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Management of pigeon pea pod borer (*Helicoverpa armigera)* using biopesticides and yield performance in arid and semi-arid areas of Kenya

Stella Jepkosgei[1], Miriam K. Charimbu[1]*, Paul Kimurto[1], Juliana J. Cheboi[2] and Nadigatla G. Rao[3]

[1]Department of Crops, Horticulture and Soils, Egerton University, Kenya
[2]Department of Plant Science and Crop Protection, University of Nairobi, Kenya.
[3]International Maize and Wheat Improvement Center (CIMMYT), Nairobi, Kenya.

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Pod borer *(Helicoverpa armigera)* is one of the major causes of low productivity in pigeon pea (*Cajanus cajan*) in Kenya. This study determined the effect of Nimbedicine, Pyagro and *Bacillus thuringiensis* on pod borer and grain yield performance of two pigeon pea varieties. The experiments were set up in Kapkayo and Koibatek during April-September, 2020 and May-October, 2021 cropping seasons. The experiment was laid in split plot with three replicates. Data on pod and flower damage, severity, percentage infestation, days to flowering, number of pods per plant, grain yield and 100 seed weight were subjected to analysis of variance and mean separated using Tukey's Honest Significant Difference test. Results show that Nimbedicine significantly reduced pod borer population in all stages of growth by 74.82%, Pyagro 58.64% and *Bt* 52.97%. Higher yields were recorded in plots sprayed with Nimbedicine (0.99) followed by Pyagro (0.72) and *Bt* (0.66) tons/ha in both sites. Koibatek had significantly higher grain yield (0.90 tons/ha) as compared to Kapkayo (0.68 tons/ha). A positive correlation between grain yield and pods per plant were observed. The findings of this study have identified and validated appropriate biopesticides for management of pigeon pea pod borer for enhanced pigeon pea productivity in Kenya.

Key words: *Bacillus thuringiensis*, biopesticides, management, pigeon pea, pod borer control, yield and yield components.

INTRODUCTION

Pigeon pea *(Cajanus cajan Millsp.)* is the 3rd most important legume in the world after common bean (*Phaseolus vulgaris* L) (FAOSTAT, 2019) with numerous uses such as food constituent (Okpala and Okoli, 2014), and as an alternative protein source in poultry feed (El-Hack et al., 2018). Green pods are used for vegetable purposes while dried peas are used as pulses (Tanuja and Kaith, 2020). Pigeon pea is a legume reported to contain 20-30% protein, 1.2% fat, 65% carbohydrate and 3.8% ash (Karri and Nalluri, 2017; Cheboi et al., 2019).

*Corresponding author. E-mail: miriam.charimbu@egerton.ac.ke.

Because of these nutritional attributes, pigeon pea has become the main source of protein and a cash crop that supports many resource poor farmers in the dry land regions of Kenya as it is a multipurpose drought tolerant crop. It is a fast growing, hardy and widely adaptable crop (Jama and Zeila, 2005). Pigeon pea is known to be incorporated as green manure into the soil thereby increasing soil carbon, available nitrogen and reduces nitrogen losses (Bashir and Ahmad, 2019). The biomass from pigeon pea rapidly decomposes to release nitrogen as compared with maize stovers. Residues of high quality organic inputs on the other hand decompose quickly and may release about 70% of the Nitrogen within a season under tropical conditions (Ibrahim et al., 2018). Additionally, it is a source of wood for fuel and it's used for fencing purposes. Being environmentally friendly by fixing nitrogen and its flexibility for mixed cropping, it has significant position in dry land farming hence adopted by small scale and marginal farmers in many parts of the world (Sameer et al., 2017). It has the ability to fix up to 235 kg nitrogen (N/ha) from atmospheric nitrogen and produce more N per unit from plant biomass compared to other legumes (ICRISAT, 2018). Its deep taproot is able to extract nutrients from deep layers of the soil and bring them to the surface for other crops to benefit from them. It enhances nutrient recycling from deeper layers by taking up forms of phosphorus that would otherwise not be available to other crops, thus providing multiple benefits to cropping systems (Valenzuela, 2011).

Pigeon pea is currently cultivated on 5.5 million Ha with an annual production of 4 million metric tons and productivity of 768 kg/ha (FAOSTAT 2018). Over 70% of the world's production is produced by India which has the largest area (3.38 million ha), (Prasad et al., 2013. In East and Southern Africa (ESA), the leading pigeon pea producing countries are Malawi (170,091.5 tons), Tanzania (142,978.8 tons), Kenya (109,623.1 tons) and Uganda (48,331.63 tons) (FAOSTAT 2017). In East Africa pigeon pea is becoming important in small scale farming systems majorly due to its ability to produce food grain under harsh conditions that are imposed by moisture stress, high temperatures and unproductive soils.

Insect pest is one of the major constraints for poor productivity of pulses in Kenya including pigeon pea. About 250 insect pest species belonging to 8 orders and 61 families have been found to infest pigeon pea from seedling to harvesting stage and literally no plant part is free from insect pest infestation (Taggar et al., 2022). Among these, nearly dozens of insect pests cause heavy crop losses and about 3.49 million tons costing 2,285.29 million USD are lost annually due to ravages of insect pest complex (Reddy, 2009). Pod borer *(Helicoverpa armigera* Hubner*)* is one of the major causes of low productivity in pigeon pea *(C. cajan* Millsp.) in Kenya especially under dryland production systems. They feed not only on tender leaves and flowers but also make holes in the pods and feed on developing grains (Srilaxmi and Paul, 2010; Sharma, 2016; Nair et al., 2017; Tanuja and Kaith, 2020), and have been estimated to cause 60 to 90% loss in the grain yield of pigeon pea under favourable conditions (Priyadarshini et al., 2013).

Over the years, synthetic pesticides have been heavily relied upon to control pod borer due to their easy availability and applicability, but they are environmentally unfriendly due to their toxicity to humans, animals and beneficial organisms and pose a potential to evolution of pesticide resistance pod borer strains (Kumar, 2015). Presence of pesticide residues in the food chain was reported by Mekonnen et al., 2021 and they survive in plants for a long period of time. The inappropriate and excessive use of synthetic pesticides has resulted in contamination of the soil and ground water. Moreover, their residues accumulate in plant parts and seriously affect the morphological, physiological and biochemical processes of the plants hence reduced crop yields (Patyka et al., 2016).

As such, the realization of these numerous negative effects of synthetic pesticides on nature and on natural resources have forced many to shift focus on more environmentally friendly methods of pest management such as the use of biopesticides. Therefore, experiments were conducted to determine the efficacy of selected biopesticides in management of pod borers in pigeon pea in major growing areas of Rift Valley in order to reduce yield losses and enhance its productivity.

MATERIALS AND METHODS

Experimental procedure

Field experiments were conducted in Kerio valley Research Station Kapkayo (37.7235°E and 2.2172°S) in Elgeyo Marakwet County and Agricultural Training Centre-ATC-Koibatek (10 35'S and 36º66'E) in Baringo County Kenya for two seasons (April-September, 2020 and May-October, 2021). Three biopesticides; (Nimbedicine (0.5 L/ha), Pyagro (0.5 L/ha), and *Bacillus thuringiensis* (1 L/ha) were evaluated for their efficacy on pod borer and the overall yield performance. Positive and negative controls included application of one commercial pesticide (Duduthrin) and unsprayed treatment respectively (Table 1).

Two medium duration pigeon pea varieties (Egerton Mbaazi M1 and EUMDP 4) were used in this study. The trials were laid out in split plot design with main plots being pigeon peas varieties while subplots were the different biopesticides and the experiment was replicated three times. The seeds were sown at 100cm row to row spacing and 30cm plant to plant spacing. All recommended agronomic practices were carried out in the experimental plots except pod borer management measures. The biopesticides were administered in five foliar sprays at vegetative stage, 50% flowering, 25% podding, 50% podding and at 75% podding stage. The sprays were applied in the evening so as to minimize the toxicity to pollinators.

Data collection

Pod borer population

Pre-treatment counts on the population of pod borer adults, larvae

Table 1. Formulation and dose rates of biopesticides and insecticide (Duduthrin) used in the study.

Trade name	Formulation	Doses (L/ha)
Nimbedicine	0.03 Azadirachtin	0.5
Pyagro	Pyrethrins 40 g/L	0.5
Duduthrin 1.75 EC (+ve control)	Lambda cyhalothrin 17.5 g/L	0.5
Bt	*Bacillus thuringiensis var* kustaki strain ABTS-351, 54%w/w+fermentation solids	1
Water (-ve control)	-	1

and eggs were made 24 h before biopesticide application. The post treatment counts were made two days after spray respectively on five randomly tagged plants per plot. Visual observations on the population of pod borer adults, larvae and eggs were carried out throughout the growing period on the tagged plants from the two middle rows starting from vegetative stage till 75% podding (Subharani and Singh, 2004). Adult, larval and egg populations after the treatment were then compared to positive and negative control treatments.

Pod damage, severity, percent incidence and percent pest reduction

Pod damage and severity rating due to pod borers was done using a nine-point visual assessment scale and were assessed every 7 days by evaluating the pods and flowers damage visually at podding and flowering stages at a 1 to 9 scale, where 1 signifies no damage hence no infestation and 9 showing a higher infestation rate of the pod borer according to Wiseman et al. (1966). Pod borer incidence levels were computed by counting the number of infested plants in the plot and percentage incidence calculated using the formula:

$$\text{Percent Incidence } (\%) = \frac{\text{N}}{\text{T}} \times 100 \quad (1)$$

where N = Number of infested plants, T = Total number of plants in the plot.
The Percent pest reduction per plot was computed as follows;

$$\text{PPR } (\%) = \left\{1 - \left(\frac{\text{PTi}}{\text{PTo}} \times \frac{\text{PCo}}{\text{PCi}}\right)\right\} \times 100 \quad (2)$$

where PTi = population after treatments, PTo = population before treatment, PCo = population in the control before spray and PCi = population in the control after spray.

Crop yield and yield components

Plant height, days to 50% flowering, days to maturity, number of pods per plant, number of seeds per pod, grain yield and 100 seed weight were taken. Days to 50% flowering was computed by recording the mean of the five tagged plants from a plot and counting the number of days from planting to when the plants had 50% flowered. Days to maturity was computed using the means of five tagged plants from the plot and recording the number of days from planting to when the plants had 75% of the pods matured. Number of pods per plant was computed using mean number of pods per plant for five tagged plants. Plant height was measured at maturity in centimeters. Data on grain yield was collected when all the dry pods in each plot had been harvested, threshed and weighed. The yield data was then converted to tonnes per hectare.

Data analysis

The population of pod borer adults, larvae and eggs data was transformed using $\sqrt{x + 0.5}$ before analysis. All data collected were subjected to analysis of variance (ANOVA) using the general linear model procedure in SAS (SAS Institute version 9.4, 2002). Pearson correlation matrix was used to test the association between the response variables.

The association was to test how larval population influenced floral and pod damage, seed weight and grain yield. The means of treatments and interactions were compared using Tukey's Honest Significant Difference (HSD) test at *P*≤0.05.
The data were analyzed using the statistical model below;

$$Y_{ijk} = \mu + R_i + V_j + RV_{ij} + T_k + TV_{k(j)} + \varepsilon_{ijkl} \quad (3)$$

where Y_{ijk} is the observation of experimental units; μ is the overall mean; B_i is the effect due to i^{th} replicate; V_j is the effect due to j^{th} variety; $T_k$is effect due to k^{th}treatment; RV_{ij} is the effect due to interaction between i^{th} replicate and j^{th} variety; T_k is the effect due to k^{th} treatment; $TV_{k(j)}$ is the effect due to interaction between k^{th} treatment in the j^{th} variety and $\varepsilon_{ijkl}$is the random error component.

RESULTS

Effects of location, seasons, crop stage and biopesticides on pod borer population

The analysis of variance (ANOVA) revealed that there was no significant difference at *P*≤0.001 in pod borer population counts across the two sites; Koibatek and Kapkayo. There were significant effects (at *P*≤0.001) on the number of eggs and larvae after application of different pesticides at different seasons of production. The results indicate that there was no significant difference among the biopesticide treatments with respect to population of *H. armigera* Hubner before spraying (Table 2). After spraying, all biopesticide treatments significantly reduced the pest population at *P*≤0.001 as compared to untreated control in both varieties (Egerton Mbaazi M1 and EUMDP 4) across all stages at both sites (Table 2). In a four-way interaction, season by site by variety by replication, the number of larvae after biopesticide treatment was significantly different at *P*≤0.05.

Table 2. Effects of location, season and varieties on pod borer growth and survival before and after treatment and Percent pest reduction.

Location	Eggs before	Larvae before	Adults before	Eggs after	Larvae after	Adults after	%PR
Koibatek	16.45±0.38[a]	4.65±0.16a	2.83±0.04a	2.67±0.09a	1.17±0.06a	2.13±0.05a	54.49±1.80a
Kapkayo	16.86±0.40[a]	4.66±0.16a	2.79±0.04a	2.66±0.09a	1.22±0.06a	2.13±0.05a	54.56±1.78a
Tukey $MSD_{0.05}$	0.81	0.19	0.08	0.13	0.07	0.06	1.41
Season							
Season 1	16.81±0.97a	4.69±0.17a	2.78±0.04a	2.92±0.08a	1.34±0.06a	2.14±0.05a	53.98±1.78a
Season 2	16.46±0.95a	4.62±0.16a	2.86±0.04a	2.40±0.10b	1.05±0.06b	2.12±0.05a	55.98±1.80a
Tukey $MSD_{0.05}$	0.81	0.19	0.08	0.13	0.07	0.06	1.41
Variety							
EUMDP2	16.61±0.40a	4.82±0.16a	2.88±0.03a	2.63±0.09a	1.23±0.06a	2.16±0.05a	54.86±1.79a
EUMDP3	16.70±0.38a	4.49±0.16a	2.75±0.04b	2.70±0.09a	1.17±0.06a	2.11±0.05a	54.86±1.79a
Tukey $MSD_{0.05}$	1.27	0.32	0.08	0.22	0.07	0.05	2.51

Means followed by the same letters along the column are not significantly different according to Tukey MSD $_{0.05}$.

Table 3. Effect of biopesticides on pod borer growth and survival before and after spray, and Percent pest reduction.

Biopesticide name	Number of Eggs		Number of larvae		Number of Adults		PPR
	Before	After	Before	After	Before	After	
Nimbecidine	15.46±0.47bc	2.14±0.08d	5.12±0.25a	0.91±0.08c	2.67±0.06c	1.54±0.03d	74.82±0.82b
Pyagro	14.54±0.55bc	2.7±0.093c	4.33±0.23c	1.29±0.07b	2.79±0.05abc	2.09±0.05c	58.65±1.16c
Duduthrin	14.67±0.62bc	0.67±0.09e	4.24±0.23c	0.17±0.04d	2.77±0.06bc	1.17±0.02e	85.79±0.65a
Bt	16.92±0.60a	3.07±0.09b	3.73±0.19d	1.27±0.07b	2.86±0.05ab	2.32±0.05b	52.97±1.18d
No spray	16.58±0.59a	16.21±0.08a	4.86±0.32b	5.64±0.10a	2.96±0.06a	3.16±0.05a	0.40±0.03e
Tukey $MSD_{0.05}$	1.79	0.28	0.43	0.16	0.18	0.13	3.11

Means followed by the same letters along the column are not significantly different according to Tukey MSD $_{0.05}$

Duduthrin insecticide was the most effective treatment in reducing pod borer infestation (Table 3). Nimbedicine and Pyagro had the lowest larvae infestation, low pod and floral damage across the 2 sites as compared to the control; while maximum larval population was observed in untreated control (Table 3). The application of Nimbedicine gave the best effects on pod borer control since it exhibited significant reduction in pod borer population in all stages of plant growth by 74.82% followed by Pyagro 58.64% and *Bt* 52.97% as compared to positive control (Duduthrin) 85.79% (Table 3).

Pigeon pea crop growth stage had significant effect on the number of eggs, larvae and adults after spray at $P≤0.001$. At 25% podding stage, there was high number of eggs and larvae before spray followed by flowering stage which had 18.50±0.50 and 3.55±0.14 eggs and larvae respectively. Flowering and podding stages are associated with higher pest incidence as compared to vegetative stage which had 0.18±0.06 larvae (Table 4). Biopesticide by crop stage interaction recorded significant effect at $P≤0.001$ in reducing the larval and adult population after spray. Site by crop stage interaction had significant effect on the number of adults after spray, while season by crop stage interaction similarly had significant effect on larval reduction after spray at $P≤0.001$. Significant difference of $P≤0.001$ was also seen in location by stage interaction in the number of adults after treatment while biopesticide by stage interaction was seen to be significant in reducing the number of adult pod borers and larvae at $P≤0.001$.

Effects of biopesticides on pod damage, severity and percent pest incidence in Egerton Mbaazi M1 and EUMDP 4 in Koibatek and Kapkayo

The ANOVA results revealed that location and season had no significant difference on pod damage, severity and Percent pest incidence at $P≤0.05$. Variety had a significant effect on pod damage at $P≤0.001$; however, there was no significant effect on percent pest incidence and severity of the pest on flowers. Biopesticide had a significant effect at $P≤0.001$ on pod damage, severity and Percent pest incidence. Location by biopesticide

Table 4. Effect of pigeon pea growth stages on pod borer growth and survival and Percent pest reduction.

Stage	Eggs		Larvae		Adults		PPR
	Before	After	Before	After	Before	After	
Vegetative	17.43±0.67[b]	2.69±0.15[a]	0.18±0.06[c]	0.18±0.05[c]	3.22±0.04[a]	2.40±0.08[a]	54.96±2.84[a]
50% flowering	18.50±0.50[b]	2.87±0.16[a]	5.55±0.14[b]	1.31±0.10[b]	3.11±0.05[a]	2.35±0.09[a]	53.47±2.82[a]
25% podding	19.82±0.46[a]	2.83±0.15[a]	5.62±0.14[b]	1.53±0.09[a]	2.36±0.04[d]	1.83±0.07[d]	56.51±2.82[a]
50% podding	17.62±0.53[b]	2.85±0.14[a]	5.49±0.14[b]	1.45±0.10[ab]	2.82±0.06[b]	2.11±0.09[b]	54.23±2.94[a]
75% podding	9.92±0.45[c]	2.07±0.12[b]	6.44±0.23[c]	1.51±0.09[ab]	2.57±0.05[c]	1.98±0.09[c]	54.46±2.75[a]
Tukey $MSD_{0.05}$	1.79	0.42	0.43	0.16	0.18	0.13	3.11

Means followed by the same letters along the column are not significantly different according to Tukey $MSD_{0.05}$, PPR – percent pest reduction

Table 5. Effects of location, season and varieties on pod damage, severity and Percent pest incidence.

Location	Pod damage	Severity	% incidence
Koibatek	5.32±0.29[a]	5.58±0.24[a]	54.05±2.39[a]
Kapkayo	5.17±0.25[a]	5.32±0.25[a]	53.73±2.44[a]
Tukey $MSD_{0.05}$	0.22	0.29	1.69
Season			
Season 1	5.30±0.27[a]	5.42±0.24[a]	54.05±2.56[a]
Season 2	5.18±0.27[a]	5.48±0.25[a]	54.73±2.27[a]
Tukey $MSD_{0.05}$	0.22	0.29	1.69
Varieties			
EU Mbaazi M1	5.45±0.28[a]	5.52±0.24[a]	54.15±2.46[a]
EUMDP 4	5.03±0.26[b]	5.38±0.25[a]	53.63±2.37[a]
Tukey $MSD_{0.05}$	0.19	0.38	2.03

Means followed by the same letter along the column are not significantly difference according to Tukey $MSD_{0.05}$.

interaction had a significant effect on pod damage at $P \leq 0.05$.

There was no significant effect on pod damage across the 2 locations; however, Koibatek had a slightly higher pod damage rating of 5.32 than Kapkayo with 5.17. Similarly, severity rating on flowers was not significantly different at both sites. Koibatek also had a slightly higher severity rating of 5.58 while Kapkayo had 5.32 severity rating. Percent pest incidence at both locations was not significantly different where Koibatek had a slightly higher pest incidence of 54.05% and Kapkayo having 53.73% (Table 5).

Pod damage, severity and Percent pest incidence were not significantly different across the two seasons at $P \leq 0.05$. However, season one had a slightly higher pod damage rating of 5.30 than season two which had 5.18. Severity of the pest on the flowers was slightly higher in season two with 5.48 than season one which had 5.42. Percent pest incidence was seen to be slightly higher in season two with 54.74% than in season one which had 54.05% (Table 5).

There was a significant difference in pod damage in both varieties. A higher pod damage rating was exhibited in Egerton Mbaazi M1 which had a pod damage rating of 5.45 followed by EUMDP 4 with 5.03. However, there was no significant difference in pod borer severity on flowers, although Egerton Mbaazi M1 had a slightly higher severity rating of 5.52 than EUMDP 4 which had 5.38. Similarly, Percent pest incidence was not significantly different; however, Egerton Mbaazi M1 had a slightly higher incidence of 54.15% than EUMDP 4 with 53.63% as shown in Table 5.

All biopesticide treatments had a significant effect (at $P \leq 0.001$) on pod damage, severity and percent pest incidence. The mean larval population of *H. armigera* Hubner varied from 30.92-75.00%. Plots sprayed with Nimbecidine and Pyagro had a relatively low percent pest incidence of 40.54 and 48.54% respectively as compared to positive control (Duduthrin) which had 30.92%. Maximum pod damage was observed in untreated control as it exhibited a higher pod damage rating as shown in Figure 1a. The effectiveness of different biopesticides used to reduce pod borer infestation was shown by grain yield. There was a significant difference at $P≤0.05$ on yield obtained among the biopesticide treatments as shown in Figure 1a. All the treatments registered higher grain yield as compared to the untreated control. Higher yields were obtained from plots sprayed with Nimbedicine (0.99 tons/ha) followed by Pyagro (0.72 tons/ha) and *Bt* (0.66 tos/ha); whereas lowest yield was recorded from untreated control plots with 0.36 tons/ha in both sites (Figure 1a). Significant grain yield was reported in Koibatek (0.89 tons/ha) than in Kapkayo (0.71 tons/ha). The highest pod borer incidence was recorded in the untreated control having 75% as shown in Figure 1b while plots that received *Bt* potrayed a relatively higher Percent pest incidence of 74.46% as compared to positive control. However, all the treatments were effective in minimizing the pod borer incidence. Similarly, the severity of pod borer damage on flowers was low in plots treated with Nimbedicine and pyagro treated plots as they had a lower severity rating of 4.50 and 5.17 respectively as compared to positive control (Duduthrin) which had a much lower rating of 2.88 while *Bt* had a higher severity rating of 7.33 as shown in Figure 1c. The percent pod damage due to *H. armigera* Hubner in different treatments was significantly different as compared to control. Plots that received Nimbecidine and Pyagro had a lower pod damage rating of 4.00 and 4.83 respectively while *Bt* had a higher pod damage rating of 7.29 as compared to the positive control (Duduthrin) with 2.42 (Figure 1c). The use of commercial pesticide Duduthrin as a positive control recorded the highest number of pods per plant (185.88), followed by nimbecidine (151.00), followed by Pyagro (131.54) and finally *Bt* (112.88) as compared to untreated control (86.08) as shown in Figure 1d.

Effects of biopesticides on yield and yield components on Egerton Mbaazi M1 and EUMDP 4 varieties in Koibatek and Kapkayo

Location had a significant effect on days at maturity, pods per plant and yield according to analysis of variance at $P≤0.001$ and no significant effect on 100 seed weight. Seasons had a significant effect on the number of days at maturity at $P≤0.001$ as well as yield at $P≤0.05$. Seasons also had no significant difference at $P≤0.05$ on 100 seed weight and pods per plant. Season by location interaction had a significant effect on the number of days at maturity at $P≤0.001$.

Varieties had a significant effect at $P≤0.05$ on the number of pods per plant and no significant difference on the number of days at maturity, yield and 100 seed weight. Season by variety by biopesticide interaction had a significant effect on the number of pods per plant at $P≤0.05$.

There was a significant difference in plant height across the two sites at $P≤0.05$. Kapkayo had relatively taller crop plants (181.13 cm) than those in Koibatek (130.75 cm). Days at 50% flowering were also significantly different at both locations with plant at Kapkayo flowering much earlier (60.67 days) than those in Koibatek (79.08 days). Days at maturity were significantly different at $P≤0.05$ where Koibatek crops matured at 143.20 days while those in Kapkayo at 134.58 days.

There were more than the number of pods per plant in Koibatek crop plants (180.47) than those in Kapkayo (86.48) which translated to a higher yield of 0.89 tons/ha in Koibatek and 0.71 tons/ha in Kapkayo as shown in table 5. A hundred seed weight was also significantly different at $P≤0.05$ at both locations where seeds from Koibatek weighed 24.54g while those from Kapkayo weighed 24.30g (Table 6). Biopesticides had no significant difference on the number of days to 50% flowering and the number of days to maturity at $P≤0.05$ (Table 6). The use of biopesticides to control pod borer had a significant effect at $P≤0.05$ on the number of pods per plant and 100 seed weight.

The two seasons had no significant difference in plant height, days to 50% flowering, number of pods per plant and 100 seed weight at $P≤0.05$, however, in season 2, plant height was slightly higher (156.23 cm) than those in season 1 (155.23 cm). The number of pods per plant was also slightly higher during season 1 (134.53) than during season 2 (132.42) as shown in Table 7. Similarly, seasons had a significant effect on the number of days after maturity and yield at $P≤0.05$. Season one crops matured much earlier (137.48 days) followed by those in season 2 (140.30 days) as shown in Table 6.

Varieties had a $P≤0.05$ significant effect on plant height, number of days to flowering and 100 seed weight. Egerton Mbaazi M1 crop plants were taller (163.12 cm) than those of EUMDP 4 (148.97 cm). Egerton Mbaazi M1 flowered much earlier (68.62 days) than EUMDP 4 (71.62). Seeds from EUMDP 4 variet weighed 24.51g while those from Egerton Mbaazi M1 weighed 24.33g.

Variety, however, had no significant effect on the number of days to maturity, the number of pods per plant and yield (Table 6). Higher 100 seed weight was recorded in insecticide treated plot (25.66g) followed by Nimbedicine (24.74g), Pyagro (24.26g) and *Bt* (23.74) as compared to untreated control (23.72g).

Grain yield showed a significant positive correlation with the number of pods per plant (r=0.75). There was a negative correlation between percent pest incidence and the number of pods per plant (r= -0.50). Negative correlation was also reported between Percent pest incidence and yield (r= -0.78). Severity of the pod borer on flowers had a negative correlation on the number of pods per plant (r= -0.45). A significant negative correlation was also observed between severity of the pod borer on flowers and yield (r= -0.71) as shown in Table 7.

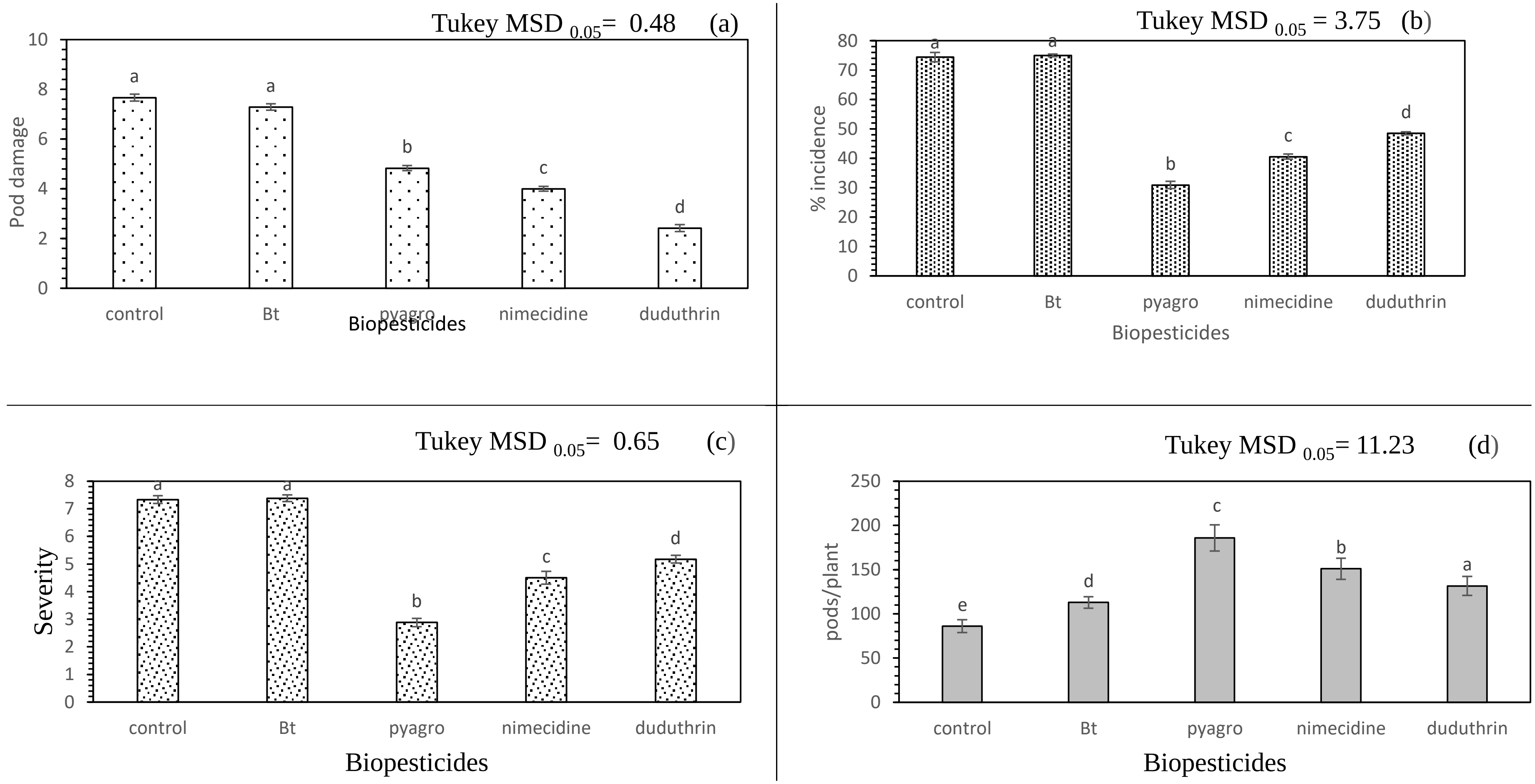

Figure 1. Effect of biopesticide Duduthrin, Nimbecidine, Pyagro, *Bt*, and no spray on a) pod damage, b) % pest incidence c) severity of pod borer on flowers, and d) pods per plant of two pigeon pea varieties evaluated in Baringo and Kapkayo during the 2020-2021 croppingseasons.

DISCUSSION

The results indicate that there was no significant difference among the biopesticide treatments with respect to population of *Helicoverpa armigera* Hubner before spraying indicating more or less uniform distribution of the pest. When observations were made after spray, all the treatments were found to be superior over the control. Duduthrin was the most effective among the treatments for reducing pod borer infestation followed by nimbecidine, pyagro and bt. This was expected taking into consideration that it is a broadspectrum insecticide widely used in the management of insect pests and registered for use on a range of crops (Belmain et al., 2013). Nimbedicine and pyagro treated plots exhibited lowest larvae infestation, low pod and floral damage. The

Table 6. Effect of location, season and varieties on plant height, DAF, DAM, pods per plant, yield and 100 seed weight.

Location	Height(cm)	DAF	DAM	Pods/plant	Yield(tons/ha)	SW(g)
Koibatek	130.95±1.09[b]	79.08±0.35[a]	143.20±0.33[a]	180.47±6.78a	0.89±0.05[a]	24.54±0.15[a]
Kapkayo	181.13±2.72[a]	60.67±0.61[b]	134.58±0.43[b]	86.48±2.77b	0.71±0.03[b]	24.30±0.11[b]
Tukey MSD $_{0.05}$	4.25	0.91	0.85	5.05	0.04	0.18
Season						
Season 1	155.23±4.19[a]	69.92±1.29[a]	137.48±0.81[b]	134.53±7.87a	0.82±0.05[a]	24.44±0.13[a]
Season 2	156.23±3.51[a]	69.83±1.30[a]	140.30±.45[a]	132.42±8.15a	0.78±0.04[b]	24.41±0.12[a]
Tukey MSD $_{0.05}$	4.25	0.91	0.85	5.05	0.04	0.18
Varieties						
Egerton MbaaziM1	163.12±3.74[a]	68.62±1.47[a]	139.17±0.65[a]	135.95±8.14[a]	0.80±0.05[a]	24.33±0.13[b]
EUMDP4	148.97±3.77[b]	71.62±1.06[b]	138.62±0.70[a]	131.00±7.88[a]	0.79±0.04[a]	24.51±0.13[a]
Tukey MSD $_{0.05}$	9.19	1.62	1.07	9.10	0.04	0.13

Means followed by the same letters along the column are not significantly different according to Tukey MSD $_{0.05,}$ DAF – Days to 50% flowering, DAM – Days to maturity, 100 SW – weight of 100 seeds.

Table 7. Correlation coefficients of Percent pest incidence, severity on flowers, pods per plant and yield.

Variables	%incidence	Severity on flowers	Pods/plant	Yield
%incidence	1.0000			
Severity on flowers	0.719	1.0000		
Pods/plant	-0.4952***	-0.4529***	1.0000	
Yield	-0.7790***	-0.7091***	0.7452***	1.0000
*** significant at $P \leq 0.001$				

application of Nimbedicine gave the best effects on pod borer control since it exhibited significant reduction in pod borer population in all stages across the two locations. The results in relation to larval population reduction of pod borer are in accordance with earlier reports by Ahmad et al. (2018) who studied comparative efficacy of biopesticides and synthetic agrochemicals on control of *H. armigera* Hubner larvae on chickpea and reported that the biopesticide of neem oil showed better results in controlling the pod borer larval population next to Chlorpyrifos and Emamectin after spray. Pezzini and Koch (2015) also reported that the active ingredients in Nimbecidine such as azadirachtin and pyrethrins in Pyagro are known to be effective against pod borers and other insect pests such as aphids with repellent and antifeedant activity, and growth and reproduction activity which was evident in this study. These results are also in agreement with Kumar et al. (2017) and Bhushan et al. (2011), who reported that neem seed kernel extracts at 5% was the most effective biopesticide in reducing larval population and pod damage among the treatments tested in the control of *H. armigera* Hubner in chickpea. Similarly, (Shekhara, 2014) reported that among the different biopesticides used, Azadirachdin 3% WSP @400G/ha sprayed per plot recorded the lowest larval population after spray. The variation of efficacy of biopesticides on insect pests has been reported and this could be partly attributed to differences in their mode of action and also the capacity of the insect pests to detoxify the acive ingredients (Sisay et al., 2019). These findings were in conformity with Ahmad (2020) who reported that the Percent pod damage due to *H. armigera* Hubner, the Chlorantraniliprole 18.5 SC @ 30 g/ha (positive control) showed significantly reduced (6.25%) per cent pod damage followed by Azadirachdin 1500 ppm@5.0 ml/l (7.33%) and *Bt*. Kurastaki @1.0g/l (9.33%) as compared to control (14.49%); and concluded that Azadirachdin could be recommended for effective and economic control of pigeon pea pod borer in pigeon pea.

The present findings in terms of weight of 100 seeds are in agreement with Byrappa et al. (2012) who studied the impact of biopesticides application on pod borer complex in organically grown field bean ecosystem and recorded the highest 100 seed weight from neem seed kernel extract-*Ha*NPV-*Bt* treated plots after insecticide insecticide treated plots. There were positive correlation coefficients between grain yield and pods per plant were observed indicating that number of pods per plant is a useful indicator in grain yield performance of pigeon pea. These results are in agreement with the report by Ahmad (2020), who reported that the grain yield by Azadirachdin was 1,249.00 Kg/ha and 44.91% more than the control. Also, Bhushan et al. (2011) reported that the maximum yield was recorded in plots treated with neem seed kernel extract (1,590 Kg/ha) which was followed by *Bt*., multineem and control plots with significant difference.

Conclusion

Results showed that the treatment of Nimbedicine (0.03% Azadirachtin) and Pyagro biopesticides were superior over all other treatments and significantly the highest yield of pigeon pea crop was also observed in these treatments.

Nimbedicine (0.03% Azadirachtin) and Pyagro reduced pod borer larval population by 74.82 and 58.60% respectively, exhibiting low pod damage (40 and 48% respectively) that translated to higher yields (0.99 and 0.72 tons/ha), as compared to other biopesticide treatments and untreated control. Therefore, the use of Nimbedicine (0.03% Azadirachtin) and Pyagro is recommended for effective control of pod borer (*H. armigera* Hubner) in pigeon pea. Hence, the use of Nimbedicine (0.03% Azadirachtin) and Pyagro is not only eco-friendly and sustainable, but also their use makes the crop safer for human consumption and greatly increases yield thus improving productivity of pigeon pea.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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