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Management of Snap Bean Insect Pests and Diseases by Use of Antagonistic Fungi and Plant Extracts

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Abstract

Use of synthetic pesticides reduces the competitiveness of Kenyan snap bean pods due to stringent regulations by importers as a result of presence of chemical residues. This study was conducted to determine the effectiveness of local biopesticides in managing insect pests and diseases of snap beans. Field experiments were set up in farmer's field where *Trichoderma* spp. and *Paecilomyce s*pp. and plant extracts from turmeric, garlic, ginger and lemon were applied weekly as foliar sprays. Plant extracts reduced the population of whiteflies and thrips by up to 58% and 41% while antagonistic fungi had a corresponding 30% and 18% reduction, respectively. *Trichoderma* spp. reduced severity of angular leaf spot (37.5%), rust (67%) and anthracnose (20.7%). Plant extracts and antagonistic fungi increased marketable pod yield by 25.6% and 17.3%, respectively. Results demonstrated that local environments are potential sources of biopesticides that can be exploited for integrated management of pests and diseases.

Keywords: Biopesticides, botanical pesticides, microbial pesticides, maximum residue limits, snap beans, sustainable agriculture

1. Introduction

Kenya is reputed in producing the world's finest snap beans (Ndung'u, 2013) which account for about 60% of all vegetable exports and 21% of all horticultural exports (HCDA, 2011). Snap bean is ranked first among the export horticultural crops in Kenya that earns foreign exchange (USAID-KHCP, 2015). This highly valued vegetable generates income to smallholder farmers and creates employment hence improving household livelihoods (Odero *et al*., 2013; Wahome *et al*., 2013). The greatest threat to snap bean production is insect pests and diseases which cause economic losses. Conventional pest and disease control methods which rely mainly on synthetic pesticides have failed in meeting the premium quality of pods desired by niche European markets (Wahome *et al*., 2013) due to accumulation of chemical residues in fresh produce, health risks to growers, development of resistance to pesticides by the target pests and environmental pollution (Aktar *et al*., 2009; Kimani, 2014; Soliman *et al.*, 2015).The European Union has set the maximum residue limit (MRL) at 0.01mg/kg (European Commission, 2012).The strict maximum residue level (MRLs) requirements could result in loss of trade because small holder snap bean growers may stop production due to fear of non-compliances, high costs and delays in clearing of consignments (KEPHIS, 2012). The stringent pesticide regulations resulted in a 25% reduction in snap bean sales in 2013 compared to 2012. Therefore, if vegetable farmers are to access the niche EU and local supermarket markets, there is need to search for alternative pest management approaches that are user friendly, that leave no harmful chemical residues on the product and safe to environment.

The negative effects of using synthetic pesticides in agricultural production has stimulated continued search for alternative pest control approaches (Nderitu *et al*., 2009). The most commonly used biological pesticides include microbial antagonists, bio-insecticides, botanical pesticides and compost teas (Nega, 2014; Quarles, 2013). Microbial antagonists used to control plant diseases include *Trichoderma harzianum*, *Gliocladium virens, Coniothyrium minitans*, *Agrobacterium radiobacter, Bacillus subtilis*, *Pseudomonas* spp. and *Streptomyces* spp. while botanical pesticides include pyrethrum, neem, rotenone, rape seed oil, quassia extract, neem oil and nicotine (Nega, 2014; Quarles, 2013). Insecticidal biopesticides include *Beauveria bassiana*, *Metarhizium anisopliae*, *Paecilomyces* spp. and *Verticillium lecanii*. Botanical pesticides such as pyrethroids and neem are as effective as the synthetic chemicals in reducing pest damage (Nega, 2014). The use of biopesticides such as microbial antagonists and botanical pesticides in management of pests and diseases in snap bean production offers an appropriate alternative to synthetic pesticides because they are highly efficacious, are relatively cheaper, safer to use and leave no toxic residues (Quarles, 2013; Koul, 2011; Krishan, 2014; Ouma *et al*., 2014). Biopesticides are relatively safe and acceptable to consumers (Gurjar *et al.*, 2012). Microbial pesticides can multiply on or in vicinity of the target pest thus giving self-perpetuating control (Chandler *et al*., 2011) and have plant growth promoting effect that trigger induced systemic resistance in plants (Islam *et al.*, 2012). Plant growth promoting rhizobacteria and other microbial antagonists widely occur in soils and rhizosphere (Kumar *et al.*, 2011). Compared to synthetic pesticides, biopesticides are less harmful to non-target organisms, are often effective in small quantities, decompose quickly and therefore have less residual effects (Gupta and Dikshit, 2010). They have been found to be effective and sustainable in management of pests and diseases in vegetable production (Killani *et al*., 2011; Srinivasan, 2012).

Trichoderma spp. produce diffusible and volatile antibiotics plus hydrolytic enzymes which are the crucial mechanisms behind their biocontrol activity (Navaneetha *et al.*, 2015). *Paecilomyces* as entomopathogenic fungi is reported to suppress several insects as a foliar spray though with varying efficacies (Archana and Ramaswamy, 2012). Plant extracts are reputed to constitute various bioactive compounds and secondary metabolites such as alkaloids, flavonoids and phenolic compounds. These substances possess synergistic effects on retarding growth of pests and suppression of pathogens hence act as insecticidal and antifungal agents (Ahmed *et al*., 2012). Plant extracts have been successfully applied against insect pests and diseases (Shahid *et al.*, 2015). In Kenya formulated products of neem and pyrethrum are currently used whereas a mixture of garlic and pepper has been recommended to manage insect pests (Infonet-Biovision, 2015; Ogala, 2013). In a study by Waiganjo *et al*., (2011), neem oil extracts, Achook® and Nimbecidine® suppressed the population of aphids and diamondback moth in cabbage. Extractsfrom garlic bulb contain allicin (Wei *et al.*, 2011) while the rhizome of turmeric contain curcuminiods (60% curcumin) all responsible for insecticidal and antimicrobial properties (Ahmed *et al*., 2013). The current study investigated the effectiveness of local antagonistic microorganisms and crude plant extracts against major pests and diseases of snap bean as alternatives to synthetic pesticides for reduced chemical residues in the produce destined for niche markets.

2. Materials and Methods

2.1 Experimental Materials

The fungal antagonists evaluated were *Trichoderma viride, T. harzianum, T. asperellum* and *Paecilomyces* while crude plant extracts were turmeric, garlic, ginger and lemon. The fungal antagonists were multiplied on sterile sorghum. Five mycelial agar plugs (10mm diameter) of each of the four antagonistic fungi were inoculated in polythene sleeves with cooled autoclaved sorghum under sterile conditions. The contents were then shaken well to evenly disperse the inocula before incubation at room temperature (23 ± 2 ℃) for 14 days. During the incubation, the contents of the polythene sleeves were shaken once after two days to prevent aggregation. Standardization of conidia in suspension was carried out in the laboratory before prior to field application. Conidia of each fungal antagonist were harvested by flooding the substrate having fungal growth with sterile distilled water then filtered through two layers of cheesecloth to obtain conidia suspension. The number of conidia in suspension in which had 0.05 % Tween 20® (polyoxyethylene sorbitol esters) added was standardized to 1×10^8 conidia ml^{-1} for each fungal antagonist. The polythene sleeves with selected antagonistic inoculant growing on sorghum for 14 days were carried to the field. The conidia suspension for each antagonist was prepared in the same way as during standardization. Fresh turmeric rhizome, garlic corm, ginger rhizome and lemon fruit each weighing 100g were finely blended and extracted with 95% ethanol. The ethanol extracts was concentrated by vacuum evaporation and 10 ml of each crude plant extract was transferred to the universal bottle. Ten ml of each of the extract was added into five litres of water having one drop of 0.05% Tween 20®.

2.2 Experimental Design and Layout

On-farm experiments were conducted in Mwea in Kirinyaga County, Kenya. The average rainfall in Mwea is about 850 mm with a range of 500-1250 mm per annum divided into long rains and short rains. The annual mean temperature ranges from 15.6 °C to 28.6 °C which meets the ecological requirements for snap bean production (Kamanu *et al*., 2012). The field was divided into plots measuring 3 m by 3 m with 1 m alleys between the plots and 1 m alleys between the blocks. The variety of snap beans mostly grown by farmers was planted in single rows with spacing of 15 cm x 30 cm in each plot. Di-ammonium phosphate (DAP) at a rate of 200kg/ha was mixed well with soil before placement of seeds. First weeding was carried out two weeks after emergence (WAE) while second weeding was at fifth WAE. The plants were side dressed with Calcium ammonium nitrate (CAN) at a rate of 100kg/ha at flowering stage. Furrow irrigation was done to field capacity twice per week in absence of rain. The antagonistic fungi and plant extracts were applied weekly as a foliar spray, commencing one week after emergence until pod setting. Each antagonistic fungus was applied at a concentration of 1×10^8 conidia ml-1 while each of the extract was at 10ml in 5litres of water having one drop of 0.05% Tween 20®. The efficacy was compared to that of synthetic pesticides Dithane M-45® and Confidor 70 WG® that were alternately applied and commercial formulations of *Trichoderma* (Trianum®) and neem (Achook®). Commercial neem, Achook® was applied at a rate of 20 ml in 20 Litres of water. Commercial *Trichoderma* (Trianum®) was applied at a rate of 5g in 5 litres of water having a concentration of 1×10^8 spores/ml**.** However, synthetic fungicide, Dithane M-45® (Mancozeb 80% m/m) was applied at a rate of 50gm in 20 Litres of water. Control plots were sprayed with water. The treatments were replicated three times and the experiment was laid out in a randomized complete block design (RCBD).

2.3 Assessment of Pest Infestation

The population of whiteflies was determined by counting the number of nymphs on lower surface of 10 leaves from ten plants through non-destructive sampling. The 10 plants were tagged in a zigzag manner from inner rows of each plot (Wafula, 2014). This was carried out five times at third, fourth, fifth, sixth and seventh week after emergence (WAE). The population of thrips was assessed through destructive sampling of one flower from ten tagged plants per plot at random from the inner rows. The harvested flowers were kept in 70% ethanol and were taken to the laboratory to determine the population. Each flower was placed in a Petri dish, dissected and washed with water making sure that no thrips was lost with the debris (Nderitu, *et al*., 2009). Thrips were counted using dissecting microscope and a tally counter (Wafula, 2014). Assessment of population of thrips was carried out three times fifth, sixth and seventhweeks after emergence.

2.4 Determination of Disease Index

Evaluation was done on the distribution, incidence and severity of angular leaf spot, rust and anthracnose from second to seven WAE. Distribution of disease was done by observing how each disease was spread in the whole field using a 0-2 distribution scale; where 0 = no disease, 1 = spots, 2 = whole plot. Assessment of incidence of disease involved counting diseased plants that showed symptoms of each disease and the percentage of disease incidence calculated according to the formula by Wheeler (1969):

$$\text{Percentage disease incidence} = \left[\frac{\text{number of infected plants}}{\text{total number of plants}}\right] 100$$

Assessment of severity was based on a scale of 0-5 (Stavely, 1985); where 0 = no disease, 1 = < 20%, 2 = 21-40%, 3 = 41-60%, 4 = 61-80%, 5 = 81-100% leaf area infected. Ten plants were randomly sampled and tagged from three inner rows in each plot by scoring three trifoliate leaves sampled at bottom, middle and top of each plant (Wahome *et al*., 2011). Total disease indices were computed using scores of distribution, incidence and severity. Percentage disease index was computed using the formula modified from McKinney (1923):

$$\text{Disease index (\%)} = \frac{\text{distribution score} + \text{incidence score} + \text{severity score}}{\text{maximum distribution score} + \text{maximum incidence} + \text{maximum severity score}} \times 100$$

Area under disease progress curve (AUDPC) was computed from the mean severity scores of data recorded at each assessment day (seven days interval) as described by Shaner and Finney (1977):

$$\text{AUDPC} = \sum_{i=1}^{n-1} [(Y_{i+1} + Y_i)/2]\,(X_{i+1} - X_i)$$

where, Y^i = disease severity at i^{th} assessment, X^i = number of days after inoculation at the i^{th}

assessment and n = total number of assessments.

2.5 Assessment of Yield and Yield Components

Harvesting of fresh pods was done once a week for three weeks in whole plots. Fresh pods harvested per plot were graded into two major categories namely marketable and non- marketable. The category of marketable was graded into extra fine and fine where the attributes for extra fine were a width of 6 mm and the fine - width between 6 mm to 8 mm (Wahome *et al*., 2011). The fresh weight of each of the grades per plot was determined in grams at every harvest. Unmarketable pods were further graded into thrips damaged and disease damaged fractions and their weight taken. The cumulative total weight was obtained at the end of the three harvests

Wahome *et al.* (2013).

2.6 Data Processing and Analysis

Data on insect pest population, disease index and yield parameters was subjected to analysis of variance using Genstat®, Release15.1. Mean separation of the treatments was accomplished using Fisher's protected Least Significant Difference (Steel *et al.*, 1997).

3. Results

Fungal antagonists and crude plant extracts significantly ($P \leq 0.05$) reduced the population of whiteflies and thrips (Figure 1; Table 1) compared to the control. Plant extracts however had a significantly ($P \leq 0.05$) higher efficacy in reducing the population of whiteflies and thrips compared to the fungal antagonists. Crude plant extracts and the antagonistic fungi compared well with commercial formulations of neem (Achook 0.15EC®), *Trichoderma* (Trianum®) and synthetic pesticide, Confidor® 70 WG (Figure 2). The most active plant extracts were garlic and ginger while the most active microbial antagonists were *Paecilomyces* and *Trichoderma* spp.. The crude plant extracts and antagonistic fungi reduced the thrips infestation by up to 45% and 19% while the antagonistic fungi *Trichoderma* spp. and *Paecilomyces*reduced the population of thrips by up to 10.5% and 20 %, respectively.

Antagonistic fungi and plant extracts significantly ($P \leq 0.05$) reduced intensity of angular leaf spot, rust and anthracnose (Table 2). The antagonistic fungi were more effective in reducing intensity of the foliar diseases compared to the plant extracts (Figure 3). *Trichoderma* spp. were the most efficacious, with *Trichoderma harzianum* and *Trichoderma viride* spray application showing the least disease intensityfor angular leaf spot, anthracnose and rust. Among the plant extracts, turmeric and garlic were more efficacious compared to the commercial neem Achook®. *Trichoderma viride* reduced disease intensity of angular leaf, rust and anthracnose by up to 37%, 51% and 33%, respectively while *T. harzianum* reduced disease intensity of angular leaf spot by up to 22% (Table 2). Turmeric reduced the disease intensity of angular leaf spot and rust by up to 18% and 33.5%, respectively while ginger reduced disease intensity of anthracnose by up to 15 %.

Antagonistic fungi and crude plant extracts significantly ($P \leq 0.05$) increased pod yield and reduced pest and disease damaged pods (Table 3). *Paecilomyces* was the only treatment that resulted in a decrease in total pod yield relative to control. Crude plant extracts and antagonistic fungi increased extra-fine pod yield by up to 26% and 17%, respectively. Application of the commercial formulation ofneem .(Achook®) resulted in the largest increase in extra fine and fine pod grades, followed by extracts from ginger and garlic. The yield from plots treated with the three products compared well with yield from plots treated with alternate application of synthetic pesticide and fungicide (Table 3). Antagonistic fungi reduced disease damaged pods more than the plant extracts but comparable to alternate application of Dithane M-45® and Confidor® 70 WG and Trianum®. Garlic extract significantly reduced thrip-damaged pods by 45.5% followed by Achook® (40.6%). *Trichoderma* spp. significantly reduced disease-damaged pods by 48.4% while Trianum® by 38.9%. Dithane® and Confidor® (49.1%) had a slight reduction in disease-damaged pods over *Trichoderma* spp.

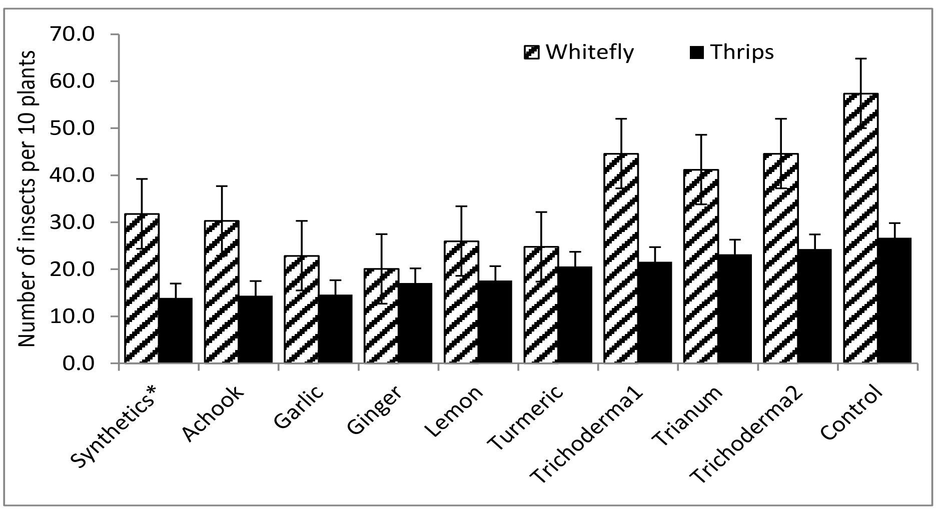
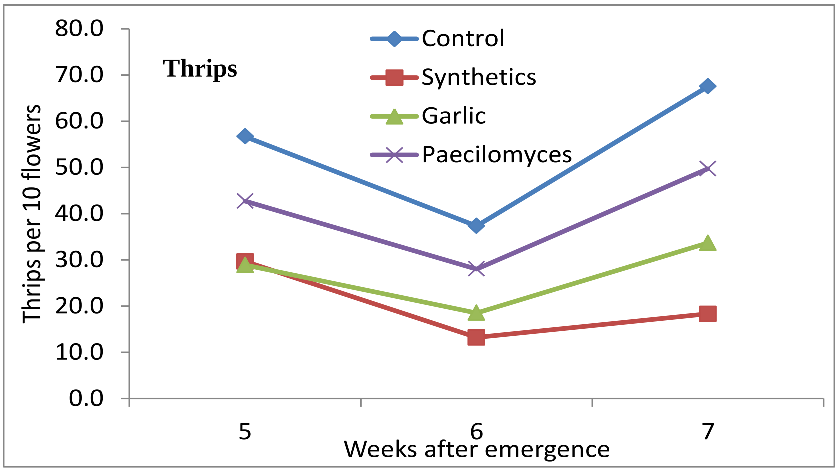


Figure 1. Mean population of white flies and thrips on snap bean crop sprayed with different plant extracts, antagonistic fungi and synthetic pesticides



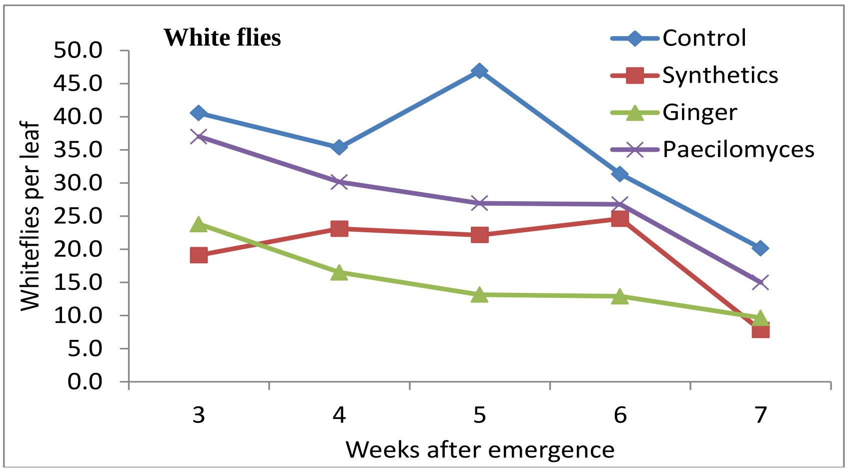


Figure 3. Changes in thrips and white fly population over time on snap sprayed with antagonistic fungi and plant extracts as compared to synthetic pesticides and untreated controls

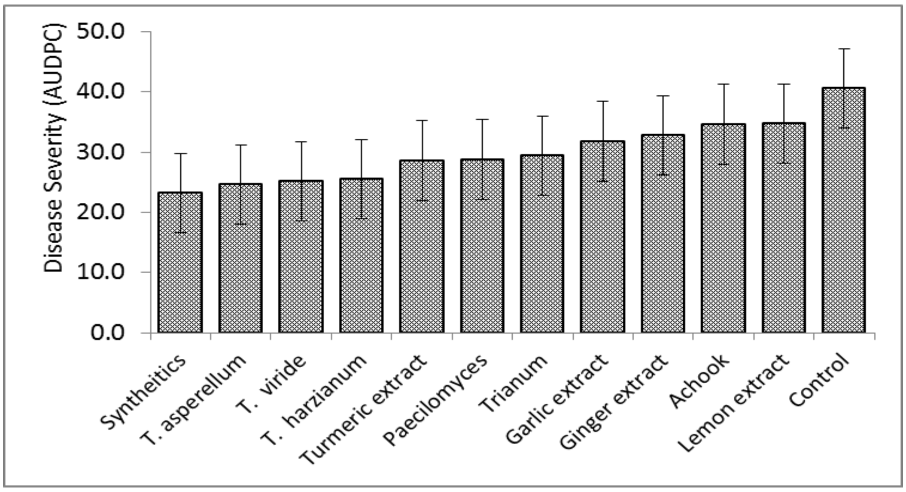


Figure 3. Mean disease severity on snap bean sprayed with antagonistic fungi and plant extracts

Table 1. Number of whiteflies and thrips on snap beans sprayed with different antagonistic fungi and crude plant extracts during the two cropping season

Treatment	November, 2015-January, 2016		March- May, 2016	
	Number of Whiteflies	Number of thrips	Number of whiteflies	Number of thrips
viride	44.6 b	34.2 bcd	6.1 bc	50.3 c
T. harzianum	44.6 b	36.4 b	5.9 cd	53.2 b
T. asperellum	42.8 b	34.9 bc	5.5 de	54.2 b
Paecilomyces	40.8 b	37.0 b	5.2 e	43.2 d
Turmeric	24.8 cde	30.6 cde	3.7 fg	34.3 f
Garlic	22.9 def	22.4 f	3.8 fg	31.6 f
Ginger	20.1 eg	29.7 de	3.7 fg	37.3 e
Lemon	26.0 cde	28.8 e	4.3 f	34.2 f
Synthetics	31.8 cd	13.3 g	4.3 f	27.4 g
Trianum®	41.2 b	36.4 b	6.6 b	52.3 bc
Achook®	30.3 c	26.6 ef	3.6 g	32.0 f
Control	57.4 a	44.6 a	7.7 a	63.1 a
LSD ($P \leq 0.05$)	7.9	4.5	0.6	2.6
CV (%)	13.1	8.5	7.0	3.6

Means accompanied by different letter(s) in each column are significantly different (Duncan's multiple range test, $P \leq 0.05$). Synthetics; Dithane® + Confidor®; LSD=Least significant difference; CV=Coefficient of variation.

Table 2. Percentage disease index on snap beans sprayed with different antagonistic fungi and crude plant extracts for two cropping seasons

Treatment	November, 2015-January, 2016			March-May, 2016		
	ALS	Rust	Anthracnose	ALS	Rust	Anthracnose
T. viride	42.1 def	12.9 f	25.1 f	32.1 fg	13.2 h	24.4 e
T. harzianum	40.7 fg	14.2 ef	25.0 f	33.9 f	15.5 gh	25.1 de
T. asperellum	40.9 efg	14.0 ef	25.1 f	37.3 e	16.2 fgh	26.2 cde
Paecilomyces	45.4 cde	15.1 ef	26.7 def	41.7 d	19.3 def	27.3 cd
Turmeric	43.0 def	16.3 de	29.7 b	42.0 d	20.4 cde	28.4 c
Garlic	43.9 cde	20.7 b	28.2 bcd	42.9 cd	21.7 cd	28.2 c
Ginger	47.9 bc	18.0 cd	27.4 cde	45.0 bc	22.2 bcd	34.0 b
Lemon	51.0 ab	19.7 bc	28.2 bcd	44.4 bc	23.5 bc	33.6 b
Synthetics	37.1 g	13.0 f	25.2 f	29.9 g	15.4 gh	23.9 e
Trianum®	42.7 def	16.6 de	25.7 ef	37.1 e	18.2 efg	26.0 cde
Achook®	46.1 cd	21.1 b	28.9 bc	45.9 b	25.2 ab	33.2 b
Control	52.3 a	24.5 a	32.2 a	50.6 a	26.9 a	36.6 a
Mean	44.4	17.2	27.3	40.0	19.8	28.9
LSD ($P \leq 0.05$)	4.1	2.4	1.7	2.2	3.1	2.5
CV (%)	5.4	8.4	3.7	3.2	9.4	5.2

Means accompanied by different letter(s) in each column are significantly different (Duncan's multiple range test, $P \leq 0.05$). Synthetics: Dithane® + Confidor®; ALS= Angular leaf spot; LSD=Least significant difference; CV=Coefficient of variation.

Table 3. Marketable pods and non-marketable pods (kg/ha) of snap beans sprayed with different antagonistic fungi and plant extracts for both cropping seasons

Treatment	November 2015-January, 2016				March-May, 2016			
	marketable pods		non-marketable pods		marketable pods		non-marketable pods	
	extra-fine	fine	thrips damage	disease damage	extra-fine	fine	thrips damage	disease damage
T. viride	1523 cd	61.1 b	1330 abc	815 d	1787 f	86.7 ef	581.5 a	407.4 d
T. harzianum	1556 cd	61.1 b	1452 ab	837 d	2120 ef	100.4 de	725.9 a	459.3 bcd
T. asperellum	1541 cd	74.1 b	1326 abc	800 d	2420 de	77.2 fg	663.0 a	400.0 d
Paecilomyces	1044 d	70.4 b	1222 abcd	867 d	1387 g	76.2 fg	611.1 a	433.3 cd
Turmeric	1730 bc	55.5 bc	1341 abc	1548 ab	3313 b	130.4 ab	670.4 a	774.1 ab
Garlic	1559 cd	29.6 c	852 d	1267 bc	2487 de	114.1 cd	548.1 a	633.3 abcd
Ginger	1400 cd	68.5 b	1189 abcd	1674 a	2587 d	105.9 cd	711.1 a	837.0 a
Lemon	1376 cd	66.5 bc	1041 bcd	1107 cd	2253 de	87.6 ef	670.4 a	737.0 ab
Synthetics	2426 a	59.3 bc	1059 bcd	807 d	3670 a	118.2 bc	663.0 a	633.3 abcd
Trianum®	1167 d	59.2 bc	1344 abc	985 cd	2203 e	84.4 efg	781.5 a	603.7 abcd
Achook®	2152 ab	104.0 a	926 cd	1600 ab	2937 c	138.5 a	463.0 a	666.7 abcd
Control	1207 cd	42.6 bc	1563 a	1585 ab	1153 g	69.6 g	655.6 a	607.4 abcd
Mean	1556.7	62.6	1220.4	1157.7	2360	99.1	645.4	599.4
LSD ($P \leq 0.05$)	482.3	27.6	371.9	364.5	338.5	15.2	291.9	283.9
CV (%)	18.3	26.1	18.0	18.6	8.5	9.1	26.7	28.0

Means accompanied by different letter(s) in each column are significantly different (Duncan's multiple range test, $P \leq 0.05$). (Synthetics=Dithane® and Confidor®).

4. Discussion

Application of antagonistic fungi and crude plant extracts reduced the population of whiteflies and thrips on snap bean and their efficacy compared well with commercial formulations of *Trichoderma* (Trianum®) and synthetic pesticide Confidor®. Plant extracts were more efficacious in reducing insect pest populations compared to the antagonistic fungi. All crude plant extracts significantly reduced the population of whiteflies while garlic extract significantly reduced the population of thrips. These findings are in agreement with those of Kiani *et al.* (2012) who showed that the garlic-onion-pepper extract controlled western flower thrips in the strawberry greenhouse. Also Prakash *et al.* (2008), Hussein *et al*. (2014) and Sarwar (2015) reported that garlic and other botanicals exhibited best anti-feedant for vegetable pests while Kalu *et al*. (2010) reported larvicidal activities of the ethanol extract of garlic bulb against larvae of *Culex quinquefasciatus.* Leaf extracts of garlic and turmeric have also been reported to be efficacious against larval, pupal and adult of *Tribolium castaneum* and *Trogoderma granarium* (Ali *et al.,* 2014; Ahmad *et al*., 2013; Nwachukwu *et al*., 2014). The repellent nature of compounds in plant extracts has been attributed to high amounts of allicin in fresh garlic (Nwachukwu *et al*., 2014; Regnault-Roger, 1997).

Foliar sprays of antagonistic microorganisms and plant extracts reduced the intensity of economically important fungal foliar diseases on snap bean. *Trichoderma* spp. was the most efficacious. The findings are in line with studies by Elkot and Derbalah (2011), Sawant (2014) and Chhetry and Mangang (2012) who reported that foliar sprays of antagonistic fungi significantly reduced grey mold on cucumber and while foliar application of *T. harzianum* and *T. viride* has been shown to significantly reduce head blight severity on wheat (Sawant, 2014).In this study, the antagonistic *Trichoderma* spp. had greater efficacy on rust compared to angular leafspot and anthracnose. Similar findings are reported by Akram (2015) who showed that *Trichoderma* spp. significantly reduced the incidence of Fusarium wilt. The activity of the antagonistic fungi against foliar diseases of snap bean can be attributed to induced systemic resistance, competition, suppression of sporulation and spore germination, suppression of enzyme production by the pathogen,production of antimicrobial toxins and plant growth promoting substances (Sawant, 2014; Živković*et al*., 2010). In mycoparasitism, the antagonist microorganism produces enzymes which hydrolyse the polysaccharides, cellulose, β-glucans and chitin present in the cell walls of the plant pathogenic fungi (Sawant, 2014). The enzymes include chitinases, N-acetylglucosaminidases, β-1,3-glucanases, proteases, celluloses, endoglucanases, glucosidases and amylases.

The observed efficacy of plant extracts in managing foliar diseases on snap bean in the present study is in line findings by Hossain and Hossain (2013) who reported the effectiveness of plant extracts in reducing Tikka disease on groundnuts by up to 63.6%. Similar findings are reported by Yashoda (2011) and Gurjar *et al*. (2012) who reported that extracts of garlic, turmeric and ginger had antimicrobial activity against fungi of agricultural significance. Extracts from turmeric and garlic were the most efficacious and this indicates that botanical extracts used in this study have active compounds that inhibit fungal pathogens. Kumar *et al.* (2012) reported that garlic, ginger and lemon have great potential as antimicrobial compounds against microorganisms and the suppressive nature of garlic bulb crude extract against phyopathogenic fungi has been attributed to the existence of allicin (Wei *et al.*, 2011). The active compounds against pests found in plant extracts include alkaloids, non-proteic amino acids, steroids, phenols, flavonoids, alkaloids, saponins, terpenoids, polyphenolics and polyacetate derivatives, glycosids, glucosinolates, quinones, tanins, salanine, meliantrol, azadiractin, piretrolone, cinerolone and jasmolone that act as contact poisons, stomach poisons, anti-feedants, repellents and confusants, leading to finally death of the insect victims (Javaid and Rehman, 2011; Reddy *et al*., 2012; Sarwar, 2015). They paralyze nerve activity, respiratory arrest, and act on the central and peripheral nervous system leading to convulsions and finally death of the pest (Sarwar, 2015). The antimicrobial activity of garlic and turmeric are attributed to allicin and curcumin, respectively (Gurjar *et al*., 2012). Garlic extract contains olerisine substance, a volatile oil made up of allyl propyl disulphide that has anti-feedant effect (Hussein *et al*., 2014). Extracts of neem are reported to stimulate the plant natural defence response and cause changes in plant metabolism leading to changes in level of enzymes and content of phenolic compounds that have adverse effects on the pathogen (Hussein *et al*., 2014).

Application of antagonistic fungi and extracts increased yield of marketable pods and reduced the yield of pest and disease damaged pods. The findings of this study are consistent with those by Soliman *et al.* (2015) and Sawant (2014) who reported that application of formulations based on fungal antagonist can promote plant growth and crop precocity, increase in legume production and reduce chemical treatment. However, Amin *et al.* (2014) reported that application of *T. viride and T. harzianum* had no effect on yield in common bean. The observed increase in pod yield can be attributed to the reduction in pest and disease damage and also to plant growth promoting substances present in produced by the antagonists and also found in the antifungal plant extracts (Sawant, 2014; Živković*et al*., 2010). This study indicated that antagonistic fungi and plant extracts are effective in managing pests and diseases in snap bean, resulting in increase in yields.

The findings of this study showed that antagonistic fungi and plant extracts are effective in management of insect pests and diseases in snap beans in fields. Crude plant extracts were effective in reducing population of whiteflies while *Trichoderma* spp. were effective in lowering development and spread of rust, anthracnose and angular leaf spot. The effectiveness of plant extracts and fungal antagonists against pests and diseases translated to increased yield of quality pods. Therefore, plant-based biopesticides and antagonistic fungi can provide alternatives to synthetic pesticides in the management of pests and diseases in snap beans, thereby reducing harmful chemical residues and loss of produce at the export market. This would minimize produce interceptions and improve the competitiveness of snap bean pods at niche markets. More studies should be conducted to determine active compounds of antagonistic fungi and botanical extracts used in this study. This will be useful in the formulation and consequent commercialization of these biopesticides. An ideal biological control agent should be economical to produce, possess good storage stability, have high residual activity, easy to handle, provide consistent and effective control against the target pests (Gašić and Tanović, 2013). Addition of carriers and adjuvants to the microbial antagonist help to protect the active microorganism from environmental conditions, allows the survival of the active biological agent and improves storage stability. Microbial pesticides have advantages over synthetic pesticides because they are biodegradable, they do not leave residues in the soil, are less harmful to humans or animals, and more accessible in less developed countries (Prakash *et al*., 2008; Leahy, 2014; Sarwar, 2015). Plant extracts as biochemical pesticides are degradable, non-persistent in the environment, lethal to target pest and are broader spectrum (Leahy, 2014) hence their effect on beneficial organisms should be investigated.

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