parts including leaves, flowers and developing fruits. The recorded counts from ten plants were averaged and expressed on a per plant basis. The larval population was recorded before each spray and at 3, 7, 10 and 14 days after spraying.

Corrected Percent Reduction (Henderson–Tilton, 1955)

PROC = (Ta/Tb)×(Cb/Ca)−1×100

Where;

T = treatment population

C = control population

a = after treatment

b = before treatment

Statistical analysis

Before statistical analysis, larval population data were subjected to appropriate transformation to stabilize variance and normalize distribution. The count data

Table 1: Treatments evaluated against *Helicoverpa armigera* in tomato during field experiments

Treatment	*Treatment description*	*Application rate (mL/ ha)*
1	Coragen (Chlorantraniliprole 18.5% SC) @ 0.5 mL/L	125
2	Fame (Flubendiamide 39.35% SC) @ 0.3 mL/L	75
3	Tracer (Spinosad 48% SC) @ 0.3 mL/L	75
4	*Bacillus thuringiensis* (Delfin WG) @ 4 g/L	1000
5	Homemade neem extract (HMNE) @12 mL/L	3000
6	Sequential spray of tracer (Spinosad) @ 0.3 mL/L + Bt @ 4 g/L along with pheromone mass trapping	25 traps/ha + foliar sprays as per dose
7	Untreated control	—

were transformed using square root transformation √(x + 0.5). The transformed values were used for statistical analysis, while the original (untransformed) means were used for presentation and biological interpretation. The experimental data were statistically analyzed using analysis of variance (ANOVA) appropriate for randomized block design (RBD). Treatment means were compared using critical difference (CD) at 5% level of significance. For seven treatments and three replications, the degrees of freedom were 6 for treatments, 2 for replications, and 12 for error. Statistical analysis was performed using OPSTAT software developed by CCS Haryana Agricultural University, Hisar.

Results and Discussion

The study evaluated the efficacy of different insecticidal and integrated management treatments against *H. armigera* larvae after two consecutive sprays, with observations recorded at 3, 7, 10 and 14 days after spraying (DAS). Overall, a consistent decline in larval population was observed in all treated plots compared to the untreated control.

The efficacy of different insecticidal treatments was evaluated based on mean larval population per plant and percent reduction over control (PROC) at 3, 7, 10 and 14 days after spraying (DAS) (Table 2). Prior to application, the larval population ranged from 1.37 to 1.43 larvae plant^{-1}, indicating a statistically uniform initial infestation across all treatments. At 3 DAS, a significant reduction in larval population was observed in all treated plots compared to the untreated control. The lowest larval population was recorded in integrated management (1.00 larvae plant^{-1}), followed by Coragen @ 0.5 mL L^{-1} (1.03 larvae plant^{-1}), with corresponding PROC values of 28.57 and 26.43%, respectively. At 7 DAS, a further decline in larval population was recorded in all treated plots, with Coragen @ 0.5 mL L^{-1} exhibiting the lowest infestation level (0.87 larvae plant^{-1}) and the highest PROC (42.00%). At 10 DAS, the treatments continued to exhibit differential efficacy. Coragen @ 0.5 mL L^{-1} recorded the lowest larval population (0.77 larvae plant^{-1}) and the highest PROC (51.08%), and was statistically at par with Tracer (0.90 larvae plant^{-1}; 42.68% PROC). Fame and Bt (0.97 larvae plant^{-1} each; 38.85% PROC) formed a statistically homogeneous group. Neem extract (1.13 larvae plant^{-1}; 27.71% PROC) and Integrated Management (1.23 larvae plant^{-1}; 21.66% PROC) were significantly inferior to the synthetic insecticides and were statistically at par with each other. The untreated control exhibited the highest infestation (1.57 larvae plant^{-1}). At 14 DAS, treatment effects became more pronounced and statistically distinct. Coragen @ 0.5 mL L^{-1} achieved the lowest larval population (0.60 larvae plant^{-1}) and the highest PROC (64.07%), and was significantly superior to all other treatments based on transformed mean comparisons. Fame and Tracer (0.77 larvae plant^{-1} each; 53.89% PROC)

Table 2: Mean larval population of *H. armigera* per plant under different treatments after first spray

Treatment	*Before spray*	*3 DAS*	*PROC*	*7 DAS*	*PROC*	*10 DAS*	*PROC*	*14 DAS*	*PROC*
Coragen @ 0.5 mL/L	1.37 (1.54)	1.03 (1.43^{c})	26.43	0.87 (1.37^{c})	42.00	0.77 (1.33^{c})	51.08	0.60 (1.26^{d})	64.07
Fame @ 0.3 mL/L	1.40 (1.55)	1.13 (1.46^{bc})	19.29	0.97 (1.40^{bc})	35.33	0.97 (1.40^{b})	38.85	0.77 (1.33^{c})	53.89
Tracer @ 0.3 mL/L	1.40 (1.55)	1.17 (1.47^{b})	16.43	1.03 (1.43^{b})	31.33	0.90 (1.38^{bc})	42.68	0.77 (1.33^{c})	53.89
Bt (Delfin-WG) @ 4 g/L	1.40 (1.55)	1.20 (1.48^{b})	14.29	1.00 (1.41^{bc})	33.33	0.97 (1.40^{b})	38.85	0.93 (1.39^{b})	44.31
Neem extract @ 12 mL/L	1.43 (1.56)	1.37 (1.54^{a})	2.14	1.20 (1.48^{a})	20.00	1.13 (1.46^{a})	27.71	1.07 (1.44^{a})	35.93
Integrated management	1.40 (1.55)	1.00 (1.41^{c})	28.57	1.17 (1.47^{ab})	22.00	1.23 (1.49^{a})	21.66	1.10 (1.45^{a})	34.13
Control	1.37 (1.54)	1.40 (1.55^{a})	0.00	1.50 (1.58^{d})	0.00	1.57 (1.60^{d})	0.00	1.67 (1.63^{e})	0.00
N/A	0.057		0.055		0.058		0.050		

Figures in parantheses are √(x + 0.5) transformed values; Percent reduction over control (PROC) was calculated using the Henderson-Tilton formula were statistically at par and constituted the second most effective treatment group. *Bt* (0.93 larvae plant^{-1}; 44.31% PROC) exhibited moderate efficacy. Neem extract (1.07 larvae plant^{-1}; 35.93% PROC) and integrated management (1.10 larvae plant^{-1}; 34.13% PROC) were statistically at par and demonstrated comparatively lower efficacy. The untreated control maintained the highest larval population (1.67 larvae plant^{-1}) with no suppression.

The efficacy of different treatments was evaluated during the second spray phase (14 days after first spray) based on mean larval population per plant and percent reduction over control (PROC) (Table 3). Prior to the second spray, the larval population ranged from 0.60 to 1.10 larvae plant^{-1} in treated plots, whereas the untreated control recorded 1.67 larvae plant^{-1}, indicating a uniform reinfestation and differential residual activity of previously applied treatments. At 3 DAS after the second spray, all treatments resulted in a reduction in larval population compared to the untreated control. The lowest population was recorded in Coragen @ 0.5 mL L^{-1} (0.56 larvae plant^{-1}), followed by Integrated Management and Neem extract (0.93 larvae plant^{-1} each). Correspondingly, Coragen recorded the highest suppression (66.47% PROC), while integrated management and neem extract recorded 44.31% PROC each. At 7 DAS, a further decline in larval population was observed across all treatments. Coragen remained the most effective treatment with the lowest larval population (0.43 larvae plant^{-1}) and highest PROC (75.14%). However, statistical comparison (CD = 0.038) indicated that Coragen was at par with Fame, Tracer, and Bt, suggesting no significant differences among these treatments despite numerical variation. Integrated management and neem extract recorded comparatively higher larval populations and lower PROC values, indicating reduced efficacy. At 10 DAS, Coragen continued to exhibit superior performance with the lowest larval population (0.23 larvae plant^{-1}) and highest PROC (87.01%). Tracer (0.33 larvae plant^{-1}; 81.36% PROC) and Fame (0.43 larvae plant^{-1}; 75.71% PROC) also showed high effectiveness and were statistically comparable with Coragen based on transformed data (CD = 0.047). Bt and neem extract showed moderate suppression, while integrated management recorded intermediate efficacy. At 14 DAS, maximum suppression of larval population was recorded. Coragen @ 0.5 mL L^{-1} recorded the lowest larval population (0.07 larvae plant^{-1}) with the highest reduction over control (96.26%), indicating excellent residual and knockdown effect. Tracer (0.13 larvae plant^{-1}; 93.05% PROC) and Fame (0.20 larvae plant^{-1}; 89.30% PROC) were highly effective and statistically at par. Bt recorded moderate efficacy (74.87% PROC), whereas neem extract (66.31% PROC) and integrated management (76.99% PROC) showed comparatively lower suppression. The untreated control consistently recorded the highest larval population (1.87 larvae plant^{-1}) throughout the observation period with no reduction.

The present findings revealed significant variation among treatments in their ability to suppress *H. armigera* populations in tomato. Chlorantraniliprole (Coragen @ 0.5 mL L^{-1}) emerged as the most effective treatment, recording the lowest larval population and highest reduction over control in both spray cycles. Its superior performance is primarily attributed to its novel mode of action on ryanodine receptors, which disrupts calcium homeostasis in muscle cells, resulting in rapid cessation of feeding and eventual larval death. The present results are in close agreement with earlier reports by Ambule et al. (2015), Abbas et al. (2015), Lalhluzuala & Kumar (2022) and Vinothkumar & Muralitharan (2024) who also documented chlorantraniliprole as highly effective against *H. armigera*, leading to significant reduction in larval incidence and fruit damage in tomato. Devi et al. (2024) further confirmed that chlorantraniliprole 18.5 SC was the most effective treatment under field conditions in Manipur, followed by Bt and botanical extracts, resulting in higher fruit yield and better pest suppression. Arya et al. (2026) reported that chlorantraniliprole 18.5 SC is the most

Table 3: Mean larval population of *H. armigera* per plant under different treatments after second spray

Treatment	*Before spray*	*3 DAS*	*PROC*	*7 DAS*	*PROC*	*10 DAS*	*PROC*	*14 DAS*	*PROC*
Coragen @ 0.5 mL/L	0.60 (1.26^{f})	0.56 (1.25^{e})	66.47	0.43 (1.20^{f})	75.14	0.23 (1.11^{f})	87.01	0.07 (1.03^{f})	96.26
Fame @ 0.3 mL/L	0.77 (1.33^{de})	0.67 (1.29^{d})	59.88	0.67 (1.29^{a})	61.27	0.43 (1.20^{e})	75.71	0.20 (1.10^{e})	89.30
Tracer @ 0.3 mL/L	0.77 (1.33^{de})	0.70 (1.30^{d})	58.08	0.60 (1.27^{b})	65.32	0.33 (1.16^{d})	81.36	0.13 (1.06^{d})	93.05
Bt (Delfin-WG) @ 4 g/L	0.93 (1.39^{c})	0.80 (1.34^{c})	52.10	0.73 (1.32^{c})	57.80	0.63 (1.28^{c})	64.41	0.47 (1.21^{c})	74.87
Neem extract @ 12 mL/L	1.07 (1.44^{b})	0.93 (1.39^{b})	44.31	0.87 (1.37^{d})	49.71	0.80 (1.34^{b})	54.80	0.63 (1.28^{b})	66.31
Integrated management	1.10 (1.45^{b})	0.93 (1.39^{b})	44.31	0.73 (1.32^{c})	57.80	0.53 (1.24^{cd})	69.94	0.43 (1.20^{c})	76.99
Control	1.67 (1.63^{a})	1.67 (1.63^{a})	0.00	1.73 (1.65^{a})	0.00	1.77 (1.66^{a})	0.00	1.87 (1.69^{a})	0.00
	0.050	0.064		0.038		0.047		0.052	

Figures in parantheses are $\sqrt{(x + 0.5)}$ transformed values
Percent reduction over control (PROC) was calculated using the Henderson-Tilton formula

effective treatment for managing *H. armigera* in tomato crops, achieving up to 68.24% control efficacy.

Spinosad 48% SC @ 0.3 mL L^{-1} ranked as the second most effective treatment and remained statistically comparable with chlorantraniliprole at several observation periods. Its efficacy can be attributed to its dual mode of action involving both contact and ingestion toxicity, leading to rapid nervous system disruption and paralysis in larvae. These results are consistent with earlier findings by Babar et al. (2016), Chowdhury et al. (2017) and Lalhluzuala & Kumar (2022), who reported spinosad as an effective alternative for managing *H. armigera* in tomato. Flubendiamide (Fame @ 0.3 ml L^{-1}) also exhibited strong and persistent control of larval population and ranked next in order of efficacy. The results corroborate the findings of Abbas et al. (2015) and Vinothkumar & Muralitharan (2024), who reported that flubendiamide provides effective suppression of *H. armigera* with prolonged residual activity and reduced fruit damage.

Among biological and botanical treatments, *B. thuringiensis* recorded moderate suppression of larval population. Although its efficacy was lower than chemical insecticides, it consistently reduced pest incidence compared to the control. Similar observations were reported by Sandhu (2013), and Omotoso et al. (2025), highlighting the importance of Bt as a key component of integrated pest management programs. Neem-based formulations such as neem oil and neem seed kernel extract (NSKE) have shown moderate but consistent suppression of *H. armigera* on tomato, primarily through antifeedant, oviposition-deterrent, and growth-regulatory effects rather than direct toxicity. Field evaluations in tomato have reported that neem products reduce larval population and fruit damage significantly compared with untreated control, although their efficacy is lower than synthetic insecticides (e.g., indoxacarb or spinosad) but suitable for inclusion in integrated pest management (IPM) programs (Jyothi & Tayde, 2022; Nagaveni & Kumar, 2022). The integrated management module showed moderate but progressive improvement in suppression of larval population, particularly after the second spray. This indicates the cumulative and synergistic effects of combining multiple control tactics such as biological agents, botanical extracts, and selective insecticides. Similar conclusions were drawn by Sandhu (2013), Khokhar & Rolania (2022) and Kharia et al. (2024) who reported that integrated approaches involving trap crops, parasitoids, neem-based formulations, Bt, and pheromone traps effectively reduce pest incidence while conserving natural enemies. Shah et al. (2017) also emphasized the role of pheromone traps in reducing adult and larval populations, strengthening the IPM framework. Overall, the present study highlights that while synthetic insecticides such as chlorantraniliprole, spinosad, and flubendiamide provide rapid and highly effective suppression of *H. armigera*, their judicious use within an integrated pest management system is essential for sustainable pest control and resistance management. Biological and botanical treatments, although slower in action, play a crucial role in reducing pesticide dependency and maintaining ecological balance in tomato agro-ecosystems.

Conclusion

The study conclusively demonstrates that all evaluated treatments significantly reduced *H. armigera* populations in tomato compared to the untreated control, with marked differences in efficacy among treatments. Chlorantraniliprole (Coragen @ 0.5 mL L^{-1}) was the most effective treatment, recording the lowest larval population and highest reduction over control. Spinosad 48% SC and flubendiamide (Fame @ 0.3 mL L^{-1}) also provided high levels of suppression, indicating their strong potential for inclusion in pest management and resistance-management programmes. Among the biological and botanical treatments, *B. thuringiensis* and neem extract provided moderate suppression of larval populations. Although their efficacy was lower than that of the synthetic insecticides, their environmental safety and compatibility with natural enemies make them valuable supplementary components of IPM programmes. The integrated management module also reduced pest incidence compared with the untreated control. So far, the specific contribution of individual module components could not be quantified. Further refinement and evaluation of the module may improve its field performance. Overall, the findings indicate that sustainable management of *H. armigera* in tomato can be achieved through the judicious use of highly effective insecticides such as chlorantraniliprole and spinosad, combined with biological and botanical interventions. Rotation of insecticides with different modes of action, together with the integration of IPM-compatible approaches, may help delay resistance development, reduce pesticide dependence, and promote long-term pest management sustainability.

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सारांश

वर्ष 2021-22 के रबी मौसम के दौरान कृषि विज्ञान केंद्र, मोगा में टमाटर (*Solanum lycopersicum* L.) पर *Helicoverpa armigera* (Hübner) के प्रबंधन हेतु जैव-तर्कसंगत कीटनाशकों एवं एकीकृत प्रबंधन दृष्टिकोण की प्रभावशीलता का मूल्यांकन करने के लिए एक क्षेत्रीय प्रयोग किया गया। यह प्रयोग यादृच्छिकीकृत ब्लॉक डिज़ाइन (RBD) में सात उपचारों तथा तीन पुनरावृत्तियों के साथ स्थापित किया गया। उपचारों में रासायनिक कीटनाशक कोराजेन (क्लोरान्ट्रानिलिप्रोल 18.5 SC), स्पिनोसैड 48 SC तथा फेम (फ्लूबेंडियामाइड 39.35 SC), जैविक एजेंट *Bacillus thuringiensis* (डेल्फिन WG), घर में तैयार नीम अर्क तथा स्पिनोसैड एवं *B. thuringiensis* के क्रमिक छिड़काव के साथ फेरोमोन मास ट्रैपिंग पर आधारित एक एकीकृत प्रबंधन दृष्टिकोण शामिल थे। परिणामों से स्पष्ट हुआ कि क्लोरान्ट्रानिलिप्रोल 18.5 SC @ 0.5 मि.ली. प्रति लीटर सबसे प्रभावी उपचार रहा, जिसने दूसरे छिड़काव के 14 दिन बाद लार्वा जनसंख्या में 96.26 प्रतिशत की कमी दर्ज की। इसके बाद स्पिनोसैड 48 SC तथा फ्लूबेंडियामाइड 39.35 SC ने क्रमशः 93.05 तथा 89.30 **प्रतिशत** कमी दर्ज कर उच्च प्रभावशीलता प्रदर्शित की। *B. thuringiensis* तथा घर में तैयार नीम अर्क ने क्रमशः 74.87 तथा 66.31 प्रतिशत का मध्यम स्तर का नियंत्रण प्रदान किया, जबकि एकीकृत प्रबंधन दृष्टिकोण ने दूसरे छिड़काव के 14 दिन बाद 76.99 प्रतिशत कमी दर्ज की। अध्ययन के निष्कर्ष दर्शाते हैं कि *H. armigera* के सतत प्रबंधन हेतु क्लोरान्ट्रानिलिप्रोल एवं स्पिनोसैड प्रभावी विकल्प हैं, जबकि जैविक एवं यांत्रिक उपाय रासायनिक कीटनाशकों पर निर्भरता कम करने तथा प्रतिरोध प्रबंधन को सुदृढ़ करने में पूरक भूमिका निभा सकते हैं।