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Field margins and botanical insecticides enhance *Lablab purpureus* yield by reducing aphid and supporting natural enemies

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Keywords:	botanicals, integrated pest management, conservation biological control, field margin, legume cropping systems

Abstract

Botanical insecticides offer an environmentally benign insect pest management option for field crops with reduced impacts on natural enemies of pests and pollinators while botanically rich field margins can augment their abundance. Here we evaluated the non-target effects on natural enemies and pest control efficacy on bean aphids in Lablab of three neem and pyrethrum based botanical insecticides (Pyerin75EC®, Nimbecidine® and Pyeneem 20EC®) and determine the influence of florally rich field margin vegetation on the recovery of beneficial insects after treatment. The botanical insecticides were applied at early and late vegetative growth stages. Data was collected on aphids (abundance, damage severity and percent incidence) and natural enemy (abundance) both at pre-spraying and post-spraying alongside Lablab bean yield. The efficacy of botanical insecticides was similar to a synthetic pesticide control and reduced aphid abundance by 88% compared to the untreated control. However, the number of natural enemies was 34% higher in botanical insecticide treated plots than in plots treated with the synthetic insecticide indicating that plant-based treatments were less harmful to beneficial insects. The presence of field margin vegetation increased further the number of parasitic wasps and tachinid flies by 16% and 20%, respectively. This indicated that non-crop habitat can enhance recovery in beneficial insect populations and that botanical insecticides integrate effectively with conservation biological control strategies. Higher grain yields of 2.55-3.04 and 2.95-3.23 t/ha were recorded for both botanical insecticide and synthetic insecticide in the presence of florally enhanced field margins in consecutive cropping seasons. Overall, these data demonstrated that commercial botanical insecticides together with florally rich field margins offer an integrated, environmentally benign and sustainable alternative to synthetic insecticides for insect pest management and increased productivity of the orphan crop legume, Lablab.

Keywords: botanical insecticides, integrated pest management, conservation biological control, field margin, legume cropping systems.

1. INTRODUCTION

Natural or engineered field margins in and around crops provide shelter and floral resources for natural enemies and can augment their abundance and pest regulating services (Knapp & Řezáč, 2015; Skirvin, Kravar-Garde, Reynolds, Wright, & Mead, 2011; Rowe, Gibson, Landis, &

Isaacs, 2021) even at low prey density (Amaral et al., 2016; Ben-Issa, Gomez, & Gautier, 2017). Natural enemies can be further supported and conserved through more sustainable agricultural practices including the use of selective and lower doses of insecticides (Roubos, Rodriguez-Saona, & Isaacs, 2014;) and using botanical insecticides (Stevenson, Isman, & Belmain, 2017). Synthetic insecticides are reported to be acutely toxic to insect pests and natural enemies (Suma, Zappalà, Mazzeo, & Siscaro, 2009). Botanical insecticides, on the other hand, include a range of active ingredients extracted from plants that exhibit insecticidal or less toxic repellent and antifeedant effects as well as growth and reproductive inhibitory effects (Braimah et al., 2014). In contrast to persistent synthetic insecticides, the active components in botanical insecticides degrade rapidly in nature often owing to their instability especially in UV light and consequently they have lower impacts on predators and parasitoids of pests (Stevenson et al., 2017). However, combining field margins and botanical insecticides requires careful assessment of their individual and combined effects on pests and natural enemies as well as the overall impact on crop yield (Amoabeng, Stevenson, Mochiah, Asare, & Gurr, 2020).

Lablab (*Lablab purpureus* L.) is a versatile multipurpose food legume that could be used as a model crop to test the integration of such strategies on orphan crops which often lack good phytosanitary support to manage pest insects (Venzon, Togni, Perez, & Oliveira, 2020). Lablab green pods and leaves are used as fresh vegetables, dry seeds provide dietary proteins and the crop is also important animal fodder (Maass et al., 2010; Mondal et al., 2017), and can be used as green manure or as a cover crop (Carsky, Oyewole, & Tian, 2001; Cheruiyot, Mumera, Nakhone, & Mwonga, 2011; Northup & Rao, 2015). Lablab is a drought tolerant crop legume (Maass et al., 2010) that is suited to cropping systems affected by increasing temperatures and drying climate and representative of a number of underutilised or orphan crops that may help mitigate the challenges of climate change. However, sustainable pest management options have not been widely studied on Lablab nor how field margin vegetation mitigates negative impacts of pesticide use or facilitates benefits towards conservation biological control. The production of Lablab is constrained by numerous insect pests including black bean aphid (*Aphis fabae*) (Cork, Dobson, Grzywacz, Hodges, & Orr, 2009; Boit, Kinyua, Kiplagat, & Chepkoech, 2018; Tembo et al., 2018). The black bean aphid damage causes yellowing of leaves, desiccation, stunting in older plants and sometimes death of affected plants (Mwangi, Deng, & Kamau, 2008). However, rigorous data on yield losses is not available for Lablab.

Current control strategies for aphids are dependent on the use of broad-spectrum synthetic insecticides (Stevenson et al., 2017). Although synthetic insecticides play an important role in aphid management, their negative effects on non-target organisms, the environment and the health of farmers and consumers continue to be a problem (Mkenda et al., 2015, 2019). Aphids have numerous natural enemies that could be conserved to replace (or minimize) the use of broad-spectrum insecticides (Kindlmann & Dixon, 2010). Pyrethrum and neem products are well-established commercial pesticides based on known active ingredients (pyrethrins and tetranortriterpenoids) (Chaudhary et al., 2017). The adoption of botanical insecticides is limited due to costs and variable efficacy against target pests, which can be attributed to the rapid breakdown of bio-active compounds (Sola et al., 2014). However, with the increasing interest in sustainable pest control and reducing persistent agricultural products, there is a need to evaluate the field performance of these botanical insecticides on insect pests and to understand their impact on natural enemies on orphan crop legumes (Venzon et al., 2020). Here we have focused on the African legume Lablab (*Lablab purpureus* (L.) Sweet).

Integrated Pest Management (IPM) draws on the combination of different pest control methods to maintain pest populations below economically important thresholds and minimise non-target effects (Amoabeng et al., 2020). Bean aphids can be controlled using natural enemies at levels that mitigate against severe losses without reliance on chemical pesticides (Bianchi, Booij, & Tscharntke, 2006; Rand, Tylianakis, & Tscharntke, 2006; Bianchi & Wäckers, 2008). Provision of suitable refuge and additional non-crop habitat can serve to augment natural enemy populations in small holder farming systems and reduce pest build-up in the crop (Nyaanga, 2008; Ndakidemi et al., 2021; Arnold et al., 2021). The floral diversity can support higher longevity, fecundity and predation rates of natural enemies promoting higher abundance and which translate to additive levels of biological control (Charles & Paine, 2016; Pan et al., 2020). Increasing natural enemy species richness has been attributed to strengthening biological control through multiple mechanisms (Jonsson, Kaartinen, & Straub, 2017). In contrast, Straub, Finke, & Snyder (2007) argued that conservation of natural enemy species can reduce or has no effect on biological control. High natural enemy abundance favoured by increased plant diversity in and around field crops provide the predators and parasitoids with wide array of alternative prey (nectar and pollen) which can take natural enemies away from crops and negatively affect biological control (Jonsson et al., 2017; Venzon, Amaral, Togni, & Chiguachi, 2019)

The use of botanical insecticides alongside natural enemy conservation potentially offers an integrated and effective alternative to synthetic insecticides for pest control. Low concentrations of botanical insecticides such as neem-based products have low negative impacts on natural enemies which is important for the conservation biological control (Venzon et al., 2020). Furthermore, conservation of natural enemies can complement insecticide use by preying on or parasitizing insect pests that survive or recolonize crops after insecticide application (Snyder, 2019). Here we hypothesised that by acting as a reservoir for natural enemies, field margin vegetation could reduce pest incidence in crop fields and support a more rapid recovery of natural enemy populations after selective application of botanical insecticides compared with synthetic products. To test this hypothesis we evaluated the impacts of botanical insecticides on aphid pests and their natural enemies used in combination with florally enriched margins around Lablab.

2. MATERIAL AND METHODS

2.1 Study site

Field trials were located at the agronomy teaching and research field, Egerton University, Nakuru County Kenya (0° 20' S, 35° 56' E) with an altitude of 2238 m above sea level, annual precipitation of about 1200 mm and a mean annual temperature range of 17°C -22°C. Soils are well-drained dark reddish clays, classified as Mollic Andosols, within an agriculturally high potential agro-ecological zone, lower highland 3 (LH3) in the Kenya Highlands.(Jaetzold, Schmidt, Hornetz, & Shisanya, 2012). The land area was 8 Ha predominantly inhabited by weed species as it had remained uncultivated from the previous season. The field was typically used for research and the crops grown on the site varied from one season to another. The region is categorized as high agricultural zone hence the soils are considered to be nutrient rich and to support high plant species richness.

2.2 Experimental design and treatment applications

Field trials were carried out during May to December 2019 and March to November 2020 cropping seasons. The experimental field was disc ploughed and harrowed before plots measuring 10 m × 10 m and 10 m apart were demarcated for use during planting. The plot dimensions used were smaller than a typical field but were considered appropriate as related studies had been conducted using similar plot sizes (Hatt, Mouchon, Lopes, & Francis, 2017). The first treatment level was for experimental blocks to be planted in the presence of field margin vegetation or for margin vegetation to be absent (Online resource 1). Thus, two weeks before the bean crop was planted, field margin vegetation was sown with plant plugs to give the field margin plants time to establish. The plot margins were created with four common flowering weed species (*Bidens Pilosa* L., *Tagetes minuta* L., *Ageratum conyzoides* L. and *Galinsoga parviflora* Cav.). These species were chosen because they are annuals and occur in abundance around the farms in the region. The selection was also guided by previous studies which indicated that these species had an effect on arthropod population (Amoabeng et al., 2020; Quispe, Mazón, & Rodríguez-Berrío, 2017; Souza, Tomazella, Santos, Moraes, & Silveira, 2019; Zhang et al., 2021). The seeds of each species were mixed in equal proportions (by weight) and sown around each plot which had plant margin treatments. The margin species were planted 0.5m from the outer row of Lablab crop and 0.5m width. To ensure uniform emergence of the plant species the planting area was prepared to fine tilth. After establishment of plot margins, lablab bean variety DL-1002 was planted at a spacing of 60 cm by 30 cm, two seeds per hill, with an equivalent of 1112 plants per plot. At planting, NPK (23:23:0) fertilizer was applied at the rate of 60 Kg N ha^{-1} and 60 Kg P_2O_5 ha^{-1}.

The second treatment level involved treatments consisting of three commercially available botanical insecticides: Pyerin 75EC®, Pyeneem 20EC® (Manufacturer: Twiga Chemical Industries Limited, Nairobi, Kenya) and Nimbecidine® (Manufacturer: T. Stanes and Company Limited, Coimbatore, India) and as well as a synthetic insecticide Duduthrin 1.75EC® (Manufacturer: Twiga Chemical Industries Limited, Nairobi, Kenya) as a positive control, and an untreated negative control. The Pyrethrum and Neem based botanical insecticides were selected since they were well-established and available in the market (Campos et al., 2019; Sola et al., 2014). The insecticides are also registered to control a wide range of insect pests including, spider mites (*Tetranycus urticae*) whiteflies (*Bemisia tabacci*) and Tomato leafminer (*Tuta absoluta*) (Stevenson et al., 2017). However, there is surprisingly little field evidence of their effects on beneficial insects and no report of their use on natural enemies of bean aphids in Lablab. The 5 insecticide treatment levels and 2 field margin treatment levels were laid out in a randomized complete block design (RCBD) with four replications per treatment combination. Many arthropods are known to be highly mobile (Sorribas, González, Domínguez-Gento, & Vercher, 2016) therefore, to minimize movement of insects within the experimental plots, all surrounding vegetation was cleared throughout the growing season except for the boarder margins. Active ingredients and applied doses are described in table 1. The application rates were followed as per the manufacturer's recommendation. The insecticides were applied twice, with the first spraying done at 42 days after planting (DAP) when the crop entered the second trifoliate and the second spraying at 70 DAP during the sixth trifoliate. These two growth stages were selected since aphids inflict severe damage at the vegetative growth stage, attacking auxiliary buds and growing points.

2.3 Aphid pests

Data on aphid abundance, damage severity and percent incidence were collected one day before spraying and 7, 14 and 21 days after spraying for the two applications across all treatments and controls. Aphid abundance measurements were obtained by visual observation and scoring numbers using an index. Due to the high reproductive rate of aphids a categorical scale was used to assess aphid abundance, 1= no aphids; 2 = a few scattered aphids (1-100); 3 = a few small colonies (101-300); 4 = several small colonies (301-600); 5 = large isolated colonies (601-1000); and 6 = large continuous colonies (>1000) (Aken, Fatokun, & Alabi, 2013; Mkenda et al., 2015). The data were collected from ten randomly selected plants from the inner five rows falling within the sampling area in each treatment. The severity of damage caused by aphids on Lablab was determined by visually observing and scoring the level of damage over the same assessment times and selected plants. The severity of damage was assessed using a 1 to 5 scale widely adopted in the literature, where; 1= no infestation or damage, 2 = light damage and infestation, < 25 % plant parts damaged or infested, 3 = average damage and infestation, 26 - 50 % plant parts damaged, 4 = high infestation and damage, 51 - 75 % plants parts damaged showing yellowing of lower leaves and 5 = severe infestation, > 75 % damage resulting to plants with high infestation levels with yellow and severely curled leaves or dead plant (Mkenda et al., 2015). The incidence of aphids was determined by visually examining and counting the number of aphid damaged/infested plants by randomly sampling 30 plants from the inner five rows in each replicate. Assessments were made over the same sampling times and expressed as percentage incidence.

2.4 Natural enemies

Yellow pan traps were deployed to collect NEs as these were shown to be effective at catching a range of species in Kenyan legume agricultural systems in previous work by Mwani et al. (2021). Additionally, the use of pan traps to assess populations of natural enemies has recently been undertaken effectively by (Shweta & Rajmohana, 2018; Thant, Phyu & Oo, 2016).

Furthermore, pan traps can be deployed easily in the crop, catching insects throughout the deployment period whereas other approaches such as sweep netting may be biased towards daytime-active insects and may miss small insects like parasitoid wasps and can also damage the crop. The traps were set up at the centre and the edge of each replicated plot to sample natural enemies. The traps were set at ground level and spaced at 20m from one experimental plot to another. The pan traps were made using 20 cm diameter yellow plastic plates filled three-quarters with water with two drops of liquid soap mixed in to help break the surface tension. Sampling was carried out twice, 1 day before and 7 days after spraying, with traps collected after 48 hours. The traps were set up concurrently with the assessment of aphids. All arthropods captured in each trap was transferred into 50 ml falcon tubes containing 75% ethanol. Arthropod samples were sorted to identify key selected families of natural enemies associated with aphids (parasitic wasps, tachinid flies, ladybird beetles), recording the number per trap.

2.5 Bean harvest and yield

Yield data are presented here to show the influence of field margins and impact of botanical insecticides as compared to conventional synthetic insecticides. Grain yield and related agronomic data were collected at physiological maturity when pods turned brown. Plant height was measured from the ground level to the tip of the main stem. Above-ground biomass from each treatment was taken from 10 plants randomly selected from the middle five rows, using destructive sampling where the selected plants were uprooted at pod set when the plants were expected to be close to the peak of dry matter accumulation. The plants were dried at 65 °C in an oven for 24 hours and dry weight was recorded. The number of pods per plant was counted in each plant from 10 plants randomly selected from the inner middle rows categorised as either clean or damaged. Similarly, the number of seeds per pod was determined by threshing each pod and counting the seeds. The weight of a hundred seeds was determined using an electronic digital weighing balance (maximum weighing 3 kg; Manufacturer: Comglobal Solutions, India). For grain yield, pods were harvested separately within the sampling area for each treatment. Pods were sun-dried for two days and threshed with the moisture content recorded using a digital moisture meter (Manufacturer: Dramiński S.A., Poland). After attaining 13 % moisture content, grains from each treatment were weighed separately using a portable digital scale (maximum weighing 40 kg; Manufacturer: Comglobal Solutions, India) and converted to tons ha^{-1} using the following formula:

$$\text{Grain yield } (\text{tons ha}^{-1}) = \frac{\text{Grain weight per plot x 10}}{\text{Harvest area } (\text{m}^2)}$$

2.6 Data analysis

The data used for analysis were the mean values from each replicate. Data on percent incidence and natural enemy counts were subjected to arcsine and square root ($\sqrt{x+1}$) transformation, respectively to correct for heterogeneity of treatment variances. Effects of cropping seasons, botanical insecticides, field margin vegetation and their interactions were subjected to Analysis of Variance (ANOVA) for aphids' abundance, damage severity, percent incidence, natural enemy abundance and grain yield. The sampling time and cropping seasons were regarded as repeated measures and the means comparisons were done for field margins, botanical insecticides and their interaction effect. Pearson correlation matrix was used to test the association between the response variables. The association was to test how aphid abundance influenced damage severity, incidence and natural enemies. The means of treatments and interactions were compared using the least significant difference (LSD) test at a significant level of $p \leq 0.05$. All analyses were done using XLSTAT version 2019.2.2.59614 (Addinsoft 2019). XLSTAT statistical and data analysis solution (Boston, MA, USA. https://www.xlstat.com).

3. RESULTS

3.1 Aphid abundance, severity and incidence

The Analysis of Variance indicated interactive effects between all three parameters of season, field margin and pesticide treatment for aphid abundance, damage severity and percent incidence (Table 2). Cropping season showed some minor differences in aphid parameters but generally followed the same trends, permitting the data to be combined for the two cropping seasons (Fig. 1 and Fig. 2). The botanical insecticides were able to reduce aphid numbers and damage in comparison to the untreated control and were often as good as the synthetic pesticide, Duduthrin (Fig. 1). The botanical insecticides in the presence of field margin vegetation provided lower reductions in aphid abundance, severity and incidence as compared to the absence of field margins (Fig. 1 and Fig 2). The Pearson corelation analysis showed a significant ($r = 0.994$*** and $r = 0.910$***) positive association between aphid abundance and damage severity and percent incidence, respectively. A positive significant (*r = 0.913****) correlation was also observed between damage severity and percent incidence.

3.2 Natural enemy abundance

Arthropods captured in the pan traps were first grouped into the general category of aphid natural enemies comprising mainly predators and parasitoids. From the initial sorting, a total of 6,808 insect natural enemies were collected during the two cropping seasons. The major groups identified were parasitic wasps (Braconidae and Ichneumonidae) 40%, tachinid flies (Tachinidae) 43% and ladybird beetles (Coccinellidae) 17%. The Analysis of Variance indicated there was only an interactive effect between season and field margin vegetation, with no significant interactions between all other parameters (Table 3). Generally, in plots with field margin vegetation, more natural enemies were collected as compared to plots with no field margin vegetation (Fig. 3) The presence of field margin vegetation was particularly beneficial to parasitic wasps and tachinid flies where their numbers were nearly doubled in comparison to plots with no field margins (Fig. 3). Ladybird beetle numbers were generally less affected by the presence or absence of field margin vegetation (Table 3). The botanical insecticides treatments reduced the number of natural enemies in comparison to the untreated controls; however, the reductions with the botanical insecticides were overall less detrimental compared with the synthetic pesticide Duduthrin (Fig. 3). Correlation analysis revealed that there was a positive significant (*r=0.638***) association between aphid abundance and natural enemy population.

3.3 Lablab harvest yield

The presence of field margin vegetation enhanced the yield for each crop protection method employed (Fig. 4). The lowest yield was observed in the untreated control. The highest yields were achieved when treating the crop with the botanical insecticide Pyeneem and the synthetic Duduthrin in the presence of field margin vegetation. The next best treatment was Pyerin with field margin present, thereafter, followed by the treatments without field margins as well as Nimbecidine. Nimbecidine and the untreated control were observed to have relatively high variability in yields compared to the other treatments. An Analysis of Variance on all the yield parameters collected at the time of harvest (plant height, undamaged pods, damaged pods, seeds per pod, 100 seed weight, grain yield, crop plant biomass) showed consistent effects of the treatments on crop production (Online Resource 2).

4. DISCUSSION

This study demonstrated the potential of integrating biorational pest management options by combining botanical insecticides and field margin vegetation to support agro-ecological intensification and sustainable management of aphid pests in the orphan crop legume Lablab. Our data showed that the use of botanical insecticides can deliver similar Lablab bean yields as those achieved with synthetic pesticides but with reduced impact on natural enemies of pests. This is consistent with other related studies undertaken by Tembo et al. (2018), Campos et al. (2019) and Soares et al. (2019). Furthermore, the abundance of natural enemies that contribute to biorational pest management can be enhanced by florally rich margins around the crop that provide food and refuge for natural enemies that later move into crop fields for biological control as well as a potential buffer against migrating pests (Bianchi and Wäckers 2008; Skirvin et al. 2011; Knapp and Řezáč 2015; Quispe et al. 2017).

Generally lower aphid abundance, damage severity and percent incidence were observed in plots with florally rich margins. The combination of botanical insecticides and field margins resulted in significantly reduced bean aphid infestation compared to applying the insecticides in plots without field margins demonstrating that co-opting multiple agroecological approaches can deliver pest management outcomes that are as effective or even more so than relying on synthetic insecticides. Our data are consistent with Amoabeng et al. (2020) who reported high insect pest suppression when botanical insecticides and habitat manipulation were integrated. Non-host plants can, however, reduce an insect herbivores capacity to locate and colonize host plants through chemical and physical interference (Mansion-Vaquié, Ferrer, Ramon-Portugal, Wezel, & Magro 2020) and this may also have contributed to the outcomes recorded here.

The application of the synthetic insecticide, Duduthrin (Lambdacyhalothrin 17.5 g/l), was the most effective treatment at reducing aphid infestation. This was expected considering that it is a broad-spectrum insecticide that is used widely in managing insect pests and registered for use on a range of crops (Belmain, Haggar, Holt, & Stevenson, 2013). The botanical insecticides evaluated here have also been demonstrated to be effective in the management of insect pests though not previously evaluated alongside crop margin flowers (Saleem, Batool, Akbar, Raza, & Shahzad, 2019). The active ingredients; pyrethrins in pyrethrum and terpenoids such as azadirachtin in neem-based insecticides, are known to be effective against aphids with repellent and antifeedant activity as well as growth and reproduction inhibition against a range of other pests arthropods (Pezzini & Koch, 2015; Ulrichs, Mewis, & Schnitzler, 2001) and notably against aphids and other hemipterans on other legume crops (Pezzini & Koch, 2015; Nahashon, Benson, & Stephen, 2016; Fite, Tefera, Negeri, & Damte, 2020). However, variable efficacy of botanical insecticides on insect pests have been reported. This loss of efficacy is partly attributed to differences in their mode of action and the capacity of pests to detoxify the active ingredients (Sisay, Tefera, Wakgari, Ayalew, & Mendesil, 2019). In addition, the active ingredients of pyrethrum and neem are labile in ultraviolet light. However, this also means they are non-persistent and thus more compatible with conservation biological control as the compounds are less likely to harm beneficial insects (Soares et al., 2019). This loss of efficacy presents a challenge to the adoption of botanical insecticides. This may be overcome by combining their use with enriched agricultural landscapes as demonstrated here with our data which shows that enriched margins around crops can enhance populations of natural enemies even in combination with botanical insecticide applications.

Nimbecidine was generally the least effective botanical insecticide in reducing aphid infestation but had comparable effects on natural enemy insect numbers to Pyerin and Pyeneem. Although Pyerin and Pyeneem were generally as effective in reducing aphid infestations as the synthetic Duduthrin, these plots showed a higher abundance of natural enemies' post-spray. Duduthrin treated plots had the lowest natural enemy abundance, and this was especially severe in plots not surrounded with non-crop margin flowers. The low abundance of natural enemies was likely due to the high entomotoxicity of lambda-cyhalothrin, the active ingredient in Duduthrin, which suppresses populations of both insect pests and their natural enemies (Mkenda et al., 2015; Mkindi et al., 2017).

The compatibility of botanical insecticides with other IPM approaches is not in itself new and has proposed and reported previously; for example, with entomopathogenic fungi and natural enemies of pests (Fernandez-Grandon, Harte, Ewany, Bray, & Stevenson, 2020). Field margin vegetation has also recently been demonstrated to be complimentary to conservation biological control as the margin plants offer alternative food resources (Mkenda et al., 2019) and illustrates the potential synergies and compatibilities of integrating botanical insecticides and enhanced non-crop habitats for improved insect pest suppression (Arnold et al., 2021; El-Wakeil, 2014). Such compatibility was demonstrated by Amoabeng et al. (2020) who evaluated the dual pest management services of botanical insecticides and conservation biological control for managing brassicas pests and along with our data further support the scope for combining direct pest management interventions with enhanced landscapes that support natural pest regulating processes. In particular this may enhance the recovery of natural enemy populations after exposure to synthetic and botanical insecticide applications.

The mortality and recovery of insects after exposure to botanical insecticide active ingredients have been shown to vary across insect families. Khan et al. (2015) reported low adult mortality of six-spotted ladybird beetles (*Menochilus sexmaculatus* Fab.) family Coccinellidae, when exposed to neem oil. Similarly, lacewings (Chrysopidae) have been shown to have a high tolerance to pyrethrins due to increased levels of pyrethroid esterase (Amarasekare & Shearer, 2013). El-Wakeil et al. (2006) reported no mortality of lacewings due to neem-based pesticides like NSE 5%, Neemark, Achook, and Nimbecidine each at 0.003%. Studies on Hymenoptera parasitoids have shown variable outcomes after exposure to botanical insecticides. High mortality on adult parasitoids, decreased parasitism and reduced parasitoid emergence after exposure to neem-based insecticides have been demonstrated (Monsreal-Ceballos, Ruiz-Sánchez, Ballina-Gómez, Reyes-Ramírez, & González-Moreno, 2018). However, the egg parasitoid *Trichogramma pretiosum* showed low mortality when treated with azadirachtin (Almeida et al., 2010). The difference in parasitoid responses to botanical insecticides has been attributed to factors such as active ingredients, type of exposure, parasitoid species and stage of development (Monsreal-Ceballos et al., 2018). The application of botanical insecticides may enhance the conservation of natural enemies owing to the reduced mortality compared with those exposed to synthetic applications and therefore, may contribute to the success of integrated pest management (IPM) programs (Mkenda et al., 2015). In particular the integration of botanical insecticides with flower rich field margin provided additional benefits in the conservation of natural enemies and insect pest suppression complimenting other recent studies (Amoabeng et al., 2020). However, precautions should be taken to ensure that the botanical insecticides are applied at the recommended rates since high rates have been reported to cause higher mortality rates of beneficial insects (Pezzini & Koch, 2015).

Bean aphids have been shown to have a significant effect on the grain yield as they directly affect the photosynthetic ability of the leaves. In a related study by Mwangi et al. (2008) who reported significant grain yield reduction on susceptible common bean (*Phaseolus vulgaris*) varieties to *Aphis fabae*. The results from this study indicated that flower rich field margins could increase grain yield. In addition, the combination of field margins and botanical insecticides resulted in higher grain yield compared to the use of botanical insecticides in absence of plot margin flowers. The impact of the three botanical insecticides on natural enemy populations was generally similar but the lower yield achieved with Nimbecidine in comparison to Pyerin or Pyeneem suggests the latter are more suitable for IPM on Lablab.

This study demonstrates that commercial botanical insecticides have reduced impacts on key natural enemies of aphids compared with synthetics, in combination with florally enhanced landscapes and illustrate the compatibility of approaches an d supporting the concepts of IPM in sustainable cropping systems and conservation biological control. Using botanical insecticides alongside field margin management for flowering plants provides a sustainable pest management approach that is environmentally benign compared to synthetic insecticides along with corresponding higher grain yield.

Conflict of interest statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contribution: PCS, SRB, JOO and SEJA conceived the study. JOO, PKB, JGN, EKC, RMSM, SEJA, SRB and PCS were involved in the study design. LOO and SRB carried out the statistical analysis, LOO wrote the first draft of the manuscript. LOO carried out field trials and data collection. All authors were involved in writing the manuscript and gave final approval for publication

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References

Addinsoft. (2019). XLSTAT statistical and data analysis solution. Retrieved February 7, 2021, from Long Island website: https://www.xlstat.com/en/

Aken, M., Fatokun, C. A., & Alabi, O. Y. (2013). Screening for resistance to cowpea aphid (*Aphis craccivora* Koch) in wild and cultivated cowpea (*Vigna unguiculata* L.) accessions. *International Journal of Science, Environment and Technology*, *2*(4), 611–621. https://doi.org/10.13140/2.1.4717.9207

Almeida, G. D., Zanuncio, J. C., Pratissoli, D., Andrade, G. S., Cecon, P. R., & Serrão, J. E. (2010). Effect of azadirachtin on the control of *Anticarsia gemmatalis* and its impact on *Trichogramma pretiosum*. *Phytoparasitica*, *38*(5), 413–419. https://doi.org/10.1007/s12600-010-0124-6

Amaral, D. S. S. L., Venzon, M., dos Santos, H. H., Sujii, E. R., Schmidt, J. M., & Harwood, J. D. (2016). Non-crop plant communities conserve spider populations in chili pepper agroecosystems. *Biological Control*, *103*, 69–77. https://doi.org/10.1016/j.biocontrol.2016.07.007

Amarasekare, K. G., & Shearer, P. W. (2013). Comparing effects of insecticides on two green lacewings species, *Chrysoperla johnsoni* and *Chrysoperla carnea* (Neuroptera: Chrysopidae). *Journal of Economic Entomology*, *106*(3), 1126–1133. https://doi.org/10.1603/EC12483

Amoabeng, B. W., Stevenson, P. C., Mochiah, B. M., Asare, K. P., & Gurr, G. M. (2020). Scope for non-crop plants to promote conservation biological control of crop pests and serve as sources of botanical insecticides. *Scientific Reports*, *10*(1), 6951. https://doi.org/10.1038/s41598-020-63709-x

Arnold, S. E. J., Elisante, F., Mkenda, P. A., Tembo, Y. L. B., Ndakidemi, P. A., Gurr, G. M., & Stevenson, P. C. (2021). Beneficial insects are associated with botanically rich margins with trees on small farms. *Scientific Reports*, *11*(1), 1–11. https://doi.org/10.1038/s41598-021-94536-3

Belmain, S., Haggar, J., Holt, J., & Stevenson, P. (2013). Managing legume pests in sub-Saharan Africa: Challenges and prospects for improving food security and nutrition through agro-ecological intensification. *University of Greenwich*, 34.

Ben-Issa, R., Gomez, L., & Gautier, H. (2017, December 1). Companion plants for aphid pest management. *Insects*, *8*(112), 2-19. https://doi.org/10.3390/insects8040112

Bianchi, F. J., Booij, C. H., & Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: A review on landscape composition, biodiversity and natural pest control. *Proceedings of the Royal Society B: Biological Sciences*, *273*(1595), 1715–1727. https://doi.org/10.1098/rspb.2006.3530

Bianchi, Felix J., & Wäckers, F. L. (2008). Effects of flower attractiveness and nectar availability in field margins on biological control by parasitoids. *Biological Control*, *46*(3), 400–408. https://doi.org/10.1016/j.biocontrol.2008.04.010

Boit, L. C., Kinyua, M., Kiplagat, O., & Chepkoech, E. (2018). Evaluating Kenyan dolichos (*Lablab purpureus* L.) genotypes for resistance to legume pod borers (*Maruca vitrata* and *Helicoverpa armigera*) using morphological markers. *International Journal of Plant Breeding and Crop Science*, *5*(1), 344–351.

Braimah, H., Mochiah, M. B., Ekyem, S. O., Owusu-Akyaw, M., Fening, K. O., Adama, I., & Narveh, E. (2014). Sustainable management of two key pests of cabbage, Brassica oleracea var. capitata L. (Brassicaceae), using homemade extracts from garlic and hot pepper. *Organic Agriculture*, *3*(3–4), 163–173. https://doi.org/10.1007/s13165-014-0058-2

Campos, E. V. R., Proença, P. L. F., Oliveira, J. L., Bakshi, M., Abhilash, P. C., & Fraceto, L. F. (2019). Use of botanical insecticides for sustainable agriculture: Future perspectives. *Ecological Indicators*, *105*, 483–495. https://doi.org/10.1016/j.ecolind.2018.04.038

Carsky, R. J., Oyewole, B., & Tian, G. (2001). Effect of phosphorus application in legume cover crop rotation on subsequent maize in the savanna zone of West Africa. *Nutrient Cycling in Agroecosystems*, *59*(2), 151–159. https://doi.org/10.1023/A:1017578628062

Charles, J. J., & Paine, T. D. (2016). Fitness effects of food resources on the polyphagous aphid parasitoid, *Aphidius colemani* Viereck (Hymenoptera: Braconidae: Aphidiinae). *PLoS ONE*, *11*(1), 1–14. https://doi.org/10.1371/journal.pone.0147551

Chaudhary, S., Kanwar, R. K., Sehgal, A., Cahill, D. M., Barrow, C. J., Sehgal, R., & Kanwar, J. R. (2017). Progress on *Azadirachta indica* based biopesticides in replacing synthetic toxic pesticides. *Frontiers in Plant Science*, *8*(5), 1–13. https://doi.org/10.3389/fpls.2017.00610

Cheruiyot, E. K., Mumera, L. M., Nakhone, L. N., & Mwonga, S. M. (2011). Rotational effects of grain legumes on maize performance in the Rift Valley Highlands of Kenya. *African Crop Science Journal*, *9*(4), 667–676. https://doi.org/10.4314/acsj.v9i4.27588

Cork, A., Dobson, H., Grzywacz, D., Hodges, R., & Orr, A. (2009). R*eview of pre-and post-harvest pest management for pulses with special reference to Eastern and Southern Africa.* In Natural Resources Institute: University of Greenwich. Retrieved from http://mcknight.ccrp.cornell.edu/program_docs/general/NRI_Legume_IPM_review2009.pdf

El-Wakeil, N. (2014). Effects of some botanical insecticides on wheat insects and their natural enemies in winter and spring wheat conservation of natural enemy populations. *Acta Advances in Agricultural Sciences*, *2*, 19–36. Retrieved from www.aaasjournal.com

El-Wakeil, N. E., Gaafar, N. M., & Vidal, S. (2006). Side effect of some neem products on natural enemies of Helicoverpa (*Trichogramma spp.*) and *Chrysoperla carnea*. *Archives of Phytopathology and Plant Protection*, *39*(6), 445–455. https://doi.org/10.1080/03235400500356160

Fernandez-Grandon, M., Harte, S. J., Ewany, J., Bray, D., & Stevenson, P. C. (2020). Additive effect of botanical insecticide and entomopathogenic fungi on pest mortality and the behavioral response of its natural enemy. *Plants*, *9*(173), 1–14. https://doi.org/10.3390/plants9020173

www.mdpi.com/journal/plantsFite, T., Tefera, T., Negeri, M., & Damte, T. (2020). Effect of *Azadirachta indica* and *Milletia ferruginea* extracts against *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) infestation management in chickpea. *Cogent Food and Agriculture*, *6*(1), 1712145. https://doi.org/10.1080/23311932.2020.1712145

Hatt, S., Mouchon, P., Lopes, T., & Francis, F. (2017). Effects of wildflower strips and an adjacent forest on aphids and their natural enemies in a pea field. *Insects*, *8*(3), 2-9. https://doi.org/10.3390/insects8030099

Jaetzold, R., Schmidt, H., Hornetz, B., & Shisanya, C. (2012). *Farm management handbook of Kenya (Western Central Eastern Nyzana Southern Rift Valley Northern Rift Valley Coast)*. Nairobi: Ministry of Agriculture.

Jonsson, M., Kaartinen, R., & Straub, C. S. (2017). Relationships between natural enemy diversity and biological control. *Current Opinion in Insect Science*, *20*, 1–6. https://doi.org/10.1016/j.cois.2017.01.001

Khan, S., Ullah, F., Khan, I., Khan, M. A., Khan, S. Z., Khan, M. A., & Khan, A. (2015). Toxicity of selected insecticides against the zig zag ladybird beetle Menochilus Sexmaculatus. *Journal of Entomology and Zoology Studies*, *3*(3), 143–147.

Kindlmann, P., & Dixon, A. F. G. (2010). Modelling population dynamics of aphids and their natural enemies. In *Aphid Biodiversity under Environmental Change* (pp. 1–20). Springer Netherlands. https://doi.org/10.1007/978-90-481-8601-3_1

Knapp, M., & Řezáč, M. (2015). Even the smallest non-crop habitat islands could be beneficial: Distribution of carabid beetles and spiders in agricultural landscape. *PLoS ONE*, *10*(4), 1–20. https://doi.org/10.1371/journal.pone.0123052

Maass, B. L., Knox, M. R., Venkatesha, S. C., Angessa, T. T., Ramme, S., & Pengelly, B. C. (2010). *Lablab purpureus*-A crop lost for Africa? *Tropical Plant Biology*, *3*(3), 123–135. https://doi.org/10.1007/s12042-010-9046-1

Mansion-Vaquié, A., Ferrer, A., Ramon-Portugal, F., Wezel, A., & Magro, A. (2020). Intercropping impacts the host location behaviour and population growth of aphids. *Entomologia Experimentalis et Applicata*, *168*(1), 41–52. https://doi.org/10.1111/eea.12848

Mkenda, P. A., Ndakidemi, P. A., Stevenson, P. C., Sarah, S. E., Belmain, S. R., Chidege, M., & Gurr, G. M. (2019). Field margin vegetation in tropical african bean systems harbours diverse natural enemies for biological pest control in adjacent crops. *Sustainability (Switzerland)*, *11*(22). https://doi.org/10.3390/su11226399

Mkenda, P., Mwanauta, R., Stevenson, P. C., Ndakidemi, P., Mtei, K., & Belmain, S. R. (2015). Extracts from field margin weeds provide economically viable and environmentally benign pest control compared to synthetic pesticides. *PLoS ONE*, *10*(11), 2–14. https://doi.org/10.1371/journal.pone.0143530

Mkindi, A., Mpumi, N., Tembo, Y., Stevenson, P. C., Ndakidemi, P. A., Mtei, K., & Belmain, S. R. (2017). Invasive weeds with pesticidal properties as potential new crops. *Industrial Crops and Products*, *110*(June), 113–122. https://doi.org/10.1016/j.indcrop.2017.06.002

Mondal, H., Roy, S. K., Hijam, L., Chakraborty, M., Dutta, P., & Hath, T. K. (2017). Differential aphid colony establishment in *Dolichos lablab* varieties correlated with some plant specific factors that impact on aphid fecundity. *American Journal of Plant Sciences*, *08*(04), 754–769. https://doi.org/10.4236/ajps.2017.84053

Monsreal-Ceballos, R. J., Ruiz-Sánchez, E., Ballina-Gómez, H. S., Reyes-Ramírez, A., & González-Moreno, A. (2018). Effects of botanical insecticides on hymenopteran parasitoids: A meta-analysis approach. *Neotropical Entomology*, *47*(5), 681–688. https://doi.org/10.1007/s13744-017-0580-5

Mwangi, S. N., Deng, A. L., & Kamau, A. W. (2008). Response of Kenyan varieties of common bean, *Phaseolus vulgaris* L., to infestation by *Aphis fabae* Scopoli. *African Entomology*, *16*(2), 196–202. https://doi.org/10.4001/1021-3589-16.2.196

Mwani, C. N., Nyaanga, J., Cheruiyot, E. K., Ogendo, J. O., Bett, P. K., Mulwa, R., & Belmain, S. R. (2021). Intercropping and diverse field margin vegetation suppress bean aphid (Homoptera: Aphididae) infestation in dolichos (*Lablab purpureus* L.). *Journal of Plant Protection Research*, *61*(3), 290–301. https://doi.org/10.24425/jppr.2021.137953

Nahashon, C. K., Benson, M. M., & Stephen, M. M. (2016). Effects of irrigated and rain fed conditions on infestation levels of thrips (Thysanoptera: Thripidae) infesting *Dolichos lablab* (L.) in Eastern Kenya. *African Journal of Agricultural Research*, *11*(18), 1656–1660. https://doi.org/10.5897/ajar2015.10721

Northup, B. K., & Rao, S. C. (2015). Green manure and forage potential of lablab in the U.S. Southern plains. *Agronomy Journal*, *107*(3), 1113–1118. https://doi.org/10.2134/agronj14.0455

Nyaanga, J. G. (2008). *The efficacy of ladybird beetles (Coleopteran; Coccinellidae) as biocontrol agents in integrated pest management (IPM) of cereal aphids in wheat (Triticum aestivum L.)*. PhD Thesis, Egerton University, Kenya.

Pan, H., Liu, B., Jaworski, C. C., Yang, L., Liu, Y., Desneux, N., & Lu, Y. (2020). Effects of aphid density and plant taxa on predatory ladybeetle abundance at field and landscape scales. *Insects*, *11*(695–707).

Pezzini, D. T., & Koch, R. L. (2015). Compatibility of flonicamid and a formulated mixture of pyrethrins and azadirachtin with predators for soybean aphid (Hemiptera: Aphididae) management. *Biocontrol Science and Technology*, *25*(9), 1024–1035. https://doi.org/10.1080/09583157.2015.1027659

Quispe, R., Mazón, M., & Rodríguez-Berrío, A. (2017). Do refuge plants favour natural pest control in maize crops? *Insects*, *8*(3), 71–85. https://doi.org/10.3390/insects8030071

Rand, T. A., Tylianakis, J. M., & Tscharntke, T. (2006). Spillover edge effects: The dispersal of agriculturally subsidized insect natural enemies into adjacent natural habitats. *Ecology Letters*, *9*(5), 603–614. https://doi.org/10.1111/j.1461-0248.2006.00911.x

Roubos, C. R., Rodriguez-Saona, C., & Isaacs, R. (2014). Mitigating the effects of insecticides on arthropod biological control at field and landscape scales. *Biological Control*, *75*, 28–38.

https://doi.org/10.1016/j.biocontrol.2014.01.006

Rowe, L., Gibson, D., Landis, D. A., & Isaacs, R. (2021). Wild bees and natural enemies prefer similar flower species and respond to similar plant traits. *Basic and Applied Ecology*, *56*, 259–269. https://doi.org/10.1016/j.baae.2021.08.009

Saleem, M. S., Batool, T. S., Akbar, M. F., Raza, S., & Shahzad, S. (2019). Efficiency of botanical pesticides against some pests infesting hydroponic cucumber, cultivated under greenhouse conditions. *Egyptian Journal of Biological Pest Control*, *29*(1), 1–7. https://doi.org/10.1186/s41938-019-0138-4

Shweta, M., & Rajmohana, K. (2018). A comparison of sweep net, yellow pan trap and malaise trap for sampling parasitic hymenoptera in a backyard habitat in kerala. *Entomon*, *43*(1), 33–44.

Sisay, B., Tefera, T., Wakgari, M., Ayalew, G., & Mendesil, E. (2019). The efficacy of selected synthetic insecticides and botanicals against fall armyworm, *Spodoptera frugiperda*, in maize. *Insects*, *10*(2). https://doi.org/10.3390/insects10020045

Skirvin, D. J., Kravar-Garde, L., Reynolds, K., Wright, C., & Mead, A. (2011). The effect of within-crop habitat manipulations on the conservation biological control of aphids in field-grown lettuce. *Bulletin of Entomological Research*, *101*(6), 623–631. https://doi.org/10.1017/S0007485310000659

Snyder, W. E. (2019). Give predators a complement: Conserving natural enemy biodiversity to improve biocontrol. *Biological Control*, *135*(4), 73–82. https://doi.org/10.1016/j.biocontrol.2019.04.017

Soares, M. A., Campos, M. R., Passos, L. C., Carvalho, G. A., Haro, M. M., Lavoir, A. V., & Desneux, N. (2019). Botanical insecticide and natural enemies: A potential combination for pest management against *Tuta absoluta*. *Journal of Pest Science*, *92*(4), 1433–1443. https://doi.org/10.1007/s10340-018-01074-5

Sola, P., Mvumi, B. M., Ogendo, J. O., Mponda, O., Kamanula, J. F., Nyirenda, S. P., & Stevenson, P. C. (2014). Botanical pesticide production, trade and regulatory mechanisms in sub-Saharan Africa: Making a case for plant-based pesticidal products. *Food Security*, *6*(3), 369–384. https://doi.org/10.1007/s12571-014-0343-7

Sorribas, J., González, S., Domínguez-Gento, A., & Vercher, R. (2016). Abundance, movements and biodiversity of flying predatory insects in crop and non-crop agroecosystems. *Agronomy* *for Sustainable Development*, *36*(2). https://doi.org/10.1007/s13593-016-0360-3

Souza, I. L., Tomazella, V. B., Santos, A. J. N., Moraes, T., & Silveira, L. C. P. (2019). Parasitoids diversity in organic sweet pepper (*Capsicum annuum*) associated with basil (*Ocimum basilicum*) and marigold (*Tagetes erecta*). *Brazilian Journal of Biology*, *79*(4), 603–611. https://doi.org/10.1590/1519-6984.185417

Stevenson, P. C., Isman, M. B., & Belmain, S. R. (2017). Pesticidal plants in Africa: A global vision of new biological control products from local uses. *Industrial Crops and Products*, *110*, 2–9. https://doi.org/10.1016/j.indcrop.2017.08.034

Straub, C. S., Finke, D. L., & Snyder, W. E. (2007). Are the conservation of natural enemy biodiversity and biological control compatible goals? *Biological Control*, *45*(2), 225–237. https://doi.org/10.1016/j.biocontrol.2007.05.013

Suma, P., Zappalà, L., Mazzeo, G., & Siscaro, G. (2009). Lethal and sub-lethal effects of insecticides on natural enemies of citrus scale pests. *BioControl*, *54*(5), 651–661. https://doi.org/10.1007/s10526-009-9215-z

Tembo, Y., Mkindi, A. G., Mkenda, P. A., Mpumi, N., Mwanauta, R., Stevenson, P. C., & Belmain, S. R. (2018). Pesticidal plant extracts improve yield and reduce insect pests on legume crops without harming beneficial arthropods. *Frontiers in Plant Science*, *9*, 1425. https://doi.org/10.3389/fpls.2018.01425

Thant, Khin Phyu, Moe Oo, Thi Thaung, M. (2016). Species diversity of natural enemy association on rice at two location. *Journal of Agricultural Research*, *4*(1), 104–112.

Ulrichs, C., Mewis, I., & Schnitzler, W. H. (2001). Efficacy of neem and diatomaceous earth against cowpea aphids and their deleterious effect on predating Coccinelidae. *Journal of Applied Entomology*, *125*, 571–575. https://doi.org/0931±2048/2001/2509±0571 $ 15.00/0

Venzon, M., Amaral, D.S., Togni, P.H., & Chiguachi, J. A. (2019). Interactions of natural enemies with non-cultivated plants. In *Natural Enemies of Insect Pests in Neotropical Agroecosystems* (pp. 15–26). Springer, Cham. https://doi.org/https://doi.org/10.1007/978-3-030-24733-1_2

Venzon, M., Togni, P. H. B., Perez, A. L., & Oliveira, J. M. (2020). Control of two-spotted spider mites with neem-based products on a leafy vegetable. *Crop Protection*, *128*, 105006. https://doi.org/10.1016/j.cropro.2019.105006

Zhang, L., Qin, Z., Liu, P., Yin, Y., Felton, G. W., & Shi, W. (2021). Influence of plant physical and anatomical characteristics on the ovipositional preference of *Orius sauteri* (hemiptera:

Anthocoridae). *Insects*, *12*(4), 2-15. https://doi.org/10.3390/insects12040326

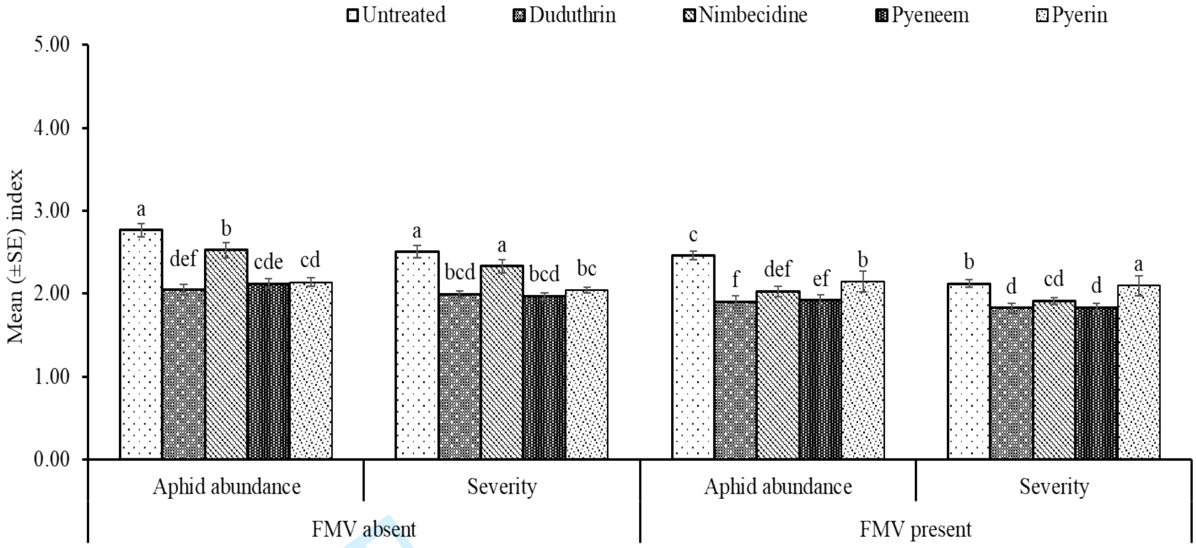
Figure Legends

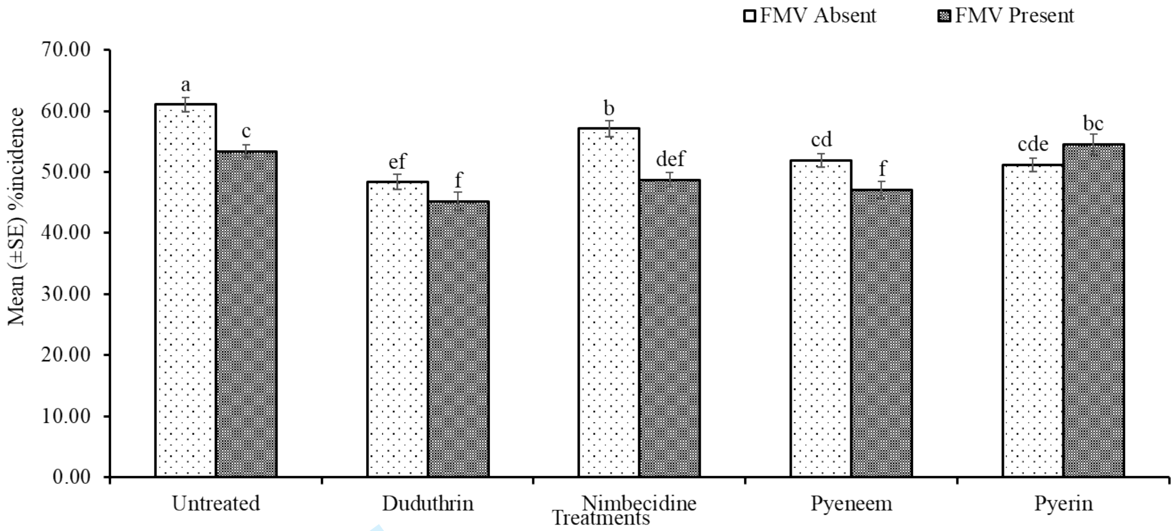
Figure 1. Mean (±SE) of aphid abundance and damage severity as influenced by botanical insecticides and field margin vegetation.

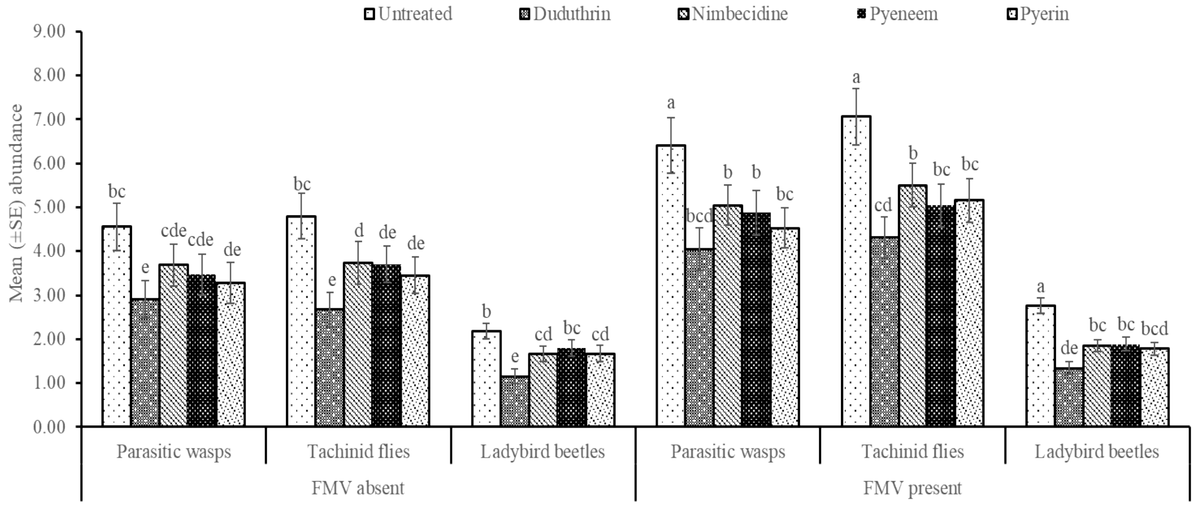
Figure 2. Mean (±SE) of aphid percent incidence as influenced by botanical insecticides and field margin vegetation.

Figure 3. Mean abundance (±SE) of parasitic wasps, tachinid flies and ladybird beetles as influenced by botanical insecticides and field margin vegetation.

Figure 4. Lablab bean yield from botanical insecticides (Nimbecidine, Pyeneem, Pyerin), Duduthrin (Lambdacyhalothrin) and untreated as positive and negative controls, respectively, in the presence or absence of field margin (FMV).


Untreated
Duduthrin
Nimbecidine
Pyeneem
Pyerin
Mean (±SE) index
5.00
4.00
3.00
2.00
1.00
0.00
a
def
b
cde
cd
a
bcd
a
bcd
bc
c
f
def
ef
b
b
d
cd
d
a
Aphid abundance
Severity
Aphid abundance
Severity
FMV absent
FMV present


FMV Absent
FMV Present
Mean (±SE) %incidence
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
a
c
ef
f
b
def
cd
f
cde
bc
Untreated
Duduthrin
Nimbecidine
Pyeneem
Pyerin
Treatments


Untreated
Duduthrin
Nimbecidine
Pyeneem
Pyerin
Mean (±SE) abundance
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
bc
e
cde
cde
de
bc
e
d
de
de
b
e
cd
bc
cd
a
bcd
b
b
bc
a
cd
b
bc
bc
a
de
bc
bc
bcd
Parasitic wasps
Tachinid flies
Ladybird beetles
Parasitic wasps
Tachinid flies
Ladybird beetles
FMV absent
FMV present

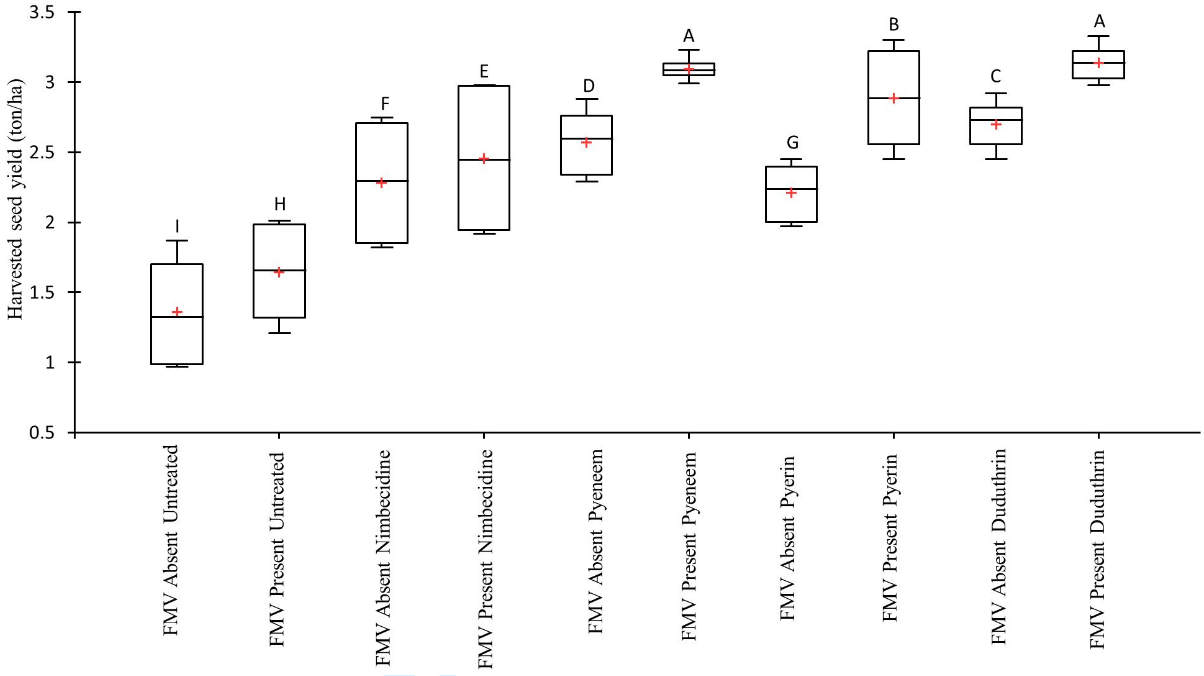

Harvested seed yield (ton/ha)
3.5
3
2.5
2
1.5
1
0.5
I
H
F
E
D
A
G
B
C
A
FMV Absent Untreated
FMV Present Untreated
FMV Absent Nimbecidine
FMV Present Nimbecidine
FMV Absent Pyeneem
FMV Present Pyeneem
FMV Absent Pyerin
FMV Present Pyerin
FMV Absent Duduthrin
FMV Present Duduthrin

Table 1: Active ingredients and dose rates of botanical insecticides and synthetic insecticide (Duduthrin) used in the study

Trade Name	**Rate of application (L/Ha)**	**Active ingredients (a.i., %)**	**% a.i. composition**	**a.i. dose (L/Ha)**
Pyeneem	2.5	Natural pyrethrins 1% w/v	1.00	0.025
		Neem oil 1% w/v	1.00	0.025
		Inert ingredients 98% w/v	98.00	2.450
Pyerin	2.5	Natural pyrethrins 1% w/v	1.00	0.025
		Neem oil 1% w/v	1.00	0.025
		Garlic extract 25% w/v	25.00	0.625
		Inert ingredients 73% w/v	73.00	1.825
Nimbecidine	3.0	Azadirachtin 0.03% w/v	0.03	0.0009
		Neem oil 90.57%	90.57	2.7171
		Inert ingredients 9.4% w/v	9.40	0.282
Dududthrin (+ve control)	2.0	Lambda cyhalothrin 1.75 % w/v	1.75	0.035
		Inert ingredients 98.25% w/v	98.25	0.197

*w/v = Weight by volume

Table 2. Analysis of variance for the aphid abundance, damage severity and percent incidence on Lablab bean for two cropping seasons (May-December 2019 and March-November 2020), botanical insecticides (Nimbecidine, Pyeneem and Pyerin), Duduthrin and Untreated control, in the presence or absence of field margin vegetation (FMV).

Source of variation	df	Abundance	Severity	Incidence
Season	1	407.129	263.076	51.826
		<0.0001	<0.0001	<0.0001
Margin vegetation	1	30.814	24.681	32.770
		<0.0001	<0.0001	<0.0001
Treatment	4	34.842	25.901	24.037
		<0.0001	<0.0001	<0.0001
Replicate	3	4.039	4.748	4.809
		0.007	0.003	0.003
Season*Margin vegetation	1	18.824	22.904	25.639
		<0.0001	<0.0001	<0.0001
Season*Treatment	4	20.370	14.548	14.983
		<0.0001	<0.0001	<0.0001
Margin vegetation*Treatment	4	23.470	17.387	8.467
		<0.0001	<0.0001	<0.0001
Season*Margin vegetation*Treatment	4	21.784	17.234	8.433
		<0.0001	<0.0001	<0.0001
R^2		0.585	0.503	0.361
F		39.579	28.418	15.834
Pr > F		<0.0001	<0.0001	<0.0001

Table 3. Analysis of variance for the abundance of key natural enemy species found on Lablab bean for two cropping seasons (May-December 2019 and March-November 2020), botanical insecticides (Nimbecidine, Pyeneem and Pyerin), Duduthrin and Untreated control, in the presence or absence of field margin vegetation (FMV).

Source of variation	df	Parasitic wasps	Tachinid flies	Ladybird beetles	Overall abundance
Season	1	339.436	380.136	42.145	269.531
		<0.0001	<0.0001	<0.0001	<0.0001
Margin vegetation	1	30.852	52.186	5.233	40.620
		<0.0001	<0.0001	0.022	<0.0001
Treatment	4	7.099	10.701	15.030	12.122
		<0.0001	<0.0001	<0.0001	<0.0001
Replicate	3	0.074	0.194	0.247	0.013
		0.974	0.901	0.863	0.998
Season*Margin vegetation	1	12.928	23.695	20.933	9.344
		0.000	<0.0001	<0.0001	0.002
Season*Treatment	4	0.780	1.623	1.981	0.510
		0.538	0.167	0.096	0.729
Margin vegetation*Treatment	4	0.227	0.382	0.773	0.405
		0.923	0.822	0.543	0.805
Season*Margin vegetation*Treatment	4	0.161	0.063	1.148	0.049
		0.958	0.993	0.333	0.995
R^2		0.403	0.451	0.190	0.376
F		18.932	23.076	6.581	16.904
Pr > F		<0.0001	<0.0001	<0.0001	<0.0001