International Journal on Food, Agriculture, and Natural Resources
Volume 06, Issue 03, Page 80-87
ISSN: 2722-4066
http://www.fanres.org

Original Paper

Determination of Optimum Rate and Spray Frequency of Indoxacarb Insecticide for the Management of Chickpea Bollworm (Helicoverpa armigera) In Eastern Amhara, Ethiopia

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Received: 22 May 2025; Revised: 25 September 2025; Accepted: 29 September 2025
DOI: https://doi.org/10.46676/ij-fanres.v6i3.546

***Abstract*— Bollworm is the major insect pest of Chickpea in Ethiopia. Field experiment was conducted at Sirinka and Cheffa research sites during 2022 main growing season to determine the appropriate rate and spraying frequency of Indoxacarb insecticide and select cost-effective management options of bollworm. A randomized complete block design was implemented with three replications. The combination of three rates and three spraying frequencies of indoxacarb insecticide and unsprayed treatments was evaluated. The lowest (0.27 and 0.03) mean larva number were scored from plots treated 0.75 L with three times spraying frequency at Sirinka and Cheffa respectively. The lowest (1606 and 1269 kg ha^{-1}) chickpea seed yield was found from untreated control plots. Similarly, the highest (2956 and 2835 kg ha^{-1}) seed yield was obtained from plots treated with 0.75 L rates with two and three times spraying frequencies at Sirinka and Cheffa respectively. However the highest (804.4%) marginal rate of return was obtained from plots treated 0.5 L with two times spraying. Generally, 0.5 liter with two times spraying of indoxacarb was effective in controlling bollworm and got the highest cost-benefit advantage as compared with other treatments. Therefore, it could be recommended for the management of chickpea bollworm in the study areas and similar agro-ecologies of chickpea growing areas in Ethiopia.**

Keywords*— *chickpea, helicoverpa armigera, indoxacarb, pod damage, seed yield

I. Introduction

Pulses are very valuable crops and are grown in a great number of varieties in most parts of the world. Chickpea is one of the most important pulse crop and belongs to the family leguminaceae [12]. And also, plays a significant role in improving soil fertility by fixing the atmospheric nitrogen [9 and 14]. Worldwide it is grown on an area of 14.56 million hectares with a production of more than 14.77 million tons [7]. While Ethiopia is the seventh largest producer worldwide and contributes about 3% to the total world chickpea production [9]. Ethiopia is the largest producer, consumer and exporter of chickpea in Africa and shares 4.5% of global chickpea market and more than 60% of Africa's global chickpea market [20].

The national average yield of this crop in Ethiopia has remained less than one ton ha-1, while the world average is 1.2 tones ha-1. This is mainly due to the lack of improved cultivars and poor agronomic practices as well as abiotic and biotic stresses such as insect pests, diseases, drought and water logging [21].

The Africa Bollworm (H. armigera) is one of the most damaging insect pests, as it has a diverse range of wild and agricultural hosts in various ecological regions. Its life-history traits, which include multiple generations, various crop hosts, the ability to enter diapause, and seasonal population fluctuations, pose significant challenges for ecological and evolutionary research [6]. African bollworm is the most important and serious insect pest of in many countries of the world including in Ethiopia [1 and 19]. This insect is one of the most significant constraints to chickpea productions, caused up to 32.5% of seed yield losses [1]. In Ethiopia, this pest feeds on a variety of plants, including beans, chickpeas, peas, sorghum, cotton, tomato, pepper, sunflower, safflower, flax, and Niger seed [13 and 18).

Management of Helicoverpa armigera through the application of pesticides (insecticide) could be an important practice to control the infestation of pest [8]. Chemical pesticides like pyrethroids, carbamates, and organophosphates are used to manage Helicoverpa pests [13]. According to [1] research result, the application of indoxacarp insecticide could minimize the mean number of bollworm larva and improve chickpea seed yield as compared with other insecticides and control plots. [19], assessment result indicated that Lambda-cyhalotrine and Dimethoate insecticides were mostly used by farmers for the management of bollworm on chickpea.

In the study areas Indoxacarb inseticide was recommended for the management of African bollworm [1]. Spraying of indoxacarb insecticide for the control of bollworm insect at different rates and spraying frequency may have different effects on the development of the insect. Thus it was essential to study the rate and spraying frequency of indoxacarb insecticide for the management of African bollworm on chickpea which are still in use in blanket recommendation. Therefore, the study was conducted to determine appropriate and cost-effective rate and spraying frequency of indoxacarb insecticide for the management of African bollworm on chickpea in Eastern Amhara, Ethiopia.

II. Materials and Methods

A. Experimental site description

The field experiment of rate and spray frequency of indoxacrab insecticide on the management of Helicoverpa armigera was conducted at Sirinka and Cheffa research sites of Sirinka Agricultural Research Center during the main cropping seasons of 2022. The altitude of experimental fields were 1850 and 1450 m.a.s.l., located 11° 45′ 10” and 10o 50′ 39” North latitude to 39o 36′ 44” and 39° 48′ 46” East longitude at Sirinka an Cheffa, respectively. The soils of the experimental sites are eutric vertisol (Sirinka agricultural research center) which is generally good for chickpea cultivation. The trial sites receive 13.6°C, 27.3° C, and 876 mm; 11.6°C, 30.4°C, and 850 mm annual minimum temperature, maximum temperature and rainfall for Sirinka and Chefa, respectively.

B. Experimental design and materials

The field experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications. The experiment had 10 treatments (Table I); with a combination of three rates of indoxacarb insecticide (0.25, 0.5, and 0.75 L/Ha) and three spraying frequencies of indoxacarb insecticide (one, two, and three times spray) and unsprayed treatment as a control check. The crop was sown on 40 × 10 cm spacing between row and plants respectively in a gross plot size of 7.2 m2 (3 m x 2.4 m) or harvestable plot area of 5.0 m2 with a buffer zone of 1 m between plots and 1.5 m between blocks. The variety Habru (Kabuli type) recommended to the area was planted without any fertilizer application in the last week of August. All other relevant field trial management practices, such as weeding, were carried out according to the recommendations. Each plot was received different rate and spray frequency of indoxacarb insecticide treatment to get the maximum protection potential of insecticides. The control plots were sprayed with water alone. The application was done with the help of “Knapsack sprayer” with 20-liter capacity. Regular inspections of the chickpea field were conducted to observe the crop's growth stages and monitor the target insect population. The first application was made when the larval population crossed the economic threshold level (one larva per meter row) at the pod setting stage of the crop [17]. The second and third sprays were applied at ten days interval to get maximum protection of the pest. To avoid insecticide and drift, plastic sheets were used during the application.

TABLE I. Treatment Combination

Treatment	Treatment Combination
1	0.25*1X
2	0.25*2X
3	0.25*3X
4	0.5*1X
5	0.5*2X
6	0.5*3X
7	0.75*1X
8	0.75*2X
9	0.75*3X
10	Control

C. Data collection

The number of larvae of H. armigera were collected from 10 randomly pre-tagged chickpea plants on the presence of the first larvae symptom appearance. Larvae were counted from the whole above-ground parts of the plants in each plot four times at ten days interval. Thus, mean larvae count per plant presented by the average number of the four larvae counts in each location. Damage to the pods was observed while harvesting the mature crop. Healthy and damaged pods were counted on randomly selected ten plants per plot and then percent pod damage was evaluated. After threshing, the hundred seed weight was measured by randomly selecting five plants from each plot and counting 100 undamaged seeds, which were then weighed. Grain yield was collected from whole harvestable plot area then changed for 1 ha. The damage on pods and loss in grain yield caused by the pest was calculated by using formulas adopted from [16]. The percentage of pod damage was estimated

$$\%Pod\ damage = \frac{\text{Total number of pods damaged}}{\text{Total number of pods}}\ x\ 100 \quad ....(1)$$

D. Relative yield loss and percentage yield increase

Relative Yield loss due to African bollworm was measured as percentage yield reduction of unsprayed plots compared with the most protected plot using the following formula of [15]:

$$RPYL = \frac{YP-YT}{YP}\ x\ 100 \quad ....(2)$$

Where RPYL = relative percent yield loss, YP = yield from the maximum protected plot and YT =Yield the respective parameter in other treatments and unprotected plot

The percent yield increase (PYI) was calculated based on the following suggested formula [11]:

$$PYI = \frac{\text{Seed yield of the respective treatments} - \text{yield of control plot}}{\text{yield of control plot}} \times 100 \quad ....(3)$$

E. Cost-benefit assessment

Cost-benefit assessment of each treatment was analyzed partially, and the marginal rate of return was computed by considering the variable cost available in the respective treatment [4]. Variable costs encompassed the expenses for chemicals and labor associated with their application. The price of indoxacarb was Ethiopian Birr 2300 per litter and the labor cost of Birr 400 man-days was used. At the end of the production total gross benefit of the field was calculated from the Seed yield of Chickpea with the local market price (Birr 52.50 kg^{-1}) of each District. Total input costs that were obtained from the summation of total cost that vary and fixed cost of the production that used. The expenses and advantages of each treatment were examined individually, and the marginal rate of return (MRR) was calculated by taking into account the variable costs associated with each treatment. Yield and economic data were computed to compare the advantage of rates and spraying of insecticide applications in different treatment combinations. The marginal rate of return indicates the value of the benefit gained for each percentage of additional cost incurred.

$$MRR = \frac{DNI}{DIC} \quad ....(4)$$

Where, MRR stands for the marginal rate of returns, DNI refers to the difference in net income relative to the control group, and DIC denotes the difference in input costs compared to the control plot.

F. Data analysis

Data on mean larvae, pod damage, yield and yield components were subjected to Analysis of variance (ANOVA) for each data by using GenStat version 18.0 Software [10]. Duncan's multiple range test was employed to separate the treatment means. The linear regression model was used to predict the relationship of mean bollworm larvae and chickpea seed yield by using GenStat version 18.0 Software.

III. RESULTS AND DISCUSSION

The analysis of the result showed that there was a significant difference among treatments ($p < 0.05$) for mean larval count per plant, percentage pod damage, pod per plant (at Sirinka), and grain yield. And also there was not significant difference among treatments on pod per plant (at Cheffa), seed per pod and hundred seed weight at both locations of Sirinka and Cheffa (Tables II and III).

A. Mean larva number per plant

Indoxacarb insecticide spray at a different rate and spraing frequency showed a significant difference ($P<0.05$) on mean larvae count per plant in 2022 cropping season. In all treatments, there was reduced bollworm larva emerged on indoxacarb insecticide treated plots compared to the control Table II and III). At Sirinka, the lowest mean larvae count (0.27 and 0.27) was scored from plots treated with 0.5 l/ha with two times and 0.75 l/ha with three times spraying frequency. Whereas, the highest mean laravae count (0.88) were recorded from unsprayed control plot, followed by 0.62 treated from 0.25 L/ha with two times spraying frequency (Table II). Similarly, at Cheffa experimental site the highest mean larvae (0.67) was recorded from the unsprayed control plot and the lowest (0.03) was scored from plots sprayed 0.75 liter indoxacarb insecticide with three times spraying frequency (Table III).

Moreover, in 2022 cropping season the first African bollworm larava assessment was started at the pod setting stage of chickpea at 46 and 54 DAP in Sirinka and Cheffa trial site respectively (Figure 1 and 2). Before the treatment began, the distribution of larval population in the plot was evenly spread out. The first application was made when the larval population crossed the economic threshold level (one larva per meter row) at the pod setting stage of the crop (Singh et al., 2018). However, after spraying indoxacarb insecticide at various rates and frequencies, the larval population in the treated plots decreased uniformly to almost zero up to the final assessment date at both locations of Chefa and Sirinka. Even in the untreated control plots, there was a decrease in the average larval count during the second and third sampling dates due to a reduction in adult boll worm visits to the field (Fig. I and II). The distribution of bollworm larval population is similar with [1] research result.

The finding of the result indicated three times spraying frequencies with 0.75 l/ha rates of indoxacarb at ten days interval could be effective to reduce the number of bollworm larvae at both locations. But partial budget analysis indicated that 0.5 L ha-1 rate with two times spraying frequency of indoxacarb insecticide was the most profitable than other combinations. The present study was in line with the result of [2], indoxacarb proved to be the best over in reducing the number of bollworm larvae based on pre-spray data. These results are in agreement with [3], who found significant reduction in the larval population of these insects on tobacco. Similarly, the lowest number of larvae count was recorded on seven days interval of all insecticide sprayed plots [1 and 6]. Insecticides reduced larvae number with lower pod damage % and enhanced yield as compared to control plot [8 and 13].

B. Pod damage

The percentage of pod damage showed significance difference ($p< 0.05$) among treatments at both locations of Sirinka and Cheffa (Table II & III). The highest pod damage (16.67 and 8.91%) were recorded from the control plots at Sirinka and Cheffa locations respectively. And also, the lowest (0.23%) pod damage was scored from plots treated 0.5 liter with three times spraying frequencies of indoxacarb insecticide at Sirinka (Table II) and 1.34% scored from 0.25 liter of indoxacarb insecticide with three times spray at Cheffa trial site (Table III). The finding of the result indicated three times the foliar sprays of indoxacarb at ten days interval could be effective to reduce the percentage of pod damage at both locations. The present study indicated that three-times spraying frequencies with all rates of indoxacarb insecticide were the best management options of African bollworm. This aligns with the research conducted by [5], which found that the highest (6.1 and 13.5%) pod damage was achieved in plots treated with highway and nimbicidine insecticides respectively. Similarly, the highest (7.94 and 21.4%) percentage of pod damage was recorded on the control unsprayed plots [1]. According to [6], insecticides reduced larvae number with lower pod damage % and enhanced yield as compared to control plot.

TABLE II. MEAN OF YIELD, YIELD COMPONENT, MEAN LARVA AND POD DAMAGE DATA OF CHICKPEA AT SIRINKA (2022)

Trt	mean larva	PD (%)	PPP	SPP	HSW	SY kg ha^{-1}
0.25*1X	0.43^{ab}	1.6^{a}	20.87^{a}	1.33	31.7	1865^{cd}
0.25*2X	0.62^{bc}	0.85^{a}	32.07^{c}	1.2	31.3	2186^{a-d}
0.25*3X	0.38^{ab}	0.65^{a}	21.2^{a}	1.133	31.7	2408^{a-d}
0.5*1X	0.37^{ab}	1.1^{a}	30.1^{bc}	1.333	31	1993^{bcd}
0.5*2X	0.27^{a}	1.42^{a}	29.27^{bc}	1.2	31.7	2644^{abc}

0.5*3X	0.42^{ab}	0.23^{a}	25^{ab}	1.133	33.3	2657^{abc}
0.75*1X	0.35^{ab}	0.31^{a}	20.33^{a}	1.133	32.3	2354^{a-d}
0.75*2X	0.34^{ab}	0.68^{a}	30.33^{bc}	1.267	31	2956^{a}
0.75*3X	0.27^{a}	1.1^{a}	31.4^{c}	1.133	31.3	2802^{ab}
Control	0.88^{c}	16.67^{b}	20.87^{a}	1.2	31	1606^{d}
GM	0.43	2.43	26.14	1.21	31.6	2347
DMRT (5%)	*	***	***	NS	NS	*
CV (%)	39.9	42.7	12.9	17.2	4.2	18.6

: Ns= No significant at p<0.05; *= Significant at P<0.05; *= Significant at P<0.001; PD= Pod damage; PPP= Pod per plant; SPP= Seed per pod; HSW= Hundred seed weight; SY= Seed yield; GM= Grand mean; DMRT= Duncan's multiple range test; CV= Coefficient of variation*

C. Pod number per plant

The result of average chickpea pod number per plant revealed a significant difference (p<0.05) among the combination of rate and spraying frequencies of indoxacarb insecticide at Sirinka locations. But there was not significant difference at Cheffa experimental site (Table II and III). At Sirinka, the highest number of pod per plant (32.07) was recorded from plots treated 0.25 L indoxacarb insecticide with two times spraying frequency whereas the lowest pod number (20.87) was recorded from untreated control plots (Table II). At Cheffa, rate and spraying frequency of indoxacarb applications did not significantly affect pod number per plant (Table III). The result indicated that the integration of rate and spraying frequency application did not affect the pod number of chickpea. The present study was supported by [6] research result, the lowest pod number per plant was found from untreated control plot.

D. Seed per pod and hundred seed weight

The analysis of variance showed there was not significant difference (p<0.05) between treatments on chickpea seed per pod and hundred seed weight at both locations of Sirinka and Cheffa (Table II and III). The result indicated that rate and spraying frequency of indoxacarb insecticide did not affect chickpea seed per pod and hundred seed weight. It is similar to the result of [1] research findings, all insecticide treated plots showed not significance difference on seed per pod and hundred seed weight.

TABLE III. MEAN OF YIELD, YIELD COMPONENT MEAN LARVA AND POD DAMAGE DATA OF CHICKPEA AT CHEFFA (2022)

Trt	mean larva	PD (%)	PPP	SPP	HSW (gm)	SY kg ha^{-1}
0.25*1X	0.25^{b}	2.11^{ab}	74.79	1.40	33.26	1931^{ab}
0.25*2X	0.3^{b}	5.55^{abc}	44.60	1.13	33.00	2085^{ab}
0.25*3X	0.15^{ab}	1.34^{a}	62.80	1.20	33.67	2506^{b}
0.5*1X	0.22^{b}	6.02^{cd}	62.37	1.00	32.00	2294^{b}
0.5*2X	0.25^{b}	4.61^{abc}	48.33	1.20	33.33	2735^{b}
0.5*3X	0.17^{ab}	4.23^{abc}	51.13	1.13	31.00	2698^{b}
0.75*1X	0.18^{ab}	4.66^{abc}	60.87	1.07	33.67	2189^{ab}
0.75*2X	0.25^{b}	4.86^{bc}	63.47	1.20	33.33	1968^{ab}
0.75*3X	0.03^{a}	3.33^{abc}	73.87	1.07	32.33	2835^{b}
Control	0.67^{c}	8.91^{d}	59.93	1.27	32.00	1269^{a}
GM	0.26	4.56	60.2	1.16	32.76	2251
DMRT (5%)	***	***	NS	NS	NS	*
CV (%)	32.8	31.6	23	13.3	5.5	22.3

*: Ns= No significant at p<0.05; *= Significant at P<0.05; ***= Significant at P<0.001; PD= Pod damage; PPP= Pod per plant; SPP= Seed per pod; HSW= Hundred seed weight; SY= Seed yield; GM= Grand mean; DMRT= Duncan's multiple range test; CV= Coefficient of variation

E. Seed yield of chickpea

The analysis of variance showed a significant difference at (p<0.05) between the combination of rate and spraying frequencies of indoxacarb insecticide application on seed yield of chickpea (Table II and III). At Sirinka, from all combinations of these rate and spraying frequencies of indoxacarb insecticide, the maximum (2956) seed yield was obtained from plots treated 0.75 L with two times spraying of indoxacarb. Followed by 2802 kg ha-1 found from plots treated with 0.75 L with three times spraying of indoxacarb. On the other hand, the minimum (1606 kg ha-1) seed yield was obtained from the untreated control plot (Table II). Similarly, at Cheffa the maximum (2835 kg ha-1) and minimum (1269 kg ha-1 g) seed yield was recorded on plots sprayed 0.75 L with three times spraying of indoxacarb insecticide and from untreated control plots respectively (Table III). Insecticides reduced larvae number with lower pod damage % and enhanced yield as compared to control plot [6]. The present study is supported by [1], research finding there is a significant difference among treatments on chickpea seed yield. His result indicated that, the maximum number of seed yield was obtained from treated plots and the lowest number of seed yield was obtained from unsprayed control plots.

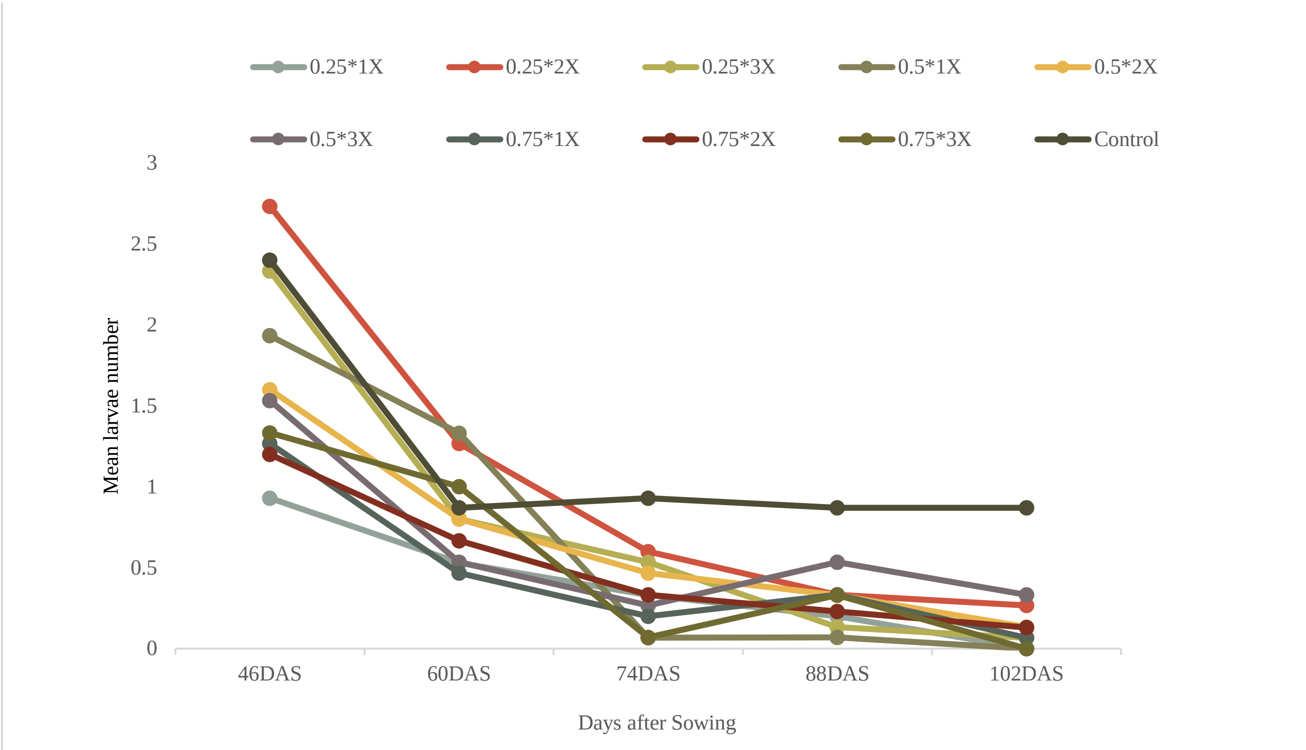

Fig. 1. Bollworm larvae progress curve at Sirinka, during 2022 cropping season

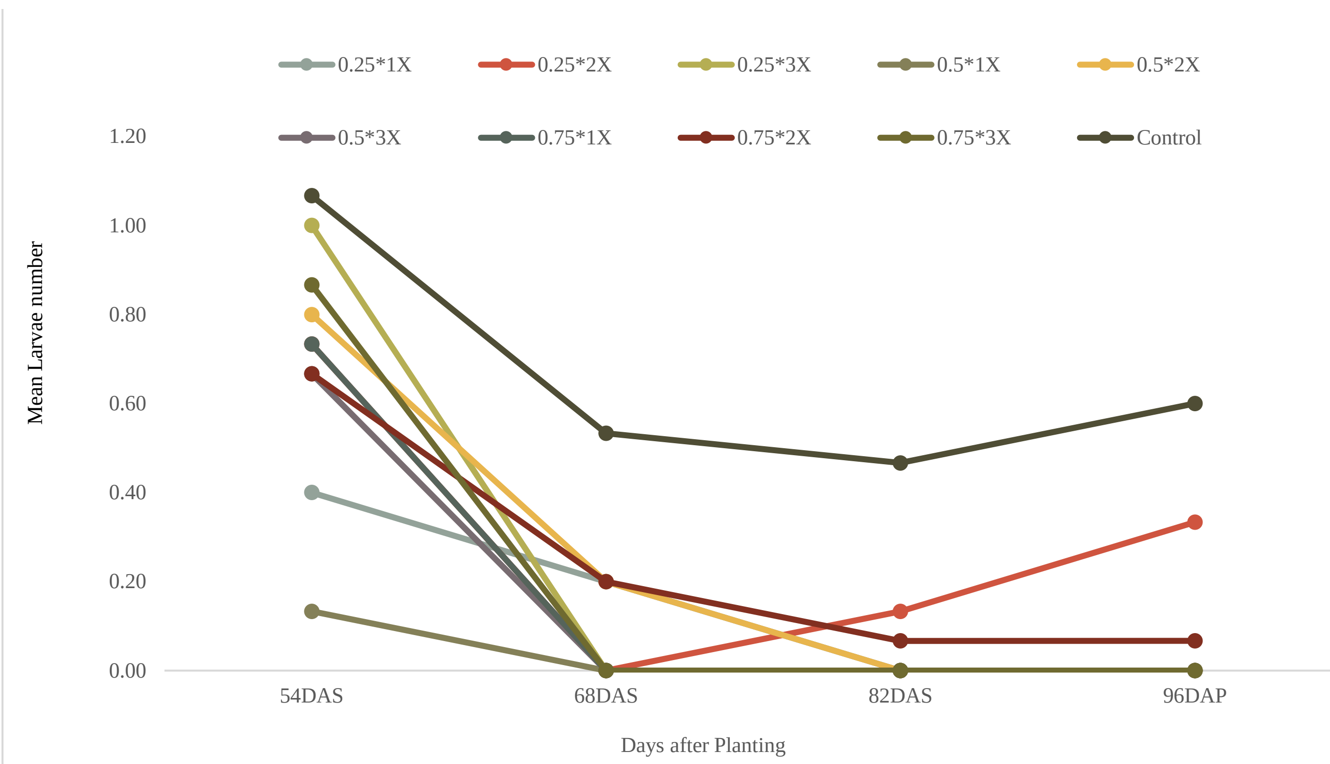

Fig. 2. Bollworm larvae progress curve at Cheffa, during 2022 cropping season

F. Relative Yield loss and percentage yield increase

Relative yield loss and percentage yield advantage of chickpea were calculated by using the average seed yield of Sirinka and Cheffa locations. The yield loss assessment was calculated for all treatments relative to the yield of a maximum protected plot of 0.75 L insecticide rate with two and three times spraying frequency of indoxacarb applications at Sirinka and Cheffa respectively. The highest (45.67 and 55.24%) relative yield loss was recorded on unsprayed control plots at Sirinka and Cheffa, respectively. Followed by 36.91 and 31.89% yield loss from plots treated 0.25 L with one-time spraying frequency of Indoxacarb insecticide spraying at Sirinka and Cheffa (Table IV). The combinations of rate and spraying frequencies of indoxacarb insecticide applications relatively reduced chickpea seed yield losses as compared with the unsprayed control plot. This indicates that how much African bollworm is damaging chickpea crops during favorable conditions when effective management practices haven't undertaken. The results indicated the application of insecticides used to minimize the effect of the insect and decreased chickpea seed yield losses. According to [1], the maximum (32.48%) seed yield loss due to bollworm larvae recorded from unsprayed control plots. In addition to that, the the lowest seed yield losses were obtained from insecticide sprayed plots as compared with unsprayed control plots [6].

The percent yield increase study was calculated from all treatments as compared to the untreated control plots. The present study indicated that the percent yield increase showed differences among treatments. The highest (84.06 and 123.4%) yield increase was obtained from plots treated 0.75 L insecticide rate with two and three times spraying frequency of indoxacarb applications at Sirinka and Cheffa respectively (Table IV). The present study supported by [1 and 22] research findings, application of insecticides resulted a greater than untreated control plots.

TABLE IV. RELATIVE YIELD LOSS AND PERCENTAGE YIELD ADVANTAGE OF CHICKPEA AT CHEFA IN 2022

Trt	Sirinka			Cheffa		
	SY kg ha^{-1}	*RYL %*	*PYI %*	*SY kg ha^{-1}*	*RYL %*	*PYI %*
0.25*1X	1865	36.91	16.13	1931	31.89	52.17
0.25*2X	2186	26.05	36.11	2085	26.46	64.30
0.25*3X	2408	18.54	49.94	2506	11.60	97.48
0.5*1X	1993	32.58	24.10	2294	19.08	80.77
0.5*2X	2644	10.55	64.63	2735	3.53	115.52
0.5*3X	2657	10.12	65.44	2698	4.83	112.61
0.75*1X	2354	20.37	46.58	2189	22.79	72.50
0.75*2X	2956	0.00	84.06	1968	30.58	55.08
0.75*3X	2802	5.21	74.47	2835	0.00	123.40
Control	1606	45.67	0.00	1269	55.24	0.00

**: SY= Seed yield, RYL= Relative yield loss, PYI= Percentage Yield Increase*

G. *Mean larva number per plant*

Linear regression analysis of chickpea seed yield and mean number of larvae was used for predicting the chickpea seed yield loss. Because mean larvae number of bollworm linear regression is a better analytical model to indicate the relationship of yield loss with the bollworm insect effects. Mean larvae number was considered to be an independent variable and chickpea seed yield considered as a dependent variable was regressed to estimate the yield loss due to the insect. The higher the mean larvae populations, the more susceptible. Thus, as mean larvae number of bollworm increases, the yield decreases and goes towards zero asymptotes, which indicates the inverse relation between mean larva number and seed yield of chickpea.

At Sirinka equation of the model was, Y = -1865.8X + 3106.9 indicated that for every one unit increases in mean larvae number, there is a corresponding 1865.8 kg ha-1 chickpea seed yield loss was occurred 2022 main cropping season (Figure III). The relationship indicated by regression linear model, 68.75% of loss in chickpea seed yield was predicted due to African bollworm insect.

Similarly, the equation of linear regression model was, Y = -2138.9X + 2779.3

indicated that for every one unit increases in mean larvae number, there is a corresponding 2138.9 kg ha-1 chickpea seed yield loss occurred at Cheffa 2022 main cropping season. The model indicated that 56.22% of loss in chickpea seed yield was predicted due to bollworm larvae at Cheffa (Figure IV). In general, the linear regression graph indicates as the mean larvae increase there was a decreasing trend in chickpea seed yield at both locations.

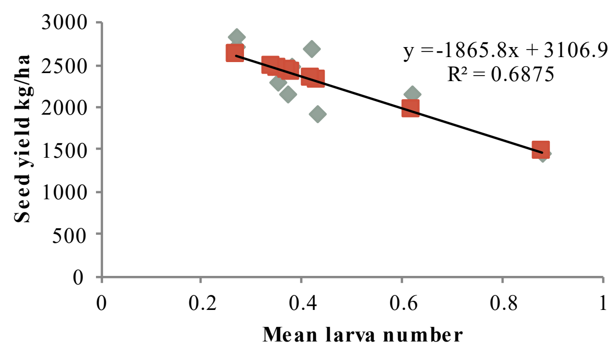

Fig. 3. Regressions analysis of Chickpea yield and mean number of larvae at Sirinka in 2022 main cropping season.

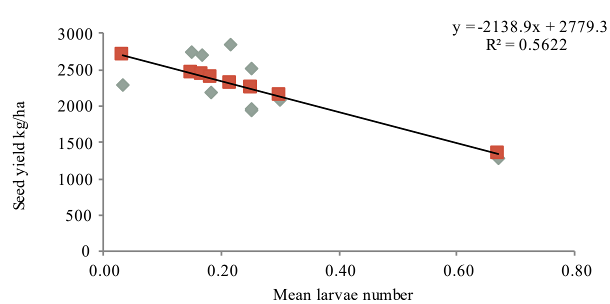

Fig. 4. Regressions analysis of Chickpea yield and mean number of larvae at Cheffa in 2022 main cropping season

H. Cost-benefit analysis

Cost-benefit analysis was done for the management of African bollworm through different rates and spraying frequencies of indoxacarb insecticide application (Table V). The result of partial budget analysis of indoxacarb application on chickpea field obtained an increase in net benefit due to indoxacarb application which resulted in maximum seed yield than unsprayed control plots. Three times spraying frequencies were giving the highest net benefit, marginal net benefit and marginal rate of return on 0.25 and 0.75 L rates as compared to 0.5 L rate and unsprayed control plots. Maximum (121053.8 and 121188.9 ETB ha-1) net benefits were obtained from plots treated with 0.5 L with two times spraying and 0.75 L with three times spraying frequency of indoxacarb insecticide respectively. And also, minimum (63941.06 ETB ha-1) net benefits were obtained from untreated control plot (Table V) Marginal net benefit had shown variations among the combination of rate and spraying frequency of indoxacarb insecticide. In addition to that marginal rate of return was describes a method for comparing the costs that vary with the net benefits of all treatment combinations. The highest (804.4 %) marginal rate of return had been obtained from plots treated 0.5 L with two times spraying; followed by 501.15 % obtained from 0.25 L with two times spraying frequency of indoxacarb insecticide. The result agrees with [1] research result, the highest (33603.9 ETB) net benefit was obtained from spraying of indoxacarb insecticide at seven days interval starting from the onset of the bollworm larvae.

TABLE V. PARTIAL BUDGET ANALYSIS OF RATE AND SPRAYING FREQUENCIES OF INDOXACARB FOR THE MANAGEMENT OF BOLLWORM

Treatment	ASY ha^{-1}	PP/kg	GB/ha	MC ha^{-1}	NB ha^{-1}	MRR (%)
0.25*1X	1723.05	52.5	90460.13	2975	87485.13	-
0.25*2X	1899.225	52.5	99709.31	5950	93759.31	501.15
0.25*3X	2233.35	52.5	117250.9	8925	108325.9	497.31
0.5*1X	1996.875	52.5	104835.9	3550	101285.9	-
0.5*2X	2441.025	52.5	128153.8	7100	121053.8	804.40
0.5*3X	2418.975	52.5	126996.2	10650	116346.2	-
0.75*1X	2007.225	52.5	105379.3	4125	101254.3	-
0.75*2X	1993.5	52.5	104658.8	8250	96408.75	-
0.75*3X	2544.075	52.5	133563.9	12375	121188.9	462.61
Control	1217.925	52.5	63941.06	0	63941.06	0.00

**: ASY=Adjusted seed yield, PP= Price per kilo gram, GB= Gross benefit, MC= Marginal cost, NB= Net benefit, MRR= Marginal rate of return*

IV. CONCLUSION AND RECOMMENDATION

This study evaluated indoxacarb insecticide rates and spraying frequencies to manage African bollworm in chickpea. Results showed that spraying frequency was more critical than application rate. Treatments at 0.5 L/ha sprayed twice effectively reduced larvae number and pod damage, but raised yield, and this treatment provided the highest marginal rate of return (804.4%), hence it was the most cost-effective.

In general, according to this outcome, the use of 0.5 L indoxacarb with two sprays is recommended for end-users. As it offered the most cost-effective benefit compared with the other treatments and the control. Additional multi-location and multi-year trials are needed to verify these findings under various agro-ecologies and develop integrated pest management plans for enhancing chickpea productivity.

ACKNOWLEDGMENT

We would like to thank Sirinka Agricultural Research Center and Amhara Agricultural Research Institute for their full budget support.

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