International Journal of Environment, Agriculture and Biotechnology
Vol-11, Issue-4; Jul-Aug, 2026
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Evaluation of Eco-Friendly Integrated Pest Management Modules against Major Insect Pests of Sorghum (*Sorghum Bicolor* L.)

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Received: 30 May 2026; Received in revised form: 25 Jun 2026; Accepted: 01 Jul 2026; Available online: 08 Jul 2026

***Abstract*— *A field experiment was conducted during the kharif seasons of 2024 and 2025 at the Instructional Dairy Farm, Pantnagar, Uttarakhand, to evaluate the efficacy of eco-friendly integrated pest management (IPM) modules against the major insect pests of sorghum (Sorghum bicolor L.), namely shoot fly (Atherigona soccata Rondani), stem borer (Chilo partellus Swinhoe), and fall armyworm (Spodoptera frugiperda J.E. Smith). The study aimed to identify sustainable and environmentally safe alternatives to conventional chemical pesticides for effective pest management and enhanced fodder productivity. Thirteen treatments comprising botanical formulations (neem oil, Neemastra, Agniastra, Brahmastra, Dashparni Ark, Panchgavya), biological control agents (Trichogramma chilonis, Metarhizium anisopliae, Bacillus thuringiensis), cultural practices, and a chemical check were evaluated in a randomized block design with three replications. The observations on shoot fly eggs and deadhearts, stem borer damage, and fall armyworm whorl damage were recorded at different crop growth stages. The results showed that 3% neem oil was the most effective treatment during both the years, recording the minimum deadhearts (10.00%) by shootfly, minimum deadhearts by stem borer (10.00 and 16.67%) and least fall armyworm damage (13.33 and 16.67%). The yield data revealed significantly more fodder yield from neem oil-based treatment (544.79 and 557.71 q/ha) as compared to control during both the years respectively. The findings demonstrate the potential of neem-based botanical formulations as a key component of sustainable IPM strategies, offering effective pest suppression, enhanced fodder yield, and reduced reliance on synthetic insecticides for residue-free sorghum production.*

Keywords— **Agniastra, fall armyworm, neem oil, Pantnagar, sorghum.**

I. INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is one of the most important cereal and fodder crops cultivated in tropical and subtropical regions of the world (FAO, 2018). It serves as a major source of food, feed, fodder and industrial raw materials, particularly in semi-arid regions due to its remarkable adaptability to drought and low-input conditions (Ashok Kumar *et al*., 2011). In India, sorghum plays a significant role in sustaining livestock production systems through the provision of nutritious green fodder. However, the productivity of sorghum is considerably affected by several insect pests that attack the crop throughout its growth stages (Daware *et al*., 2012).

More than 150 insect species have been reported to infest sorghum, causing substantial quantitative and qualitative losses (Daware *et al.,* 2012). Among these, shoot fly, *Atherigona soccata* Rondani, stem borer, *Chilo partellus* Swinhoe and fall armyworm, *Spodoptera frugiperda* (J.E. Smith), are considered the most destructive pests of economic importance (Prasad *et al*., 2021; Okosun *et al*., 2021). Shoot fly infestation during the seedling stage results in the formation of deadhearts and poor plant establishment, leading to significant yield reduction (Kahate *et al*., 2014). Similarly, stem borer infestation causes stem tunnelling, deadheart formation and reduced translocation of nutrients, resulting in severe yield losses (Sharma, 1997; Khadioli *et al*., 2014). In recent years, the invasion of fall armyworm has emerged as a serious threat to sorghum production owing to its high reproductive potential, migratory behaviour and broad host range (Abrahams *et al*., 2017; Deshmukh *et al*., 2020).

Insect pests are responsible for substantial crop losses globally, and in India alone, insect-induced yield losses continue to pose a major challenge to agricultural production (Dhaliwal *et al*., 2015). The management of these pests has traditionally relied on synthetic insecticides, which provide rapid and effective suppression of pest populations. However, indiscriminate and repeated use of chemical pesticides has resulted in several adverse consequences, including environmental contamination, pesticide resistance, pest resurgence, destruction of natural enemies and accumulation of pesticide residues in agricultural produce (Koli and Bhardwaj, 2018; Sable, 2009). In fodder crops such as sorghum, pesticide residues may also adversely affect livestock health and subsequently enter the food chain (Joshi *et al.,* 2016).

The growing concern for environmental sustainability and safe agricultural production has stimulated interest in eco-friendly pest management approaches (Anandhi and Ambethgar, 2023). Botanical pesticides derived from plants have received considerable attention due to their biodegradability, safety to non-target organisms and compatibility with integrated pest management (IPM) programmes. Neem (*Azadirachta indica*)-based products are particularly important because of their antifeedant, repellent, oviposition-deterrent and insect growth-regulating properties Tesfaye and Dejen, 2006; Gautam *et al*., 2014; Joshi *et al*., 2016). In addition to neem, several plant-derived extracts and essential oils have demonstrated significant insecticidal and repellent activity against agricultural pests. Essential oils obtained from lemongrass (*Cymbopogon citratus*), eucalyptus (*Eucalyptus globulus*), peppermint (*Mentha piperita*), basil (*Ocimum basilicum*), clove (*Syzygium aromaticum*), citronella (*Cymbopogon nardus*), and garlic (*Allium sativum*) contain diverse bioactive compounds such as terpenoids, phenolics, and alkaloids that interfere with insect feeding, oviposition, growth, and survival (Sharaby and Nojiban, 2015; Regnault-Roger *et al*., 2012; Pavela, 2016). These botanicals have been shown to possess fumigant, contact toxic, repellent, and growth-inhibitory properties against several lepidopteran and dipteran pests, making them valuable components of sustainable crop protection systems (Regnault-Roger *et al*., 2012; Pavela, 2016).

In recent years, there has been a renewed interest in traditional agricultural knowledge systems such as Vrikshayurveda, driven by the need for sustainable and environmentally safe alternatives to synthetic pesticides (Silva *et al*., 2024). These ancient practices advocate the use of botanical extracts and cow-based formulations like Agniastra, Neemastra, Brahmastra, Dashparni Ark, etc. which are prepared from locally available plant materials and animal derivatives (Kumar and Sarada, 2020). Such formulations act through multiple mechanisms including repellency, antifeedant action, oviposition deterrence, and growth inhibition of pests (Bishnoi and Bhati, 2017; Sharaby and Nojiban, 2015), and when integrated into an IPM framework, they can reduce reliance on synthetic pesticides and delay resistance development. Additionally, these organic inputs contribute positively to soil health by enhancing microbial activity, improving nutrient cycling, and maintaining soil structure, unlike synthetic chemicals that often disrupt soil ecology (Shailaja *et al*., 2014). Therefore, eco-friendly insect pest management in sorghum is not merely an alternative but a necessity for sustainable agriculture, as it addresses rising pest pressures, minimizes pesticide residues, prevents resistance development, and promotes ecological balance, ultimately ensuring better crop productivity, environmental safety, and long-term farm profitability (Anandhi and Ambethgar, 2023).

Biological control agents also constitute an important component of eco-friendly pest management. Egg parasitoids such as *Trichogramma chilonis*, entomopathogenic fungi such as *Metarhizium anisopliae* and microbial insecticides such as *Bacillus thuringiensis* have been widely utilized for suppressing insect pests while conserving beneficial arthropods (Shekhara *et al*., 2014). Furthermore, natural enemies play a crucial role in regulating populations of fall armyworm and other lepidopteran pests (Shylesha and Sravika, 2018). Cultural practices including intercropping, border cropping, ecological engineering, mulching and habitat diversification can significantly reduce pest incidence by disrupting host location, improving crop diversity and enhancing the abundance of natural enemies (Smith and McSorley, 2000; Zongo *et al*., 1993; Bashyala *et al*., 2022). Intercropping systems involving sorghum and legumes have been reported to suppress insect pests and promote biological control (Degri and Richard, 2014). Similarly, trap cropping and ecological engineering approaches have emerged as important components of sustainable IPM programmes (Panwar *et al*., 2021).

Although several eco-friendly approaches have been individually evaluated against sorghum insect pests, comparative information on the effectiveness of different botanical, biological and cultural management modules against multiple key pests under field conditions remains limited. Moreover, there is a need to identify sustainable pest management options that can simultaneously suppress shoot fly, stem borer and fall armyworm while maintaining fodder productivity. Therefore, the present investigation was undertaken to evaluate different eco-friendly integrated pest management modules against major insect pests of sorghum and to assess their influence on green fodder yield under field conditions at Pantnagar, Uttarakhand.

II. MATERIALS AND METHOD

EXPERIMENTAL SITE

A comprehensive field experiment was conducted at Instructional Dairy Farm (IDF), Nagla, G.B. Pant University of Agriculture and Technology, Pantnagar for two seasons i.e., Kharif 2024 and 2025. Pantnagar is situated at 290˚ N latitude, 79.30˚ E longitude and at an altitude of 243.84 meters above the mean sea level in the "tarai" region of state Uttarakhand in Northern India. The soil of experimental field was slightly clay loam with an average fertility.

EXPERIMENTAL DESIGN

The experiment was laid out in Randomized Block Design (RBD) with thirteen treatments which were replicated thrice with a plot size of 4 x 4 m. Pant Chari-6 variety of sorghum was used for the experiment and sown by following the recommended package of practices except for protection measures.

EXPERIMENTAL DETAILS

The experiment comprised thirteen treatments involving botanical formulations, biological control agents, cultural practices, indigenous formulations and a chemical check. The treatment details are as under: T1: foliar spray of neem oil (3%) at 10-day intervals from 20 DAS; T2: Panchgavya seed treatment followed by foliar spray of Panchgavya at 10-day intervals from 20 DAS; T3:release of *Trichogramma chilonis* @ 50,000–1,50,000 parasitoids ha^{-1} from 20 DAS at weekly intervals along with maize as a border crop; T4:seed treatment with Agniastra followed by foliar spray of Agniastra at 10-day intervals from 20 DAS; T5:an ecological engineering module comprising Intercropping with cowpea + maize border crop + FYM @ 10 t ha^{-1} + neem cake @ 500 kg ha^{-1} + mulching with crop residues.; T6:foliar application of *Metarhizium anisopliae* @ 5 g l^{-1} water at 15–20 DAS; T7:neem cake application @ 10 t ha^{-1} during field preparation; T8:seed treatment with Neemastra followed by foliar spray at 10-day intervals from 20 DAS; T9;seed treatment with Brahmastra followed by foliar spray at 10-day intervals from 20 DAS; T10:seed treatment with Dashparni Ark followed by foliar spray at 10-day intervals from 20 DAS; T11:foliar spray of *Bacillus thuringiensis* @ 1–2 g l^{-1} water at 20–25 DAS; T12:seed treatment with chlorantraniliprole 50 FS @ 4 ml kg^{-1} seed followed by foliar application of isocycloseram 18.1 SC @ 200 ml ha^{-1} at 15–25 DAS and again at 35–45 DAS as the chemical check; T13: untreated control.

OBSERVATIONS

The observations on the damage caused by *A. soccata*, *C. partellus* and *S. frugiperda* were recorded consistently on 10 plants. The data on *A. soccata* infestation was recorded in terms of number of eggs at 14 days after emergence (DAE), percent deadhearts at 21 and 28 DAE of plants. Similarly, the data on *C. partellus* infestation was recorded also as deadhearts at 45 DAE of plants and then expressed in percentage. The plants were visually examined for the damage caused by natural infestation of *S. frugiperda* larvae for whorl damage percent at 45 DAE.

STATISTICAL ANALYSIS

The collected data were rigorously analyzed statistically to evaluate the effectiveness of each treatment in managing these insect pests and improving crop performance.

III. RESULTS

Effect of ecofriendly modules on shootfly damage

During 2024, all the treatments had significantly reduced shoot fly oviposition compared to the control (Table 1). The number of shootfly eggs were found to be lowest on T1 (1.33 eggs) followed by T4 (1.67 eggs) as compared to control (4.67 eggs). The percent deadhearts due to shoot fly at 21 DAE and 28 DAE were also observed which revealed lower percent deadhearts in T1 (10.00%) followed by T4 (16.67%) as compared to control (43.33%) during 21 DAE. At 28 DAE, the data showed the lowest deadhearts in T1 (20.00%) followed by T4 (23.33%) as compared to the control (50.00%). Similarly, during 2025 (Table 2), the number of shootfly eggs were found to be the lowest on T1 (1.33 eggs) followed by T4 (1.67 eggs) as compared to control (4.67 eggs). In case of percent deadhearts at 21 DAE, the lowest was found to be on T1 (10.00%) followed by T4 (16.67%) as compared to control (40.00%). At 28 DAE, the lowest percent deadhearts was recorded in T1 (20.00%) followed by T4 (23.33%).

Table 1: Effect of different ecofriendly treatments on the damage caused by major insect pests of sorghum during 2024

S.N.	Treatment details	SF-eggs @ 14 DAE	SF-DH@ 21 DAE (%)	SF-DH @ 28 DAE (%)	SB- DH @ 45 DAE (%)	FAW whorl damage (%) @ 45 DAE	Yield (q/ha)
1.	**3% Neem oil**	1.33 (1.52)*	10.00 (14.99)**	20.00 (26.06)**	10.00 (18.42)**	13.33 (21.13)**	544.79
2.	**Panchgavya seed treatment + foliar spray of Panchgavya**	2.33 (1.82)	23.33 (28.76)	26.67 (30.98)	23.33 (28.27)	23.33 (28.27)	446.67
3.	**Release *Trichogramma chilonis* (50,000-150000 eggs/ha) + Maize as border crop**	2.67 (1.91)	26.67 (30.98)	26.67 (30.98)	20.00 (26.55)	20.00 (26.06)	444.38
4.	**Seed treatment with Agniastra + Agniastra foliar spray**	1.67 (1.62)	16.67 (23.84)	23.33 (28.76)	13.33 (21.13)	23.33 (28.27)	526.25
5.	**Intercropping with cowpea + Maize as a border crop + FYM application + Neem cake application + Mulching with crop residues**	2.33 (1.79)	23.33 (28.06)	26.67 (30.77)	23.33 (28.76)	26.67 (30.98)	432.50
6.	***Metarhizium anisopliae* spray @ 5g/L**	2.67 (1.91)	26.67 (30.77)	30.00 (32.98)	30.00 (32.28)	23.33 (28.76)	407.08
7.	**Neem cake application**	2.67 (1.91)	33.33 (35.20)	36.67 (37.21)	33.33 (35.20)	23.33 (28.76)	417.50
8.	**Neemastra seed treatment + Foliar Spray**	2.33 (1.82)	23.33 (28.76)	26.67 (30.98)	23.33 (28.76)	16.67 (23.35)	455.00
9.	**Brahmastra seed treatment + Foliar Spray**	2.33 (1.82)	23.33 (28.76)	30.00 (32.98)	26.67 (30.28)	23.33 (27.27)	428.75
10.	**Dashparni ark Seed Treatment + Foliar Spray**	3.00 (2.00)	30.00 (32.98)	33.33 (35.20)	23.33 (28.76)	20.00 (26.06)	425.00
11.	***Bacillus thuringiensis* (Bt) Spray @ 1-2g/L**	3.00 (2.00)	26.67 (30.28)	30.00 (32.98)	30.00 (32.98)	23.33 (28.76)	422.92
12.	**Seed treatment with Chlorantraniliprole 50% FS @ 4ml/kg seed followed by foliar spray of Isocycloseram 18.1% SC @ 200ml/ha**	1.00 (1.38)	6.67 (12.28)	13.33 (21.13)	6.67 (12.28)	10.00 (18.42)	643.75
13.	**Untreated**	4.67 (2.27)	43.33 (41.13)	50.00 (42.23)	56.67 (48.91)	43.33 (41.13)	257.29
SE(m)±		(0.11)	(4.41)	(3.08)	(4.07)	(3.12)	(21.34)
C.D. (P=0.05)		(0.34)	(12.95)	(9.07)	(11.96)	(9.16)	(62.67)

**Figures in parentheses are ($\sqrt{x+1}$) transformed values **Figures in parentheses are arc sine transformed values, DAE: Days after emergence*

Table 2: Effect of different ecofriendly treatments on the damage caused by major insect pests of sorghum during 2025

S.N.	Treatment details	SF-eggs @ 14 DAE	SF-DH @ 21 DAE (%)	SF-DH @ 28 DAE (%)	SB- DH @ 45 DAE (%)	FAW whorl damage @ 45 DAE	Yield (q/ha)
1.	3% Neem oil	1.33 (1.48)	10.00 (14.99)	20.00 (26.06)	16.67 (23.84)	16.67 (23.84)	557.71
2.	Panchgavya seed treatment + foliar spray of Panchgavya	2.67 (1.91)	23.33 (28.76)	26.67 (30.77)	26.67 (30.98)	33.33 (34.91)	455.83
3.	Release *Trichogramma chilonis* (50,000-150000 eggs/ha) + Maize as border crop	2.33 (1.82)	26.67 (30.77)	30.00 (32.98)	33.33 (35.20)	30.00 (32.98)	448.96
4.	Seed treatment with Agniastra + Agniastra foliar spray	1.67 (1.62)	16.67 (23.84)	23.33 (28.76)	23.33 (28.76)	23.33 (28.27)	531.04
5.	Intercropping with cowpea + Maize as a border crop + FYM application + Neem cake application + Mulching with crop residues	2.00 (1.65)	26.67 (30.98)	30.00 (32.98)	30.00 (33.19)	26.67 (30.28)	435.42
6.	*Metarhizium anisopliae* spray @ 5g/L	2.33 (1.82)	23.33 (28.27)	26.67 (30.77)	33.33 (34.99)	23.33 (28.27)	411.88
7.	Neem cake application	2.67 (1.91)	26.67 (30.77)	30.00 (32.98)	36.67 (37.21)	30.00 (32.98)	422.50
8.	Neemastra seed treatment + Foliar Spray	2.00 (1.71)	20.00 (26.55)	26.67 (30.98)	26.67 (30.98)	20.00 (26.06)	465.00
9.	Brahmastra seed treatment + Foliar Spray	2.33 (1.82)	23.33 (28.76)	30.00 (33.19)	30.00 (32.20)	30.00 (32.20)	437.08
10.	Dashparni ark Seed Treatment + Foliar Spray	2.67 (1.91)	30.00 (32.98)	36.67 (36.91)	26.67 (30.98)	26.67 (30.28)	420.83
11.	*Bacillus thuringiensis* (*Bt*) Spray @ 1-2g/L	3.00 (1.98)	26.67 (29.98)	33.33 (34.12)	33.33 (34.91)	23.33 (28.27)	429.17
12.	Seed treatment with Chlorantraniliprole 50% FS @ 4ml/kg seed followed by foliar spray of Isocycloseram 18.1% @ 200ml/ha	0.67 (1.24)	6.67 (12.28)	10.00 (18.42)	13.33 (21.13)	13.33 (21.13)	658.54
13.	Untreated	4.67 (2.37)	40.00 (39.13)	50.00 (44.98)	50.00 (44.98)	43.33 (41.13)	265.00
	SE(m)	(0.14)	(4.64)	(4.23)	(3.56)	(2.54)	(21.71)
	CD	(0.42)	(13.62)	(12.56)	(10.45)	(7.48)	(63.74)

**Figures in parentheses are (√x+1) transformed values **Figures in parentheses are arc sine transformed values, DAE: Days after emergence*

Effect of ecofriendly modules on stem borer damage

During 2024, the percent deadhearts caused by stem borer were found to be lowest on T1 (10.00%) followed by T4 (13.33%) as compared to control (56.67%). Similarly, during 2025, the lowest deadhearts were found on T1 (16.67%) followed by T4 (23.33%) as compared to control (50.00%).

Effect of ecofriendly modules on fall armyworm damage

The data on percent whorl damage by FAW at 45 DAE during 2024 revealed T1 (13.33%) as the best treatment followed by T8 (16.67%) as compared to control (56.67%). Similarly, during, 2024-25 the lowest FAW damage was recorded on T1 (16.67%) followed by T8 (20.00%). The effectiveness of neem-based products against fall armyworm may be attributed to their antifeedant, repellent and insect growth-regulating properties, which adversely affect larval feeding and survival.

Effect of ecofriendly modules on green fodder yield

The yield data revealed that all the treatments significantly outperformed the control. Significantly more fodder yield was obtained from T1 (544.79 and 557.71 q/ha) as compared to control (257.29 and 265.00 q/ha) during both the years respectively. The higher fodder yield obtained under neem oil and Agniastra treatments may be attributed to effective suppression of major insect pests, resulting in reduced crop damage and improved plant growth. The substantial reduction in yield observed in untreated plots clearly demonstrates the economic importance of pest management in sorghum.

IV. DISCUSSION

The present study demonstrated that eco-friendly IPM strategies can effectively manage the major insect pests of sorghum under field conditions. Among the treatments evaluated, neem oil (3%) consistently provided the best control of shoot fly, stem borer, and fall armyworm during both years of the study and performed comparably to the chemical treatment. Its superior efficacy may be attributed to the antifeedant, repellent, and growth-regulating properties of azadirachtin. Agniastra was the next most effective treatment against shoot fly and stem borer, while Neemastra showed promising control of fall armyworm, highlighting the potential of indigenous botanical formulations in sustainable pest management. Although the chemical treatment also effectively suppressed pest infestation, its prolonged use may result in pesticide residues, environmental pollution, resistance development, and adverse effects on beneficial organisms. In contrast, botanical and biological IPM components are biodegradable, environmentally safe, and compatible with sustainable agriculture. Therefore, the present findings indicate that neem oil, Agniastra, and Neemastra can serve as effective eco-friendly alternatives to synthetic insecticides for the integrated management of major insect pests in sorghum.

The effectiveness of neem oil may be attributed to the presence of azadirachtin and related limonoids that act as oviposition deterrents, feeding inhibitors and insect growth regulators. Similar observations have been reported by Gautam *et al*. (2014) and Joshi *et al.* (2016), who reported significant suppression of shoot fly infestation following neem-based treatments. The lower infestation observed in neem oil-treated plots may be due to its antifeedant and growth-disrupting effects on stem borer larvae, which reduce larval establishment and feeding activity. Tekie *et al.* (2006) reported that neem seed powder and neem seed extract provided protection against *C. partellus* in maize comparable to conventional insecticides. Similar observations were reported by Mudigoudra and Shekharappa (2009) and Sable (2009) reported that NSKE (5%) and neem oil (2%) spray in sorghum at 21DAT reduced deadhearts and gave maximum yield; similar results were observed with 3% neem oil (Gautam *et al.,* 2014). The antifeedant properties of neem oil 3%, NSKE with shoot fly had been earlier reported (Zongo *et al*., 1993; Tesfaye and Dejen, 2006). Moreover, botanical formulations are generally safer to natural enemies and therefore support the biological regulation of pest populations. Similar findings have been reported by Tesfaye and Dejen (2006), Gautam *et al*. (2014) and Kumar and Sarada (2020), who observed enhanced crop productivity following the adoption of botanical and integrated pest management practices in sorghum.

V. CONCLUSION

The present study demonstrated that eco-friendly IPM strategies can effectively reduce the incidence of shoot fly, stem borer, and fall armyworm in sorghum under field conditions. Among the treatments evaluated, neem oil (3%) emerged as the most effective eco-friendly option, while Agniastra and Neemastra also showed promising pest suppression against specific target pests. These findings highlight the potential of botanical formulations as sustainable alternatives to synthetic insecticides, contributing to environmentally safe pest management and reducing reliance on chemical pesticides. However, the study was conducted at a single location over two cropping seasons, and the effectiveness of these treatments may vary under different agro-climatic conditions and pest pressures. Therefore, further multi-location and long-term studies, including economic analyses and integration with other IPM components, are needed to validate their wider applicability. The adoption of neem oil- and botanical-based IPM strategies can promote sustainable sorghum production by minimizing environmental risks, conserving beneficial organisms, and supporting eco-friendly crop protection.

ACKNOWLEDGEMENTS

The authors are grateful to Director, Research, G. B. Pant University of Agriculture and Technology, Pantnagar, India for providing field and other basic research facilities.

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ISSN: 2456-1878 (Int. J. Environ. Agric. Biotech.)
https://dx.doi.org/10.22161/ijeab.114.3