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Population Dynamics of Selected Field Pests and Their Effect on Grain Yield and Yield Components of Common Bean in Uganda

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Posted Date: 15 September 2023

doi: 10.20944/preprints202309.1026.v1

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Article

Population Dynamics of Selected Field Pests and Their Effect on Grain Yield and Yield Components of Common Bean in Uganda

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Simple Summary: The common bean is often attacked by a complex of insect pests with some such as the bean fly, bean leaf beetles, and aphids existing throughout the growing period. However, there is limited information on the abundance of these pests at different common bean growth stages and subsequent effect on yield and yield components in Uganda. This study therefore aimed at determining the abundance of existing insect pests in common bean at different growth stages and their impact on yield and yield components. Experiments for monitoring insect pests were established in three agro-ecological zones during two consecutive rainy seasons of 2016 second rains and 2017 first rains. Bean fly, bean aphids, bean leaf beetles, whitefly, striped bean weevil, leaf hoppers, and caterpillars of Lepidopteran species were the main insects observed. Pest populations varied among bean growth stages, locations and between seasons. The impact of insect pests on yield varied among individual pests and was generally low. Our study is important in informing growers on the stage of crop growth at which management tactics can be applied for different insect pests.

Abstract: In Uganda, the common bean (*Phaseolus vulgaris*) is often infested by a complex of insect pests, but the bean stem maggots, aphids, bean leaf beetles, and flower thrips are the most important. Whereas yield losses due to these pests have been established, there is limited information on their population dynamics at different stages of crop growth and their effect on yield and yield components. In order to describe the population dynamics of selected common bean pests at various phases of bean crop growth, and their impact on yield and yield components, a study was carried out in Uganda during 2016 second rains and 2017 first rains in three agro-ecological zones. Bean fly, bean aphids, bean leaf beetles, whitefly, striped bean weevil, leaf hoppers, and caterpillars of Lepidopteran species were the main insects observed. Pesticide spray schedules were imposed to generate different populations of insect pests whose effects on yield and its components were determined. The findings indicate that spray regimes significantly influenced the abundance of bean fly, aphids, whitefly, striped bean weevil, and leaf hoppers but not bean leaf beetles and caterpillars. Additionally, except caterpillars, insect pests were significantly influenced by crop growth stages, but only aphids, whiteflies, bean flies and leaf hoppers exhibited a significant negative relationship with grain yield. Furthermore, yield and yield components varied significantly between spray regimes, agro-ecological zones, and seasons. Our study is important in informing growers on the stage of crop growth at which management tactics such as use of insecticides can be applied for different insect pests.

Keywords: common bean; pests complex; abundance; insecticides; spray regimes

1. Introduction

Common bean (*Phaseolus vulgaris* L) forms part of the major diet in Uganda, contributing to nutrition and food security as a cheaper alternative to more expensive protein items [1]. With 24.7% of the crop exported in 2018, common bean is also an important source of income for farmers and traders in Uganda [2]. The crop is cultivated by 54% of the agricultural households, mainly

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smallholder farmers [3]. Despite the significance of common bean, its productivity has remained below optimum. For instance, in 2018, the total area planted with common bean was about 1.2 M Ha and the annual total production of beans was 728,000 tones with a yield of 0.6 MT/Ha in the second season [3]. The low yield of common bean in Uganda is attributed to poor agronomic practices, poor cultivars, low soil fertility, moisture stress, weed competition and damage caused by diseases and pests [4].

Insect pests are one of the most important bean production constraints in tropical and subtropical Africa [5,6]. Insect pests often occur in complexes, which are responsible for severe injury and reduction in bean yields [5]. In Uganda, the bean pests complex include, bean aphid (*Aphis fabae*) [7], bean fly (*Ophiomyia* spp.) [8–10], thrips (*Frankliniella occidentalis* and *Megalurothrips sjostedti*) [11], legume pod borers (*Maruca* sp and *Helicoverpa armigera*), pod suckers (*Clavigralla* sp, *Riptortus* sp and *Nezara viridula*), semi-looper (*Trichoplusia* sp), cutworm (*Agrotis* sp), flower and pollen beetles (*Mylabris* sp and *Coryna* sp), common whitefly (*Bemisia tabaci*) [12], and bean leaf beetles (*Ootheca* spp) [13,14]. In Uganda, the bean fly, causing up to 100% yield loss [10], aphids causing up to 90% yield loss [15], bean leaf beetles causing up to 49% yield loss [14], and thrips causing up to 27% yield loss [11], are the most devastating.

Management of common bean pests varies from one pest to another but generally rely on use of cultural practices and insecticides. For instance, the bean fly is managed by soil fertility enhancement and mulching [9], variety mixtures [8], intercropping [16], early planting [17] and insecticide seed dressing [18]. Recommended management practices against bean leaf beetles include intercropping with non-hosts, deep tillage, crop rotation [18], trap cropping [19], early planting [20], insecticides [20,21] and use of aqueous botanical extracts [22,23]. Aphids and thrips are given little attention by farmers, although resistance to insecticides by bean flower thrips has been reported [15].

There is a dearth of information on the population dynamics of these pests at various growth stages of the bean crop and their impact on yield and yield components. Moreover, grain yield losses for the majority of these pests have been established for single pest species despite common bean being attacked by a complex of pest species. Understanding the population dynamics of bean pests at various phases of bean crop development and their impact on yield and yield parameters is necessary for improving control of bean pests. The objectives of this study therefore were to determine the effect of insecticide spray regimes on the: (i) population dynamics of selected common bean field pests at different stages of bean crop growth and (ii) effect of the selected pests on yield and yield components of common bean in Uganda.

2. Materials and Methods

2.1. Trial Sites

Trials were conducted in three agro-ecological zones of Northern Moist Farmlands (NMF), West Nile Farmlands (WNF) and Western Mid-Altitude Farmlands and the Semliki Flats (WMAFSF) at Zonal Agriculture and Research Development institutes (ZARDIs). Trials were established at Ngetta ZARDI in Lira district (N02.29889, E032.91667) in NMF, Abi ZARDI located in Arua district (N03.07694, E030.94147) in WNF and Bulindi ZARDI located in Hoima district (N01.50052, E031.49667) in WMAFSF. The trials were conducted for two consecutive seasons during short rains of 2016 (July to November) (2016B) and long rainy season of 2017 (March to June) (2017A).

During 2016B season, planting was done on 18th July 2016 in NMF, 12th July 2016 in WNF, and 25th August 2016 in WMAFSF. During 2017A, planting was conducted on 8th April 2017 in NMF, 24th April 2017 in WNF, and 4th April 2017 in WMAFSF.

2.2. Treatments and Experimental Layout

The treatments were seven different pesticide schedules, which were applied with the aim of generating different populations of insect pests (Table 1). The treatments were arranged in a randomized complete block design with four replicates. Cypermethrin (Cyper lacer 5% EC) was used for all the foliar sprays while imidacloprid (imidacloprid 200 GL) was used in soil drenching. Each

 doi:10.20944/preprints202309.1026.v1

experimental plot measured 5 m by 3 m, with 0.5 m alleys between plots and 1 m between blocks. A local bean variety commonly known as *Kawula*, which is farmer preferred and also reportedly susceptible to most bean pests was used. Beans were planted at a spacing of 0.5 m between rows and 0.2 m within rows resulting into seven rows per plot.

Table 1. Schedule of insecticide application on common bean during 2016B and 2017A seasons in the three study Agro-ecological zones.

Treatment code	Description	Number of sprays	Time of foliar insecticide application (DAE)					
1	Weekly foliar application of cypermethrin from 7 to 42 Days after emergence (DAE)	6	7	14	21	28	35	42
2	weekly foliar application of cypermethrin from 14 to 42 DAE	5		14	21	28	35	42
3	Weekly foliar application of cypermethrin from 21 to 42DAE	4			21	28	35	42
4	weekly foliar application of cypermethrin from 28 to 42 DAE	3				28	35	42
5	Weekly foliar application of cypermethrin from 35 to 42 DAE	2					35	42
6	Soil drench of imidacloprid at planting combined with weekly foliar application of cypermethrin from 7 to 42 DAE	6+ Soil drench	7	14	21	28	35	42
7	Untreated control	0	-	-	-	-	-	-

2.3. Sampling for the Insect Pests

Data were collected on adults of bean fly, bean leaf beetles, aphids, striped bean weevil, leaf hoppers, whiteflies, and larvae of different unknown lepidopteran species (caterpillars). These were the pests observed from V1 growth stage up to R1 growth stage when sampling was stopped. Bean fly, bean leaf beetles, stripped bean weevils, leaf hoppers and caterpillars were assessed by direct counting. Aphids and whiteflies were assessed using a scale of 0-4, where 0=no infestation, 1=1-10 aphids, 2=10-50 aphids, 3=50-200 aphids, 4= over 200 aphids [24]. Sampling was conducted on 30 plants per plot, from three middle rows with 10 plants selected from each row at various stages of bean crop growth. These were V1 (completely unfurled leaves at the primary leaf node), V2 (first node above primary leaf node), V3 (three nodes on the primary stem including the primary leaf node), V4 (four nodes on the main stem), V5 (five nodes on the main stem), and R1 (one blossom open at any node).

2.4. Data Collection on Yield and Its Components

Data on plant stand, number of pods, number of seeds in a pod, number of primary branches, number of secondary branches and grain yield were taken at harvest. Plant stand was obtained by counting the total number of plants in a plot prior to harvesting. Number of pods, primary branches, secondary branches and number of seeds in a pod were obtained from 10 plants per plot. Total grain yield was obtained by harvesting all the plants in a plot. Yield obtained was then standardized to Kg/Ha.

2.5. Data Analysis

Data was first subjected to a mixed design analysis of variance model in order to determine significant factors and their interactions. For insect count data, season, agro-ecological zone, crop growth stage and spray regimes were treated as fixed effects while replicates were treated as random. Before analysis, insect pest counts were transformed into square root (x+0.5) to homogenize variances. For yield and yield components, season, agro-ecological zone and spray regimes were treated as fixed effects while replicates were treated as random. From the model, differences between the means for selected significant interactions were tested using contrast post hoc tests with lme4 and

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multicomp packages. Differences were considered significant at $\alpha = 0.05$. Multiple regression analysis was used to determine the relationship between the different insect pests and grain yield, and different yield components and grain yield.

3. Results

3.1. Effects of Different Factors on Populations of Insect Pests

The insect pests observed in this study include bean fly, bean aphids, bean leaf beetles, whitefly, striped bean weevil, leaf hoppers, and caterpillars of Lepidopteran species. All main treatment effects of season, agro-ecological zone, spray regimes and growth stages were significant (p<0.001) for all insect pests under this study except for caterpillars (Table 2). There were also significant two-way interactions of season × agro-ecological zone for all insect pests except caterpillars; season × growth stage for all insect pests except caterpillars; agro-ecological zone × growth stage for all insect pests; season × spray regimes for all insect pests except bean fly and caterpillars; agro-ecological zone × spray regimes for only aphids, whiteflies, and bean leaf beetles; and growth stage × spray regimes for all insect pests except bean fly and striped bean weevils (Table 2). There were also significant three-way interactions of season × agro-ecological zone × growth stage for all insect pests except caterpillars, season × agro-ecological zone × spray regimes for all insect pests except caterpillars, season × growth stage × spray regimes for all insect pests except caterpillars, and agro-ecological zone × growth stage × spray regimes for all insect pests except caterpillars and bean leaf beetles (Table 2). Furthermore, the four-factor interaction of season × agro-ecological zone × growth stage × spray regimes was significant for all insect pests except bean fly and caterpillars (Table 2). Due to the complexity of four factor and three-way interactions, two-way interactions of agro-ecological zone and season, and main effects of spray regimes and growth stages are presented.

Table 2. F statistics for different parameters analyzed for different insect pests of common bean.

Sov	Df	Bean fly	Aphids	Caterpillars	Whitefly	Bean Leaf beetles	Striped weevils	Leaf hoppers
Season (S)	1	12.4***	328.4***	0.7ns	568.2***	95.7***	61.0***	91.9***
AEZ (A)	2	57.7***	1231.3***	0.2ns	2838.5***	80.8***	18.0***	44.2***
Stage (G)	5	17.6***	121.9***	1.9ns	59.2***	24.0***	7.5***	13.4***
Spray regimes (T)	6	11.3***	168.9***	3.7**	177.1***	1.9ns	5.7***	16.9***
S×A	2	212.0***	427.5***	2.2ns	727.7***	95.7***	35.7***	128.7***
S×G	5	9.9***	30.5***	0.7ns	73.8***	15.6***	6.2***	14.0***
A×G	10	9.1***	121.7***	2.8**	64.3***	15.7***	11.8***	22.4***
S×T	6	1.8ns	27.4***	0.7ns	32.6***	1.7ns	2.8*	3.7**
A×T	12	1.5ns	140.0***	0.8ns	162.8***	2.0*	1.3ns	1.1ns
G×T	30	1.0ns	19.3***	1.9**	23.3***	2.3***	1.4ns	1.8**
S×A×G	10	13.0***	35.5***	0.4ns	50.7***	20.1***	12.9***	17.6***
S×A×T	12	5.7***	38.1***	1.6ns	36.5***	3.7***	2.6**	5.1***
S×G×T	30	1.7*	4.7***	1.1ns	13.0***	1.8**	1.7*	1.6*
A×G×T	60	1.4*	18.8***	1.3ns	23.6***	1.3ns	1.6**	1.7**
S×A×G×T	60	1.3ns	5.4***	1.0ns	11.9***	1.6**	1.4*	2.2***

SoV =Source of variation, AEZ =Agro-ecological zone, df = degrees of freedom, *** = significant at 0.001, **= significant at 0.01, * = significant at 0.05, ns= Not significant.

3.2. Effect of Insecticide Spray Regimes on Insect Pest Populations

Insecticide spray regimes significantly influenced the abundance of bean fly (df=6, F=5.8, p<0.001), aphids (df=6, F= 16.6, p<0.001), caterpillars (df=6, F=2.8, p<0.05), whitefly (df=6, F=10.9, P<0.001), striped bean weevils (df=6, F=3.2, p<0.001), and leaf hoppers (df=6, F=7.2, p<0.001); and not the abundance of bean leaf beetles (Table 3). Generally, the longer the delay to start insecticide application, the higher the numbers of the insect pests. A combination of soil drench and weekly application of foliar insecticides having the lowest pests' abundance.

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Table 3. Main effect of spray regimes on the abundance of different insect pests, averaged over the two seasons.

Spray regimes	Insect pests						
	Bean fly	Aphids	Caterpillars	Whiteflies	Bean leaf beetles	Striped bean weevils	Leaf hoppers
1	0.26 ± 0.007ab	0.23 ± 0.023a	0.22 ± 0.001a	0.32 ± 0.031ab	0.24 ± 0.006ns	0.23 ± 0.003ab	0.26 ± 0.008ab
2	0.27 ± 0.007b	0.27± 0.023ab	0.23 ± 0.001ab	0.39 ± 0.031abc	0.24 ± 0.006ns	0.23 ± 0.003ab	0.27 ± 0.008ab
3	0.28 ± 0.007b	0.35 ± 0.023bc	0.23 ± 0.001ab	0.44 ± 0.031bcd	0.25 ± 0.006ns	0.24 ± 0.003b	0.28 ± 0.008bc
4	0.28 ± 0.007b	0.39 ± 0.023cd	0.23 ± 0.001ab	0.46 ± 0.031cd	0.24 ± 0.006ns	0.24 ± 0.003b	0.29 ± 0.008bc
5	0.28 ± 0.007b	0.44 ± 0.023cd	0.22 ± 0.001a	0.52 ± 0.031d	0.25 ± 0.006ns	0.24 ± 0.003b	0.29 ± 0.008bc
6	0.24 ± 0.007a	0.23 ± 0.023a	0.22 ± 0.001a	0.28 ± 0.031a	0.23 ± 0.006ns	0.22 ± 0.003a	0.24± 0.008a
7	0.29 ± 0.007b	0.46 ± 0.023d	0.24 ± 0.001b	0.55 ± 0.031d	0.25 ± 0.006ns	0.23 ± 0.003ab	0.30 ± 0.008c

Within a column, values bearing the same letters are not significantly different at α = 0.05; ns=Not significant; Spray regimes: 1= Weekly foliar application of cypermethrin from 7 to 42 Days after emergence (DAE), 2= Weekly foliar application of cypermethrin from 14 to 42 DAE, 3=Weekly foliar application of cypermethrin from 21 to 42 DAE, 4=Weekly foliar application of cypermethrin from 28 to 42 DAE, 5=Weekly foliar application of cypermethrin from 35 to 42DAE, 6= Soil drench of imidacloprid at planting combined with weekly foliar application of cypermethrin from 7 to 42 DAE, 7=Untreated control.

3.3. Effect of Crop Growth Stage on Insect Pests

Bean fly, beans aphids, caterpillars, whiteflies, bean leaf beetles, striped bean weevils and leaf hoppers occurred at all growth stages considered in this study, and their abundance varied significantly between growth stages. Significantly (df=5, F=8.6, $p<0.001$) higher bean fly populations were associated with V2 and V5 (Figure 1). For aphids, significantly (df=5, F=10.4, $p<0.001$) higher populations were recorded at V4, V5 and R1 (Figure 2). For whiteflies, significantly (df=5, F=3.1, $p<0.05$) higher populations were recorded at V2, V4, and V5 (Figure 3). For bean leaf beetles, there were significantly (df= 5, F=11.0, $p<0.001$) higher populations at V2 and V1 (Figure 4). For striped bean weevil, there were significantly (df=5, F=4.3, $p<0.001$) higher populations at V2 (Figure 5). For leaf hoppers, there were significantly higher populations at V4 (Figure 6).

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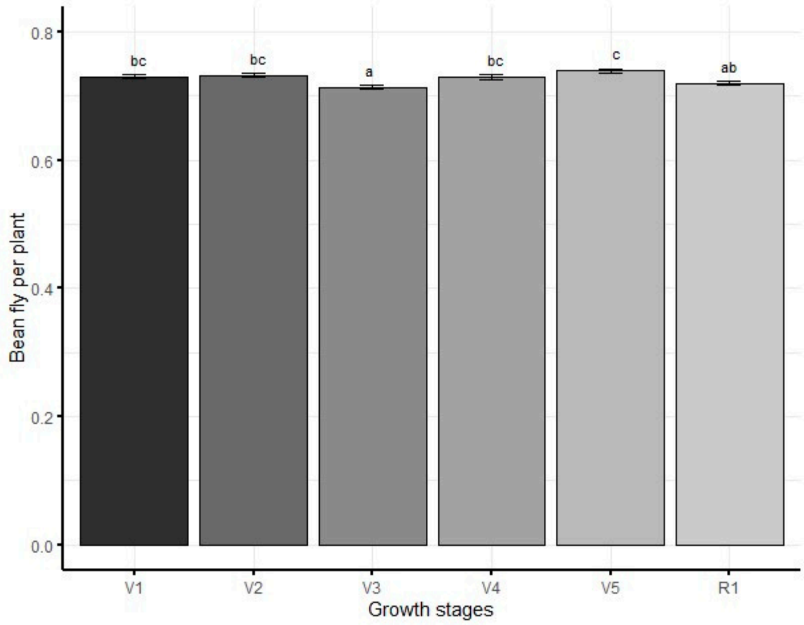

Figure 1. Main effect of bean growth stage on the abundance of bean fly. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05.

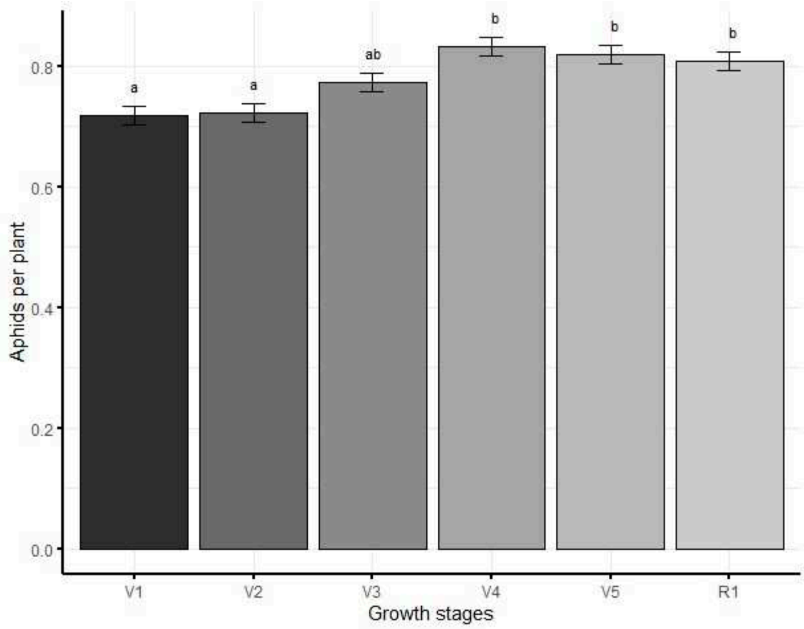

Figure 2. Effect of bean growth stage on the abundance of aphids. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05.

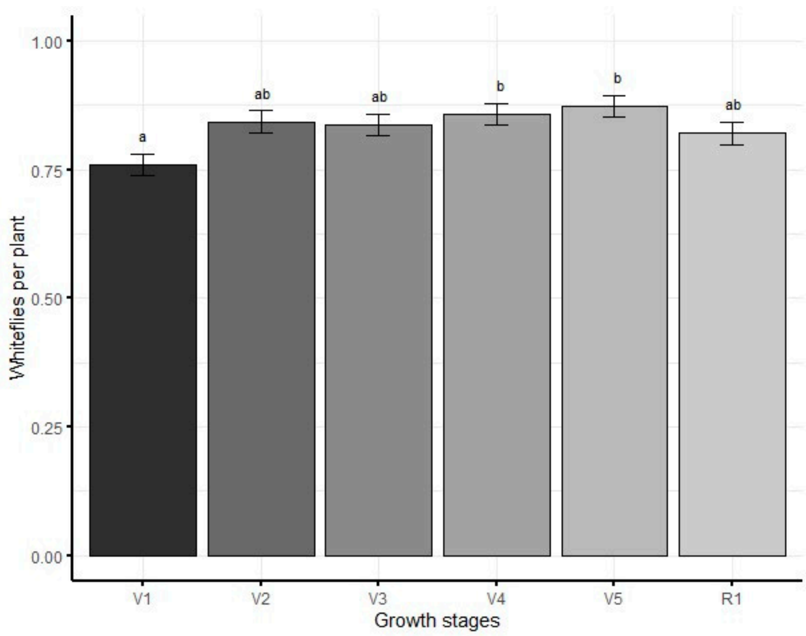

Figure 3. Effect of bean growth stage on the abundance of whiteflies. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05.

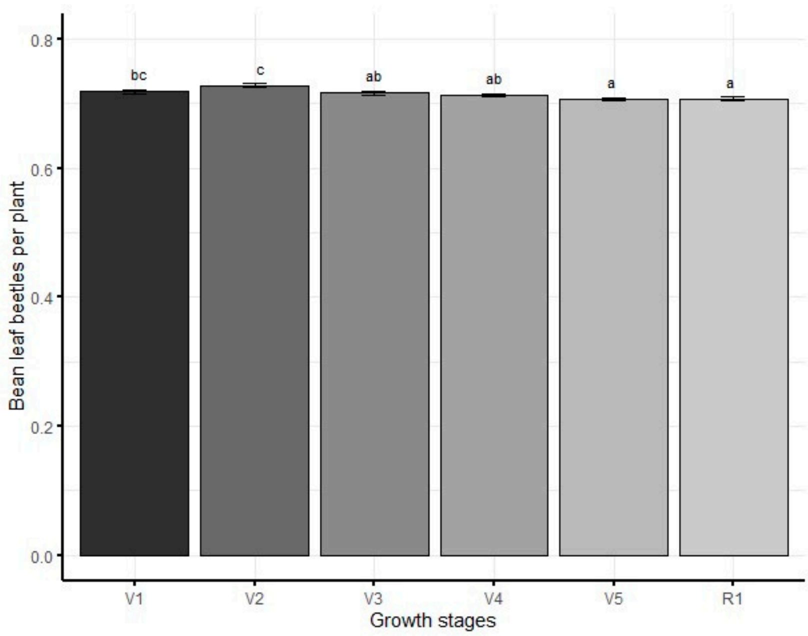

Figure 4. Effect of bean growth stage on the abundance of bean leaf beetles. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05.

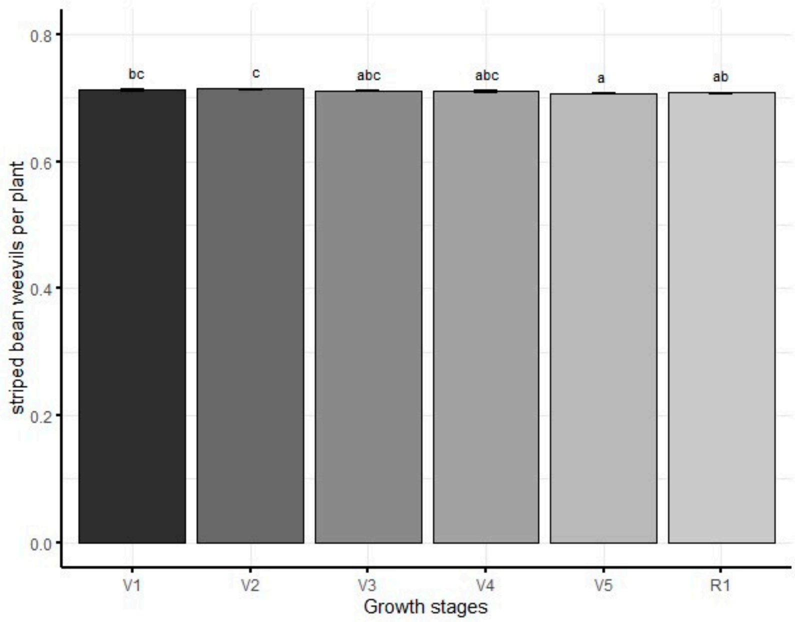

Figure 5. Effect of bean crop growth on the abundance of striped bean weevils. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05.

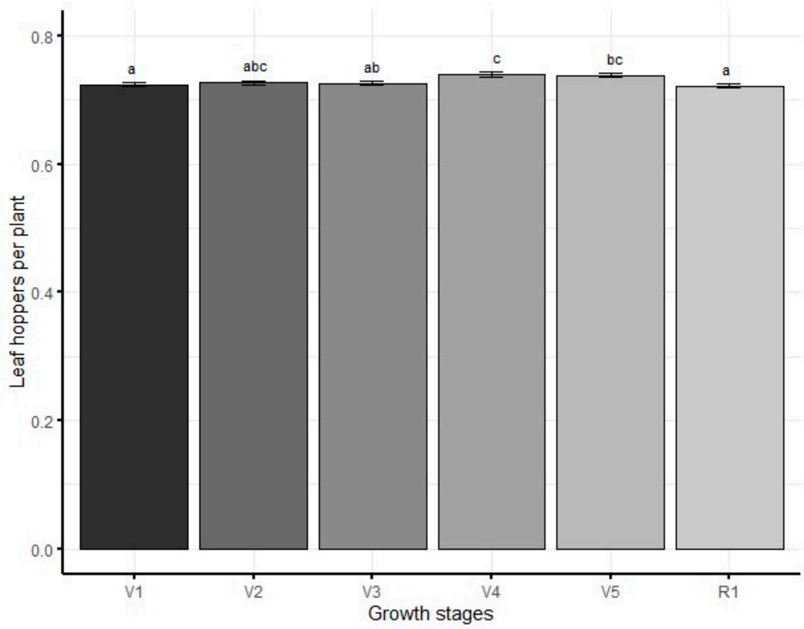

Figure 6. Effect of bean growth stage on the abundance of leaf hoppers. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05.

3.4. Effects of Agro-Ecological Zone and Season on Insect Pest Populations

There were significant interactions between agro-ecological zones and seasons on the populations of bean fly (Figure 7), aphids (Figure 8), whiteflies (Figure 9), bean leaf beetles (Figure 10), striped bean weevils (Figure 11), and leaf hoppers (Figure 12). With the exception of WMAFSF, the abundance of bean fly and leafhoppers were higher in 2016B than in 2017A. In the case of aphids and whiteflies, the abundance was only significantly higher in 2017A than 2016B in WMAFSF. For bean leaf beetles, significant seasonal differences were only observed in WNF where higher populations were recorded in 2017A than 2016B. Striped bean weevils were higher in 2016B than

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2017A in both NMF and WNF. There were no differences in their populations between the two in WMAFSF.

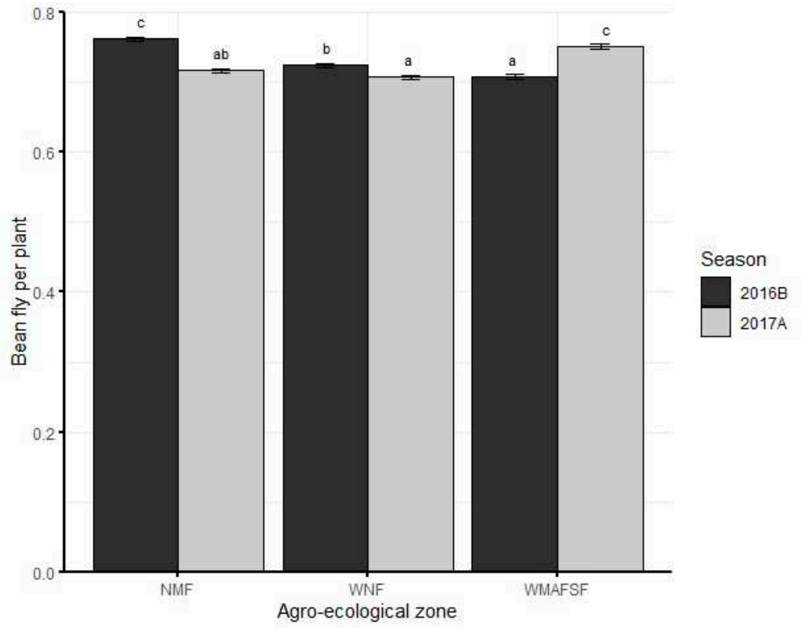

Figure 7. Interaction effect of agro-ecological zone and season on the abundance of bean fly. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05).

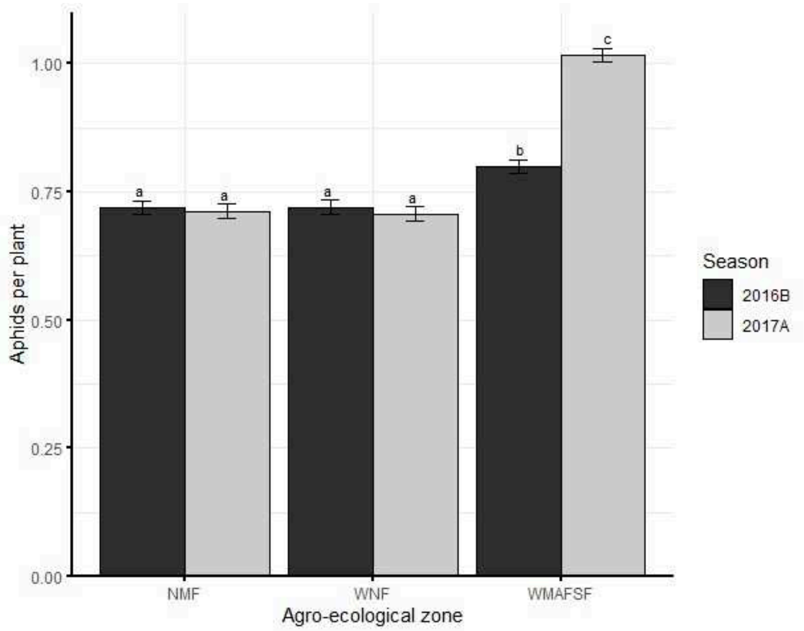

Figure 8. Interaction effect of agro-ecological zone and season on the abundance of aphids. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05).

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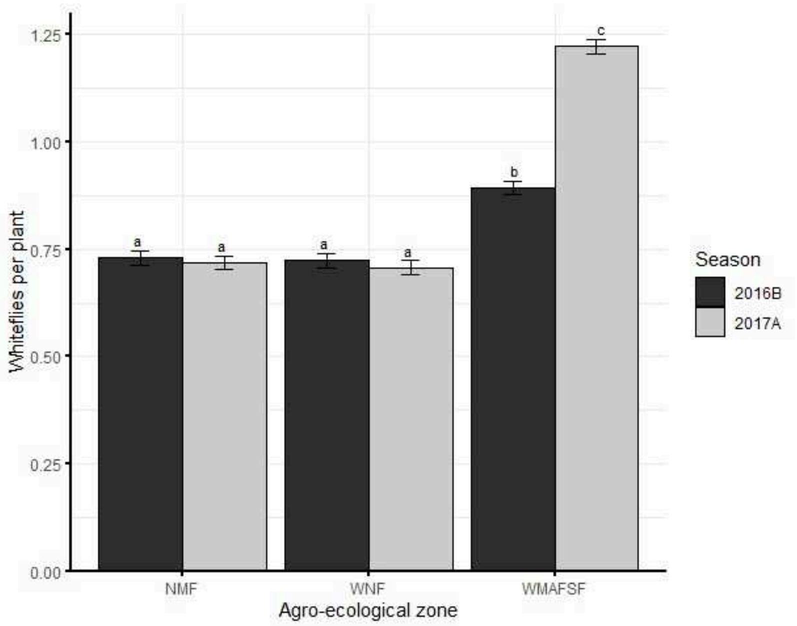

Figure 9. Interaction effect of agro-ecological zone and season on the abundance of whiteflies Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05).

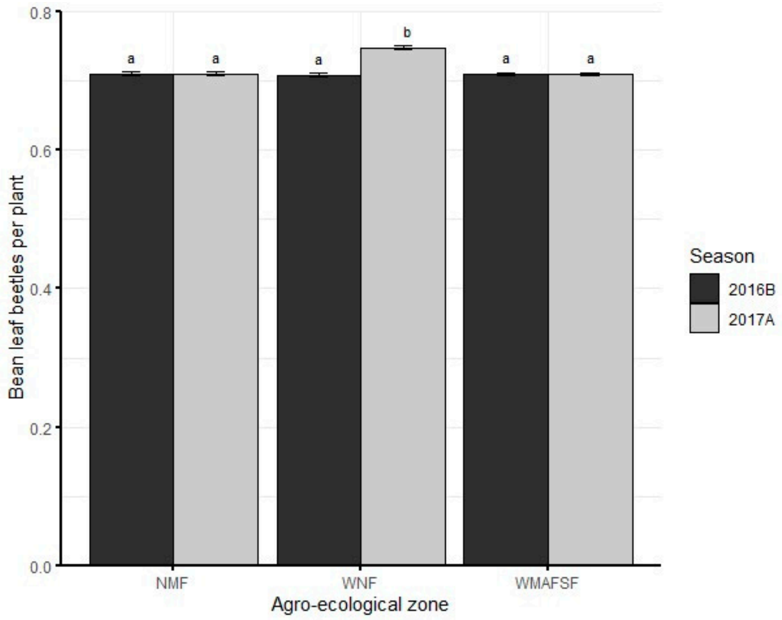

Figure 10. Interaction effect of agro-ecological zone and season on the abundance of bean leaf beetles. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05).

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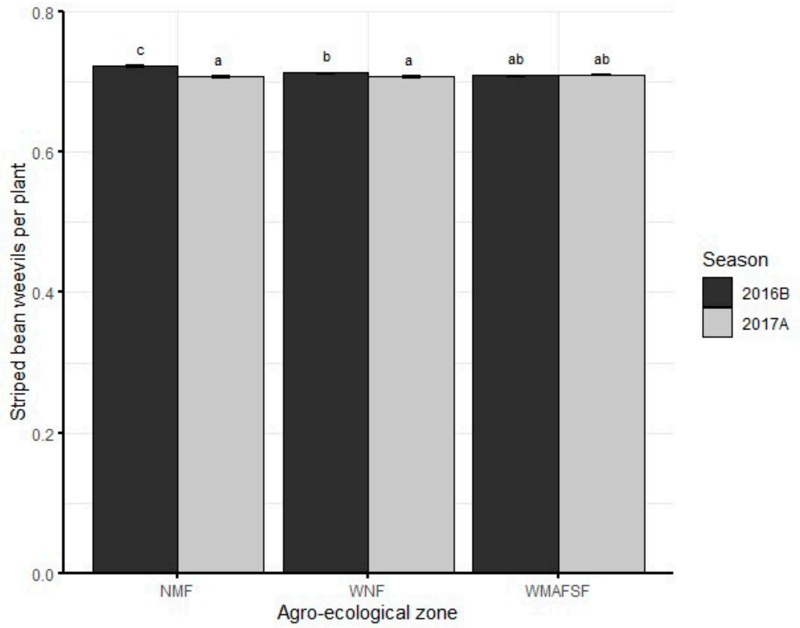

Figure 11. Interaction effect of agro-ecological zone and season on the abundance of striped bean weevils. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05).

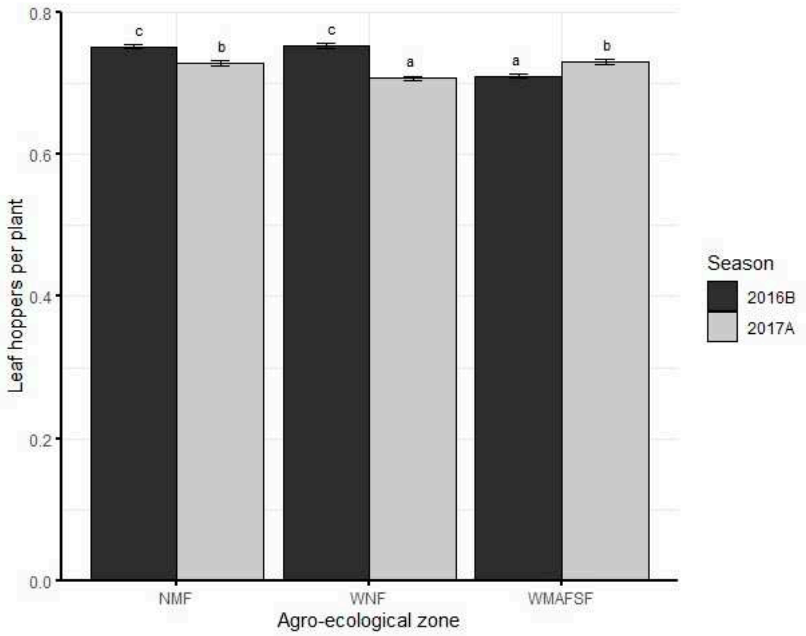

Figure 12. Interaction effect of agro-ecological zone and season on the abundance of leaf hoppers. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05).

3.5. Effect of Fixed Factors on Yield and Yield Parameters

All main effects of season, agro-ecological zone and spray regimes significantly affected yield and all yield components of beans (Table 4). There were significant two-way interactions of season × agro-ecological zone on yield and all yield components; season × spray regimes for plant stand, number of primary and secondary branches, and number of seeds per pod; agro-ecological zone × treatment for yield and all yield components (Table 4). There was also a significant three-way interaction of season × agro-ecological zone × spray regimes on yield and all yield components except for the number of pods per plant (Table 4).

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Table 4. F statistics for different parameters analyzed for yield and yield components.

SoV	Df	Plant stand	Grain yield (Kg/Ha)	Primary branches (per plant)	Secondary branches (per plant)	Pods (per plant)	Seeds (per plant)
Season (S)	1	662.3***	50.3***	3008.3***	5398.8***	169.2***	66.8***
AEZ (A)	2	515.5***	73.9***	422.1***	310.4***	143.9***	11.6***
Spray regimes (T)	6	52.1***	68.9***	189.9***	83.0***	13.9*	48.7***
S×A	2	447.8***	48.8***	767.8***	199.3***	210.7***	372.5***
S×T	6	56.1***	1.4ns	169.7***	7.4***	10.8ns	15.5***
A×T	12	18.1***	10.7***	100.1***	55.4***	13.8*	7.0***
S×A×T	12	10.2***	6.9***	93.1***	68.3***	10.6ns	18.1***

Sov=source of variation, df = degrees of freedom, *** = significant at 0.001, **= significant at 0.01, * = significant at 0.05, ns= Not significantly different at p=0.05.

3.6. Effect of Insecticide Spray Regimes on Grain Yield and Yield Parameters

Insecticide spray regime significantly affected grain yield and all yield components (Table 5). Grain yield (df=6, F=45.6, p<0.001), plant stand (df=6, F=12.3, p<0.001), number of pods (df=6, F=6.2, p<0.001), number of seeds in a pod (df=6, F=19.9, p<0.001) and number of secondary branches (df=6, F=9.3, p<0.001 were significantly (df=6, F=6.2, p<0.001) higher in plots that received a soil drench of imidacloprid combined with early foliar spray of cypermethrin than the other applications (Table 5). However, primary branches were significantly (df=6, F=19.6, p<0.001) higher in early foliar applications up to 21 DAE than in soil drench and late foliar applications (Table 5).

Table 5. Main effect of insecticide spray regimes on yield and yield components, averaged over the two seasons.

Spray regimes	Grain yield and yield components					
	Grain yield (Kg/Ha)	Plant stand/15m²	No. primary branches per plant	No. secondary branches per plant	No. pods per plant	No. seeds per pod
1	868 ± 23.5d	211 ± 7.1b	2.6 ± 0.1b	3.7 ± 0.1c	6.5 ± 0.3ab	3.5 ± 0.1b
2	818 ± 23.5cd	218 ± 7.1b	2.4 ± 0.1b	3.4 ± 0.1bc	6.2 ± 0.3ab	3.3 ± 0.1ab
3	729 ± 23.5bc	197 ± 7.1ab	2.5 ± 0.1b	3.1 ± 0.1ab	6.2 ± 0.3a	3.4 ± 0.1b
4	697 ± 23.5b	207 ± 7.1ab	2.2 ± 0.1a	2.6 ± 0.1a	6.2 ± 0.3ab	3.4 ± 0.1b
5	595 ± 23.5a	210 ± 7.1b	2.1 ± 0.1a	3.1 ± 0.1ab	6.9 ± 0.3bc	3.1 ± 0.1a
6	982 ± 3.5e	251 ± 7.1c	2.2 ± 0.1a	3.7 ± 0.1c	7.2 ± 0.3c	3.7 ± 0.1c
7	541 ± 23.5a	182 ± 7.1a	2.2 ± 0.1a	3.4 ± 0.1bc	6.5 ± 0.3ab	3.2 ± 0.1ab

Within a column, values bearing the same letters are not significantly different at α=0.05; Spray regimes: 1= Weekly foliar application of cypermethrin from 7 to 42 Days after emergence (DAE), 2= Weekly foliar application of cypermethrin from 14 to 42 DAE, 3=Weekly foliar application of cypermethrin from 21 to 42 DAE, 4=Weekly foliar application of cypermethrin from 28 to 42 DAE, 5=Weekly foliar application of cypermethrin from 35 to 42DAE, 6= Soil drench of imidacloprid at planting combined with weekly foliar application of cypermethrin from 7 to 42 DAE, 7=Untreated control.

3.7. Effect of Agro-Ecological Zone and Season on Grain Yield and Yield Components

The interaction between agro-ecological zone and season was significant on grain yield and all yield components. Grain yield (df=2, F=30.0, P<0.001) (Figure 13), plant stand (df=2, F=225.5, p<0.001) (Figure 14), number of primary branches (df=2, F=140.7, p<0.001) (Figure 15), secondary branches (df=2, F=66.0, p<0.001) (Figure 16), and number of pods per plant (df=2, F=146.4, p<0.001) (Figure 17) were all significantly higher in 2016B than in 2017A in both NMF and WNF. In WMASFS, plant stand (Figure 14), number of primary branches (Figure 15) and number of pods per plant (Figure 10) were higher in 2017A than in 2016B, whilst, number of secondary branches (Figure 16) was higher in 2016B. Seed quantity (Figure 18) only differed significantly between seasons in NMF and WMAFSF, being higher in the former in 2017A and the latter in 2016B.

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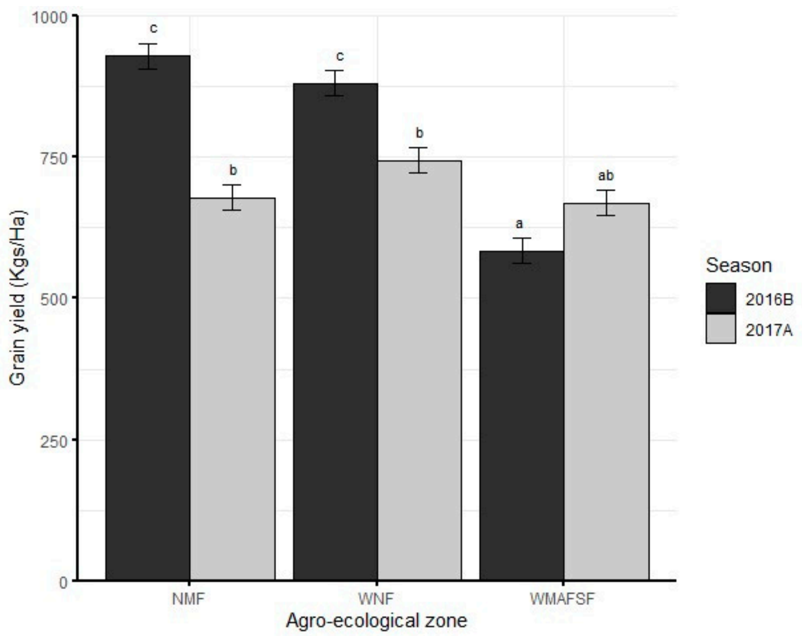

Figure 13. Interaction effect of agro-ecological zone and season on grain yield. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05).

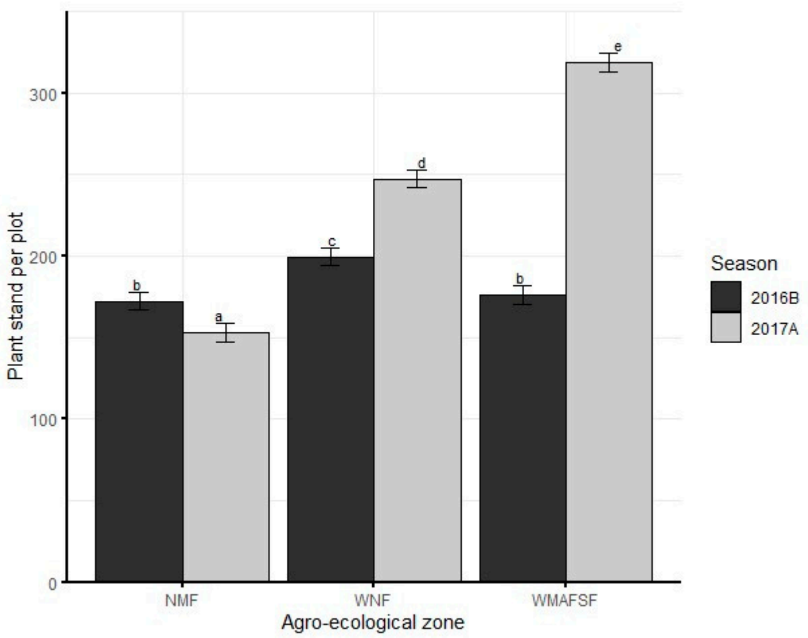

Figure 14. Interaction effect of agro-ecological zone and season on plant stand. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05).

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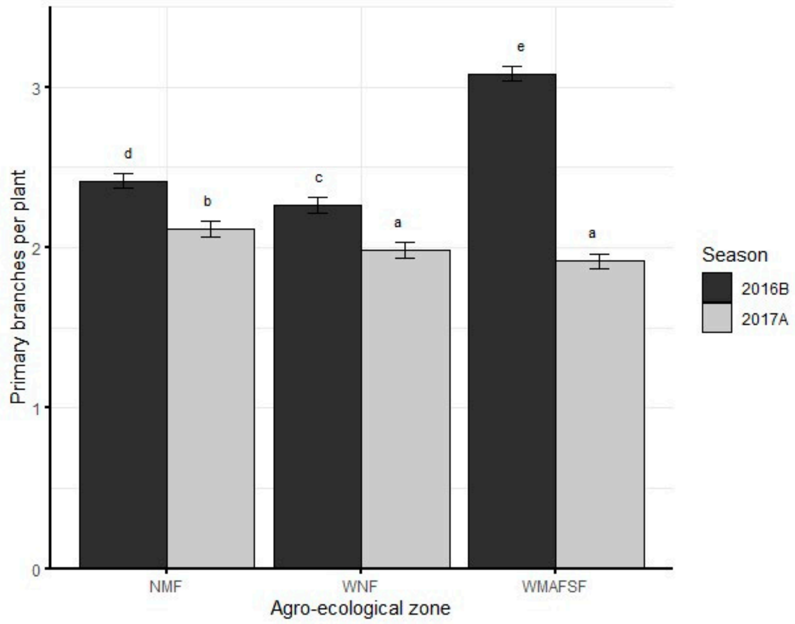

Figure 15. Interaction effect of agro-ecological zone and season on primary branches. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05).

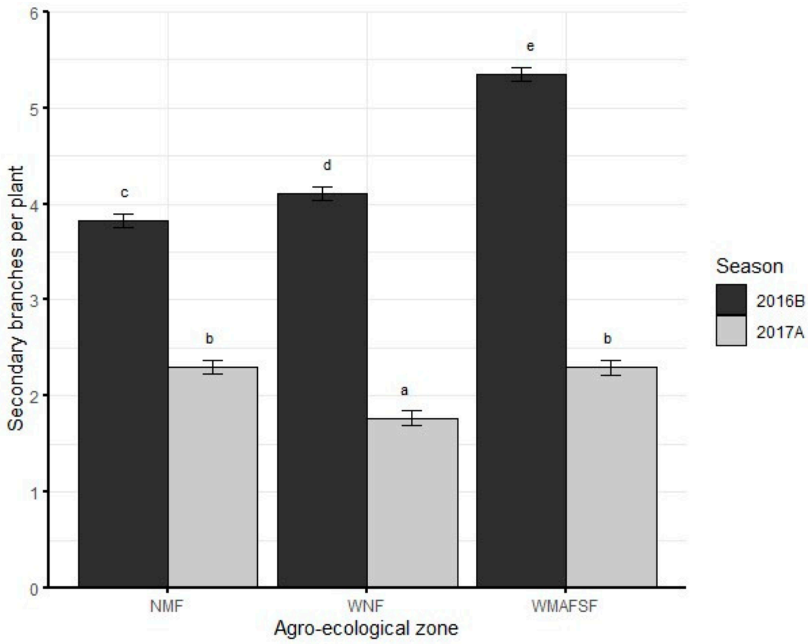

Figure 16. Interaction effect of agro-ecological zone and season on secondary branches. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05).

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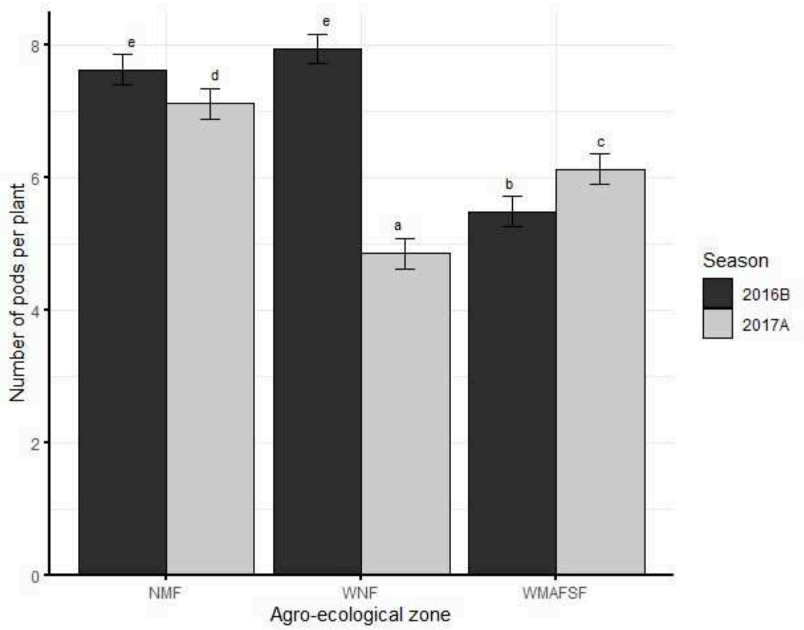

Figure 17. Interaction effect of agro-ecological zone and season on the number of pods. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05.

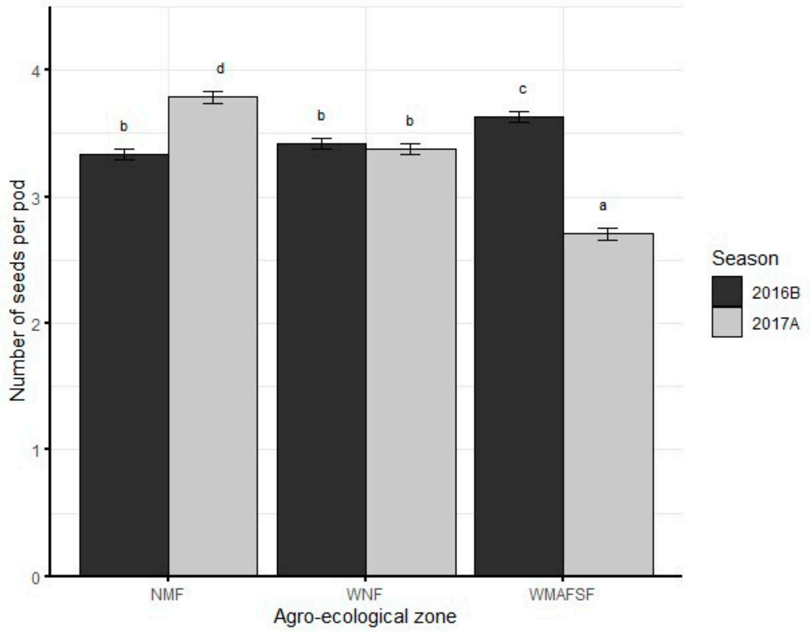

Figure 18. Interaction effect of agro-ecological zone and season on the number of seeds. Bars bearing the same letters represents means (±SE) that are not significantly different at α=0.05.

3.8. Relationship between the Abundance of Insect Pests and Grain Yield

In 2016B, there was no significant relationship between the abundance of insect species and grain yield in NMF (Table 6). However, significant negative relationships were only observed between bean aphids and grain yield in WNF, and whiteflies and grain yield in WMASFSF. In 2017, there was a significant negative relationship between the abundance of bean fly and grain yield in NMF, and leaf hoppers and grain yield in WMAFSF). No significant relationships were observed between abundance and grain yield for the other insect species (Table 6).

Table 6. Relationship between the abundance of insect pests and grain yield during 2016B and 2017A.

Agro-ecological zone	Parameter	Estimate	Std. Error	t value	P(>|t|)
		2016B			
NMF	Intercept	957.951	29.252	32.749	<2e-16 ***
	Bean leaf beetles	-675.847	1186.683	-0.570	0.570
	Aphids	-131.796	309.740	-0.426	0.671
	Striped bean weevils	-134.750	508.260	-0.265	0.791
	Caterpillars	-1587.309	3190.118	-0.498	0.619
	Bean fly	5.103	204.839	0.025	0.980
	Leaf hoppers	-360.824	226.633	-1.592	0.113
	Whiteflies	91.566	330.366	0.277	0.782
WNF	Intercept	935.97	25.27	37.032	< 2e-16 ***
	Bean leaf beetles	1545.88	1737.58	0.890	0.374975
	Aphids	-1420.62	420.63	-3.377	0.000919 ***
	Striped bean weevils	473.75	741.30	0.639	0.523682
	Caterpillars	-2369.78	1403.55	-1.688	0.093279
	Bean fly	-249.86	424.62	-0.588	0.557074
	Leaf hoppers	-223.67	234.16	-0.955	0.340908
	Whiteflies	-290.86	287.42693	-1.012	0.313088
WMAFSF	Intercept	668.58	30.99	21.577	< 2e-16 ***
	Bean leaf beetles	-523.93	1552.87	-0.337	0.73626
	Aphids	-102.86	90.96	-1.131	0.25981
	Striped bean weevils	1033.57	1686.07	0.613	0.54074
	Caterpillars	-2309.91	3142.13	-0.735	0.46333
	Bean fly	-3016.39	3051.98	-0.988	0.32448
	Leaf hoppers	-134.84	1233.67	-0.109	0.91310
	Whiteflies	-191.83	65.57	-2.925	0.00394 **
		2017A			
NMF	Intercept	693.32	28.32	24.484	<2e-16 ***
	Leaf beetles	184.70	1150.04	0.161	0.8726
	Aphids	73.12	814.81	0.090	0.9286
	Striped weevils	NA	NA	NA	NA
	Caterpillars	136.82	2055.10	0.067	0.9470
	Bean fly	-1244.77	605.76	-2.055	0.0415 *
	Hoppers	171.39	464.62	0.369	0.7127
	White flies	-284.36	585.60	-0.486	0.6279
WNF	Intercept	740.88	33.63	22.028	<2e-16 ***
	Bean leaf beetles	71.99	260.84	0.276	0.783
	Aphids	-3008.79	3779.73	-0.796	0.427
	Striped weevils	NA	NA	NA	NA
	Caterpillars	NA	NA	NA	NA
	Bean fly	NA	NA	NA	NA
	Hoppers	NA	NA	NA	NA
	Whiteflies	921.21	3779.73	0.244	0.808
WMAFSF	Intercept	761.166	23.422	32.498	<2e-16 ***
	Bean leaf beetles	-648.573	897.768	-0.722	0.4711
	Aphids	-59.825	36.434	-1.642	0.1026
	Striped weevils	-365.837	460.634	-0.794	0.4283
	Caterpillars	806.086	2006.899	0.402	0.6885
	Bean fly	-193.946	291.887	-0.664	0.5074
	Leaf hoppers	-858.590	354.072	-2.425	0.0164 *
	Whiteflies	-5.491	22.566	-0.243	0.8080

AEZ=Agro-ecological zone; NMF=Northern Moist Farmlands, WNF=West Nile Farmlands, WMAFSF=Western Mid-Altitude Farmlands and the Semliki Flats; NA=Not available (Counts of the affected insects were zero).

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3.9. Relationship between Grain Yield and Yield Components

In 2016B, there was a significant positive relationship between yield and plant stand, number of pods and primary branches in NMF (Table 7). There was no significant relationship between yield and secondary branches, and seeds in NMF (Table 7). In WNF, there was a significant positive relationship between yield and plant stand, number of pods, and primary branches. However, there was a significant negative relationship between yield and secondary branches, and number of seeds per pod (Table 7). In WMAFSF, there was a significant positive relationship between yield and plant stand, number of pods, and secondary branches. There was no significant relationship between yield and primary branches, and seeds (Table 7).

During 2017A, there was a significant positive relationship between yield and plant stand, number of pods, and number of seeds in NMF (Table 7). However, there was a significant negative relationship between yield and primary branches. In WNF, there was a significant positive relationship between yield and plant stand, primary branches, secondary branches, and seeds. However, there was a significant negative relationship between yield and the number of pods (Table 7). In WMAFSF, there was a significant positive relationship between yield and plant stand, secondary branches, and seeds. The relationship between yield and pods, and primary branches was also positive but not significant in WMAFSF (Table 7)

Table 7. Relationship between grain yield and yield components during 2016B and 2017A.

Agro-ecological zone	Parameter	Estimate	Std.Error	t value	P(>|t|)
			2016B		
NMF	Intercept	-1024.8828	192.5356	-5.323	3.36e-07 ***
	Plant stand	3.3063	0.4305	7.680	1.42e-12 ***
	Pods	80.0495	9.2680	8.637	5.21e-15 ***
	Primary branches	276.9659	64.8771	4.269	3.33e-05 ***
	Secondary branches	-9.8796	14.5255	-0.680	0.497
	Seeds	42.5304	36.1971	1.175	0.242
WNF	Intercept	412.2939	284.9471	1.447	0.15
	Plant stand	3.0273	0.1802	16.799	< 2e-16 ***
	Pods	55.9925	9.1857	6.096	7.70e-09 ***
	Primary branches	494.5447	41.9517	11.788	< 2e-16 ***
	Secondary branches	-106.8359	14.3601	-7.440	5.58e-12 ***
	Seeds	-369.2702	59.2918	-6.228	3.91e-09 ***
WMAFSF	Intercept	-554.2015	117.2379	-4.727	4.92e-06 ***
	Plant stand	3.4726	0.2127	16.328	< 2e-16 ***
	Pods	34.0400	8.2376	4.132	5.75e-05 ***
	Primary branches	-1.0866	22.2284	-0.049	0.961
	Secondary branches	71.5302	13.8825	5.153	7.39e-07 ***
	Seeds	-10.8774	31.1252	-0.349	0.727
			2017A		
NMF	Intercept	-171.0474	218.0122	-0.785	0.433847
	Plant stand	2.8733	0.3245	8.854	1.41e-15 ***
	Pods	63.2226	12.4506	5.078	1.04e-06 ***
	Primary branches	-329.2429	102.5269	-3.211	0.001594 **
	Secondary branches	4.8322	42.3783	0.114	0.909359
	Seeds	170.5797	45.1524	3.778	0.000222 ***
WNF	Intercept	-2138.6993	269.6837	-7.930	3.37e-13 ***
	Plant stand	2.1430	0.3403	6.297	2.74e-09 ***
	Pods	-72.9528	35.7332	-2.042	0.04281 *
	Primary branches	569.7009	127.7380	4.460	1.53e-05 ***
	Secondary branches	572.1609	119.8345	4.775	4.00e-06 ***
	Seeds	167.1908	50.1415	3.334	0.00106 **
WMAFSF	Intercept	-1027.4810	198.7678	-5.169	6.85e-07 ***
	Plant stand	1.8548	0.5392	3.440	0.00074 ***

Pods	18.9161	11.8112	1.602	0.11121
Primary branches	123.0619	93.1070	1.322	0.18812
Secondary branches	123.6570	25.3551	4.877	2.55e-06 ***
Seeds	173.9219	30.5156	5.699	5.55e-08 ***

AEZ=Agro-ecological zone; NMF=Northern Moist Farmlands, WNF=West Nile Farmlands, WMAFSF=Western Mid-Altitude Farmlands and the Semliki Flats.

4. Discussion

Our study aimed at determining the population dynamics of multiple pests on common bean and their effect on yield and yield components in different agro-ecological zones of Uganda.

The results indicate that the importance of a pest depends on the agro-ecological zone and season. For instance, there were higher bean fly populations in 2016B (shorter rainy season) than 2017A (long rainy season) in NMF and WNF but the opposite was true in WMAFSF. Similar to our observations in NMF and WNF, earlier studies indicate that the bean fly is associated with shorter rainy seasons than longer rainy seasons [9]. Our observation in WMAFSF, however, indicate otherwise and this requires further investigation to determine whether this can be consistent over many seasons. The differences in pest abundance in different agro-ecologies may be attributed to differences in weather [20].

Combining imidacloprid soil drench with cypermethrin foliar spray reduced insect pests' populations except for bean leaf beetles and caterpillars. Generally, insecticides have been reported to reduce insect pest populations and increase grain yield [25–28], including bean leaf beetles [20]. Low insect populations as a result of soil drench and foliar spray combinations may be attributed to imidacloprid unique ability to combat a variety of insect pests, when applied either as a soil drench or a foliar spray since it is easily translocated in the xylem [29].

The effect of growth stage varied for different insect pests. The bean fly, leaf hoppers, and whiteflies populations fluctuated throughout the stages. Aphids were more abundant in the latter bean growth stages (V4-R1) while bean leaf beetles and striped bean weevils were more abundant in the early bean growth stages (V1 and V2). The relationship between injury and yield varies with the growth stage of the plant at the time of injury for many crops [30]. Bean fly reportedly attack common bean from seedling stage to maturity but the impact is pronounced in seedling stage when it causes complete loss of individual plants [9], and hence the potential to cause 100% yield loss [10]. Higher bean leaf beetle populations at V2 stage confirm reports that the beetles are higher at early stages of crop growth [13,19]. In early infestation, the bean leaf beetle larvae attack roots of seedlings leading to drying of the plant or stunted growth and subsequently bearing empty pods [12]. Overall, the occurrence of a complex of insect pests on all the bean growth stages further emphasizes the significance of pests as a common bean production constraint in Uganda. This also suggests that growers may need to apply management tactics at all stages which may increase the costs of production. However, this will need to be guided by economic injury levels for each insect pest.

Contrary to single insect studies of aphids [15], bean fly [10] and leaf beetles [14], majority of the insect pests did not show a significant negative relationship with grain yield in this study. According to [31], overcompensation for pest-induced damage may be the cause. Plants with high levels of early herbivory can be less damaged by late herbivores as a result of changes in plant characteristics [32]. Additionally, there are biotic and environmental elements that influence crop response to insect pests when the experiment is carried out under natural infestation. For instance, in agricultural fields where plants interact closely, exposure to volatile organic chemicals from nearby plants may improve the plants' ability to defend themselves against herbivore attacks after being attacked themselves [33].

Among all the yield components, only plant stand exhibited a significant positive relationship with grain yield across the three agro-ecological zones during both seasons. Reducing crop stands by eliminating plants is one of the ways through which insect pests reduce yield [30]. For instance, bean fly attack causes drying of seedlings hence directly reducing plant populations [9]. This is attributed to the larvae which pupates in the main stem [10]. In addition, the larvae of bean leaf beetles feed on roots causing stunted growth and premature drying of the plants [12]

5. Conclusions and Recommendations

Population dynamics of the observed insect pests differed among crop growth stages. Bean leaf beetles and striped bean weevils were dominant during early stages while bean fly and aphids were dominant towards flowering. Only the bean fly, aphids and leaf hoppers had a significant negative influence on grain yield but their effect was also not consistent across agro-ecological zones and between seasons.

In our study however, monitoring of insect pests ended at R1 stage of bean crop growth and therefore does not cover other key pests like flower thrips, pod borers which come after flowering. Future studies should include flowering and post flowering pests such as thrips and pod borers but also monitor these other pests throughout the growing period. Future studies will also need to focus on multi-seasonal monitoring of common bean pests across all common bean growing agro-ecologies in Uganda, considering that this study was conducted in only three agro-ecological zones.

Author Contributions: Conceptualization: C.H., S.K., M.H.O.; Methodology, C.H., S.K., M.H.O.; Formal Analysis, C.H.; Investigation, C.H., S.K., M.H.O.; Resources, M.H.O.,S.K.; Data Curation, C.H.; Writing—Original Draft Preparation, C.H.; Writing—Review & Editing, C.H., S.K., M.H.O.; Visualization, C.H.; Supervision, M.H.O., S.K.; Project Administration, M.H.O.; Funding Acquisition, M.H.O. All authors read and approved the manuscript.

Funding: This study was funded by the Bill & Melinda Gates Foundation's Program for Emerging Agricultural Research Leaders Project [Grant No: OPP1131470 2015].

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon request.

Acknowledgments: The authors acknowledge the support given by farmers who provided their plots for establishing the experiments.

Conflicts of Interest: The authors declare no conflict of interests. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. CASA. Commercial Agriculture for Smallholder Agribusiness. *Beans Sector Strategy – Uganda, April*, 2020, pp 5–37.
2. FAOSTAT. Food and Agriculture Organization. *Statistics Department*. Available online: http://www.fao.org/faostat/en/#data/QC Accessed 7 July 2023
3. UBOS. Uganda Bureau of statistics. *The annual agricultural survey (AAS) 2018 statistical release, May 2020*, pp 9
4. Lance, H.G; Andrew, W.L.; Yost, R.S.; Luvaga, E.S.; Semalulu, O.; Tenywa, M.; Mazur, R.E. Improved production systems for common bean on Phaeozem soil in South-Central Uganda. *Afr. J. Agric. Res* **2016**, 11, 4796–4809. https://doi.org/10.5897/ajar2016.11760
5. Abate, T.; Ampofo, J.K.O. Insect pests of beans in Africa. Their ecology and management. *Annu. Rev. Entomol* **1996**, 41, 45–73. https://doi.org/10.1146/annurev.en.41.010196.000401.
6. Singh, S.R.; Emden, H.F.V. Insect pests of grain legumes. *Annu. Rev. Entomol* ***1979***, *24*, 255–278. https://doi.org/10.1146/annurev.en.24.010179.001351
7. Ogenga-Latigo, M.W.; Baliddawa, C.; Ampofo, J.K. Factors influencing the incidence of the black bean aphid on common beans intercropped with maize. *Afr. Crop Sci. J* ***1993***, 1, 49–58.
8. Ssekandi, W.; Mulumba, J.W.; Colangelo, P.; Nankya, R.; Fadda, C.; Karungi, j.; Otim, M.; De Santis, P.; Jarvis, D.I. The use of common bean (*Phaseolus vulgaris*) traditional varieties and their mixtures with commercial varieties to manage bean fly (*Ophiomyia* spp.) infestations in Uganda. *J. Pest Sci* ***2016***, 89, 45–57. https://doi.org/10.1007/s10340-015-0678-7
9. Byabagambi, S.; Kyamanywa, S.; Ogenga-Latigo, M.W. Effect of fertiliser and mulching on bean infestation and damage by bean fly. *Afr. Crop Sci. J* ***1999***, 7, 599–604. https://doi.org/10.4314/acsj.v7i4.27754
10. Greathead, D.J. A study in East Africa of the bean flies (Dipt., Agromyzidae) affecting *Phaseolus vulgaris* and of their natural enemies, with the description of a new species of Melanagromyza Hend. *Bull. Ent. Res* ***1969***, 9, 541–561. https://doi.org/10.1017/S0007485300003539
11. Ingram, W.R. Observations on the pest status of bean flower Thrips in Uganda. *East Afr. agric. for. j* ***1969***, *34*, 482–484. https://doi.org/10.1080/00128325.1969.11662333

12. Buruchara, R.; Mukankusi, C.; Ampofo, K. Bean disease and pest identification and management. In Handbook for Small-Scale Seed Producers; Handbook four, CIAT publication Series No 371; International Center for Tropical Agriculture: Kampala, Uganda, ***2010***; pp. 6–8
13. Halerimana, C.; Kyamanywa, S.; Olaboro, S.; Paparu, P.; Nkalubo, S.T.; Colvin, J.; Cheke, R.A.; Wagner, T.; Seal, S.E.; Kriticos, D.J.; Otim, M.H. Distribution and relative abundance of bean leaf beetles (*Ootheca* spp.) (Insecta: Coleoptera: Chrysomelidae) in Uganda. *Insects* **2021**, Vol. 12, 1048. https://doi.org/10.3390/insectS12111048
14. Halerimana, C. Distribution of bean leaf beetles and associated yield losses in Uganda. Master's Thesis, Makerere University, Kampala, Uganda, 2019; p. 53.
15. Nyiira, Z.M. Pest Status of Thrips and Lepidopterous species on vegetables in Uganda. *East Afr. agric. for. j* **1993**, *39*, 131–135. https://doi.org/10.1080/00128325.1973.11662628
16. Peter, K.H.; Swella, G.B.; Mushobozy, D.M.K. Effect of plant populations on the incidence of bean stem maggot (*Ophiomyia* spp.) in common bean intercropped with maize. *Plant Prot. Sci* ***2009***, *45*, 148–155. https://doi.org/10.17221/19/2009-pps
17. Nderitu, J.H.; Kayumbo, H.Y.; Mueke, J.M. Effect of date of sowing on beanfly infestation of the bean crop. *Int. J. Trop. Insect Sci.* ***1990***, *11*, 97–101. https://doi.org/10.1017/s1742758400019901
18. Ampofo, J.K.O.; Massomo, S.M. Some cultural strategies for the management of bean stem maggots (Diptera: Agromyzidae) on beans in Tanzania. *Afr. Crop Sci. J* ***1998***, 6, 4–6. https://doi.org/10.4314/acsj.v6i4.27785
19. Kyamanywa, S.; Mukibi, J.; Otim, M. Use of trap crops for management of Bean leaf beetles (*Ootheca* spp) in Apac district of Uganda. African Crop Science Comference Proceedings ***2001***, Vol *5*, 167–170.
20. Halerimana, C.; Kyamanywa, S.; Olaboro, S.; Paparu, P.; Nkalubo, S.T.; Colvin, J.; Cheke, R.A.; Kriticos, D.J.; Otim, M.H. Bean Leaf Beetle (*Ootheca* spp.) (Coleoptera: Chrysomelidae) Management via Planting Timing and Insecticides. *Insects* **2022**, *13*, 709. https://doi.org/10.3390/ insects13080709
21. Karel, A.K.; Rweyemamu, C.L. Yield losses in field beans following foliar damage by Ootheca bennigseni (Coleoptera: Chrysomelidae). *J. Econ. Entomol* **1984**, 77, 762–765. https://doi.org/10.1093/jee/77.3.762
22. Paul, U.V.; Ampofo, J.K.O.; Hilbeck, A.; Edwards, P. Evaluation of organic control methods of the bean leaf beetle, *Ootheca bennigseni*, in East Africa. *New Zeal. Plant Prot* **2007**, 60, 189–198. https://doi.org/10.30843/nzpp.2007.60.4599
23. Udo, I.O.; Akpan, E. Evaluation of Local spices as biopesticides for the control of *Ootheca mutabilis*, Shalbera and *Clavigralla tomentosicollis* (Stal.) on Cultivated Cowpea (*Vigna unguiculata* L.) in Nigeria. *J. Agric. Sci* ***2012***, *4*, 7–11. https://doi.org/10.5539/jas.v4n10p7
24. Kavitha, K.; Reddy, K.D. Screening techniques for different insect pests in crop plants. *Int. j. bio-resour. stress manag* ***2012***, 3, 188-195
25. Kyamanywa, S. Influence of time of insecticide application on control of insect pests of cowpea and grain yield of cowpea at Mtwapa, Coastal province of Kenya. *Afr. crop Sci. J* **1996**, 4, 373–382.
26. Nderitu, J.H.; Wambua, E.M.; Olubayo, F.; Kasina, J.M.; Waturu, C.N. Management of thrips (Thysanoptera: Thripidae) in Kenya by combination of insectidies and varietal resistance. *J. Econ. Entomol* ***2007***, *4*, 469–473.
27. Ajeigbe, H.A.; Adamu, R.S.; Singh, B.B. Yield performance of cowpea as influenced by insecticide types and their combinations in the dry savannas of Nigeria. *Afr. J. Agric. Res* ***2012***, *7*, 5930–5938. https://doi.org/10.5897/ajar12.431
28. Karel, A.K.; Mghogho R.M.K. Effects of insecticide and plant populations on the insect pests and yield of common bean (*Phaseolus vulgaris* L.). *J. Econ. Entomol* ***1985***, 78, 917–921. https://doi.org/10.1093/jee/78.4.917
29. Buchholz, A.; Nauen, R. Translocation and translaminar bio-availability of two neonicotinoid insecticides after foliar application to cabbage and cotton. *Pest Mgt. Sci* ***2001***, 58, 10–16.
30. Bardner, R.; Fletcher, K.E. Insect infestations and their effects on growth and yield of field crops: a review. *Bull. Ent. Res* ***1974***, 64, 141-160
31. Gagic, V.; Riggi, L.G.A.; Ekbom, B.; Malsher, G.; Rusch, A.; Bommarco, R. Interactive effects of pests increase seed yield. *Ecol. Evol* ***2016***, 6, 2149–2157. doi: 10.1002/ece3.2003
32. Barber, N.A; Adler, L.S.; Theis, N.; Hazzard, R.V.; Kiers, E.T. Herbivory reduces plant interactions with above- and belowground antagonists and mutualists. *Ecology* ***2012***, 93, 1560–1570. https://doi.org/10.1890/11-1691.1
33. Heil, M.; Kost, C. Priming of indirect defenses. *Eco. Lett* ***2006***, 9, 813–817.