sustainability

MDPI

Article

Insecticidal Activity of Selected Plant-Derived Essential Oils against Papaya Mealybug (*Paracoccus marginatus*)

Regina W. Mwanauta [1,2,*], Pavithravani B. Venkataramana [1] and Patrick A. Ndakidemi [1]

[1] School of Life Sciences and Bioengineering (LiSBE), Nelson Mandela African Institution of Science and Technology, Arusha P.O. Box 447, Tanzania; pavithravani.venkataramana@nm-aist.ac.tz (P.B.V.); patrick.ndakidemi@nm-aist.ac.tz (P.A.N.)
[2] Tanzania Plant Health and Pesticides Authority (TPHPA), Arusha P.O. Box 3024, Tanzania
* Correspondence: mwanautar@nm-aist.ac.tz or regina.mwanauta@tphpa.go.tz

Abstract: The current study aims to assess the effectiveness of three essential oils derived from neem, citrus, and garlic against papaya mealybug. Papaya seedlings were transplanted in the field in a completely randomized block design with eight treatments with four replications. The treatments included neem, citrus, and garlic oils in combination with isopropyl alcohol or paraffin oil as an adjuvant. Results from this study showed that neem oil at 1.5% + 0.2% isopropyl alcohol was effective against papaya mealybug by 93.0% equivalent to the positive control (imidacloprid) (99.4%), followed by citrus oil at 1.5% + isopropyl alcohol (76.3%) and citrus oil at 1.5% + paraffin oil (68.8%), compared with the untreated 0.01%. Similarly, application of the plant-derived essential oils and adjuvants resulted in positive effects on plant parameters (plant height, number of leaves, flower buds, number of fruits, and fruit weight) and, hence, increased papaya yield from an average of 38 to 90 fruits/plant at first harvest. The finding from this study provides an understanding of papaya farmers towards the use of natural plant products, particularly plant-derived essential oils, and their benefits, which may encourage farmers to increase papaya production and minimize the usage of synthetic pesticides to avoid pest resistance.

Keywords: azadirachtin; *Paracoccus marginatus*; biopesticide; adjuvants; insecticides

check for updates

Citation: Mwanauta, R.W.; Venkataramana, P.B.; Ndakidemi, P.A. Insecticidal Activity of Selected Plant-Derived Essential Oils against Papaya Mealybug (*Paracoccus marginatus*). *Sustainability* **2023**, *15*, 16501. https://doi.org/10.3390/su152316501

Academic Editors: Marko Vinceković, James W. Muthomi, Alex M. Fulano and Nancy Karimi Njeru

Received: 16 July 2023
Revised: 1 November 2023
Accepted: 13 November 2023
Published: 2 December 2023

1. Introduction

Papaya (*Carica papaya*) is a perennial plant belonging to the family Caricaceae with a wide range of beneficial nutritive values [1]. The papaya plant originates from Costa Rica and the south of Mexico [2]. The plant is commonly grown in most sub-Saharan countries and all over the world. Papaya cultivation in Tanzania is normally performed in lower- and mid-altitudinal zones with temperatures ranging from 20 °C to 32 °C and a mean annual rainfall of between 1000–2000 mm and in soil with a pH value between 6–7 [3,4]. The leading papaya-producing regions in Tanzania are Pwani, Dodoma, Tanga, Katavi, Morogoro, and Zanzibar, totaling 8244 tons of production [5].

Papaya is an important fruit containing a wide variety of antioxidant nutrients (e.g., vitamins A, B, and C, minerals such as potassium for blood electrolyte balance, and magnesium for strong bones). The fruit is normally consumed raw or processed into juice or jams [6–8]. Nutritionally, it contains an enzyme called papain used to reduce constipation and tenderize meat. It is also used in cosmetic products such as soaps and body oils [9]. Papaya is one of the richest fruits in carotenoids [10]. Biochemically, the papaya plant produces numerous secondary plant metabolites with significant therapeutic and manufacturing applications [11].

Despite its significance, papaya production has decreased due to challenges caused by abiotic and biotic stresses, including stress induced by climate change variability, decreases in area under production, decreases in soil fertility, unreliable markets, and diseases such as ringspot virus, anthracnose, and powdery mildew [12,13]. In addition, insect pests such as papaya mealybug, leaf hoppers, white flies, aphids, and mites are challenging for papaya production [14]. The most damaging insect is the papaya mealybug, which has been ranked as a major constraint in papaya production worldwide, causing 75 to 100% yield loss when left uncontrolled [15].

Papaya mealybug (*Paracoccus marginatus* Williams and Granara de Willink) is an invasive pest from Mexico and Central America [16]. It was distributed to Asian and African countries including Tanzania through agricultural trade, leading to a serious agricultural cost. In 2010, Ghana was the first African country to report the presence of papaya mealybug followed by other tropical countries of the world [1,17–19]. The insect can be dispersed by wind and black ants within and between plant species [20]. It has become a serious pest, attacking several crops, triggering substantial fruit loss, and depressing the horticultural production sector [21].

In Tanzania, a huge invasion of papaya mealybug was observed in coastal regions of the country, including Dar es Salaam, Pwani, Tanga, and Zanzibar [21]. Recently, the pest has been detected in other regions such as Morogoro, Katavi, and Dodoma. Papaya mealybug starts to attack crops at a vegetative stage. The pest expels honeydew, which attracts ants and black mold and deters photosynthesis and gaseous exchange of plants [22–24]. Papaya mealybug feeds on the plant sap from the tender leaves of plants and fruits using its stylets [25]. Affected plants become yellowish and stunted [26].

Currently, farmers are using synthetic pesticides such as Chlorpyrifos 50EC and Imidacloprid 200SL against papaya mealybug [27]. However, synthetic pesticides are ineffective against the wax coating of papaya mealybug. The wax coating of papaya mealybug is waterproof against chemical pesticides, preventing them from penetrating the insect body [28,29]. Considering the biosecurity of ecosystems, the usage of chemical pesticides by most smallholder farmers has been recognized to have harmful effects on biodiversity and humans [30,31]. Synthetic pesticides have been documented to cause insect resistance due to intensive and frequent application [31,32]. Studies have demonstrated the use of essential oils derived from citrus peel, garlic bulb, and castor seeds with great success in controlling insect pests such as aphids and caterpillars [33]. The chemical compounds of plant-derived essential oils in the form of azadirachtin, limonene, and cycloalliin from neem, citrus, and garlic and their lipophilic nature have proven to be significant in controlling most scale insects by dissolving the wax layer [34–36]. However, papaya production has gained popularity and consumption demand in major cities of East Africa and Tanzania. This has led to increased commercial papaya farming; hence, it is important to set in place all needed measures to ensure higher production through effective pest management. The use of synthetic chemicals, plant-based products, and biological programs against scale insects including papaya mealybug has been conducted previously but less consideration has been given to plant-derived essential oils [37].

Using plant essential oils against papaya mealybug is promising in sustainable pest management due to the presence of more than one bioactive compound hindering the development of pest resistance. Thus, the current work aims to assess three essential oils derived from neem, citrus, and garlic and their insecticidal activity against papaya mealybug in Tanzania.

2. Materials and Methods

2.1. Study Site

A field trial was conducted at the Nelson Mandela African Institution of Science and Technology (NM-AIST), Arusha, Tanzania for a period of 12 months from October 2020 to September 2021. A trial was set in a randomized completely block design (RCBD) in four replications per treatment.

2.2. Materials

2.2.1. Preparation of Plant Essential Oils

The plant materials were collected from different sites within Arusha city. The citrus fruit was bought from the market; its exocarp was peeled and sliced into smaller pieces. The sliced pieces were shade-dried for seven days and were ground to a fine powder. Likewise, the garlic bulbs were bought from the market peeled, sliced into small pieces, shade-dried for 10 days, and ground into fine powder. The neem oil was purchased from the shop.

2.2.2. Extraction of Plant Essential Oils

The essential oils were extracted using a Soxhlet apparatus (Shiva Scientific Glass Pvt. Ltd., New Delhi, India). The extraction was performed using protocol by [38] with some modifications. Around 5 kg of powdered sample from each plant sample was draped in a thimble filter and placed in the Soxhlet apparatus. n-hexane (VWR-Chemical, Paris, France) with 97% purity was used as a solvent during the extraction. For six hours, the n-hexane and sample were left to boil (55 °C to 60 °C). After 6 h, to remove the n-hexane, the oil was reflexed at 70 °C. The obtained essential oils were kept in a fridge at 2 °C for further use.

2.2.3. Papaya Seeds

Papaya seeds of the carina variety (hybrid) were purchased from the market and raised for one month in a nursery.

2.2.4. Rearing of Papaya Mealybug

Papaya mealybugs were collected from an infested papaya field located in the Meru district (latitude = 3°17′32.33″ S and longitude = 36°49′30.1″ E). Rearing was conducted in the screenhouse at Tanzania Plant Health and Pesticides Authority (TPHPA) in the Department of Entomology. One-month-old papaya seedlings were placed in pots 14 cm wide and 15 cm high. The 2nd and 3rd mealybug instars were released on the papaya plant. The rearing temperature and relative humidity were 26–28 °C and 57–66%, respectively.

2.2.5. Dilutions of Plant Essential Oils

A total of eight treatments were evaluated under field conditions as seen in Table 1. Three essential oils from citrus, garlic, and neem were diluted and used at 1.5% (v/v) + isopropyl alcohol and paraffin oil at 0.2%. Imidacloprid (0.2%) was used as the standard and untreated as a negative control.

Table 1. Treatments used in the field experiment.

No	Treatment	Concentration (%)	Adjuvants	Concentration (%)
1	Citrus	1.5	Isopropyl alcohol	0.2
2	Citrus		Paraffin oil	
3	Garlic		Paraffin oil	
4	Neem		Isopropyl alcohol	
5	Neem		Paraffin	
6	Neem			
7	Imidacloprid	0.2		
8	Untreated			

The 1.5% v/v plant essential oils were diluted in 98.5 mL of normal water with 0.2% v/v of adjuvants. Likewise, Confidor 200SC (imidacloprid 200 g/L) at 0.2% as a standard was diluted in 99.8 mL of normal water [37].

2.3. Methodology

2.3.1. Papaya Transplantation

One-month-old seedlings (40) were transplanted to the field with a spacing of 1.5 m within rows and 2 m between rows, in an area of 25 m to 30 m. One seedling was planted per hill to avoid insecticidal drift to other leaves while spraying.

2.3.2. Papaya Mealybug Inoculation

Two months after the seedling transplantation, papaya plants were infested with (2nd and 3rd instar) papaya mealybugs from the cultured populations using a fine camelhair brush with special care during transferal to avoid injury. The inoculation was performed by placing the papaya mealybugs on the inferior leaves and the plant apex. The plants were maintained for four months until the papaya plants reached the vegetative stage with a sufficient mealybug population. Normal agronomical practices were maintained the same in each block.

2.3.3. Treatments Spraying

Treatments were applied together with positive and negative controls, where 250 mL, 300 mL, and 350 mL of each treatment formulation were sprayed during vegetative, flowering, and fruiting stages. A total of six (6) sprays per treatment were performed (Table 2).

Table 2. Treatments spraying.

No	Plant Stage	Days after Papaya Mealybug Inoculation	Quantity Applied	Number of Plants Applied
1	Vegetative	2 months	250 mL	4
2	Vegetative	3 months	250 mL	4
3	Flowering	4 months	300 mL	4
4	Flowering	4 and 1/2 months	300 mL	4
5	Fruiting	5 and 1/2 months	350 mL	4
6	Fruiting	6 and 1/2 months	350 mL	4

The spraying was performed twice in each plant growth stage using a one-liter hand sprayer in the evening to escape the heat in the daytime.

2.4. Data Collection

2.4.1. Assessment of Papaya Mealybug Mortality

A magnifying hand lens was used to count the live and dead papaya mealybugs at 10 cm apical shoots at 24 h, 48 h, and 72 h intervals after treatment application of each plant development stage (vegetative, flowering, and fruiting stages) [39].

The collected data were transformed into % using the below formula:

$$\%\ Mortality = \frac{Number\ of\ dead\ mealybugs}{Total\ number\ of\ mealybugs} \times 100$$

2.4.2. Assessment of Treatments on Papaya Yield

The papaya growth and yield parameters were assessed in all plant stages using different measurement techniques as indicated in Table 3.

Table 3. Assessment of treatments on papaya growth and yield parameters during the first harvest.

No	Yield Parameters	Assessment
1	Number of leaves	Determined by counting the number of leaves of papaya in each treatment
2	Plant height (cm)	Calculated by measuring the plant height from the soil base to the plant apex using a measuring tape in each treatment
3	The number of flower buds and fruits	Determined by counting the number of flower buds per plant in each treatment
4	Number of fruits	Determined by counting the number of fruits per plant in each treatment
5	Fruit length (cm)	Calculated by measuring five random selected fruits from each treatment using a ruler
6	Stem girth (mm)	Calculated by measuring five selected papaya plants in each treatment
7	Fruit weight (kg)	Calculated by weighing five random selected fruits in each treatment

2.5. Data Analysis

The collected data were analyzed using STATISTICA version 10 software [40]. The yield parameters and differences among treatments in insect mortality were assessed by analysis of variance (ANOVA). The mean separation test was performed using Tukey's post hoc test at a 95% confidence interval.

3. Results

3.1. Effect of the Treatments on Papaya Mealybug Mortality

The mortality of papaya mealybug differed significantly ($p = 0.001$) in treated plants as compared with untreated plants (Table 4). Irrespective of plant stage, the mortality increased significantly ($p = 0.001$) by 73.3% for plant essential oils and92.6% for synthetic pesticides (imidacloprid) compared with untreated plants (0.01%). Among the treatments, imidacloprid (chemical pesticide) had higher papaya mealybug mortality (99.4%) followed by neem oil (93.3%). However, very low mortality of papaya mealybug (0.01%) was observed in untreated plants (Table 4).

Papaya mealybug mortality increased with time from 24 h to 72 h when the plant was treated with plant essential oils and imidacloprid compared with the untreated plants. A high mortality rate was observed for imidacloprid: 99.4% at 72 h, 94% at 48 h, and 85% at 24 h; 99.3% at 72 h, 94% at 48 h, and 86% at 24 h; and 99.0% at 72 h, 92.7% at 48, and 84% at 24 h during fruiting, flowering and vegetative stages, respectively. For plant essential oils, the high mortality was observed to be 80.2% at 72 h, 74.4% at 48 h, and 68% at 24; 79.8% at 72 h, 74.7% at 48 h, and 62% at 24 h; and 79.3% at 72 h, 73.7% at 48 h, and 67.2% at 24 h during fruiting, flowering and vegetative stages, respectively.

A nonsignificant difference in papaya mealybug mortality was observed with plant stage for papaya plants treated with plant essential oils and synthetic pesticides. However, during the fruiting stage, a high mortality rate (93.3%) was observed in plant essential oils and in imidacloprid (99.4%) (Table 4).

The mortality rate increased from 84% to 99.0% (imidacloprid) during the vegetative stage, from 86.0% to 99.3% during the flowering stage, and from 85.2% to 99.4% during the fruiting stage from 24 h to 72 h after spraying. Likewise, for plant essential oils, the mortality rate increased from 67.2% to 79.3% at the vegetative stage, from 62.0% to 79.8% at the flowering stage, and from 68.3% to 80.2% at the fruiting stage from 24 h to 72 h after spraying (Table 4).

Moreover, among these treatments, the best treatment was imidacloprid (99.4%), followed by neem essential oil at 1.5% + 0.2% isopropyl alcohol (93.3%), citrus oil at 1.5% + isopropyl alcohol 76.3.7%, and citrus oil at 1.5% + paraffin oil 68.8%.

Table 4. Effects of treatments of papaya mealybug mortality on time intervals and papaya growing stages (values are means ± SE).

Treatments	Vegetative Stage				Flowering Stage				Fruiting Stage				Overall Mean
	24 h	48 h	72 h	Overall Mean	24 h	48 h	72 h	Overall Mean	24 h	48 h	72 h	Overall Mean	
Citrus oil 1.5% + P	64.6 ± 2.4 bc	67.3 ± 1.7 bc	72.7 ± 0.7 c	64.2	64 ± 3.0 bcd	68.3 ± 1.8 bcd	73.4 ± 0.7 cd	68.5	65 ± 3.05 bc	68.6 ± 1.7 bc	74 ± 0.00 d	68.8	67.1
Citrus oil 1.5% + I	65.3 ± 8.1 bc	78 ± 3.1 de	84 ± 2.3 e	68.8	64.4 ± 8.6 cd	79.7 ± 2.9 de	83.3 ± 3.5 de	75.8	66.6 ± 8.8 bcd	79.3 ± 2.9 d	83.1 ± 3.5 ef	76.3	75.9
Garlic oil 1.5% + P	56.6 ± 1.7 b	64 ± 1.2 b	73.3 ± 2.4 bc	64.6	56.8 ± 2.4 bc	64 ± 1.2 b	73.46 ± 2.4 bcd	64.6	60 ± 4.61 bc	65 ± 0.58 b	73.0 ± 2.4 bc	66	65.0
Neem oil 1.5% + I	86.6 ± 3.1 d	92.7 ± 1.8 f	91 ± 1.2 f	91.4	86.5 ± 3.7 e	92.6 ± 1.8 f	90.2 ± 1.2 f	90.4	89 ± 2.64 e	92.1 ± 0.3 e	93. ± 0.6 gh	93.3	91.7
Neem oil 1.5% + P	66.6 ± 13.3 c	83.3 ± 0.7 e	89.3 ± 0.6 ef	82.7	82.4 ± 3.2 e	88.2 ± 2.7 ef	93 ± 1.7 f	87.8	76.0 ± 3.3 cde	82.1 ± 1.8 d	89.3 ± 0.6 fg	82.4	83.3
Neem oil 1.5%	79.3 ± 0.6 bc	80 ± 3.5 de	84.6 ± 2.9 de	81.3	79.2 ± 0.7 de	78 ± 2.0 d	84 ± 3.1 e	80.4	76.1 ± 3.3 cde	78 ± 2.0d	84 ± 3.1g	79.3	80.3
Overall mean	67.2	73.7	79.3	73.02	62.02	74.7	79.8	74.2	68.3	74.4	80.2	75.0	73.3
Imidacloprid 0.2%	84 ± 3.0 d	92.7 ± 1.3 f	99.0 ± 0.6 f	92.1	86 ± 2.3 e	94 ± 2.0 f	99.3 ± 0.7 f	93	85.2 ± 2.9 de	94 ± 2.00 e	99.4 ± 0.7 h	92.8	92.6
Untreated	0.01 ± 0.01 a	0.00 ± 0.01 a	0.02 ± 0.01 a	0.01	0.01 ± 0.01 a	0.01 ± 0.0 a	0.02 ± 0.0 a	0.01	0.01 ± 0.00 a	0.03 ± 0.03 a	0.02 ± 0.01 a	0.02	0.01
One-Way ANOVA (F-Statistics)	32.3 ***	27.0 ***	32.8 ***		31.9 ***	20.4 ***	27.3 ***		47.9 ***	37.5 ***	28.2 ***		

Each value is a mean ± standard error of four replicates; *** indicate significance at $p \leq 0.001$. Means within the same column followed by the same letter(s) are not significantly different (at $p = 0.05$) from each other using Tukey's test. I = isopropyl alcohol, P = paraffin oil, SE = standard error.

3.2. Assessment of Treatments on the Papaya Growth Parameters and Yield at First Harvest

3.2.1. Effects of Treatments on the Number of Leaves of Papaya Plants

The number of leaves on the papaya plants was significantly different between treatments (p = 0.001). The highest number of leaves was observed on papaya plants treated with neem oil (46.3) at 1% followed by neem oil (46.0) at 1.5% and imidacloprid (44.4). The lowest number of leaves was observed in untreated plants (21.3) (Table 5).

Table 5. Effects of treatments with and without adjuvants on growth parameters and papaya yield during first harvest (values are means ± SE).

Treatments	No. of Leaves	Plant Height	Average Stem Girth (cm)	No. of Flower Bud/Plant	No. of Fruits/Plant	Fruit Length (cm)	Average Fruit Weight (kg)/Plant
Citrus oil 1.5% + P	42.08 ± 4.91 bc	164 ± 13.11 c	28.73 ± 1.19 c	175 ± 0.58 bc	60.07 ± 6.84 c	22.07 ± 2.07 b	1.50 ± 0.20 bc
Citrus oil 1.5% + I	44.30 ± 7.54 bc	156 ± 4.58 bc	30.53 ± 1.13 c	159. ±2.33 c	58.61 ± 9.28 bcb	23.83 ± 1.87 bc	1.45 ± 0.13 b
Garlic oil 1.5% + P	36.03 ± 3.2 bc	167.3 ± 3.00 c	30.46.5 ± 4.41 bc	172 ± 1.45 bc	55.10 ± 12.84 b	21.26 ± 1.16 b	1.80 ± 0.14 bc
Neem oil 1.5% + I	46.00 ± 1.6 c	167.04 ± 12.45 c	28.4.46 ± 0.69 c	180 ± 0.88 c	92.90 ± 6.39 c	29.86 ± 1.22 bc	2.11 ± 0.36 cd
Neem oil 1.5% + P	44.32 ± 3.8 bc	162.15 ± 9.96 bc	26.45 ± 3.82 c	165. ±1.20 bc	72 ± 7.57 bc	28.60 ± 1.64 bcbc	1.57 ± 0.13 bc
Neem oil 1.5%	46 ± 0.0 bc	134 ± 14.53 ab	30.08 ± 1.43 c	150 ± 2.52 c	82.50 ± 35.43 c	29.05 ± 0.12 bc	1.90 ± 0.47 cd
Imidacloprid 0.2%	44 ± 4.6 bc	162 ± 7.57 bc	28.27 ± 0.91 c	160 ± 2.52 c	74 ± 3.61 babc	27.42 ± 2.14 bc	2.05 ± 0.30 cd
Untreated	21.32 ± 1.4 a	68.0 ± 6.6 a	10.56 ± 1.19 a	70 ± 1.53 a	28 ± 4.73 a	9.76 ± 0.96 a	0.3 ± 0.01 a
One-Way ANOVA (F-Statistics)	38.2 ***	1.7 ***	4.8 ***	5.6 **	2.4 **	7.8 ***	29 ***

I = isopropyl alcohol, P = paraffin oil, SE = standard error. Each value is a mean ± standard error of four replicates; ** and *** indicate significance at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$. Means within the same column followed by the same letter(s) are not significantly different at (p = 0.05) from each other using the Tukey's test.

3.2.2. Effects of Treatments on the Height of Papaya Plants

The results showed a significant difference ($p \leq 0.001$) between treatments regarding the height of the papaya plants measured during the first harvest. The highest (167.3 cm) plant height was observed in garlic at 1.5% in combination with paraffin oil, followed by neem oil (167.0 cm) at 1.5% in combination with isopropyl alcohol, and citrus oil (164 cm) at 1.5% in combination with paraffin oil. All tested PEO influenced the height of papaya plants in the field. The lowest height was found in the untreated plants (68 cm) (Table 5)

3.2.3. Effects of Treatments on Stem Girth of Papaya Plants

There was a significant difference ($p \leq 0.001$) between treatments for stem girth. The largest stem girth of 30.5 cm was observed when sprayed with citrus oil at 1.5% + isopropyl alcohol followed by garlic oil (30.4 cm) at 1.5% + isopropyl alcohol compared with untreated plants (10.5 cm) (Table 5)

3.2.4. Effects of Treatments on Flower Bud of Papaya Plants

There was a significant difference ($p \leq 0.001$) among treatments in flower buds of papaya plants. The highest number of flower buds on the papaya plants was observed for treatment using neem oil (180) at 1% in combination with isopropyl alcohol followed by citrus oil (175) at 1.5% in combination with paraffin oil and garlic oil (172) at 1.5% in combination with paraffin oil. The lowest number of flower buds was recorded in the untreated control (9.0) (Table 5).

3.2.5. Effects of Treatments on the Number of Fruits of Papaya Plants

Table 5 shows the effect of the treatments on the number of fruits per papaya plant. The number of fruits per plant was significantly different ($p \leq 0.01$) between the treatments. More fruits per plant were obtained using a treatment of neem oil (92.9) at 1.5% + isopropyl alcohol followed by neem oil alone (82.5) and 1.5% imidacloprid (74.0), and the lowest number of fruits was recorded for the untreated control (15.0) (Table 5).

3.2.6. Effects of Treatments on Papaya Fruit Length

The treatments sprayed showed a significant difference ($p \leq 0.001$) in the fruit length between treatments. Among treatments, neem oil at 1.5% in combination with isopropyl alcohol recorded the highest fruit length (29.8 cm) followed by neem oil alone (29.0 cm at 1.5%), neem oil (28.6 cm) at 1.5% in combination with paraffin oil and imidacloprid (27.4 cm) compared with untreated plants (9.7 cm) (Table 5).

3.2.7. Effects of Treatments on Fruit Weight of Papaya in the Field

The results indicated in Table 5 indicate a significant difference ($p \leq 0.001$) between treatments. Neem oil alone at 1% concentration produced the highest fruit weight (2.1 kg/fruit) followed by neem oil (2.0 kg/fruit) at 1.5% in combination with isopropyl alcohol and imidacloprid (2.0 kg/fruit). The untreated plants produced the lowest papaya fruit weight of 0.3 kg/fruit.

4. Discussion

In the current study, it was observed that among the three tested plant materials from citrus, garlic, and neem + adjuvants (isopropyl alcohol and paraffin oils) against papaya mealybug, neem essential oil + isopropyl alcohol was identified to be superior to the rest. Neem essential oils in combination with an adjuvant highly reduced the papaya mealybug population as indicated in the results section. In line with this study, [41–46] described the success of plant essential oils from neem, citrus, and garlic containing the compounds azadirachtin, limonene, and cycloalliin against different mealybug species.

Results from the current study revealed that neem oil outshined other plant essential oils such as those from citrus and garlic that were formerly described to have pesticidal properties against papaya mealybug. The effectiveness of these plant essential oils in this study might be due to their neurotoxic effect and capability to degrade the papaya mealybug's wax coating, causing mealybug immobility and death as reported by [41,45,47–52]. The present study observed a decrease in the papaya mealybug population for the evaluated plant essential oils irrespective of concentration. The phenolic compounds found in neem oil and not in citrus and garlic were the reason for neem oil being superior against papaya mealybug. The phenolic compounds found in neem oil act by interfering with insect feeding and possess repellent properties. Neem oil is also reported to interfere with insect hormone systems, making it harder for insects to grow and lay eggs [52–54].

The efficacy of plant essential oils significantly increased from 24 to 72 h after treatment exposure. However, at 48 and 72 h, there was no significant difference between plant essential oils mixed with the adjuvants. This could be due to the volatile nature of the isopropyl alcohol and paraffin oil; thus, they could not last for more than 24 h after spraying. In line with this study, [55] explained the volatile nature of organic solvents as one of the advantages when used in pest control. The studied adjuvants (isopropyl alcohol and paraffin oil) have been used widely in dissolving non-polar compounds and evaporate rapidly, exiting nontoxic residues [56–61].

The present study observed an increase in papaya mealybug mortality which could be due to the synergic interaction that occurred upon mixing the plant essential oils and adjuvants. The evaluated mixtures can help combat pests' resistance but we recommend further studies to evaluate the effects of these combinations on natural enemies.

The experiment showed a progressive decrease in insect infestation from the vegetative stage to the fruiting stage due to the antifeedant, growth regulators, and repellent properties found in the tested plant essential oils, similar to what was reported by [46,62].

Synthetic pesticides are widely used by farmers against papaya mealybug with low success. However, most farmers use contact pesticides which are ineffective due to papaya mealybug's wax coating. This study used systemic chemical insecticide (imidacloprid in 0.2%) as a standard pesticide which was 99.4% effective. The applied synthetic pesticide (imidacloprid) has a systemic mode of action causing the blocking of nicotinic acetylcholine receptors [63]. Thus, this could be the reason why it performed better against papaya mealybug as it was reported by [64]. The systemic nature of imidacloprid is more stable in the field environment than the plant essential oils studied [65,66]. However, the papaya mealybug has started to develop resistance to imidacloprid in some areas due to intensive and frequent application.

This study has shown the significance of using natural products, particularly plant essential oils, because they are less harmful to the humans and ecosystem and demonstrate promising pest management potentials. This significance has been reported in different works in the literature [67–69]. An additional advantage of using plant essential oils against papaya mealybug was observed in improving the growth of papaya plants, as compared with untreated plants. The reduction in papaya mealybug infestation alongside high papaya yield observed with neem oil and garlic oil treatments was also reported [70]. Neem and its parts have been demonstrated to contain nitrogen, potassium, phosphorus, calcium, manganese, and sulfur which have potential in the industrial processing of urea for soil fertility improvement and upholding soil nutrients [71].

Therefore, this study reveals the potential of plant essential oils from neem, citrus, and garlic + adjuvants (isopropyl alcohol and paraffin oil) against papaya mealybug. Since the tested neem and citrus oils in combination with the adjuvants (isopropyl alcohol and paraffin oil) have shown positive results under field conditions, commercialization should be pursued for farmers to access this product.

5. Conclusions

The findings from this study indicate the need for sustainable management of papaya mealybug which has been a drawback to papaya-growing farmers in Tanzania. The insect is fast spreading in the papaya-growing areas in Tanzania. The current control practices used by farmers are ineffective due to the wax coating of papaya mealybug. In addition, the papaya mealybug in most areas has started developing resistance to the chemical pesticides currently used by farmers. Thus, quick and sustainable intervention is required to rescue papaya production. Our results have demonstrated the effectiveness of neem, garlic, and citrus oils in combination with adjuvants against papaya mealybug under field conditions. Furthermore, the spraying of these plant essential oils caused equivalent mortality rates when compared to a synthetic insecticide (imidacloprid). Therefore, among the plant essential oils assessed, neem oil in combination with isopropyl alcohol is a good product for suppressing the papaya mealybug population and minimizing insect resistance.

Author Contributions: Concept, R.W.M., P.B.V. and P.A.N.; Methodology, R.W.M., P.B.V. and P.A.N.; Formal analysis, R.W.M. and P.B.V.; Original draft preparation, R.W.M.; Review and editing, P.A.N. and P.B.V. All co-authors contributed to finalizing the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: The present study was supported by the Germany Academic Exchange Service (DAAD), Germany, funding number (PF-91711367).

Data Availability Statement: The datasets used and analyzed during the current study are available from the corresponding author upon request.

Acknowledgments: The authors wish to thank all laboratory technicians and technical staff at Nelson Mandela African Institution of Science and Technology (NM-AIST), Arusha, Tanzania, for their technical and guidance support and the Germany Academic Exchange Service (DAAD), and Sokoine University of Agriculture under Agro-ecological hub Tanzania for partial funding support.

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

References

1. Carvalho, F.A.; Renner, S.S. The phylogeny of the Caricaceae. In *Genetics and Genomics of Papaya*; Springer: Berlin/Heidelberg, Germany, 2014; Volume 6, pp. 81–92.
2. Fuentes, G.; Santamaría, J.M. Papaya (*Carica papaya* L.): Origin, domestication, and production. In *Genetics and Genomics of Papaya*; Springer: Berlin/Heidelberg, Germany, 2013; pp. 3–15.
3. Roshan-Moniri, M.; Hsing, M.; Butler, M.S.; Cherkasov, A.; Rennie, P.S. Orphan nuclear receptors as drug targets for the treatment of prostate and breast cancers. *Cancer Treat. Rev.* **2014**, *40*, 1137–1152. [CrossRef] [PubMed]
4. Santana, A.P.; Mora-Vargas, J.A.; Guimaraes, T.G.; Amaral, C.D.; Oliveira, A.; Gonzalez, M.H. Sustainable synthesis of natural deep eutectic solvents (NADES) by different methods. *J. Mol. Liq.* **2019**, *293*, 111–452. [CrossRef]
5. Mwanauta, R.W.; Ndakidemi, P.A.; Venkataramana, P.B. Characterization of Farmer's knowledge and management practices of papaya mealybug *Paracoccus magnatus* (Hemiptera: Pseudococcidae) in Tanzania. *Saudi J. Biol. Sci.* **2022**, *29*, 3539–3545. [CrossRef] [PubMed]
6. Villegas, A.; Galindo, A.; Whitehead, P.J.; Mills, S.J.; Jackson, G.; Burgess, A.N. Statistical associating fluid theory for chain molecules with attractive potentials of variable range. *J. Chem. Phys.* **1997**, *106*, 4168–4186. [CrossRef]
7. Bitto, I.I.; Arubi, J.A.; Gumel, A.A. Reproductive tract morphometry and some haematological characteristics of female rabbits fed pawpaw peel meal based diets. *Afr. J. Biomed. Res.* **2006**, *9*, 199–204. [CrossRef]
8. Tulamandi, S.; Rangarajan, V.; Rizvi, S.S.; Singhal, R.S.; Chattopadhyay, S.K.; Saha, N.C. A biodegradable and edible packaging film based on papaya puree, gelatin, and defatted soy protein. *Food Packag. Shelf Life* **2016**, *10*, 60–71. [CrossRef]
9. Ramachandran, P.; Nagarajan, S. Quality characteristics, nutraceutical profile, and storage stability of aloe gel-papaya functional beverage blend. *Int. J. Food Sci. Technol.* **2014**, *8*, 1–7. [CrossRef]
10. Karunamoorthi, K. The counterfeit anti-malarial is a crime against humanity: A systematic review of the scientific evidence. *Malar. J.* **2014**, *13*, 1–13. [CrossRef]
11. Moussaoui, A.; Nijs, M.; Paul, C.; Wintjens, R.; Vincentelli, J.; Azarkan, M.; Looze, Y. Revisiting the enzymes stored in the laticifers of *Carica papaya* in the context of their possible participation in the plant defence mechanism. *Cell. Mol. Life Sci.* **2001**, *58*, 556–570. [CrossRef]
12. Franco, J.C.; Zada, A.; Mendel, Z. Novel approaches for the management of mealybug pests. In *Biorational Control of Arthropod Pests: Application and Resistance Managements*; Ishaaya, I., Horowitz, A.R., Eds.; Springer: Dordrecht, The Netherlands, 2009; Volume 11, pp. 233–278.
13. Tanwar, R.K.; Prakash, A.; Panda, S.K.; Swain, N.C.; Garg, D.K.; Singh, S.P.; Kumar, S.S.; Bambawale, O.M. Rice swarming caterpillar (*Spodoptera mauritia*) and its management strategies. In *Technical Bulletin 24*; NCIPM: New Delhi, India, 2010.
14. Constantinides, L.N.; McHugh, J.J., Jr. Pest Management Strategic Plan for Papaya Production in Hawaii. In *Workshop Summary*; University of Hawaii at Mānoa: Hilo, HI, USA, 2005.
15. Anang, B.T.; Zulkarnain, Z.A.; Yusif, S. Production constraints and measures to enhance the competitiveness of the tomato industry in Wenchi Municipal District of Ghana. *Am. J. Exp. Agric.* **2013**, *3*, 765–824. [CrossRef]
16. Miller, D.N.; Bryant, J.E.; Madsen, E.L.; Ghiorse, W. Evaluation and optimization of DNA extraction and purification procedures for soil and sediment samples. *Appl. Environ. Microbiol.* **1999**, *65*, 4715–4724. [CrossRef]
17. Daane, K.; Bentley, W.; Walton, V.; Malakar-Kuenen, R.; Millar, J.; Ingels, C.; Weber, E.A.; Gispert, C. New controls investigated for vine mealybug. *Calif. Agric.* **2002**, *60*, 31–38. [CrossRef]
18. Gullan, P.J.; Martin, J.H. Sternorrhyncha: (Jumping plant-lice, whiteflies, aphids, and scale insects). In *Encyclopedia of Insects*; Academic Press: Cambridge, MA, USA, 2009; Volume 4, pp. 957–967.
19. Al-Halal, H.; Kezouh, A.; Abenhaim, H.A. Incidence and obstetrical outcomes of cervical intraepithelial neoplasia and cervical cancer in pregnancy: A population-based study on 8.8 million births. *Arch. Gynecol. Obstet.* **2013**, *287*, 245–250. [CrossRef]
20. Mani, M.; Shivaraju, C. (Eds.) *Mealybugs and Their Management in Agricultural and Horticultural Crops*; Springer: Berlin/Heidelberg, Germany, 2016; Volume 9, pp. 600–655.
21. Macharia, I.; Kimani, E.; Koome, F.; Kosiom, T.; Heya, H.; Otipa, M.; Oronje, M. First report and distribution of the papaya mealybug, *Paracoccus marginatus*, in Kenya1. *J. Agric. Urban Entomol.* **2017**, *33*, 142–150. [CrossRef]
22. Mani, M.; Joshi, S.; Kalyanasundaram, M.; Shivaraju, C.; Krishnamoorthy, A.; Asokan, R.; Rebijith, K.B. A new invasive Jack Beardsley mealybug, Pseudococcus jackbeardsleyi (Hemiptera: Pseudococcidae) on papaya in India. *Fla. Entomol.* **2013**, *96*, 242–245. [CrossRef]
23. Huang, J.; Zhang, P.J.; Zhang, J.; Lu, Y.B.; Huang, F.; Li, M.J. Chlorophyll content and chlorophyll fluorescence in tomato leaves infested with an invasive mealybug, *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae). *Environ. Entomol.* **2013**, *42*, 973–979. [CrossRef] [PubMed]

24. Sartiami, D.; Watson, G.W.; Mohd Noor, M.R.; Hanifah, Y.M.; Abd Ghani, I. First record of cassava mealybug, *Phenacoccus manihoti* (Hemiptera: Pseudococcidae), in Malaysia. *Zootaxa* **2015**, *3957*, 235–238. [CrossRef] [PubMed]
25. Meyerdirk, D.E.; Kauffman, W.C. Status on the development of a biological control program for *Paracoccus marginatus* Williams, papaya mealybug, in the Caribbean. In *IV International Scientific Seminar of Plant Health*; Veradero, Cuba, 2001; Volume 23, pp. 10–15. Available online: https://scholar.google.com/scholar?hl=en&as_sdt=0%252C5&q=Status+on+the+development+of+a+biological+control+program+for+Paracoccus+marginatus+Williams%252C+papaya+mealybug%252C+in+the+Car-ibbean&btnG=#d=gs_cit&t=1701442405432&u=%252Fscholar%253Fq%253Dinfo%253AnZzND0bjhm4J%253Ascholar.google.com%252F%2526output%253Dcite%2526scirp%253D0%2526hl%253Den (accessed on 12 November 2023).
26. Mahfoudhi, N.; Digiaro, M.; Dhouibi, M.H. Transmission of grapevine leafroll viruses by *Planococcus ficus* (Hemiptera: Pseudococcidae) and Ceroplastes rusci (Hemiptera: Coccidae). *Plant Dis.* **2009**, *93*, 999–1002. [CrossRef] [PubMed]
27. Fatima, S.; Hussain, M.; Shafqat, S.; Faheem Malik, M.; Abbas, Z.; Noureen, N. Laboratory evaluation of different insecticides against hibiscus mealybug, *Maconellicoccus hirsutus* (Hemiptera: Pseudococcidae). *Scientifica* **2016**, *5*, 1–7. [CrossRef]
28. Shrewsbury, P.M.; Bejleri, K.; Lea-Cox, J.D. Integrating cultural management practices and biological control to suppress citrus mealybug. *Acta Hortic.* **2002**, *633*, 425–434. [CrossRef]
29. Laflin, H.M.; Parrella, M.P. Developmental biology of citrus mealybug under conditions typical of California rose production. *Ann. Entomol. Soc. Am.* **2004**, *97*, 982–988. [CrossRef]
30. Stuart, S. The University of Notre Dame. 2003. Available online: http://www.nd.edu/chem191/e2.html (accessed on 12 November 2023).
31. Wilson, L.J.; Whitehouse, M.E.; Herron, G.A. The management of insect pests in Australian cotton: An evolving story. *Annu. Rev. Entomol.* **2018**, *63*, 215–237. [CrossRef] [PubMed]
32. Kapeleka, J.A.; Sauli, E.; Sadik, O.; Ndakidemi, P.A. Biomonitoring of acetylcholinesterase (AChE) activity among smallholder horticultural farmers occupationally exposed to mixtures of pesticides in Tanzania. *J. Environ. Res. Public Health.* **2019**, *2019*, 3084501. [CrossRef] [PubMed]
33. Haghtalab, N.; Shayesteh, N.; Aramideh, S. Insecticidal efficacy of castor and hazelnut oils in stored cowpea against Callosobruchus macula-tus (F.) (Coleoptera: Bruchidae). *J. Biol. Sci.* **2009**, *9*, 175–179. [CrossRef]
34. Patil, S.V.; Salunke, B.K.; Patil, C.D.; Salunkhe, R.B.; Gavit, P.; Maheshwari, V.L. Potential of extracts of the tropical plant Balanites aegyptiaca (L) Del. (Balanitaceae) to control the mealybug, *Maconellicoccus hirsutus* (Homoptera: Pseudococcidae). *Crop Prot.* **2010**, *29*, 1293–1296. [CrossRef]
35. Ahmed, K.; Al-Helal, M.; Khanom, N.; Bulbul, S. Control strategie of papaya mealybug, *Paracoccus marginatus* Williams Willink infesting vegetable crops in Bangladesh. *Plant Prot. Sci.* **2011**, *3*, 44–47.
36. Gowtham, M.; Shanthi, M.; Kumar, S.V.; Premalatha, K. Insecticidal property of Citrus sinensis fruit waste against papaya mealybug *Paracoccus marginatus*. *Indian J. Entomol.* **2019**, *81*, 423–430. [CrossRef]
37. Galanihe, L.D.; Jayasundera, M.U.P.; Vithana, A.; Asselaarachchi, N.; Watson, G.W. Occurrence, distribution and control of papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae), an invasive alien pest in Sri Lanka. *Trop. Agric. Res. Ext.* **2010**, *13*, 2010. [CrossRef]
38. Wara, A.K.; Foo, S.; Croce, K.; Sun, X.; Icli, B.; Tesmenitsky, Y.; Feinberg, M.W. TGF-β1 signaling and Krüppel-like factor 10 regulate bone marrow–derived proangiogenic cell differentiation, function, and neovascularization. *Blood. Am. J. Hematol.* **2011**, *118*, 6450–6460. [CrossRef]
39. Tembo, Y.; Mkindi, A.G.; Mkenda, P.A.; Mpumi, N.; Mwanauta, R.; Stevenson, P.C.; Ndakidemi, P.A.; Belmain, S.R. Pesticidal plant extracts improve yield and reduce insect pests on legume crops without harming beneficial arthropods. *Front. Plant Sci.* **2018**, *9*, 1425. [CrossRef]
40. Mwanauta, R.W.; Ndakidemi, P.A.; Venkataramana, P. Biopesticide efficacy of four plant essential oils against papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae). *Heliyon* **2023**, *9*, e14162. [CrossRef]
41. Hollingsworth, R.G. Limonene, a citrus extract, for control of mealybugs and scale insects. *J. Econ. Entomol.* **2005**, *98*, 772–779. [CrossRef] [PubMed]
42. Lanzotti, V.; Bonanomi, G.; Scala, F. What makes Allium species effective against pathogenic microbes? *Phytochem. Rev.* **2013**, *12*, 751–772. [CrossRef]
43. Roonjho, A.R.; Gillani, W.A.; Rasool, A.; Akhtar, N.; Mahmood, T.; Arsalan, A.; Afzal, M.; Khan, I.; Ranjha, M.A.; Irfan, M.; et al. Repellency effects of different plant extracts to cotton mealy bug, Tinsley (Hemiptera: Pseudococcidae). *Pak. J. Agric. Sci.* **2013**, *26*, 213–219.
44. Lanzotti, V.; Scala, F.; Bonanomi, G. Compounds from Allium species with cytotoxic and antimicrobial activity. *Phytochem. Rev.* **2014**, *13*, 769–791. [CrossRef]
45. Piragalathan, A.; Pakeerathan, K.; Thirukkumaran, G.; Mikunthan, G. Efficacy of different insecticides and bio-rationals against papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococidae) infestation in home gardens. *Middle East J. Sci. Res.* **2014**, *21*, 1689–1693.
46. Peschiutta, M.L.; Achimón, F.; Brito, V.D.; Pizzolitto, R.P.; Zygadlo, J.A.; Zunino, M.P. Fumigant toxicity of essential oils against *Sitophilus zeamais* (Motschulsky)(Coleoptera: Curculionidae): A systematic review and meta-analysis. *J. Pest Sci.* **2017**, *95*, 1037–1056. [CrossRef]
47. Isman, M.B. Plant essential oils for pest and disease management. *Crop Prot.* **2000**, *19*, 603–608. [CrossRef]

48. Arain, M.I. Effect of Botanical Pesticides against Mealy Bug on Cotton. Master's Thesis, Sindh Agriculture University Tandojam, Sindh, Pakistan, 2009.
49. Karamaouna, F.; Kimbaris, A.; Michaelakis, A.; Papachristos, D.; Polissiou, M.; Papatsakona, P.; Tsora, E. Insecticidal activity of plant essential oils against the vine mealybug, *Planococcus ficus*. *J. Insect Sci.* **2013**, *13*, 1–13. [CrossRef]
50. Patel, V.R.; Dumancas, G.G.; Viswanath, L.C.K.; Maples, R.; Subong, B.J.J. Castor oil: Properties, uses, and optimization of processing parameters in commercial production. *Lipid Insights* **2016**, *9*, LPI-S40233. [CrossRef]
51. Rehman, R.; Hanif, M.A.; Mushtaq, Z.; Mochona, B.; Qi, X. Biosynthetic factories of essential oils: The aromatic plants. *Stud. Nat. Prod. Chem.* **2016**, *4*, 100–227. [CrossRef]
52. Uchegbu, M.; Okoli, I.; Esonu, B.; Iloeje, M. The grovving importance of neem (*Azadirachta indica* A. Juss) in agriculture, industry, medicine and Eenvironment: A review. *Res. J. Med. Plants* **2011**, *5*, 230–245.
53. Ezena, G.N.; Akotsen-Mensah, C.; Fening, K.O. Exploiting the insecticidal potential of the invasive siam weed, *Chromolaena odorata* L. Asteraceae) in the management of the major pests of cabbage and their natural enemies in Southern Ghana. *Adv. Crop Sci. Technol.* **2016**, *4*, 2329-8.
54. Campos, Á.L.; Riquelme, I.; Brebi-Mieville, P. Tools for sequence-based miRNA target prediction: What to choose? *Int. J. Mol. Sci.* **2016**, *17*, 1987. [CrossRef] [PubMed]
55. Sanjay Pai, P.N.; Rao, G.K. Determination of organic volatile impurities in herbal formulations and extracts by capillary gas chromatography. *Int. J. Appl. Res. Nat. Prod.* **2009**, *2*, 32–46.
56. Beattie, G.A.C.; Kaldor, C.J. Comparison of high-volume oscillating boom and low-volume fan-assisted rotary atomiser sprayers for the control of Chinese wax scale, '*Ceroplastes sinensis*' del Guercio (Hemiptera: Coccidae), on valencia orange, '*Citrus sinensis*' (L.) Osbeck. *Gen. Appl. Entomol. J. Entomol. Soc. N. S. W.* **1990**, *22*, 49–53.
57. Im, M.K.; Lee, S.J. Antiviral effect of several disinfectant solutions. *Restor. Dent. Endod.* **1994**, *19*, 106–113.
58. Herron, G.A.; Beattie, G.A.C.; Parkes, R.A.; Barchia, I. Potter spray tower bioassay of selected citrus pests to petroleum spray oil. *Aust. J. Entomol.* **1995**, *34*, 255–263. [CrossRef]
59. Cheremisinoff, N. (Ed.) *Industrial Solvents Handbook, Chemical Industries*; Marcel Dekker: New York, NY, USA, 2003; Volume 94.
60. Willcocks, L.C.; Carr, E.J.; Niederer, H.A.; Rayner, T.F.; Williams, T.N.; Yang, W.; Scott, J.A.G.; Urban, B.C.; Peshu, N.; Vyse, T.J.; et al. A defunctioning polymorphism in FCGR2B is associated with protection against malaria but susceptibility to systemic lupus erythematosus. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 7881–7885. [CrossRef]
61. Seo, M.J.; Shin, H.S.; Jo, S.H.; Gawk, C.S.; Kwon, H.R.; Park, M.W.; Kim, S.; Cho, D.; Yu, Y.-M.; Youn, Y.N. Selection of environmental-friendly control agents for controlling the comstock mealybug [*Pseudococcus comstocki* (Kuwana), Pseudococcidae, Hemiptera]. *Korean J. Agric. Sci.* **2011**, *15*, 479–484.
62. Sousa, R.M.O.; Rosa, J.S.; Oliveira, L.; Cunha, A.; Fernandes-Ferreira, M. Activities of Apiaceae essential oils and volatile compounds on hatchability, development, reproduction and nutrition of *Pseudaletia unipuncta* (Lepidoptera: Noctuidae). *Ind. Crop. Prod.* **2015**, *63*, 226–237. [CrossRef]
63. Déglise, P.; Grünewald, B.; Gauthier, M. The insecticide imidacloprid is a partial agonist of the nicotinic receptor of honeybee Kenyon cells. *Neurosci. Lett.* **2002**, *321*, 13–16. [CrossRef]
64. Morgan, K. Feeding the city: The challenge of urban food planning. *Int. Plan Stud.* **2009**, *14*, 341–348. [CrossRef]
65. Opolot, H.N.; Agona, A.; Kyamanywa, S.; Mbata, G.N.; Adipala, E. Integrated field management of cowpea pests using selected synthetic and botanical pesticides. *Crop Prot.* **2006**, *25*, 1145–1152. [CrossRef]
66. Isman, M.B. Botanical insecticides: For richer, for poorer. *Pest Manag. Sci.* **2008**, *64*, 8–11. [CrossRef] [PubMed]
67. Mkindi, A.; Mpumi, N.; Tembo, Y.; Stevenson, P.C.; Ndakidemi, P.A.; Mtei, K.; Machunda, R.; Belmain, S.R. Invasive weeds with pesticidal properties as potential new crops. *Ind. Crops Prod.* **2017**, *110*, 113–122. [CrossRef]
68. Stevenson, P.C.; Isman, M.B.; Belmain, S.R. Pesticidal plants in Africa: A global vision of new biological control products from local uses. *Ind. Crops Prod.* **2017**, *110*, 2–9. [CrossRef]
69. Mwanauta, R.W.; Ndakidemi, P.A.; Venkataramana, P. A review on Papaya mealybug identification and management through plant essential oils. *Environ. Entomol.* **2021**, *50*, 1016–1027. [CrossRef]
70. Lokanadhan, S.; Muthukrishnan, P.; Jeyaraman, S. Neem products and their agricultural applications. *J. Biopestic.* **2012**, *5*, 72.
71. Yanling Zhao, D.; Gish, G.; Braunschweig, U.; Li, Y.; Ni, Z.; Schmitges, F.W.; Zhong, G.; Liu, K.; Li, W.; Moffat, J.; et al. SMN and symmetric arginine dimethylation of RNA polymerase II C-terminal domain control termination. *Nature* **2016**, *529*, 48–53. [CrossRef]