Fundamental and Applied Agriculture
Vol. 6(2), pp. 183–192: 2021
doi: 10.5455/faa.71183

PLANT PROTECTION | ORIGINAL ARTICLE

Spatial orientations of common bean influence the activities and population dynamics of bean stem maggot (*Ophiomyia phaseoli*) and bean foliage beetle (*Ootheca mutabilis*)

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ARTICLE INFORMATION

Article History
Submitted: 07 Apr 2021
Accepted: 07 Jun 2021
First online: 30 Jun 2021

Academic Editor
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ABSTRACT

Bean stem maggot (BSM) (*Ophiomyia phaseoli*) and bean foliage beetle (BFB) (*Ootheca mutabilis*) pose a serious challenge to production. Many practices have been employed to manage these pests. However, little or no emphasis has been on basic agronomic practices such as plant spacing as a tool for pest management of BSM and BFB. In the present study, the role of plant orientation (plant spacing) on the activities and population dynamics of BSM and BFB was examined in a pesticide-free field trial in Bamenda, Cameroon. Different plant orientations namely 15 cm $\times$ 15 cm ($\sim$442500 plants ha^{-1}), 20 cm $\times$ 20 cm ($\sim$250000 plants ha^{-1}), 30 cm $\times$ 30 cm ($\sim$110000 plants ha^{-1}) and 40 cm $\times$ 40 cm ($\sim$62500 plants ha^{-1}) were test in a randomized complete block design with 4 replicates. Data was collected on oviposition holes on leaves of common bean by BSM, BSM population dynamics, leaf damage score by BFB, and population dynamics of BFB. The number of oviposition holes, the mean cumulative number of BSM, the mean leaf damage scores and the mean cumulative number of BFB were significantly higher ($p<0.05$) in dense plots (15 cm $\times$ 15 cm) than in the other plots. The activity of BSM and BFM increased over time. The principal component analysis revealed that the first two components accounted for 99.17% of the variation. Linear discriminant analysis with Mahalanobus distances with an 87.5% cross-validation by Jacknife procedure revealed that spatial orientation of 20 cm $\times$ 20 cm and 30 cm $\times$ 30 cm were very similar and significantly ($p<0.001$) different from the others. For pest management purposes, plant orientations of 20 cm $\times$ 20 cm and 30 cm $\times$ 30 cm can be recommended since they recorded low BSM and BFB activity. For future perspective, it is important assess the effect of different plant orientation on yield and pest parameters concurrently.

Keywords: Common bean, plant orientation, plant spacing, bean stem maggot, bean foliage beetle, plant density

Cite this article: Achiri TD, Ngone AM, Nuigho KB, Nsobinenyui D, Abdulai AN, Njualem DK. 2021. Spatial orientations of common bean influence the activities and population dynamics of bean stem maggot (*Ophiomyia phaseoli*) and bean foliage beetle (*Ootheca mutabilis*). Fundamental and Applied Agriculture 6(2): 183–192. doi: 10.5455/faa.71183

1 Introduction

Common bean (*Phaseolus vulgaris* L.) is one of the most important legume in the world for human consumption (van Schoonhonem and Pastor-Corrales, 1991) and fodder. It is estimated that about 23.1 million tons of common bean is produced annually worldwide on an acreage of about 8.7 million hectares (FAO, 2014). This legume is cultivated principally for its dry (mature) beans and fresh green pods. When consumed as seed, it constitutes an important source of dietary fiber and complex carbohydrates (Filella and Penuelas, 1994). In Africa, common bean constitutes about 57% of recommended dietary protein and 23% of energy (Montoya et al., 2006). The high nutrient and commercial potential of common bean position it as one of the vital crops to fight hunger, increase income, improve soil fertility and alleviate poverty in sub-Saharan Africa (Akibode and Maredia, 2011). In Africa, common beans are usually cultivated by small-scale farmers, particularly women (CIA, 2001), in intercropping system with crops such as cassava, cocoyam, plantain and maize (Legesse et al., 2006).

In Cameroon, the Western Highland contributes about 90% of national bean production (Ngoh et al., 2017). Common bean is an annual crop that is cultivated in the rainy season (March – June) and in the dry season (August – December), intercropped with other crops such as maize. However, like many parts of Africa, common bean production is severely constraint by different biotic, abiotic and socio-economic factors (Katungi et al., 2009). Among the biotic constraints weeds and insect pests are serious limiting factors. Major insect pests of common bean include bean stem maggot (BSM) *Ophiomyia phaseoli* Tryon (Diptera: Agromyzidae), bean foliage beetle (BFB) *Ootheca mutabilis* (Schonherr) (Coleoptera: Chrysomelidae), and black bean aphids (BBA) *Aphis fabae* (Hemiptera: Aphididae), which cause yield loss of 37% to 100% (Ochilo and Nyamasyo, 2011), 18% - 31% (Kapeya et al., 2013), and 37% (Kapeya et al., 2005), respectively.

The BSM also known as the bean fly is considered the most important field pest of bean in Africa. Adult oviposits in leaves, stem and hypocotyl of young seedlings. The young maggots mine their way to the root zone were pupation occurs and feeding becomes severe between the epidermal tissues and woody stem (Ochilo and Nyamasyo, 2011) interrupting smooth flow of water and nutrients, and establishing avenues for disease organisms (Ampofo and Massomo, 1998). The BFB is mostly found in mainland Africa on bean plants. Both larvae and adults can cause extensive defoliation. In severe infestation, complete crop destruction can occur (Abate and Ampofo, 1996). Also, wilting and premature senescence may result from feeding activity of larvae on lateral roots.

Farmers in Cameroon and Africa at large have employed several techniques to combat the BSM and BFB. Firstly, farmers rely almost mostly on synthetic insecticides such as endosulfan, diazinon, lindane, cypermethion, carbaryl and imidachloprid (Kapeya et al., 2005; Stoddard et al., 2010). Nonetheless, the negative effects of pesticides on the environment, human health and non-target organisms as well as cost of purchase and availability concerns have necessitated the need for other benign and eco-friendly pest management alternatives (Achiri et al., 2016). Botanicals such as tobacco extracts, garlic, eucalyptus, neem oil, chilli pepper and pyrethrum have been investigated (Khan and Wasim, 2001; Haque et al., 2002; Koona and Dorn, 2005; Roy et al., 2005; Sharma et al., 2014). Many agronomic practices are being investigated on their role in pest management (Mwanauta et al., 2015). Cultural practices such as field selection, cultivar and seed choice, crop rotation, sowing dates, weed control and plant density have been exploited for pest management (Mueke et al., 1990; Aheer et al., 1993). For instance, there is evidence that pest populations are lower in mixed cropping systems than in mono-cropping system (Abate and Ampofo, 1996). Since these agronomic practices are cheap and requires minimal technological inputs, they require ample research attentions for adaptation, especially for poor resource small-scale farmers. Of particular interest is plant density or spatial arrangement. Plant spatial arrangement has the potential to influence pest populations and yield. In a maize-bean intercrop, Peter et al. (2009) reported that the incidence of BSM decreased with increasing plant population. Ogenga-Latigo et al. (1992) observed that the incidence of aphids was lower on beans intercropped with densely planted maize. Little is known about the population dynamics of some major pests of common bean in sole bean field. This study was designed to ascertain the population dynamics of two major pests of common bean; BSM and BFB under different spatial arrangement regimes of sole common beans.

2 Materials and Methods

2.1 Study site

The study was conducted in the experimental field of Catholic University of Cameroon, Bamenda (CATUC), during the rainy season of 2020. Bamenda is the regional capital of North West Region Cameroon. It is a city council dubbed Bamenda City Council (BCC) made up of three councils. Bamenda is 1250 m above sea level and it is situated between 9°58′16″N, 6°3′14″E and 10°14′16″N, 5°51′8″E. The annual rainfall is 2567 mm and average temperature is 23 °C, ranging between 15 – 32 °C. There are two seasons, the rainy (March – October) and dry (November to February) season. The vegetation in this west-

Table 1. Common bean plant spacing tested and corresponding plant densities

Treatment	Plant spacing	Plant density plot^{-1}	Plant density ha^{-1}
T1	40 cm × 40 cm	25	62500
T2	30 cm × 30 cm	44	110000
T3	20 cm × 20 cm	100	250000
T4	15 cm × 15 cm	177	442500

ern highland city is mostly savanna with shrubs dotted here and there (Olayiwola et al., 2011).

2.2 Experimental site and design

A surface area of 100 m^2 was cleared with a cutlass and ploughed with a hoe. The experimental design was randomized complete block design (RCBD) with four blocks. Each block was divided into four plots, making a total of 16 experimental units in the experimental universe. Each experimental unit (sowing bed) measured 2 m × 2 m. The beds were raised during ploughing to a height of 5 cm. The plots were separated by 0.25 m and 0.5 m gap within and between blocks, respectively. The experimental universe was surrounded by a border of 1 m. There were four treatments (T) – plant spatial arrangements. The different plant spatial arrangements resulted into varying common bean plant densities. The treatments and the number of common bean plants per plot are summarized in Table 1.

2.3 Agronomic practices

Common bean was sown on March 26, 2020. Three bean seeds were sown per hole. After germination, each plant stand was thinned to two. Weeding was done when necessary by hand and hoe. No insecticide was applied since the objective of the experiment was to investigate the population dynamics of insect pests: BSM and BFB. The experiment relied entirely on rain fed irrigation. One week to sowing, 10 kg of poultry manure was broadcasted on each bed and thoroughly mixed with the soil during bed preparation.

2.4 Data collection

Data was collected on the number of oviposition holes on the leaves by BSM *Ophiomyia phaseoli*, the number of larvae and pupae on dissected stems, visual score of leaf defoliation by BFB *ootheca mutabilis* and number of adult BFB from a sweep net. Five plants were randomly selected per plot and three leaves (one from the upper, middle and lower plants parts) per selected plants were examined (15 leaves per plot) for oviposition holes with the aid of a hand lens. The number of larvae and pupae were examined on three randomly selected dying plants per plot. The stems were gently dissected with an alcohol (70%) sterilized razor blade at the point of injury and slightly peeled to count the number of larvae and pupae (hence referred to only as BSM) on the stem; beneath the epidermis of the stem. Three leaves per plant and five plants per plot were observed and the degree of defoliation on the leaves by BFB was scored from 0 – 5: 0 – no defoliation, 1: 1% - 20% defoliation, 2: 21% – 40% defoliation, 3: 41% - 60% defoliation, 4: 61% – 80% defoliation, and 5: 81% – 100% defoliation. A sweep net was used to ascertain the number of adult BFB on leaves of common bean. The researchers walked from one end of the plot to the other once, swinging the sweep net from left to right with every walking step (30 cm) and the content in the sweep net was emptied in a glass jar (1 L) and cocked. The number of BFB adults were counted and recorded. All field data collections were done between the hours of 7.30am – 9.30am. Sampling began 14 days after germination and thereafter once every fortnight.

2.5 Statistical analyses

Normality and homogeneity of variance tests were conducted using Kolmogorov-Smirnov test and Levene's test in SPSS (ver 23), respectively. The data were subjected to General Linear Model (GLM) one-way Analysis of Variance (ANOVA) test and significantly different means were separated using Duncan's Multiple Range Test (DMRT) at alpha (α) level of 0.05 using SPSS (ver. 23). Where the blocking effect was not statistically significant, the ANOVA was redone with the blocking effect in GLM removed in order to increase the degree of freedom of the error term, thus increasing the reliability of the analysis. A multivariate analysis, principal component analysis (PCA) with variance-covariance matrix was conducted for some dependent variables (number of oviposition holes, cumulative number of BSM, leaf damage scores of common bean and cumulative number of BFB) across the different common bean spatial orientation, in order to investigate their inter-correlations by reducing the dimensionality. The first two components which accounted for more than 90.0% of the variance in the data set were selected. The PCA biplot is provided. The PCA was done using the PAleontological STatistics (PAST) statistical package (ver. 4.0).

3 Results

3.1 Oviposition by BSM

The distribution of oviposition holes on leaves of common bean caused by bean stem maggot (BSM) from different plant orientations is represented in Fig. 1. The number of oviposition holes per leaf range from 2 to 36. The distribution of oviposition holes increased for all planting distance over time. Generally, the average oviposition holes on common bean leaves from 15 cm × 15 cm plots was higher than all others for the sampling period. It was followed by that of 20 cm × 20 cm plots. The results were further expressed as mean cumulative number of oviposition holes per plant per plot (Fig. 2). The mean cumulative number of ovpositon holes per plant per plot from 15 cm × 15 cm plant was significantly higher (F = 49.80, df = 3, 12, p<0.001) than those from other common bean orientations. The mean cumulative number of oviposition holes ranged from 40 (40 cm × 40 cm) to 94 (15 cm × 15 cm). It is evident that there is a direct linear relation between mean cumulative number of oviposition holes by BSM and the common bean diversity, i.e the higher the plant density (e.g. 15 cm × 15 cm), the higher the mean cumulative number of oviposition holes by BSM.

3.2 Population dynamics of BSM

The population fluctuation of BSM (larvae + pupae) on common bean from different spatial orientation (different common bean densities) is presented in Fig. 3. The results show that the mean number of BSM per plant increased slowly over time. The mean numbers were fairly constant over time except for 15 cm × 15 cm spatial orientation, which had a dramatic spike after week 6. The mean cumulative values ranged from 7 to 18. The box plot in Fig. 4 shows the cumulative number of BSM from different spatial arrangement. There was a statistically significant difference (F = 11.97, df = 3, 12, p = 0.001) in the cumulative numbers of BSM. The highest cumulative number of BSM/plot/plant was from 15 cm × 15 cm spatial orientation. There was no significant difference in the cumulative number of BSM among the spatial arrangements 40 cm × 40 cm, 30 cm × 30 cm and 20 cm × 20 cm.

3.3 Leaf damage by BFB

The leaf damage scores of common bean by bean foliage beetle bean foliage beetle (BFB) was scored and average over time (Fig. 5). The leaf damage score by BFB generally increased over time. The mean leaf damage score ranged from 1.0 to 3.25. All the mean leaf damage scores from the 15 cm × 15 cm spatial arrangement were greater than those of the other spatial arrangements. The mean leaf damage score increased steadily for 40 cm × 40 cm spatial arrangement until week 6, after which, the mean leaf damage score leveled. For spatial arrangement of 30 cm × 30 cm and 20 cm × 20 cm, the mean leaf damage score increased from week 2 to week 4 and declined until week 6, and eventually increased in week 8. The cumulative mean leaf damage scores over the study period are summarized in Fig. 6. There was a statistically significant difference (F = 24.07, df = 1, 3, p<0.001) in the mean leaf damage scores from the different common bean spatial arrangements. The highest (3 ± 0.08) and lowest (1.75 ± 0.20) mean leaf damage score were recorded from the 15 cm × 15 cm and 40 cm × 40 cm plant spatial orientation, respectively.

3.4 Population dynamics of BFB

The population dynamics of BFB is shown in Fig. 7. For all spatial arrangements, there was a steady increase in the mean number of BFB per plot over time. The BFB population ranged from 5 to 18 per plot over the sampling period. For all time periods investigated, the BFB population from 15 cm × 15 cm plant spatial orientation was higher than those from the other plant spatial arrangements. Throughout the study, the population of the BFB from spatial treatments (except 15 cm × 15 cm) remained constant between 5 and 10 BFB per plot, unlike that of 15 cm × 15 cm spatial orientation which fluctuated between 9 and 18 per plot. Analyzing the mean cumulative numbers of the BFB revealed that the BFB population from 15 cm × 15 cm plant spatial orientation was statistically significantly higher (F = 22.69, df = 3, 12, p<0.001) than those of other plant spatial orientation (Table 2). The highest mean cumulative BFB population (13.8 ± 0.62) was recorded on 15 cm × 15 cm plant spatial orientation, followed by 7.81 (± 0.75), 7.75 (± 0.72) and 6.63 (± 0.21) from 20 cm × 20 cm, 30 cm × 30 cm and 40 cm × 40 cm plant spatial orientation, respectively.

3.5 PCA of studied parameters

The multivariate analysis, principal component analysis (PCA) was conducted to ascertain the intercorrelation between some measured parameters; mean number of oviposition holes per leaf by BSM, mean number of BSM, mean cumulative leaf damage score by BFB and mean cumulative number of BFB per plot over different plant orientations. The first two components with eigen values greater than 1 were selected, and these first two components (conical variate - CV) accounted for 99.17% (CV1 = 88.32% and CV2 = 10.85) of the total variability in the multidimensional data set. The data was clustered into four distinct groups based on the four common bean spatial orientation (plant density).

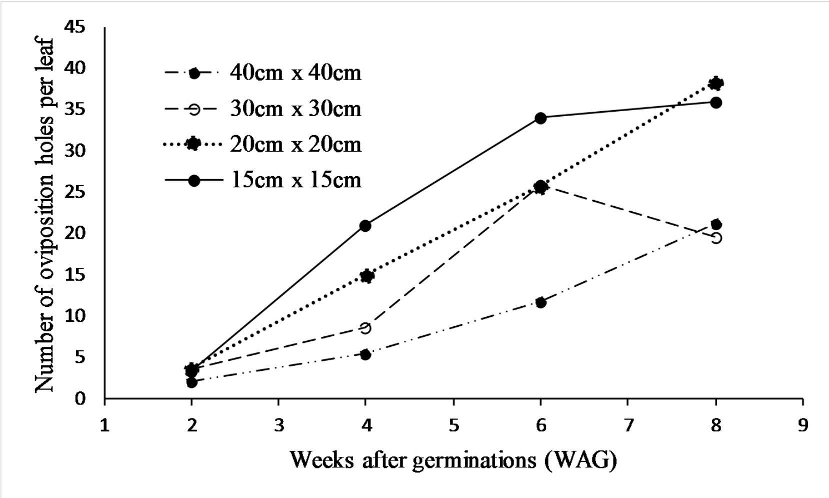

Figure 1. Oviposition holes on common bean leaves caused by bean stem maggot *Ophiomyia phaseoli* over time from different plant orientation

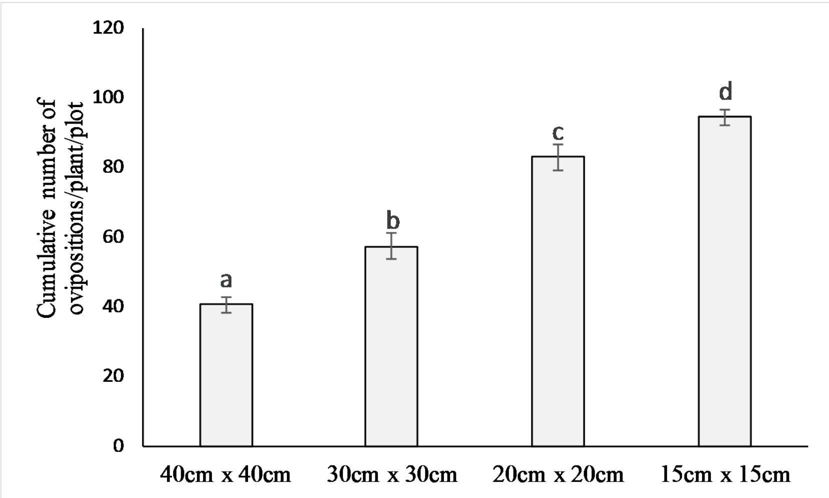

Figure 2. Mean cumulative number of oviposition holes on common beans leaves caused by bean stem maggot *Ophiomyia phaseoli* from different plant orientation. Mean bars with the same letter(s) are not significantly different according to Duncan's Multiple Range Test (DMRT, α = 0.05)

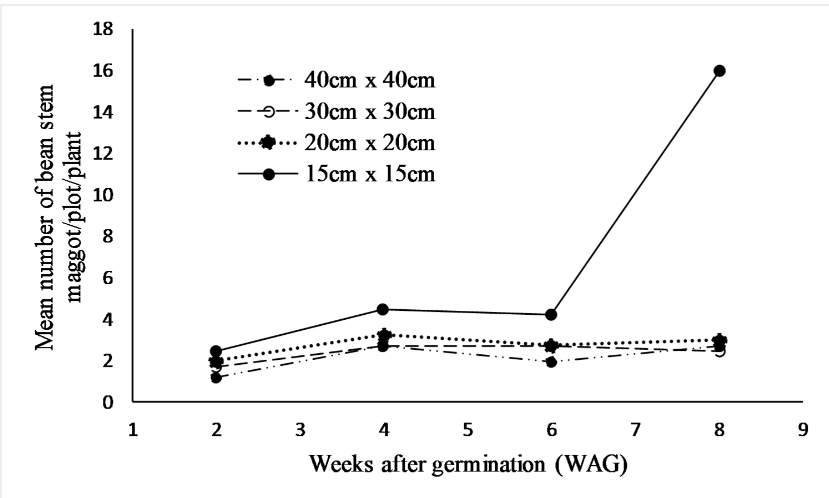

Figure 3. Population dynamics of bean stem maggot *Ophiomyia phaseoli* from different plant orientations over time

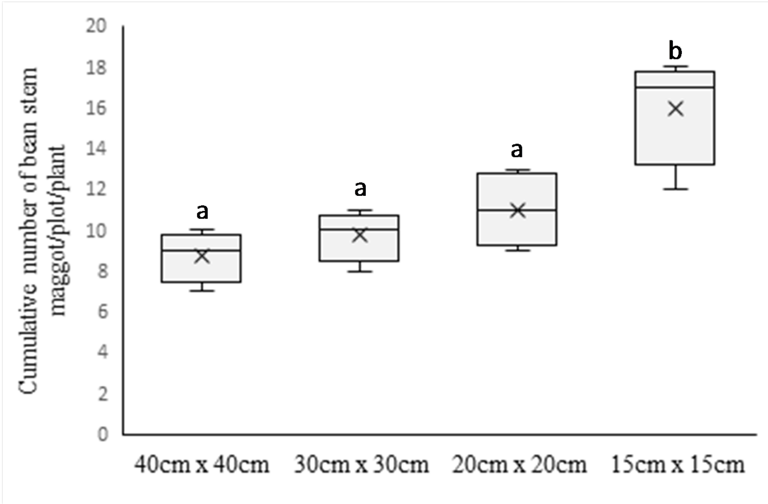

Figure 4. Mean cumulative number of bean stem maggot *Ophiomyia phaseoli* from different plant orientation over time. Box plots with the same letter(s) are not significantly different according to Duncan's Multiple Range Test (DMRT, $\alpha = 0.05$)

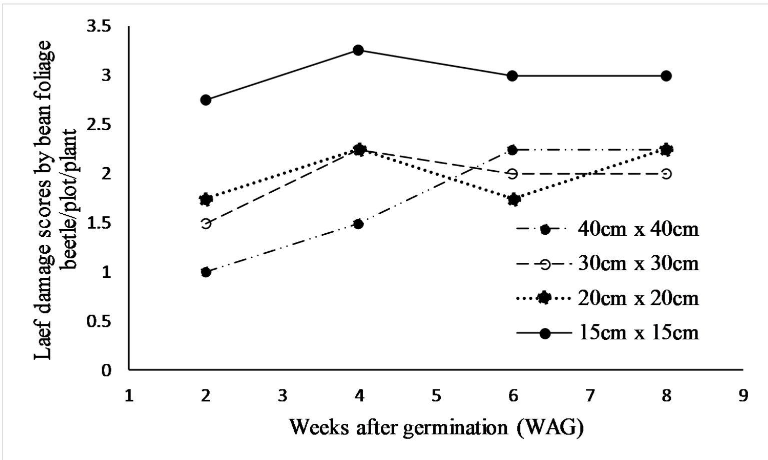

Figure 5. Common bean leaf damage score by bean foliage beetle *Ootheca mutabilis* on different plant orientation over time

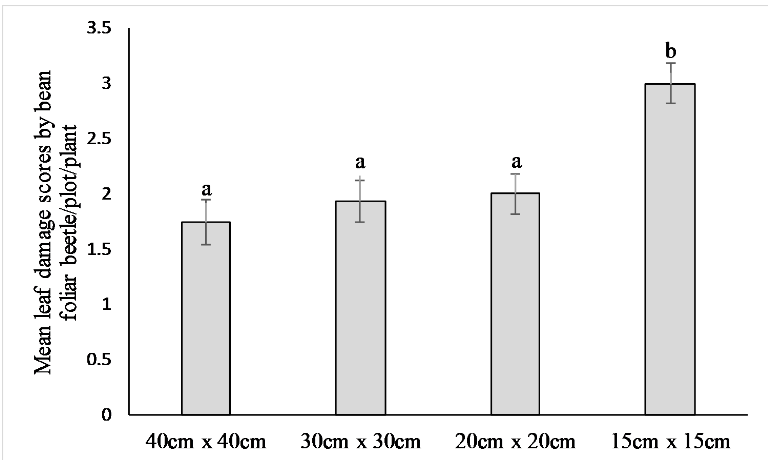

Figure 6. Mean cumulative common bean leaf damage score by bean foliage beetle *Ootheca mutabilis* on different plant orientation over time. Mean bars with the same letter(s) are not significantly different according to Duncan's Multiple Range Test (DMRT, $\alpha = 0.05$)

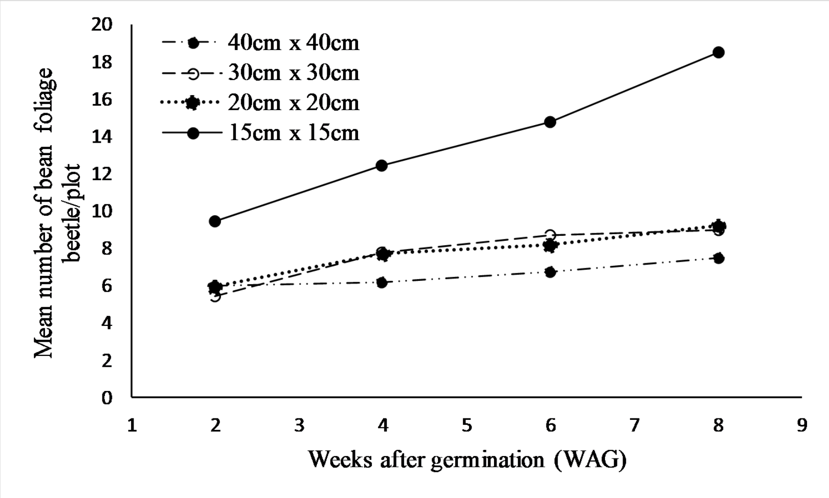

Figure 7. Population dynamics of bean foliage beetle Ootheca mutabilis on different spatial orientation of common bean

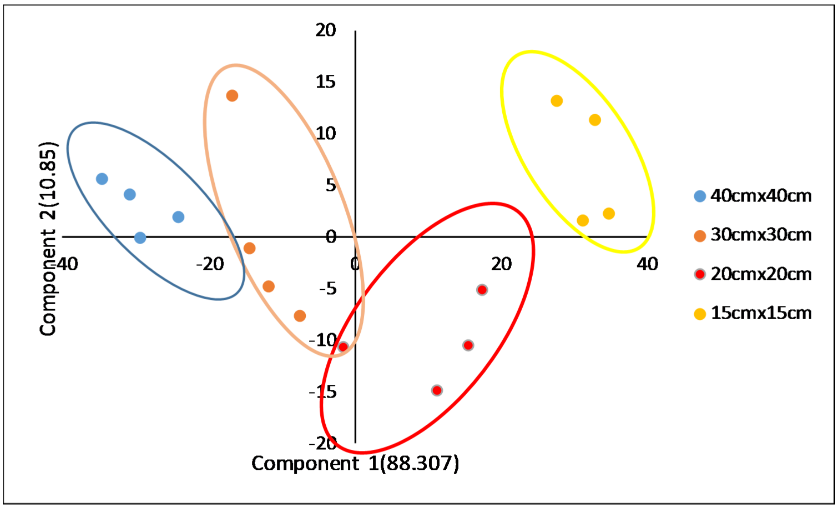

Figure 8. Principal component analysis of studied variables

Pairwise comparisons using linear discriminant analysis (LDA) with Mahalanobis distances and group assignments with an 87.5% cross-validation by Jacknife (leave-one-out) procedure revealed a highly significant difference ($F = 99.27$, $df = 3, 12$, $p<0.001$) in common bean spatial orientation, after 99999 simulations for the measured parameters. Common bean plant spatial orientation of 20 cm × 20 cm and 30 cm × 30 cm were not significantly different ($p>0.05$). Overall, common bean spatial arrangement of 40 cm × 40 cm, 30 cm × 30 cm and 20 cm × 20 cm were similar to each other than with 15 cm × 15 cm (Fig. 8).

Table 2. Mean cumulative number (± standard error) of bean foliage beetle (*Ootheca mutabilis*) on common bean with different plant orientation

Plant orientation	No. of bean foliage beetle plot^{-1}
15 cm × 15 cm	13.81 ± 0.62 a
20 cm × 20 cm	7.81 ± 0.75 b
30 cm × 30 cm	7.75 ± 0.93 b
40 cm × 40 cm	6.63 ± 0.22 b

4 Discussion

In the current study, the oviposition holes on the leaves of common bean due to the activities of BSM showed a linear relationship with plant density. The higher the plant density, the higher the number of oviposition holes. The mean number of oviposition holes increased overtime. This could be explained by the increase in plant growth and availability food and more substrate for oviposition. The mean cumulative number of eggs on leaves from the highest plant density (15 cm × 15 cm) was twice that from the lowest plant density (40 cm × 40 cm), i.e. 40.5 and 94.25, respectively. The trend is also observed with the cumulative mean number of BSM, where higher plant densities had higher BSM populations.

Many studies have investigated the effect of plant spacing or plant orientation on pest activities and pest population dynamics. Asiwe et al. (2005) concluded that the severity of damage on plants by insect infestation increased with reduction in plant spacing. The same observation was recorded by Akinkunmi and Akintoye (2012) and Momtaz et al. (2019) who investigated pest activity on different plant spacing of sunflower and cotton, respectively. Although Razaq et al. (2012) demonstrated plant density had no significant effect on aphid type and population fluctuation on late sown canola, *Brassica napus* L. (Brassicaceae).

The finding of the number of oviposition holes was similar to that of the mean number of BSM, although the population of BSM did not substantially change over time. Like the mean cumulative number of oviposition holes, the mean cumulative number bean stem maggot showed a linear relationship with plant density. The mean cumulative number of BSM was two-fold higher than those of lower plant density (40 cm × 40 cm and 30 cm × 30 cm). This disparity in BSM population and activity over plant orientation (plant density) may such that the photosynthetic activity and overall physiochemical performance of the plant is interfered with differently. This may have real consequences on the yield. Oso and Falade (2010) investigated the effect of plant density (maize/cowpea intercrop) in Nigeria and concluded pest activity was higher in higher plant density field with a significant reduction in pod number, seed number and seed weight. The findings of the current study are in stark contrast with that of Peter et al. (2009). They investigated the role of plant spacing of common bean intercropped with maize and concluded that the incidence of *Ophiomyia* spp. decreased with increasing plant populations. This dissimilarity in the result of the current study and that of Peter et al. (2009) could be as a result of the intercropping effect of maize, which provide a mechanical barrier and limited *Ophiomyia* spp. mobility and colonization. Thus, attempting to increase yield by increasing plant density does not always translate to reality.

The leaf damage score from BFB also increased over time. i.e. increase in plant maturity and availability of food. Very similar result trends to that of oviposition hole were observed. Leaf damage score increased with plant density (15 cm × 15 cm). The bean leaf damage from dense plots (15 cm × 15 cm) was almost two-fold that of the sparse or less dense plots (40 cm × 40 cm). The incidence and damage of BFB in common bean is plant density-dependent, i.e the higher the plant density, the higher the incidence and damage. This could be linked to the availability of food and abundant foliage – providing a hiding place for pest. The reverse is true for sparsely planted field; little food and foliage available thus exposing the pest to natural enemies. However, this situation seems to be applicable in sole common bean fields. Oso and Falade (2010) evaluated the incidence and damage of *Ootheca mutabilis* in a 2:3 maize/cowpea and 1:1 maize/cowpea intercrop. They found no significant differences in BFB incidence and damage and concluded that planting pattern in intercropping seem not to be a determinant variable for leaf infestation by BFB. Obanyi et al. (2017) also reported a 15% reduction in BFB incidence in plots with mixed bean cultivars compared to monoculture. Intercropping common bean with other crops especially cereals has been reported as a viable pest management strategy for some pests of common bean (Slumpa et al., 2013) and increase yield (Singh and Ajeigbe, 2002).

The principal component analysis revealed that there was a close relationship between the plant orientations of 20 cm × 20 cm (250000 plants ha^{-1}) and 30 cm × 30 cm (110000 plants ha^{-1}) compared to other plant spacing-for all variables measured. It is important to note that the parameters measured (number of oviposition holes by BSM, cumulative number of BSM, leaf damage by BFB and cumulative number of BFB on common bean leaves) were similar for plant orientations of 20 cm × 20 cm and 30 cm × 30 cm, and sometimes with 40 cm × 40 cm. One limitation of this study is that yield parameters were not examined. Although the present study did not examine the effect of plant spacing on yield of common bean, it has been reported already that common bean density of 250000 plants ha^{-1} (20 cm × 20 cm) is recommended to small-scale farmers for optimal growth and yield (Musana et al., 2020).

5 Conclusion

The present study examines the effect of common bean spatial orientation on the activities and the population dynamics of two major pests of common beans: bean stem maggot *Ophiomyia phaseoli* and bean foliage beetle *Ootheca mutabilis*. It was found that common bean spatial orientation (plant density) influenced the activity and population dynamics of both pests.

The highest activity and populations of BSM and BFB were recorded from the very dense plots with plant orientation of 15 cm × 15 cm (∼442500 plants ha^{-1}). In contrast, lowest activity and pest populations were found in the fields planted at 20 cm × 20 cm spacing. In line with previous studies, common bean spatial arrangements of 20 cm × 20 cm (∼250000 plants ha^{-1}) is recommended in order to mitigate the harmful effects of BSM and BFB. For future perspective, it is important assess the effect of different plant orientation on yield and pest parameters concurrently.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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The Official Journal of the
Farm to Fork Foundation
ISSN: 2518–2021 (print)
ISSN: 2415–4474 (electronic)
http://www.f2ffoundation.org/faa