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Combination of variety with cultural as well as chemical tactics reduce damage and yield loss caused by *Helicoverpa armigera* (Hubner) (Lepidoptere:Noctuidae), enhance agronomic performance and influence nodule formation in chickpeas

Zemenu Fentahun[1,2]*, Getachew Gudero Mengesha[1,2], Asnake Abera[1,2], Biniam Boraysho[1,2], Tariku Simion[1,3]

[1]Arba Minch Agricultural Research Center (AmARC), SEARI, P.O. Box 2228, Arba Minch, Ethiopia, [2]Crop protection Department, SEARI, AmARC, P.O.BOX. 2228, Arba Minch, Ethiopia, [3]Crop Improvement Research Department, AmARC, SEARI, P.O.BOX. 2228, Arba Minch, Ethiopia

ABSTRACT

Helicoverpa armigera is a key polyphagous insect that causes significant qualitative and quantitative chickpea yield reductions worldwide, including in Ethiopia. Field trials were conducted to assess the success of the combined effects of variety, cultural practices, and insecticide application to reduce damage and yield loss caused by *H. armigera* and improve nodulation and agronomic traits of chickpea around Arba Minch, southern Ethiopia, in 2022 and 2023. Eight treatments were arrayed in a completely randomized block design with three replicas. Dimtu variety maintained with insecticide sprays had the lowest mean number of larvae per plant (NLPP) after 72 hours of exposure (0.33), the number of damaged pods per plant (NDPP) (3.13) and the highest grain yield (2234.13 kg ha^{-1}), which were statistically on par with Habru variety in the same manner. However, the highest number of effective nodules (NEN) (17.37) was noted from the Habru variety combined with trap cropping, which was statistically similar to the same variety combined with intercropping and the Dimtu variety combined with each intercropping and trap cropping. Control plots of both varieties exhibited the highest NLPP and NDPP and the lowest NEN and grain yields over the years. Insecticide sprays on Dimtu and Habru varieties reduced yield loss by 69.13% and 67.79% and increased yield advantage by 223.89% and 210.42%, respectively, over control plots. Economic analyses also confirmed that production of Dimtu and Habru varieties with insecticide spray resulted in superior net benefits ($2775.80 and $2686.47 ha^{-1}, respectively) and benefit-cost ratios (4.46 and 4.32, respectively) over control plots across years. Thus, employing the varieties Dimtu and partly Habru with insecticide spray exhibited the most efficient and cost-effective option in decreasing pest pressure, improving agronomic performance, reducing yield losses, and attaining maximum economic returns. So, it could be suggested for farmers in the study and other related areas to manage *H. armigera* and sustain chickpea productivity.

KEYWORDS: Cultural practices, Chickpea varieties, Economic analyses, Grain yield, *Helicoverpa* components, Insecticide application, Nodules, Yield advantage

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***Corresponding Author:**
Zemenu Fentahun
E-mail: zemenufentahun20@gmail.com

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is widely produced and arguably among the most important pulse crops for human consumption worldwide (FAO, 2022). According to Roy *et al.* (2010), the crop provides a great source of complex carbohydrates, vitamins, minerals, soluble and insoluble fiber, and is low in fat and sodium. It is an inexpensive source of protein in underdeveloped nations and enhances soil fertility status through N-fixation (Millan *et al.*, 2006; Gaur *et al.*, 2012). Globally, it was cultivated on about 14.81 million hectares of land and produced more than 18 million tons of grains in 2022. In Ethiopia, it is one of the most important pulse crops, widely grown in diverse agroecologies and soil types. It is the third most important pulse crop in terms of the number of households engaged, area coverage, and grain production, following faba bean and common bean (CSA, 2022). There are two types of chickpeas, Kabuli and Desi, which differ from one another in terms of seed size, shape, and color, as well as growth patterns (Patil *et al.*, 2017). In 2022, chickpea cultivation occupied more than 201,274 hectares and 401,238 tons of production in Ethiopia (CSA, 2022).

Although production of the crop is insufficient relative to the needs of human nutrition in Ethiopia, mainly due to many restraints of chickpea production (MoANR & EATA, 2018), which are diseases like wilt caused by a complex of many pathogens (Beniwal *et al.*, 2008; Yimer *et al.*, 2018) and ascochyta blight caused by various pathogens (Bretag *et al.*, 2003), insect pests like *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) and cutworms (*Agrotis ipsilon*), a shortage of improved varieties, the consequences of climate change, and improper agronomic practices (Fite *et al.*, 2019). These could worsen by the occurrence of destructive biotypes that affect the crop, causing a serious threat to maintaining food security. Because of this, the average chickpea productivity in the study areas as well as the country remains less than 2 t ha^{-1} (CSA, 2022), while the crop potential yield reached up to 5 t ha^{-1} in Ethiopia (Verkaart *et al.*, 2017). The productivity is even less than the world's productivity, which was 1.22 t ha^{-1} (FAO, 2022). Among several factors responsible for the low productivity of the crop, *H. armigra* is one of the most economically key insect pests in Ethiopia (MoANR & EATA, 2018). The pest commonly known as the African bollworm, chickpea pod borer, or gram pod borer is widely distributed and a critical challenge for chickpea productivity and it causes severe qualitative and quantitative yield losses around the world, depending on cultivar susceptibility and conducive environments (Ahmad, 2003; Bhagat *et al.*, 2020).

Patil *et al.* (2017) and Sheikh *et al.* (2024) argued that *H. armigera* is widely dispersed in agriculture originating in the Old world, all over Asia, Africa, Europe, and the Middle East. According to the authors, it is characterized by its polyphagous nature and has many alternate hosts. Robust bodies and wide thoraxes are characteristics of female moths, which have a great potential for reproduction. She may produce up to 4400 eggs in a lab setting and 500-1000 eggs on leaves, pods, or flowers (Shanower *et al.*, 1997; Mironidis & Savopoulou-Soultani, 2012). It can complete its life cycle within four to five weeks, depending on environmental conditions (Patil *et al.*, 2017; Bhagat *et al.*, 2020). Oviposition periods extend five to twenty-four days, and the incubation of eggs takes three to five days, which is influenced by host preferences and temperature. Pupation takes ten to sixteen days; it commonly occurs in the soil or within a protective cocoon. Depending on the temperature, pupation can last anywhere from six days at 35 °C to up to 30 days at 15 °C (Hackett & Gatehouse, 1982; Shanower *et al.*, 1997). Larvae go through six different instars. They devour young twigs, leaves, and flowers at first, then gradually enter developing pods by making holes at the pod's base (Singh & Singh, 2007). It can adapt, survive, and overwinter in a wide range of environmental conditions by staying where they are or navigating to different ecosystems (Shanower *et al.*, 1997; Bhagat *et al.*, 2020). Due to its frequent occurrence from the vegetative growth to the pod formation stage, yield losses might exceed 90% if no control measures are implemented (Patil *et al.*, 2017; Sheikh *et al.*, 2024). A yield loss of 57.56% caused by chickpea pod borer was reported in Ethiopia (Shumi *et al.*, 2021).

Such phenomena suggest that control measures to minimize yield losses and prevent *H. armigera* are of great importance in chickpea production. The use of resistant varieties, biological control, insecticide application, cultural practices (larval handpicking, manipulation of sowing dates, proper plant density, intercropping, crop rotation, use of trap cropping, nutrient management, and field sanitation), and integrated pest management (IPM) are the main methods of controlling *H. armigera* worldwide (Shanower *et al.*, 1997; Sheikh *et al.*, 2024). However, studies have shown that the independent use of cultural measures may be limited for a variety of reasons and that the breakdown of resistance genes may make the simple adoption of resistant cultivars unreliable (Sheikh *et al.*, 2024). Similarly, several challenges pertaining to the use of agrochemicals include farmers' inability to buy pesticides due to high cost, the accumulation of harmful chemical residues in seeds, water, and soil, and the overcoming of resistance by the pest (Green *et al.*, 1990; Sheikh *et al.*, 2024). Insecticide application is the main solution during *H. armigera* outbreaks in Ethiopia (Gebretsadkan *et al.*, 2019; Fite *et al.*, 2019), despite the adverse side effects of insecticides on the environment, humans, animals, and non-target organisms (Mostafalou & Abdollahi, 2012). Environmentally friendly *H. armigera* control approaches, like the integration of host resistance with each of the cultural practices as well as insecticide spray as IPM packages, are considered the most reliable methods, which should be practiced and used regularly. This strategy would enable the use of IPM packages and lower yield losses, chemical use, production costs, and *H. armigera* activities (Patil *et al.*, 2017; Sheikh *et al.*, 2024).

Such circumstances suggest the need to generate empirical data regarding IPM measures, including the integration of host resistance, cultural practices, and insecticide application, for the control of *H. armigera* in the study areas as well as having similar agroecologies and deploy alternative options to access by chickpea-cultivating farmers. Ahmed *et al.* (1990), Patil *et al.* (2017) and Sheikh *et al.* (2024) reported that empirical studies conducted somewhere have shown the effectiveness of the integrated use of insecticides, either host resistance with different levels of reactions to *H. armigra* or cultural tactics like intercropping, trap cropping, sowing date manipulation, and others against the pest. However, a review of the existing research works indicated limited evaluation experiments regarding IPM packages carried out under Ethiopian conditions for *H. armigera*; however, growers entirely relied on insecticide application for the control of this aggravating pest (MoANR & EATA, 2018). So, it is vital to search for and assess the efficacy of alternative methods, such as the integration of host resistance, cultural practices, and insecticide use to control *H. armigera*, to reduce reliance on insecticides, delay pesticide resistance, lower the cost of insecticides, and strengthen IPM. Thus, field experiments were carried out to determine the combined effect of host resistance either with cultural practices or insecticide sprays to reduce larval activities, pod damage, and yield loss caused by *H. armigera* and improve agronomic performances on the vegetative to physiological maturity growth stages of chickpea in southern Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

Fieldwork was carried out at the Chano Mille sub-experimental site of the Arba Minch Agricultural Research Center at Arba Minch, southern Ethiopia, during the main rainy seasons of 2022 and 2023 (mid-August to December). It is found at an altitude of 1216 meters above sea level with a geographical location of 06°06'841" N latitude and 037°35'122" E longitude. The area experiences a bimodal rainfall pattern from August to November (the main rainy season) and March to April (the short rainy season). Additionally, it receives mean annual precipitation, and temperatures for the last ten years have been 758.61 mm and 27.2 °C in that order. Figure 1 shows the average monthly minimum and maximum temperatures, total precipitation, and relative humidity for the region across the study periods. The Ethiopian Meteorological Agency's Hawassa Branch has given the meteorological data. Characteristically, soil in the study plots has a slightly alkaline pH and is texturally clay in both its physical and chemical characteristics. While the soil's organic matter, total nitrogen, and accessible phosphorus concentrations are modest, its available sulfur, organic carbon, and carbon-to-nitrogen ratio are low (Terefe *et al.*, 2024).

Treatments, Experimental Design, and Field Procedures

Two chickpea varieties (Dimtu and Habru), intercropping, trap cropping, and insecticide application were used as study treatments. A total of eight treatments, alone and in combinations of each of them, were formed and implemented as a single-factor experiment during the study. That is, each variety combined with each intercropping, trap cropping, and insecticide application, and untreated controls of each of the two chickpea varieties. The two varieties exhibited Desi (Dimtu) and Kabuli (Habru) types and are sourced from the Debre Zeit Agricultural Research Center, Ethiopia, and are currently under production across the country. The varieties are reported to have moderate and susceptible responses to *Helicoverpa armigera* in that order (MoANR & EATA, 2018). Maize and sunflower were used as intercrops and trap crops, respectively, in the study. Additionally, Farrate (a.i. = Lambda Cyhalothrin 5% w/v) insecticide, which has a contact stomach action, was collected from MDD Chemical Products Importer, Ethiopia. The insecticide is registered and is presently being applied as a foliar application for *H. armigera* on chickpeas under production in the country. As the design of the experiment, a completely randomized block design (CRBD) with three replicas was utilized in both years.

The field was first plowed using a field tractor up to 45 cm deep, followed by oxen-driven harrowing to bring the soil to a fine tilth. In this study, the total field size was projected to be 10.0 m width by 26.5 m length, with a unit plot size of 3.0 m width by 2.0 m length in both years. Ten rows made up each plot under investigation, and each variety was planted with an inter-row spacing of 0.3 m and an intra-row spacing of 0.1 m. Plots and replications were separated by 1.5 and 2.0 meters in that order. In 2022 and 2023, sowing was performed in the last week of August. The seed was sown in rows, and each row consisted of 20 plants. Both sunflowers employed as a trap crop and maize planted as intercrop were maintained at the ratio of 4:1 in both years. Chickpeas, maize, and sunflowers were planted at the same time in the experimental plot. Two sprays of insecticide were performed during the growth stage of early flowering, at 43 (in 2022) and 45 (in 2023) days after sowing, and the pod, which has reached full size, has at least one or two seeds

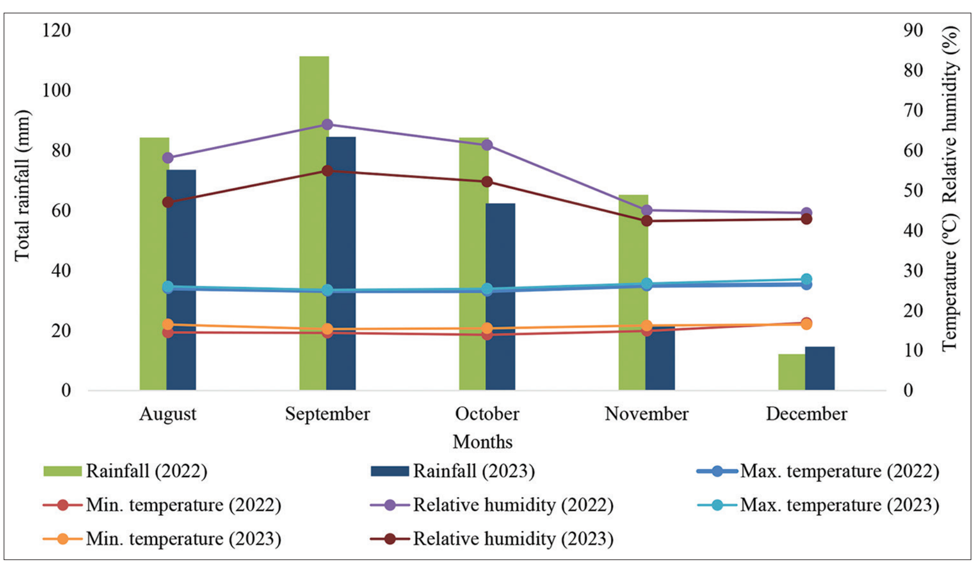

Figure 1: Monthly mean minimum and maximum temperatures, total rainfall and relative humidity for the growing periods around Arba Minch, southern Ethiopia, during the 2022 and 2023 main cropping seasons

initiated per pod, and seeds fill rounded pod cavities when one pod bores larvae per one meter of row length, following the Zahid *et al.* (2008) procedure. NPS mixed fertilizer was uniformly applied at the time of planting at a rate of 121 kg ha^{-1}. The insecticide was applied at a rate of 500 mL diluted with 200 liters of water in one hectare. Every other agronomic technique was used consistently in accordance with guidelines.

Helicoverpa Armigera, Agronomic Traits, Nodule and Yield Loss Assessments

For evaluation parameters, the number of larvae per plant (NLPP), number of damaged pods per plant (NDPP) (*H. armigera* components), plant height (PH), number of primary branches (NPB), number of pods per plant (NPPP), hundred seed weight, and grain yield (GY) (agronomic parameters), and nodulation were considered. Monitoring for larval conditions of *H. armigera* was carried out regularly and recorded at intervals of 24 hours. The number of live larvae per plant was assessed on 10 randomly selected plants before and after insecticide exposure in each plot. The number of damaged pods, NPB, and NPPP were assessed by counting the total number of infested pods, primary branches, and pods per plant, respectively, from 10 randomly taken sample plants per plot. Similarly, PH was measured in cm from the base up to the tip of the plant using a meter in 10 randomly selected plants during physiological maturity. The average values of each parameter were used for data analyses.

After harvest on plot bases, GY was transformed into kg ha^{-1} for data analysis. The GY was corrected to 12% on the basis of the storable moisture content of the grain following Taran *et al.* (1998) procedure. Hundred seed weights were weighed in grams using a sensitive balance from sample grains randomly taken from the total storable grains of each plot. Moreover, the number of effective nodules (NEN) was determined by counting 10 randomly selected plants from the middle rows for the period of the flowering stage. The plants were gently uprooted, and the roots were thoroughly washed with tap water to remove the adhering soil, and NEN were detached and counted based on the colour they produced during dissection. As a result, the nodules that exhibited pink in colour were considered effective, whereas those that were white were considered ineffective (Dobert & Blevins, 1993).

On the other hand, the relative yield loss (%) of chickpea due to *H. armigera* pressure was appraised as the percentage yield reduction (%) of the less protected plots related to the maximum protected plots for all tested chickpea varieties and intercropping, trap cropping, and insecticide over the two years using the following formula:

$$\text{Relative yield loss}(\%) = \frac{Y_{mt} - Y_{lt}}{Y_{mt}} \times 100$$

Where Y_{mt} = mean yield of the best-performing treatment in the study (maximum protected plot) and Y_{lt} = mean yield of the other treatments (low to medium protected plots). Yield increase over control plots was ciphered from the difference in GY between maintained and control plots and articulated in percentage as proposed by Bitew *et al.* (2022) and Terefe *et al.* (2024).

Data Analyses

Collected data were subjected to analyses of variance (ANOVA) to evaluate the effects of treatment on *H. armigera* components and agronomic traits of chickpeas using SAS version 9.3 software (SAS, 2014). As the study was carried out in distinct years, the F-test of the error variances for the study parameters per year was tested to determine if there was heterogeneity between years. Following Gomez and Gomez's (1984) procedure, combined data analysis was employed for the two years due to homogeneity in error variances for the majority of study parameters in the two years. Mean separations for the study treatments were made using Fisher's protected least significant difference at a 5% probability level (Gomez & Gomez, 1984). Spearman correlation (r) studies were employed to determine the magnitude of relationships between and among *H. armigera* components, nodulation, and agronomic traits. Moreover, a linear regression analysis was accomplished by plotting percentage pod damage versus grain yield data, which was constructed using MS Excel 2013 for Windows. For the regression analysis component, the counted NDPP obtained from sampled plants was converted into the percentage of damaged pods as the ratio of the number of damaged pods to the total number of pods per plant (Kora & Teshome, 2021).

Economic Analysis for IPM Strategies Implementations

Combined yield data were utilized to analyze the economics of IPM packages following CIMMYT (1988) procedures. Partial budgeting was employed to see the cost-effectiveness of control options implemented for *H. armigera* in chickpea cultivation. Costs of seed, knapsack sprayer, insecticide, labor, and chickpea market price were considered for the analysis. In this study, total variable cost, gross return, net benefit, and benefit-cost ratio were taken into account. Total variable cost was calculated as the sum of all variable input costs, while gross return was determined as the multiplication of market price and grain yield. Net benefit was obtained from differences between gross return and total variable costs, whereas the benefit-cost ratio was calculated as the ratio of net return to the total input expenses. Existent yields were downward by 10% to regulate farmers' expectations of the yield that may be incurred from the same IPM package followed. Mean costs of insecticide and seeds were \$18.19 L^{-1} and \$4.37 kg^{-1} in that order, whereas the cost of a knapsack sprayer was \$60.64 per unit item. Similarly, the mean costs of labor per man per day were \$6.06 per local wage rate, while the mean yield was sold for \$1.69 based on a \$1 = 49.47 ETB exchange rate at Arba Minch during marketing. All costs were changed to a hectare basis for economic return analysis.

RESULTS

Analysis of Variance

Combined analyses of variance showed that there were different levels of significance in mean squares for *H. armigera*

Table 1: Combined analysis of variance for study parameters in the study area, southern Ethiopia, during the 2022 and 2023 cropping seasons

Parameter	Source of variations					
	Rep (year) (4)	Year (1)	Treatment (7)	YR*T (7)	Error (28)	CV (%)
NLBS	0.09^{ns}	141.45***	41.40***	110.53***	31.85	14.29
24 hrs.	2.32^{ns}	83.11***	65.81***	19.79*	1.13	17.22
48 hrs.	0.15^{ns}	0.85^{ns}	106.35***	0.27^{ns}	0.36	9.98
72 hrs.	0.50^{ns}	0.54^{ns}	118.93****	2.97***	0.46	12.55
NPB	0.18^{ns}	0.14^{ns}	1.12^{ns}	0.27^{ns}	0.52	20.99
NEN	2.09^{ns}	9.01^{ns}	70.97***	1.68^{ns}	4.42	15.74
PH	14.46^{ns}	7823.41^{ns}	147.22**	84.74*	9.34	9.34
NPPP	62.00^{ns}	402.52^{ns}	379.33***	19.34^{ns}	25.86	25.86
NDPP	1.64^{ns}	1856.94***	73.97****	55.48***	37.79	32.82
HSW	0.77^{ns}	35.02^{ns}	17.26**	1.59^{ns}	4.94	6.12
GY	22156.52^{ns}	3067839.56***	94256.26****	170684.56***	16940.44	13.03

Rep (year)=Replication within years; YR*T=Year×treatment interaction; NLBS=Number of larva before spray; 24, 48 and 72 hrs.=Represent time for mean number of live larvae after each sprays in every 24 hours interval across treatments; NPR=Number of primary branches; NEN=Number of effective nodules; PH=Plant height measured in cm; NPPP=Number of pod per plant; DP=Damaged pod estimated in percent; HSW=Hundred seed weight in gram; GY=Grain yield assessed in kg ha^{-1}. Numbers in parenthesis refer to degree (s) of freedom to each respective parameter; ****=highly significant difference at $P<0.0001$; ***=highly significant difference at $P<0.001$; **=highly significant difference at $P<0.01$; *=significant difference at $P<0.05$; ns=non-significant difference at $P>0.05$; CV=Coefficient of variation

components, nodulation, agronomic parameters, and their interactions among treatments and years (Table 1). This implies there was variation in the effects of *H. armigera* components, nodule formation, and agronomic traits within the treatments across the years. Except for NPB, the mean squares for all study parameters significantly ($P<0.0001$ to 0.01) varied among the evaluated treatments. However, the majority of study parameters had non-significant ($P>0.05$) effects on the mean square of years and year × treatment interactions, except for the number of larvae before spray, after spray of 24 and 72 hours, damaged pods, and grain yield (Table 1). So, *H. armigera* activities, nodule formation, and agronomic traits appeared unaffected by the treatments across years, indicating consistent responses to the treatments, and the effects of the treatments on study parameters over multiple years were not significantly influenced by variations in environmental conditions or temporal factors.

Larval Conditions and Extent of Damage Caused by *Helicoverpa Armigera*

Analyses of variance revealed there were variable levels of significant ($P<0.0001$ and <0.05) differences for NLPP due to treatment effects across years (Table 1 & Figure 2). In this study, insecticide spray served as a reference for the before and after assessment of larval conditions. Accordingly, studies demonstrated that NLPP before and after insecticide exposure was considerably more effective when IPM strategies were followed. Maximum mean NLPP before and after spray at 24, 48, and 72 hours was counted from control plots of the Dimtu variety with 10.42, 10.83, 11.72, and 11.95 and the Habru variety with 9.82, 11.70, 12.78, and 12.82 in that order across years. Contrariwise, the lowest (2.43, 0.35, and 0.25) mean NLPP after 24, 48, and 72 hours was recorded from the cultivation of the Dimtu variety maintained with insecticide application, followed by the Habru variety integrated with insecticide application (2.98, 0.58, and 0.33 in that hour order) across years. Results also showed that practicing trap cropping had the lowest NLPP compared with intercropped and control plots of both varieties (Figure 2).

Field demonstration indicated that demonstration of the IPM package highly reduced further progression of NLPP after spray compared with control plots in both varieties across years. For instance, the protection of the Dimtu variety from *H. armigera* using insecticide application reduced NLPP by 77.53, 97.01, and 97.91% after exposure of 24, 48, and 72 hours, respectively, over control plots across cropping years. On the Habru variety, reductions of 74.50, 95.44, and 97.40% at 24, 48, and 72 hours after exposure due to insecticide application over control plots were also demonstrated during the study.

Combined ANOVA over years discovered significant ($P<0.001$) differences in NDPP caused by *H. armigera* among treatments (Table 2 & Figure 2). According to ANOVA, the NDPP was higher (7.43) on control plots of the Dimtu variety, which was statistically on par with the variety Habru (7.33) on the same plots across years. However, the lowest mean NDPP was recorded from the planting of the Dimtu variety (3.13) maintained with insecticide application, which statistically did not vary from the cultivation of the same variety (3.33) combined with trap cropping and the Habru variety (3.90) integrated with the insecticide application over the years (Figure 2). In this connection, the magnitude of NDPP was considerably kept down by 57.87, 55.18, and 46.79 on the Dimtu variety maintained with insecticide application and trap cropping and the Habru variety integrated with insecticide application over control plots, which had the highest NDPP across years.

Effects of IPM Packages on Nodulation and Agronomic Traits

Combined ANOVA over the years for nodulation and agronomic parameters showed different levels of significant ($P<0.0001$ to <0.05) variation among treatments (Tables 1 & 2). The

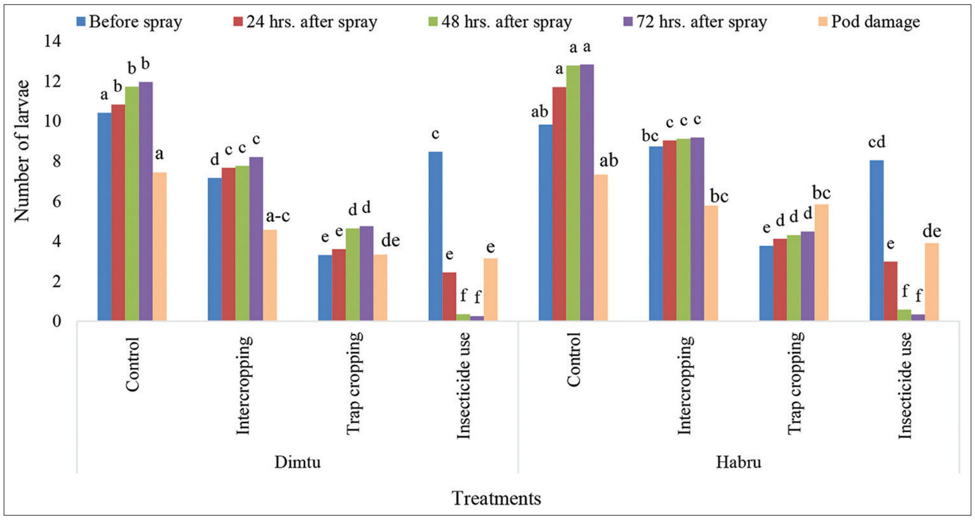

Figure 2: Mean number of mean live larva per infested plant due to *Helicoverpa armigera* before and different hours after spray in the study areas during the 2022 and 2023 main cropping seasons Means followed by the same letters within each column are not significantly different

Table 2: Mean effects of integrated pest management on nodulation and agronomic traits of chickpea around Arba Minch areas in southern Ethiopia during the 2022 and 2023 main cropping seasons

Treatments		Nodule	Growth, yield and yield related traits of chickpea			
Variety	Field husbandry	NEN	PH (cm)	NPPP	HSW (g)	GY (kg ha^{-1})
Dimtu	Control	10.83^{b}	51.20^{d}	25.53^{cd}	30.67^{bc}	689.77^{de}
	Intercropping	15.33^{a}	57.63^{b-d}	35.63^{b}	38.83^{a}	1655.11^{bc}
	Trap cropping	16.60^{a}	56.30^{cd}	27.97^{b-d}	37.00^{a-c}	972.22^{b-e}
	Insecticide use	11.00^{b}	58.83^{bc}	46.63^{a}	38.17^{a}	2234.13^{a}
Habru	Control	7.50^{c}	60.63^{a-c}	19.70^{d}	32.50^{c}	700.79^{c-e}
	Intercropping	15.67^{a}	66.93^{a}	31.80^{bc}	36.83^{bc}	1516.31^{bd}
	Trap cropping	17.37^{a}	63.77^{ab}	28.97^{b-d}	35.33^{bc}	947.00^{b-e}
	Insecticide use	12.50^{b}	64.97^{ab}	33.33^{bc}	37.17^{ab}	2175.40^{a}
P-value		<0.05	<0.05	<0.05	<0.05	<0.0001
LSD (5%)		2.43	6.47	9.49	2.54	155.03
CV (%)		15.46	9.17	25.82	5.95	13.16

Means followed by the same letters within each column are not significantly different. NEN=Number of effective nodules; PH=Plant height measured in cm; NPPP=Number of pod per plant; HSW=Hundred seed weight in gram; GY=Grain yield assessed in kg ha-1; LSD=Least significant difference at *P*<0.05 probability level; CV=Coefficient of variation

highest NEN (15.67-17.37) was attained from the Habru variety cultivated with intercropping and trap cropping practices, in which the lowest was for intercropping and the highest was for trap cropping. The NEN recorded from the aforementioned treatments was not statistically different from the Dimtu variety combined with each of the intercropping and trap cropping practices, which recorded NENs of 15.33 and 16.60, respectively. Conversely, the lowest NEN was recorded from control plots of the Habru variety (7.50), followed by the Dimtu variety (10.83) (Table 2). Trap cropping and intercropping practices improved effective nodule formation by 131.60% and 108.93% (Habru variety) and 53.78% and 41.55% (Dimtu variety), in that order, over sole cropping of the respective varieties in the two years.

Regarding agronomic traits, the implementation of the IPM package on the Habru variety increased PH compared with the Dimtu variety. The sole crop of the Dimtu variety exhibited the shortest (51.20 cm) plant height compared to other treatments evaluated over the years. The Habru variety integrated with intercropping practice had the tallest plant height (66.93 cm) compared with other treatments; however, it was statistically similar to the values recorded from the same variety maintained with trap cropping and insecticide application. The highest (38.83) NPPP was found by combining insecticide spray with the Dimtu variety over other treatments. The NPPP in the sole-cropped Habru variety was significantly lower (19.70) than in the rest of the treatments evaluated across years (Table 2).

Likewise, the heaviest (38.83 g) hundred seeds were achieved from the integration of the Dimtu variety and intercropping practices. However, there were no statistically significant differences detected between the aforementioned treatment combinations and trap cropping, insecticide spray with the same variety, and the Habru variety combined with insecticide application for hundred seeds weight across years. The sole crop of both varieties had the lightest hundred-seed weight in the two years (Table 2). The topmost (2234.13 kg ha^{-1}) grain yield was achieved as a result of the operation of the Dimtu variety and insecticide application together, followed by Habru variety cultivation with insecticide application (2175.40 kg ha^{-1}). The integration of intercropping practice with each of the Dimtu and Habru varieties also had the highest (1655.1 and 1516.31 kg ha^{-1}, respectively) grain yields compared with control plot of the respective varieties over the years. In contrast, the lowest (873.5 kg ha^{-1}) mean grain yield was gained from control plots of both varieties that were statistically on par with one another (Table 2).

Relative Yield Loss and Yield Increase

Yield loss and yield increase varied among plots assigned diverse treatments across years. Average relative seed yield losses and yield increases figured out for each treatment over control plots of each variety across years are depicted in Table 3. Yield losses of chickpea varieties due to *H. armigera* pressure from control plots of Dimtu and Habru were 69.13% and 67.79%, respectively. Both chickpea varieties evaluated with insecticide application attained the lowest relative yield loss related to the implementation of intercropping and trap cropping over the years. Insecticide application reduced the yield losses on both varieties more than other evaluated treatments (Table 3). Insecticide applications on the Dimtu variety minimized the relative yield loss on average by 41.20% compared with intercropping and trap cropping implementations, which recorded a relative yield loss of 25.92% and 56.56%, respectively. Likewise, cultivating the Habru variety with insecticide application had an average yield loss of 43.39% over intercropping and trap cropping, in which yield reductions of 30.30% and 56.47% were recorded in that order of presentation (Table 3). Regarding yield advantage, evaluated chickpea varieties exhibited yield increases of 40.95-223.89% (Dimtu) and 35.13-210.42% (Habru) when maintained with IPM package implementation, in which the lowest range was for trap cropping and the highest range was for insecticide application, over the control plots for the two varieties across years. Specifically, for both varieties, practicing intercropping also reduced relative yield loss and enhanced yield gain over control plots (Table 3).

Table 3: Effects of integrated pest management strategy on chickpea yield advantage and yield loss due to *Helicoverpa armigera* around Arba Minch in southern Ethiopia during the 2022 and 2023 main cropping seasons

Treatments		Yield (kg ha^{-1})	Relative yield (%)	Yield loss (%)	Yield increase (%)
Variety	Field husbandry				
Dimtu	Control	689.77	30.87	-69.13	0
	Intercropping	1655.11	74.08	-25.92	139.95
	Trap cropping	972.22	43.52	-56.48	40.95
	Insecticide use	2234.13	100	0	223.89
Habru	Control	700.79	32.21	-67.79	0
	Intercropping	1516.31	69.70	-30.30	116.37
	Trap cropping	947.00	43.53	-56.47	35.13
	Insecticide use	2175.40	100	0	210.42

Yield increase over control plots was estimated as the change between treated and untreated plots and expressed in percentage for each chickpea variety

Spearman Correlation (*r*) and Regression Analyses

Spearman correlation analysis revealed there were variable levels of significant (P>0.05 to <0.0001) relationships between study parameters across years (Table 4). There were highly significant (*P*<0.05) and positive (r>0.27) correlations among each of the *H. armigera* components and agronomic parameters over the years. As indicated in Table 5, NLBS had a significant and positive correlation with 72 hours after spray (r=0.287*) and damaged pods (r=0.270*), while 72 hours after spray exhibited a significant and positive correlation with damaged pods (r=0.497***). Likewise, NPPP had a significant and positive correlation with HSW (r = 0.593**) and GY (r=0.344**), while

Table 4: Spearman correlation coefficients (r) of the association between and among *Helicoverpa armigera* components, nodules and agronomic traits of chickpea around Arba Minch in southern Ethiopia during the 2022 and 2023 main cropping seasons

Variables	NLBS	72 hrs.	DP	NEN	PH	NPPP	HSW	GY
NLBS	1	0.287*	0.270*	-0.362*	-0.427**	-0.289*	-0.328*	-0.592***
72 hrs.	0.0479	1	0.497***	-0.277*	-0.356*	-0.296*	-0.074^{ns}	-0.584****
PD	0.0157	0.0003	1	-0.309*	-0.556****	-0.314*	-0.497**	-0.628****
NEN	0.0116	0.0501	0.0306	1	0.113^{ns}	0.065^{ns}	0.063^{ns}	0.063^{ns}
PH	0.0025	0.0101	<0.0001	0.4451	1	0.062^{ns}	0.348*	0.250^{ns}
NPPP	0.0453	0.0413	0.0297	0.6625	0.8667	1	0.593***	0.344*
HSW	0.0298	0.6178	0.0078	0.0986	0.0152	0.0001	1	0.292*
GY	0.0001	<0.0001	<0.0001	0.6726	0.0861	0.0165	0.0437	1

NLBS=Number of larva before spray; 72 hrs.=Represent time for mean number of live larvae after each sprays across treatments; DP=Damage pod estimated in percent; NEN=Number of effective nodules; PH=Plant height measured in cm; NPPP=Number of pod per plant; HSW=Hundred seed weight in gram; GY=Grain yield assessed in kg ha^{-1}. Numbers presented above and below the diagonal are referring to the correlation coefficient and P-values, respectively

Table 5: Mean economic returns against implementation of IPM package for the control of *Helicoverpa armigra* around Arba Minch in southern Ethiopia during the 2022 and 2023 main cropping seasons

Treatments		Yield (kg ha^{-1})	AGY (kg ha^{-1})	TIC ($ ha^{-1})	GR ($ ha^{-1})	NB ($ ha^{-1})	BCR
Variety	Field husbandry						
Dimtu	Control	689.77	620.79	428.20	1049.14	620.94	1.45
	Intercropping	1655.11	1489.60	501.64	2517.42	2015.78	4.02
	Trap cropping	972.22	875.00	538.06	1478.75	940.69	1.75
	Insecticide use	2234.13	2010.72	622.31	3398.11	2775.80	4.46
Habru	Control	700.79	630.71	428.20	1065.90	637.71	1.49
	Intercropping	1516.31	1364.68	501.64	2306.31	1804.66	3.60
	Trap cropping	947.00	852.30	538.06	1440.39	902.33	1.68
	Insecticide use	2175.40	1957.86	622.31	3308.78	2686.47	4.32

GY=Grain yield; AGY=Adjustable grain yield (at 10% down); TIC=Total input cost; GR=Gross return; NB=Net benefit; BCR=Benefit cost ratio. Mean unit price of grain yield was $1.69 kg^{-1} at Arba Minch during the two cropping seasons at the time of marketing, at the mean exchange rate of 1$=ETB 49.47.89 for the two years

PH and HSW were significantly and positively associated with HSW (r=0.348**) and GY (r=0.292*) in that order (Table 4).

Contrariwise, there were significant and negative connections among *H. armigera* components, nodulation, and crop parameters. For instance, NEN had a highly significant and negative link with NLBS (r=-0.362*), 72 hours after spray (r=-0.277*), and damaged pod (r=-0.309*). Highly significant and negative associations were established between GY with NLBS (r=-0.592**), 72 hours after spray (r=-0.584****), and damaged pods (r=-0.628****). Moreover, NPPP showed a significant and negative correlation with NLBS (r=-0.289*), 72 hours after spray (r=-0.296*), and damaged pods (r=-0.314*). Similar trends were also demonstrated between agronomic parameters and *H. armigera* components (Table 4).

Results of yield loss estimation on cultivated chickpeas were displayed as a plot of damage levels and grain yield (Figure 3). The regression model explained that 45.04% of the yield loss was caused by *H. armigera* pressure, regardless of chickpea varieties and treatments evaluated. The model also revealed that for every unit increase in *H. armigera* pressure, there was 53.37 kg ha^{-1} of yield loss in chickpea production. Additionally, the relationship study between values of damage level and grain yield exhibited that when the cumulative *H. armigera* gradient increased, grain yield was found to linearly decline towards the horizontal axis. Such a relationship could suggest that cumulative *H. armigera* had a reverse link with the yield performances of the evaluated chickpea varieties, irrespective of the IPM package options employed over the years.

Economic Returns for IPM Strategies Uses

Results of economic return analyses of IPM packages for the control of *H. armigera* are summarized in Table 5. In view of that, the highest (\$2775.80 ha^{-1}) net benefit was computed from the variety Dimtu combined with insecticide applications, followed by the Habru variety combined with insecticide application

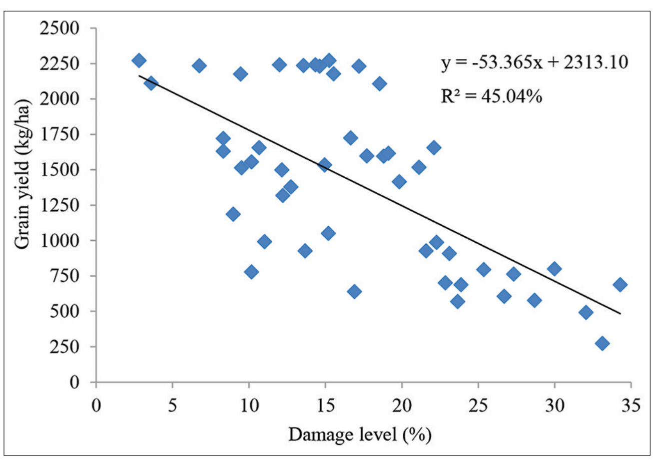

Figure 3: Linear regression of chickpea grain yield against pod damage caused by *Helicoverpa armigera* in plot-wise assessments under different integrated pest management strategies around Arba Minch in southern Ethiopia over the years, 2022 and 2023

(\$2686.47 ha^{-1}). Cultivation of each of the Dimtu and Habru varieties maintained with intercropping practices also resulted in a net benefit of \$2015.78 and 1804.66 ha^{-1} compared to control plots of each variety, respectively. Contrariwise, the lowest net benefit of \$620.94 and \$637.71 ha^{-1} was received from control plots of the Dimtu and Habru varieties, respectively. Likewise, insecticide applications gave a higher benefit-cost ratio on both Dimtu (4.46) and Habru (4.32) varieties, followed by the same varieties maintained with intercropping practices (4.02 and 3.60 respectively), than the respective control plots (Table 5). The highest economic returns calculated from both varieties due to insecticide application and intercropping practices could be ascribed to high yield and vice versa in both seasons. Findings indicated that the combination of each of the Dimtu and Habru varieties with insecticide application increased net benefit by 436.90% and 321.19% and the benefit-cost ratio by 207.57% and 189.93% over the respective control plots, respectively. Economically, it was apparent that Dimtu variety cultivation with insecticide application at a 10-day interval was the most cost-effective of all the other treatments considered in the study.

DISCUSSION

Chickpea pod borer (*H. armigera*) is the major challenge threat to chickpea production throughout the world. It is widely distributed and causes severe pod damage to chickpeas in Ethiopia (Gebretsadkan *et al.*, 2019; Shumi *et al.*, 2024). In the current study, different levels of pod borer larva population were observed on IPM packages, but they were highest in control plots regardless of the varieties in both seasons studied. The existence of susceptible hosts (chickpeas) may be the cause of the high level of pod borer infestation in the studied area. In addition, the favorable weather conditions in both cropping seasons (Figure 1) aggravated the larval density of *H. armigera* on unprotected plots. Similar reports made by Galav *et al.* (2018), Mehra and Singh (2023) and Sahu *et al.* (2024) showed that the large population and damaging status were strongly related to weather conditions. Adult females more preference for control plots over intercropping and protected plots for egg laying and frequent hatching coupled with the absence of biological agents leads to high larva population of *H. armigera* and damage in sole chickpea. In agreement with this study scholars stated that monocultures have eliminated food and habitat resources that beneficial insects need to survive (Thorbek & Bilde, 2004), limiting their ability to counter potential increases in pest pressure under climate change with biological control services (Gurr *et al.*, 2017).

The current study revealed that intercropping and trap cropping practices were significantly effective in reducing the larval population and percent pod damage over control of the Dimtu and Habru varieties of the two cropping seasons. Trap cropping attracts the ovipositor moths to lay eggs away from the target host crops. Similarly, intercropping also creates physical interference for moths while searching for the target host and provides space for prey predators. Consequently, predatory birds freely move in intercropping plots to hunt for and feed on pod borer larvae. In addition, trap cropping and intercropping create unfavorable conditions for *H. armigera* and expose the larvae to different natural enemies such as predators, parasitoids, and pathogens. In agreement with the findings of this study, the results of previous studies demonstrated by Renu and Ram (2008), Singh (2014) and Huss *et al.* (2022) reported that crop diversification through trap cropping and intercropping with chickpeas reduced the population of *H. armigera* and percent pod damage in various methods. Accordingly, chickpea-maize intercropping mitigates the microclimate and significantly reduces the percentage of pod damage over mono-cropped plots (Singh, 2014). Similarly, sunflowers release volatile compounds that attract adults for egg-laying and larval feeding. In a previous study, Kumar and Singh (2015) and Kumar (2017) reported that the use of sunflowers as a trap crop significantly reduced the larval density and prevented damage to chickpeas.

The lowest *H. armigera* larval density and pod damage were obtained from faratte insecticide-applied plots of Habru and Dimtu varieties over two cropping seasons. This indicates that the application of faratte insecticide for the management of chickpea pod borers was found to be effective in reducing larva density and consecutive pod damage. These findings are closely in agreement with the results of Kora and Teshome (2021), Shumi *et al.* (2021) and Shumi *et al.* (2024), who reported that foliar application of insecticides significantly reduced the population of chickpea pod borers and percent pod damage. Similarly, Hossain *et al.* (2010) reported that the active ingredient Lambda Cyhalothrin 5% w/v in faratte acts as a contact insecticide by directly interacting with the insect, leading to rapid knockdown effects due to its mode of action as a sodium channel modulator. In addition, it works by disrupting the insect's nervous system by binding to and interfering with the function of sodium channels in the nerve cells, causing paralysis and immediate death, which significantly reduces the percentage of pod damage (Nandha & Madesh, 2023). Comparatively, the highest nodulation numbers and agronomic traits were recorded from trap-cropped and intercropped plots, respectively, compared with other IPM packages applied to plots of both varieties. However, yield and yield-related traits were higher in insecticide-sprayed plots than in trap-cropped and intercropped plots in both cropping seasons. Chickpea varieties and the application of insecticide showed significant variation in the pod borer larval density, which adversely affects the agronomic traits and yield of chickpeas. A similar study reported that the integration of chickpea varieties and foliar application of insecticide significantly reduced larval density and increased yield and yield components (Temam & Tsegaye, 2022).

Accordingly, our study showed that 69.13% yield loss was obtained from untreated control plots compared with the best treatment. Both Dimtu and Habru varieties exhibited the highest yield losses (69.13% and 67.79%, respectively) during the two growing seasons. The highest yield losses encountered in the current study were mainly due to the highest larval invasion of chickpeas in both cropping seasons. According to Patel *et al.* (2010), *H. armigera* boring pattern and larval density accelerated in favorable weather conditions, and the phenomenon led to huge yield losses of 50% to 100%. Application of insecticide on the Dimtu variety reduced yield loss by 41.20% compared with untreated plots in both cropping seasons. This might be the effectiveness of insecticide and genetic diversity in the qualitative and quantitative traits present in the Dimtu variety. Regarding the yield advantage, the highest percentage (223.89%) of yield advantage over the control plot was recorded from the Dimtu variety treated with insecticide.

The present study demonstrated a significant and negative correlation between borer damage and yield components in both cropping seasons. This implies that *H. armigera* was strongly associated with chickpea yield losses in the study area. This finding is in line with the previous report by Narayanamma *et al.* (2007) and El Fakhouri *et al.* (2022) showed that there was a significant and negative association between yield parameters and pod borer damage in India and Morocco.

Economic analysis revealed that faratte foliar spray showed a higher cost-benefit ratio than the other applied IPM packages in two cropping seasons. The study demonstrated that foliar applications of faratte on Dimtu and Habru varieties were more cost-effective management options than other IPM packages. A similar study in Morocco reported that applications of foliar insecticide were cost-effective and exhibited a higher cost-benefit ratio in two cropping years (El Fakhouri *et al.*, 2022).

CONCLUSION

As evidenced by high pest pressure and yield losses, reduced growth, yield traits, and nodulation processes on control plots, and a strong negative correlation between pest parameters and agronomic traits during the growing seasons in both years, *H. armigera* activities had a significant impact on the performance of chickpea varieties. Comparatively, results suggested that the integrated use of chickpea varieties and insecticides with the right time and spray frequency minimized *H. armigera* activities and improved agronomic performances. As a result, chickpea cultivation, along with insecticide application, was found to be the most effective treatment combination in lowering pest pressure, enhancing agronomic features, and minimizing pest-related yield losses in both Dimtu and Habru varieties. However, the study found that when chickpea cultivation was maintained using either trap cropping or intercropping practices, a better nodulation process was observed. This suggests that other management strategies, like applying insecticides, had a negative effect on nodulation processes, despite having a significant impact on lowering *H. armigera* pressure and yield losses and improving agronomic performances. According to an economic evaluation of the IPM strategy, the integration of each of Dimtu and Habru with insecticide spray was found to have the highest net benefit and benefit-cost ratio when compared to sole cropping and other treatment combinations. Thus, combining the variety Dimtu and partly Habru with insecticide turned out to be a comparatively economical and cost-effective tactic for lowering *H. armigera* pressure and yield losses while improving agronomic features. For farmers in the study and other relevant regions, it could therefore be suggested, with other suitable agronomic practices to stop the harm caused by *H. armigera*, minimize pest-related yield losses, and maximize chickpea productivity. However, given the changing climate scenarios and the introduction of new agricultural technologies, like the introduction of new varieties and insecticides into the production systems, more research of such type should be conducted over years in diverse agro-ecological conditions to develop a sound recommendation for the wider farming community regarding the roles of integrating chickpea varieties and insecticide spray in reducing *H. armigera* damages and improving crop agronomic performances.

AUTHORS' CONTRIBUTION

Conceptualization, Z.F. and G.G.M.; Field investigation, Z.F., G.G.M., A.A. B.B., and T.S.; Data collection, Z.F. and A.A.; Methodology, Z.F., G.G.M. and A.A.; Curation and data analysis, Z.F. and G.G.M.; Draft paper writing, Z.F., G.G.M. and A.A.; Visualization, G.G.M. and T.S.; Reviewing and editing, Z.F., G.G.M., A.A. B.B., and T.S. All authors have read and agreed to the final version of the manuscript.

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