agronomy

MDPI

Article

Efficacy of Plant Materials in Controlling Aphids on Okra (*Abelmoschus esculentus* L. Moench) in Limpopo Province of South Africa

Jeremia Murovhi [1,*], Mutondwa Masindi Phophi [2] and Paramu Mafongoya [2]

[1] Department of Agriculture, Land Reform and Rural Development, Private Bag x9487, Polokwane 0700, South Africa

[2] Department of Crop Science, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Private Bag x01, Pietermaritzburg 3201, South Africa; Phophim@ukzn.ac.za (M.M.P.); mafongoya@ukzn.ac.za (P.M.)

* Correspondence: murovhij@gmail.com

Received: 15 November 2020; Accepted: 9 December 2020; Published: 14 December 2020

check for updates

Abstract: Smallholder farmers in Limpopo Province generate income through growing vegetable crops such as cabbage, tomato, and okra. These crops are produced for local and national markets. Okra crops are highly constrained by aphids. Smallholder farmers rely only on synthetic insecticides to manage aphids. This paper evaluated the efficacy of five plant materials (bio pesticides): pawpaw (*Carica papaya* L.), Mexican marigold (*Tagetes minuta* L.), serrano pepper (*Capsicum annuum* L.), common lantana (*Lantana camara* L.) and tobacco (*Nicotiana tabacum* L.) on *Aphis gossypii* population in okra production. The field experiment was laid in a randomized complete block design, with seven treatments (five plant materials, mercaptothion insecticide as a control and the absolute control) replicated three times. Aphid abundance, leaf damage and the correlation between leaf damage and aphid abundance were analyzed using analysis of variance. *Carica papaya* L. (0.87) and *Tagetes minuta* L. (0.87) were more effective in reducing aphid abundance. Leaf damage caused by aphids was lowest in the *Carica papaya* L. treatment (1.11) and the *Tagetes minuta* L. treatment (1.12). There was a strong positive correlation between aphid abundance and leaf damage (r = 0.86). Plant materials: *Carica papaya* L. and *Tagetes minuta* L. could be incorporated into an overall integrated pest management system to reduce aphid abundance and leaf damage.

Keywords: bio pesticides; integrated pest management; leaf damage

---

1. Introduction

Okra (*Abelmoschus esculentus* L. Moench) is mostly grown in Africa and Asia under warm climatic conditions [1]. Smallholder farmers grow okra for its young immature pods which are consumed as a vegetable. Many smallholder farmers in the Vhembe District produce okra for local and national markets. However, little is known on the production of okra crop in South Africa, especially in the Limpopo Province. Insect pests are one of the major constraints limiting the production of okra in Vhembe District. Cotton aphid (*Aphis gossypii*) has been identified as one of the major problematic insect pests that reduce okra pod yield [2].

Various methods of insect pest management have been used to protect crops from insect pest damage, to increase crop production and to enhance food security. Smallholder farmers in Limpopo Province heavily rely on the use of synthetic pesticides to manage insect pests on vegetables [3]. South Africa is one of the countries with an increase in the use of synthetic pesticides by farmers [4]. The Department of Agriculture, Forestry and Fisheries (DAFF) reported that there are over 3000 synthetic pesticide products approved for insect pest management to be used by South African farmers [5]. The frequent use of synthetic insecticides by smallholder farmers has led to many problems such as environmental contamination, pest resistance development and human health [6]. The availability and cost of synthetic insecticides also remain a major challenge, especially in remote rural areas where agriculture is the major source of income and food security. There is a need to use other pest management methods such as plant materials (bio pesticides) and their extracts, cultural methods and biological control to reduce the level of resistance, pesticide residues on crops and increasing crop yield. The use of biological control to manage problematic insect pests is an environmentally friendly method which poses no danger to farmers and consumers [7]. Natural enemies such as lady beetles, lace wings, parasitic wasps such as *Aphidius matricariae* and *Aphelinus semiflavus* are used to manage the green peach aphid (*Myzus persicae*) [8].

Plant materials and their extracts have been used for more than 150 years and majority of African smallholder farmers have been efficiently using various plant materials to manage problematic insect pests [9]. These plant materials contain different chemical substances or compounds and mode of action that have different properties such as repellent, insecticidal, antifeedants, growth inhibitors, oviposition inhibitors, ovicides, and growth-reducing effects on a variety of insect pests [10,11]. Smallholder farmers in Southern Africa have been using various plant materials and other natural products such as *Capsicum frutescens*, *Tagetes* spp., *Nicotiana tabacum* L., *Cypressus* spp., *Azadirachta indica*, *Moringa oleifera*, *Tithonia diversifolia*, *Lantana camara* L., *Vernonia amygdalina*, *Aloe* spp., *Eucalyptus* spp., cow dung and urine, ashes and many more for insect pest management [12,13].

The knowledge and use of plant materials to protect plant against pest damage has been in existence for decades [14]. Although this method has been around and has been used for many years, it is still not recognized as an alternative measure to synthetic pesticides by farmers in the Vhembe District. The use of plant materials might be limited by several factors including lack of field research, development of new pesticidal products, and proper regulations [15]. Researchers and scientists should do more field research to stimulate local knowledge that smallholder farmers possess on plant materials for pest management. This is one of the few studies conducted in Limpopo Province on the use of plant extracts to reduce aphid population on okra crops.

The objective of this study was to assess the efficacy of five plant material extracts found in Vhembe District on aphid abundance, leaf damage and okra yield under field conditions. We hypothesized that the plant material extracts will reduce the abundance and leaf damage resulting from aphid infestations compared to the synthetic insecticide. The study sought to provide smallholder farmers with a cheaper and safer way of managing insect pests through using locally available plant material extracts in managing insect pests that would guarantee lower residue accumulation in their products and increase their production. The use of locally based plant materials such as *Carica papaya* L., *Tagetes minuta* L., *Capsicum annuum* L., *Lantana camara* L., *Nicotiana tabacum* L. and many more can contribute to the enhancement of integrated pest management (IPM) implementation for smallholder farmers in Limpopo Province [16].

2. Materials and Methods

2.1. The Study Area

The field experiment was conducted at Bale area (latitude 22°43′0450′′ S, longitude 30°67′0104′′ E) which is situated in Musina local municipality, Vhembe District municipality, Limpopo Province in South Africa. Musina municipality is one of the driest municipalities in Vhembe District. The mean monthly rainfall and mean monthly temperatures are shown in Table 1. The average maximum temperature was 31.5 °C and the minimum average temperature was 19.2 °C. The average rainfall in the Bale area was 23.5 mm.

Table 1. Monthly rainfall and mean temperatures in Bale village recorded in 2019.

Month	January	February	March	April	May	June
Max temp °C	33.5	31.1	32.3	29.2	27.8	24.4
Min temp °C	20.5	20	19.6	16.7	11.6	7.3
Rainfall mm	0.0	88.2	30	23	0.0	0.0

2.2. Experimental Design

The field experiment was laid in a Randomized Complete Block Design, with seven treatments replicated three times. An absolute control where no pesticides or plant materials solution were applied, and a treatment treated with a synthetic chemical (mercaptothion at a rate of 25 mL/20 L recommended label) were used as control to compare the efficacy with five plant material extracts. Mercaptothion was chosen because it is the mostly used insecticide by local smallholder farmers for insect pest management. The land was properly ploughed before plots were demarcated. Three blocks of seven plots were demarcated per different treatment. Each of the experimental plots was measured 10 m length × 4.2 m width. The inter-row spacing for the okra was 60 cm and intra-row spacing 30 cm. Plots were separated by 1 m wide border margins and blocks were separated by 2 m apart. Okra variety clemson spineless was planted as one of the main crops grown by smallholder farmers in some of the local municipalities around the Vhembe District. Planting was done during the fourth week of January 2019. Two seeds were planted per hole and thinned to one plant per hole two weeks after germination when the seedlings were well established. The germination rate was 85%. 2:3:4: (30) (nitrogen, phosphorus, and potassium) fertilizer was applied during planting at 250 kg/ha. Weeding was done three times using a hand hoe in a three-week interval after planting. KAN (28% N) was applied on the sixth week after planting, a day after weeding at a recommendation of 200 kg/ha.

2.3. Sampling

Soil sample was taken before planting and analyzed at Madzivhandila College of Agriculture laboratory (Table 2). A rainfall gauge was installed onsite to measure the amount of rain during the period of the experiment. Scouting of aphids was done once a week before spraying plant material extracts. Spraying of plant material extracts was applied once pest infestations had established on the crop as per smallholder farmers' practice. Data sampling and spraying of plant extracts were done between 6:00 a.m. and 9:00 a.m. when the insects were least active. From each plot, ten plants were randomly selected and visually examined to record the number of aphids and leaf damage caused by aphids. The aphid abundance and leave damage of okra crops were recorded. The leaves and stems were carefully examined for the presence of aphids. Aphid infestation was assessed by using visual scoring rating from 0–5; where 0—meant no aphid presence; 1—few individuals; 2—few isolated small colonies; 3—several small colonies; 4—large isolated colonies; 5—large continuous colonies [16]. The leaf damage caused by aphids was measured by the following ratings: 1—meant no damage; 3—leaves slightly cupped; 5—leaves moderately cupped with some leaf yellowing; 7—severe distortion of leaves with considerable yellowing combined with honeydew production and 9—very severe foliar distortion and yellowing combined with abundant honeydew production [16]. Harvesting was done manually twice a week from the net plots. All the harvested pods were weighed and recorded to compare the yield per treatment.

Table 2. Soil chemical and physical properties in Bale Village before planting.

pH (H_2O)	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	K (mg/kg)	P (mg/kg)	Clay %	Silt %	Sand %
6.47	654.66	260.302	63.597	144.746	9.0	22	4	74

2.4. Preparation of Plant Materials Extracts

The plant materials evaluated were *Nicotiana tabacum* L., *Tagetes minuta* L., *Carica papaya* L., *Capsicum annuum* L. and *Lantana camara* L. All the plant materials were collected from different areas of Vhembe District Municipality. To ensure uniformity, the same measurement of 300 g/20 L or 15 g/L was used across the plant material extracts. Dry tobacco leaves were obtained from local farmers at Tshivhilwi village (latitude 22°84′9474′′ S, longitude 30°64′3682′′ E) in Thulamela local Municipality. Pestle and mortar were used to pound the leaves into powder. Three hundred grams of the pounded leaves was mixed with 20 L of water, sealed and allowed to stay for 24 h. The ripe fruits of *Capsicum annum* L. were obtained from local famers at Bale village (latitude 22°43′0450′′ S, longitude 30°67′0104′′ E) in Musina local Municipality. They were finely chopped, and three hundred grams was added into 20 L of water, sealed and allowed to stay for 24 h before spraying. The *Carica papaya* L. leaves were obtained at Manavhela village (latitude 23°10′4722′′ S, longitude 30°45′6975′′ E) in Collins Chabane local Municipality. The leaves of *Tagetes minuta* L. were obtained along the street at two different locations (Mashau village, latitude 23°14′2606′′ S, latitude 30°19′3829′′ E and Tshino village, latitude 23°10′8177′′ S, latitude 30°401′4177′′ E) in Makhado local Municipality. The leaves of *Lantana camara* L. were obtained from Tshino village, the same area where the leaves of *Tagetes minuta* L. were obtained. Fresh leaves were plucked and shade-dried to a very low moisture level. This was to ensure that the process of drying did not affect the potency of the active ingredients. Then, a pestle and mortar were used to pound the leaves to pulverize them to freely release the active ingredient in the leaves in water. Three hundred grams of the pounded leaves was mixed into 20 L of water, sealed and allowed to stay for 24 h before spraying. All the mixtures were then filtered using a filter to obtain a homogenous substance that was used for spraying the okra crops.

2.5. Data Analysis

Aphid abundance, leaf damage across sampling time and okra yield data were subjected to analysis of variance (ANOVA) using GenStat Release 18.2, VSN International Limited, Hempstead, UK. Mean comparisons for the individual treatments were done using Fishers Protected Least Significant Difference (LSD, $p \leq 0.05$). A regression analysis was performed on aphids' abundance against leaf damage and total leaf damage against okra yield using MS Excel 2016.

3. Results

3.1. Aphid Abundance and Leaf Damage of Okra Crops

Our result shows that the control (1.24) and mercaptothion (1.24) treatments were significantly different in terms of aphid abundance variation from the rest of the treatments ($p < 0.05$). However, they were not significantly different from each other in the variation of aphid abundance (Table 3). All plant materials were not significantly different from each other with respect to aphid abundance variation (Table 3). However, the most effective treatments on reducing aphid abundance were *Carica papaya* L. (0.87) and *Tagetes minuta* L. (0.87) (Table 3). The least effective treatments on reducing aphid abundance were mercaptothion (1.24) and control (1.24). The leaf damage of okra crops by aphids varied significantly among treatments ($p < 0.05$) (Table 3). The mercaptothion (1.34) and control (1.37) treatments did not significantly differ, but significantly differed from the rest of the treatments ($p < 0.05$). The treatment with the least okra leaf damage was *Carica papaya* L. (1.11) and the highest leaf damage was recorded in the control treatment (1.37) (Table 3).

Table 3. Variation in aphid abundance and leaf damage of okra crops.

Treatment	Aphid Abundance	Leaf Damage
Control	1.24 b	1.37 b
Mercaptothion	1.24 b	1.34 b
Nicotiana Tabacum L.	0.88 a	1.14 a
Lantana camara L.	0.89 a	1.13 a
Carica papaya L.	0.87 a	1.11 a
Tagetes minuta L.	0.87 a	1.12 a
Capsicum annuum L.	0.93 a	1.19 a
Least Significant Difference	**0.1**	**0.12**

Means with different letters showing significant difference at $p < 0.05$.

3.2. Aphid Abundance across Sampling Time

There was a significant difference on the aphid abundance and sampling time between plant extracts, mercaptothion and control treatments ($p < 0.05$) (Table 4). In February, the control and mercaptothion treatments were not significantly different from each other but were significantly different from the rest of the treatments ($p < 0.05$). The highest aphid abundance in February was found in the mercaptothion treatment (1.69) and the least aphid abundance was found in the *Nicotiana tabacum* L. (0.81) and *Carica papaya* L. treatments (0.81) (Table 4). In March, the highest aphid abundance was recorded in mercaptothion (0.93) followed by the control treatment (0.72). The treatment with the least aphid abundance was *Carica papaya* L. (0.05) (Table 4). There was a significant difference within treatments in April ($p < 0.05$). Mercaptothion treatment (1.16) was significantly different from *Nicotiana tabacum* L. (1.48) but was not significantly different from the rest of the treatments (Table 4). The highest aphid abundance in all the treatments was found in the month of May (Table 4).

Table 4. Aphid abundance across sampling time.

Treatment	Sampling Time			
	February	March	April	May
Control	1.49 ef	0.72 b	1.26 de	2.75 i
Mercaptothion	1.69 ef	0.93 bc	1.16 cd	2.42 h
Nicotiana tabacum L.	0.81 b	0.09 a	1.48 ef	2.03 g
Lantana camara L.	0.94 bc	0.12 a	1.37 de	2.02 g
Carica papaya L.	0.81 b	0.05 a	1.41 de	2.08 g
Tagetes minuta L.	0.83 b	0.06 a	1.33 de	2.17 g
Capsicum annuum L.	0.91 bc	0.16 a	1.38 de	2.20 gh
Least Significant Difference		**0.23**		

Means with different letters showing significant difference at $p < 0.05$.

3.3. Okra Leaf Damage across Sampling Times

There was no significant difference between the control and mercaptothion treatments across sampling time except for May. In February, the treatment with the least leaf damage was *Nicotiana tabacum* L. (1.08) and the highest leaf damage was found in the mercaptothion treatment (1.37) (Table 5). In March, the control treatment (133) was significantly different from *Lantana camara* L. (1), *Carica papaya* L. (1), *Tagetes minuta* L. (1) and *Capsicum annuum* L. (1) ($p < 0.05$), but was not significantly different from mercaptothion (1.23) and *Nicotiana tabacum* L. treatments (1.07). In April, there was no significant different across sampling time. During May, the control treatment and mercaptothion were significantly different from other treatments ($p < 0.05$) (Table 5).

Table 5. Okra leaf damage across sampling times.

Treatment	Sampling Time			
	February	March	April	May
Control	1.32 abc	1.33 bc	1.16 abc	2.97 d
Mercaptothion	1.37 bc	1.23 abc	1.19 abc	1.90 d
Nicotiana tabacum L.	1.08 ab	1.07 ab	1.25 abc	1.30 abc
Lantana camara L.	1.15 abc	1 a	1.21 abc	1.27 abc
Carica papaya L.	1.13 abc	1 a	1.28 abc	1.33 abc
Tagetes minuta L.	1.10 ab	1 a	1.37 bc	1.12 ab
Capsicum annuum L.	1.23 abc	1 a	1.44 c	1.27 abc
Least Significant Difference		**0.26**		

Means with different letters showing significant difference at $p < 0.05$.

3.4. Okra Pod Yield

There was a significant difference within treatments between harvesting time ($p < 0.05$) (Table 6). During the first and average total harvest, control (2058 kg) and mercaptothion (1915 kg) treatments were significantly different from plant material treatments. During the second harvest, *carica papaya* L. (4148 kg) and *Tagetes minuta* L. (4123 kg) were significantly different from the rest of the treatments. Control (3801 kg) and mercaptothion (3208 kg) were significantly different from other treatments except for *Nicotiana tabacum* L. (4032 kg) on the third harvest. *Carica papaya* L. (3640 kg) had the highest average yield and the least average yield was obtained from mercaptothion treatments.

Table 6. Harvest of okra pod yield in kg/ha.

Treatment	First Harvest (kg)	Second Harvest (kg)	Third Harvest (kg)	Total Average Harvest (kg)
Control	2058 a	3906 a	3801 a	3255 a
Mercaptothion	1915 a	3924 ab	3786 a	3208 a
Nicotiana tabacum L.	2295 b	4068 abc	4032 ab	3465 b
Lantana Camara L.	2357 b	4080 bc	4217 b	3551 bc
Carica papaya L.	2380 b	4148 c	4390 b	3640 c
Tagetes minuta L.	2398 b	4123 c	4272 b	3598 bc
Pepper	2353 b	4079 bc	4221 b	3551 bc
Least Significant Difference	**90.8**	**94.2**	**209.6**	**89**

Means with different letters showing significant difference at $p < 0.05$.

3.5. Aphid Abundance within Sampling Time

Figure 1 shows that aphid abundance was not consistent with sampling time. During January, there was no aphid recorded and the build-up started in February. During February and March, the aphid abundance decreased over sampling time. Between March and May, the aphid abundance increased over sampling time.

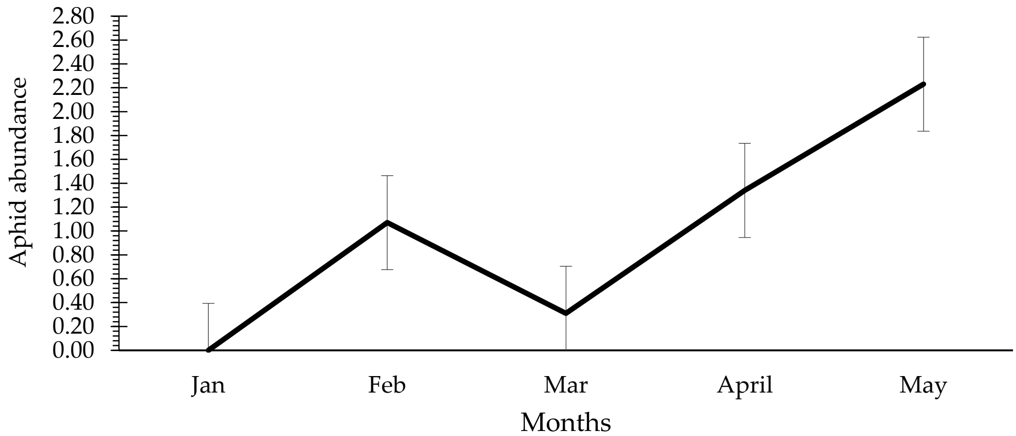

Figure 1. Aphid abundance across sampling time

3.6. Okra Leaf Damage across Sampling Time

Leaf damage was not consistent with sampling time (Figure 2). During January, there was no leaf damage recorded because there were no aphids recorded during this period. Between February and March, there was a slight decrease in the leaf damage and between March and May, the leaf damage increased over sampling time.

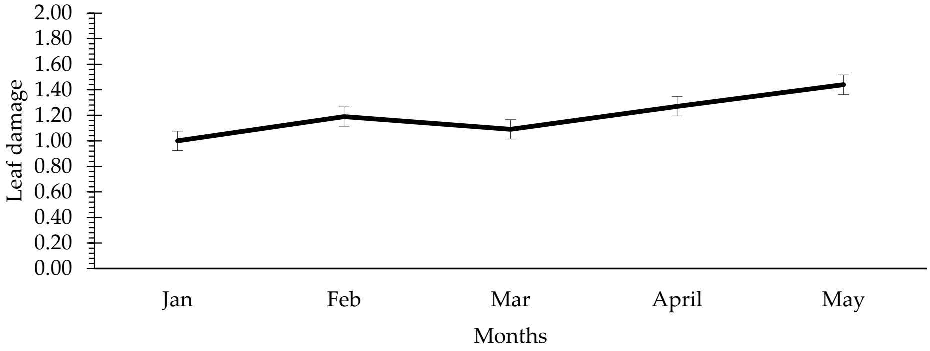

Figure 2. Okra leaf damage within sampling time.

3.7. The Correlation between Leaf Damage and Aphid Abundance

Our results showed that there was a strong positive relationship between aphid abundance and okra leaf damage (r = 0.8592, $p > 0.05$) (Figure 3). The regression analysis results of aphid abundance and leaf damage showed that aphid abundance accounted for 86% of the variation on okra leaf damage.

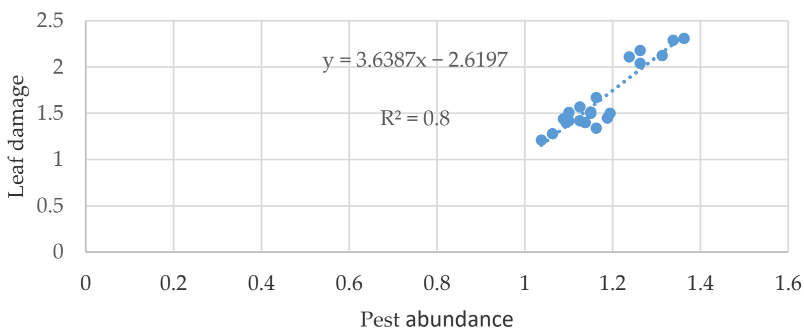

Figure 3. Correlation between leaf damage and aphid abundance.

3.8. Relationship between Total Leaf Damage and Total Yield

There was a negative linear relationship (r = 0.744, $p > 0.05$) between total yield in kg/ha and total leaf damage (Figure 4). The regression analysis results of total okra pod yield and total leaf damage showed that total okra pod yield accounted for 74% of the variation in total leaf damage.

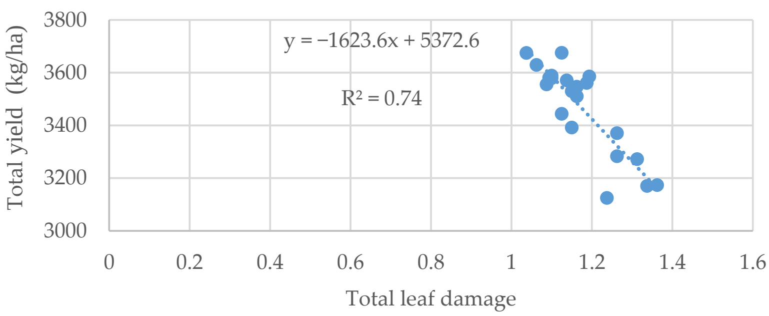

Figure 4. Correlation between total leaf damage and total yield.

4. Discussion

This study showed that all five plant material extracts (*Carica papaya* L., *Tagetes minuta* L., *Nicotiana tabacum* L., *Lantana camara* L. and *Capsicum annuum* L.) varied in degrees of reduction of the aphid abundance. Plant material extract treatments were effective in reducing aphid abundance compared to synthetic pesticide (mercaptothion). *Carica papaya* L. and *Targets minuta* treatments were the most effective in reducing the aphid abundance and leaf damage. This might be attributed to the different insecticidal activity that are contained in these plant materials. Muzemu, et al. [17] reported that plant extracts such as *Carica papaya* L., *Tagetes minuta* L., *Nicotiana tabacum* L., *Lantana camara* L. and *Capsicum annuum* L. contain insecticidal activities that act against different insect pests including aphids. Although the toxic level of *Carica papaya* L. was not measured, its efficacy might be attributed to its leaf sap which contains groups of cysteine protease enzymes such as papain and produces alkaloid group compounds, terpenoids, flavonoids, and non-protein amino acids that are highly toxic to plant sucking insect pests such as aphids, spotted bollworms, and whiteflies [18,19]. This result is in support of Ahmad, et al. [18] who reported that cysteine protease in *Carica papaya* L. latex contains compounds such as alkaloids and flavonoids which inhibit the feeding power and the growth of insect pests and works as an efficient defense against insect pests. As suggested by Dunkel, et al. [20] the efficacy of *Tagetes minuta* L. extract might be attributed to different insecticidal compounds on leaves such as phenylpropanoids, carotenoids, flavonoids, phototoxin alphaterthieenyl and thiophenes which are effective in controlling insect pests. The other plant materials (*Nicotiana tabacum* L., *Lantana camara* L. and *Capsicum annuum* L.) were also effective in controlling the aphids than Mercaptothion. Due to the level of aphid resistance to mercaptothion observed, the smallholder farmers in Bale might be using this chemical without rotation which might have resulted in the aphids developing resistance. Regular application of the same synthetic pesticide often results in the build-up of insect pest resistance [21]. Major problematic vegetable insect pests such as tomato bollworm (*Helicoverpa armigera*), aphid (*Aphis gossypii*), whitefly (*Bemisia tabaci*) and the diamondback moth (*Plutella xylostella*) have developed resistance because of using same insecticides such as pyrethroids and organophosphates, [22]. Smallholder farmers in Vhembe District are expected to remain vulnerable to insect pests such as aphids in vegetable production if they continue using same insecticides such as mercaptothion to manage insect pests.

The build-up of aphids started in February across all the treatments. However, the plant extract solutions were effective in reducing aphid abundance during that month. These plant material extract solutions might have been able to penetrate the whole plant during an early stage resulting in the potency of the treatments. This is supported by Baryakabonaa and Mwineb [23] who reported that the reduction in the aphid abundance after spraying is an indication that the plant extracts possessed pesticidal activities which is effective in the insect pest management. The aphid abundance decreased during March across the treatments which might have occurred due to different factors including plant extract repellent activities and rain. Although it was not concluded that the decrease in aphid abundance was a result of repellent activities from plant materials, plant extracts used such as *Tagetes minuta* L. possess repellent activities which reduce the number of pests. However, there was heavy rainfall that was recorded during the same period of sampling (Table 1). Rainfall reduced the aphid abundance on the okra crops. Heavy rainfalls have a negative effect on the aphid abundance [24]. During May, the crops were reaching the maturity stage which might have influenced the efficacy of the plant extract solutions on the crops as the aphid abundance and leaf damage were increasing with time. When the okra crops mature, they become bushy which require more plant extract solution as observed by Ngowi, et al. [25] who found that the efficacy of plant extracts varies according to the stage of the crops to which the solution is applied. However, the increase in the aphid abundance during May did not show serious impact on the okra pod yield (Table 5). There was also no significant difference within the leaf okra damage in all plant extracts. The reduction of leaf damage within treatments clearly shows that the plant extract solutions were effective in reducing aphid abundance.

This study further showed that there was a significant difference in okra pod yield in across harvesting time. Generally, higher okra pod yield in was obtained in all the plant extracts treatments compared to the mercaptothion and control treatments. This result is in support of Panhwar [26] who found that plant extracts applied on field crops increase flower production per plant which result in higher yield. The okra pod yield showed an increase over harvesting period. All the plant material extracts solutions were effective in reducing aphid abundance and leaf damage, thus helping to improve crop yield. Throughout the three harvests, mercaptothion and control treatments had the lowest yield. These results suggest that the mercaptothion treatment which is regularly used by smallholder famers around the region is no longer effective in controlling aphids due to aphid resistance as reported by Pedigo and Rice [27] who found that excessive use of the same insecticide induces resistance development in target pests.

The present study also showed that there was significant correlation between aphid abundance, leaf damage and okra pod yield. Aphid abundance was significantly reduced across the plant extract treatments, thus reducing the leaf damage on crops. A significant variation was found between aphid abundance and leaf damage. The result showed a strong positive relationship between aphid abundance and okra leaf damage (r = 0.86, $p > 0.05$). These results were supported by Mandal, et al. [28] who reported that aphids damage the crops by feeding on leaves, causing serious yield losses. The regression analysis results of aphid abundance and leaf damage showed that aphids accounted for 86% for the variation in leaf damages. The result in Figure 3 showed a very strong negative relationship (r = 0.74, $p < 0.05$) between the total yield in kg/ha and total leaf damage. The negative linear relationship between total leaf damage and total yield of okra (Figure 4) shows that total leaf damage results in low total yield of okra. Therefore, the higher the total leaf damage, the lower the total yield of the okra in kg/ha. This was clearly indicated by the okra pod yield in kg/ha (Table 6) where the yield of mercaptothion and control treatments were very low due to leaf damage. This correlation results agree with Waceke [29] who found out that leaf damages on crops normally leads to reduction in yield which has a negative impact on the market value and can also lead to total crop failure. The regression analysis results of total okra pod yield and total leaf damage showed that total okra pod yield accounted for 74% of the variation in total leaf damage (Figure 4). The negative linear relationships amongst total okra yield, total aphid abundance and total leaf damage (Figure 4) showed that the total okra yield was influenced by the total aphid abundance and total leaf damage. These results showed that the direct feeding of aphids on okra leaves adversely affected plant leaves and reduced their ability to perform their functions on the plant. This was supported by Heng-Moss, et al. [30] who found a significant decline of the photosynthetic rate on the leaves damaged by aphids. This correlation study shows that aphids can be controlled effectively by all the five plant extracts, especially *Carica papaya* L. and *Tagetes minuta* L.

5. Conclusions

This study assessed the effectiveness of plant extracts in reducing aphid population on okra crops. This study tested five different plant extracts, namely: *Carica papaya* L., *Tagetes minuta* L., *Nicotiana tabacum* L., *Lantana camara* L. and *Capsicum annuum* L. All plant material extracts tested were effective in controlling aphids compared to mercaptothion insecticide. *Carica papaya* L. and *Tagetes minuta* L. leaf extracts were the most effective when compared to the rest of the plant material extracts and can be potentially used as an alternative to synthetic pesticides. This study also concluded that all plant extracts used, especially *Carica papaya* L. and *Tagetes minuta* L., were effective in reducing leaf damage resulting from aphid infestations, thus increasing crop yield. Therefore, it is recommended that smallholder farmers should use *Carica papaya* L. and *Tagetes minuta* L. to manage aphids as an alternative method to synthetic pesticides. This study proved that insect pests, especially aphids, can be managed in the field with some bio-pesticides. These plant extracts which are easily obtained by smallholder farmers could form the basis for a successful formulation and commercialization of bio-pesticides in developing countries where agriculture is the major source of income. The use of these plant material extracts can also be advantageous in reducing health risks and the level of pesticide residues on crops as they are less harmful to the environment and lead to lower rates of pest resistance to pesticides.

Author Contributions: Conceptualization, J.M. and M.M.P.; methodology, J.M.; formal analysis, J.M.; data curation, J.M.; writing-original draft preparation, J.M.; writing-review and editing, J.M.; supervision, P.M. and M.M.P. project administration. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Research Foundation, grant number 86893.

Acknowledgments: To Bale cooperative project in Musina, South Africa for providing us with land for field trials. We acknowledge the University of KwaZulu-Natal for providing with research facilities.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Schippers, R.R. *African Indigenous Vegetables: An Overview of the Cultivated Species*; Department for International Development: London, UK, 2000; p. 370.
2. Kekeunou, S.; Messi, J.; Weise, S.; Tindo, M. Insect pests' incidence and variations due to forest landscape degradation in the humid forest zone of Southern Cameroon: Farmers' perception and need for adopting an integrated pest management strategy. *Afr. J. Biotechnol.* **2006**, *5*, 555–562.
3. Phophi, M.M.; Mafongoya, P.L.; Lottering, S. Perceptions of Climate Change and Drivers of Insect Pest Outbreaks in Vegetable Crops in Limpopo Province of South Africa. *Climate* **2020**, *8*, 27. [CrossRef]
4. Schreinemachers, P.; Tipraqsa, P. Agricultural pesticides and land use intensification in high-, middle- and low-income countries. *Food Policy* **2012**, *37*, 616–626. [CrossRef]
5. Department of Agriculture South Africa F and F. *Pesticide Management Policy for South Africa*; Government Gazette Pretoria: Pretoria, South Africa, 2010; p. 1.
6. Nyirenda, S.P.; Sileshi, G.W.; Belmain, S.R.; Kamanula, J.F.; Mvumi, B.M.; Sola, P. Farmers' ethno-ecological knowledge of vegetable pests and pesticidal plant use in Malawi and Zambia. *Afr. J. Agric. Res.* **2011**, *6*, 1525–1537.
7. Lundström, N.L.; Zhang, H.; Brännström, A. Pareto-efficient biological pest control enable high efficacy at small costs. *Ecol. Model.* **2017**, *364*, 89–97. [CrossRef]
8. Mpumi, N.; Machunda, R.L.; Mtei, K.; Ndakidemi, P. Selected Insect Pests of Economic Importance to Brassica oleracea, Their Control Strategies and the Potential Threat to Environmental Pollution in Africa. *Sustainability* **2020**, *12*, 3824. [CrossRef]
9. El-Wakeil, N.E. Retracted Article: Botanical Pesticides and Their Mode of Action. *Gesunde Pflanz.* **2013**, *65*, 125–149. [CrossRef]
10. Beltagy, B.I.; Omar, G.A. Alteration in some biological and biochemical parameters in Tribolium castaneum (Coleoptera: Tenebrionidae) due to garlic oil effect. *J. Adv. Biol.* **2016**, *9*, 1704–1714.
11. Mohan, M.; Gujar, G.T. Geographical variation in larval susceptibility of the diamondback moth, Plutella xylostella (Lepidoptera: Plutellidae) to Bacillus thuringiensis spore-crystal mixtures and purified crystal proteins and associated resistance development in India. *Bull. Entomol. Res.* **2002**, *92*, 489. [CrossRef]
12. Mugisha-Kamatenesi, M.; Deng, A.L.; Ogendo, J.O.; Omolo, E.O.; Mihale, M.J.; Otim, M. Indigenous knowledge of field insect pests and their management around Lake Victoria basin in Uganda. *Afr. J. Environ. Sci. Technol.* **2008**, *2*, 342–348.
13. Mihale, M.J.; Deng, A.L.; Selemani, H.O.; Kamatenesi, M.M.; Kidukuli, A.W.; Ogendo, J.O. Use of indigenous knowledge in the management of field and storage pests around Lake Victoria basin in Tanzania. *Afr. J. Environ. Sci. Technol.* **2009**, *3*, 251–259.
14. Isman, M.B. Plant essential oils for pest and disease management. *Crop. Prot.* **2000**, *19*, 603–608. [CrossRef]
15. Belmain, S.R.; Haggar, J.; Holt, J.; Stevenson, P.C. *Managing Legume Pests in Sub-Saharan Africa: Challenges and Prospects for Improving Food Security and Nutrition through Agro-Ecological Intensification*; Natural Resources Institute: London, UK, 2013; pp. 1–34.
16. Tropical, C.; van Schoonhoven, A. *Standard System for the Evaluation of Bean Germplasm*; CIAT: Culoz, France, 1987; p. 54.

17. Muzemu, S.; Mvumi, B.M.; Nyirenda, S.P.M.; Sileshi, G.W.; Sola, P.; Chikukura, L. *Pesticidal Effects of Indigenous Plants Extracts against Rape Aphids and Tomato Red Spider Mites*; Midlands State University: Gwaru, Zimbabwe, 2011; pp. 169–171.
18. Ahmad, T.; Fauzy, Z.M.; Yoshia; Utami, T.; Arbianti, R.; Hermansyah, H. *Production of Bio-Insecticide from Extracted Carica Papaya Using NADES Solvent with Ultrasound-Assisted Extraction (UAE)*; EDP Sciences: Les Ulis, France, 2018; Volume 67, p. 03007.
19. Zobayer, N.; Hasan, R. Effects of manually processed Bio-pesticides on crop production and pest managements in okra (Abelmoschus Esculentus (L.) Moench). *J. Nat. Sci. Res.* **2013**, *3*, 112–118.
20. Dunkel, F.V.; Jaronski, S.T.; Sedlak, C.W.; Meiler, S.U.; Veo, K.D. Effects of Steam-Distilled Shoot Extract ofTagetes minuta L. (Asterales: Asteraceae) and Entomopathogenic Fungi on Larval Tetanops myopaeformis. *Environ. Èntomol.* **2010**, *39*, 979–988. [CrossRef] [PubMed]
21. de Bon, H.; Huat, J.; Parrot, L.; Sinzogan, A.A.C.; Martin, T.; Malézieux, E.; Vayssières, J.-F. Pesticide risks from fruit and vegetable pest management by small farmers in sub-Saharan Africa. A review. *Agron. Sustain. Dev.* **2014**, *34*, 723–736. [CrossRef]
22. Martin, T.; Ochou, G.O.; Hala-N'Klo, F.; Vassal, J.; Vaissayre, M. Pyrethroid resistance in the cotton bollworm, Helicoverpa armigera (Hübner), in West Africa. *Pest Manag. Sci.* **2000**, *56*, 549–554. [CrossRef]
23. Baryakabonaa, S.; Mwine, J. Evaluation of the Efficacy of Crude Extracts of Tick Berry Lantana camara and Mexican Marigold Tagetes manuta Against Cabbage Aphids Brevicoryne brassicae. *Am. Sci. Res. J. Eng. Tehnol. Sci.* **2017**, *33*, 168–169.
24. Tomar, S.P.S. Impact of weather parameters on aphid population in cotton. *Ind. J. Agric. Res.* **2010**, *44*, 125–130.
25. Ngowi, A.; Mbise, T.; Ijani, A.; London, L.; Ajayi, O.C. Smallholder vegetable farmers in Northern Tanzania: Pesticides use practices, perceptions, cost and health effects. *Crop. Prot.* **2007**, *26*, 1617–1624. [CrossRef]
26. Panhwar, S.B. Farmers adoption of plant materials for insects' control. *Int. Serv. Natl. Agric. Res.* **2002**, *4*, 61–68.
27. Pedigo, L.P.; Rice, M.E. *Entomology and Pest Management*; Waveland Press: Long Grove, IL, USA, 2014; p. 287.
28. Mandal, E.; Amin, M.R.; Rahman, H.; Akanda, A. Infestation level and population dynamics of aphid on mustard. *Bangladesh J. Agric. Res.* **2018**, *43*, 611–618. [CrossRef]
29. Waceke, J.W. Plant parasitic nematodes associated with cabbages in Kenya. *Afr. Crop Sci. J.* **2007**, *8*, 1071–1074.
30. Heng-Moss, T.M.; Ni, X.; Macedo, T.; Markwell, J.P.; Baxendale, F.P.; Quisenberry, S.S.; Tolmay, V. Comparison of chlorophyll and carotenoid concentrations among Russian wheat aphid (Homoptera: Aphididae)-infested wheat isolines. *J. Econ. Èntomol.* **2003**, *96*, 475–481. [CrossRef] [PubMed]

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.