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Research Article

Field and Laboratory Evaluation of Pesticidal Plants for Bioactivity against Rape and Tomato Pests in Malawi

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Insect pests cause serious damage through feeding in the process and may also transmit plant diseases. Although most resource-poor farmers rely on the use of synthetic insecticides for controlling insect pests, it is generally considered too expensive for them. Plant products may be a safer alternative approach and play a significant role in insect pest management and crop protection amongst resource-poor farmers. Laboratory and field evaluation of locally available pesticidal plants were evaluated. The study was conducted at Jenda and Nchenachena in Malawi with rape and tomato to assess the efficacy of some selected pesticidal plants for the control of vegetable pests. Largely, the choice of the selected pesticidal plants was based on resource-poor farmers' knowledge in the area. The results of the tested plant extracts suggested that some plant extracts could reduce the infestation of red mites and aphids below economic threshold levels. Under laboratory experiments, all plant species caused a significant increase in mortality of *Trypanosoma evansi* after 24 h. However, *Dolichos kilimandscarichus*, *Tephrosia vogelii*, *Azadirachta indica*, and *Bedotia madagascarensis* had significantly at $P < 0.05$ greater mite mortality than the untreated. This suggests that these pesticidal plants could be an alternative to acaricidal and insecticidal pesticides against vegetable pests. These pesticidal plants caused an impressive reduction of red mites and aphids and protected tomatoes and rapes from serious damage and hence could be incorporated into integrated management for the control of vegetable pests.

1. Introduction

Pesticidal plant species have a long history and continue to be used for crop protection amongst various resource-poor farmers in southern Africa [1–3]. Plants produce an enormous diversity of secondary metabolites that are effective against a broad range of insects. An age-old practice of using traditional plant materials to protect field crops and stored commodities has been used for long, particularly in India, China, and Africa [4]. Amongst plant protectants, the neem tree (*Azadirachta indica*) is the most prominent example such that farmers have had its use in protecting stored cereals and pulses against insect attack, particularly by rural communities in Asia and Africa [5].

Several plant species have reached considerable economic importance due to the identification of their active constituents. These active constituents include pyrethrins from *Chrysanthemum cinerariaefolium*, the nicotine from *Nicotiana* spp., or rotenone from *Lonchocarpus* spp. and *Derris elliptica* [4, 6]. Some of the compounds have high lethal activity toward insects, low mammalian toxicity, and a short environmental lifetime [7]. In addition, plant species are abundant in most localities and grow locally in sub-Saharan miombo woodlands vegetation.

Traditionally, most farmers use pounded dried material either by mixing it with stored commodities [8] or locally extracting it in water and spraying on the crops. Several studies have been conducted worldwide on the use of biopesticides to control various insect pests in crop production. Nyirenda [9] reported that *Neorautanemia mites* (Mphanjobvu) and *Melia azedarach* (China Berry) had no effect on the control of spider mites in tomatoes. Schmutterer [5] reported that *A. indica* (neem) effectively reduced the populations of diamondback moth and most pests in vegetable crops. Mtambo and Hoeschle-Zeledon [10] reported that a concoction of tobacco ash and soap resulted in lower spider mites mite infestation as compared with *Tephrosia vogelli* and *Neorautanemia mitis*. Skatulla and Meisner [11] reported the effects of 0.02, 0.2, and 0.5% extracts of the seeds of neem, *A. indica*, on the larvae of *Lymantria dispar* (L). Experiments with larvae reared either on leaves or on an artificial diet showed that these inhibited feeding and development and prevented moulting. Egunjobi and Afolami [12] reported that water extracts of neem leaves in concentrations of 1.5, 1.0, or 0.5 kg fresh leaves in 3 litres of water were toxic to *Pratylenchus brachyurus*.

Understanding and applying traditional farming knowledge is important to solving agricultural problems. Ethnoecology or traditional ecological knowledge is important for the formulation of sustainable pest management [13], and natural ecosystems are potentially important sources of natural pest control materials for both biological and plant-based pesticides [14]. Traditional ecological knowledge is defined as "a cumulative body of knowledge, practice, and belief evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings with one another and with their environment" [15–18].

For decades, smallholder farmers across Africa have struggled to maintain food security for their families. There are diverse and mixed views about the causes of food shortages within different communities in Africa [19]. Vegetables are easily attacked by many pests and diseases. It is, therefore, important that farmers use recommended measures to protect their vegetables from pest damage. A growing body of literature suggests that many farming communities have a thorough knowledge of the history, biology, and bionomics of pests that affect their crops [20–22]. Amongst other pests, red mites have evolved resistance against many synthetic pesticides, Chapman [23] and it is important to develop other techniques to protect crops. This study evaluates the insecticidal and acaricidal activities of plant materials against aphids and red mites on rape and tomato.

2. Materials and Methods

2.1. Experimental Field Sites. Field experiments were conducted for two seasons from August to November at Jenda and Nchenachena in Malawi. These two extension planning areas in Mzimba and Rumphi districts were selected based on their high vegetable production including tomato and rape under the Mzuzu Agricultural Development Division. Jenda lies at 1,404 m above sea level on southing and easting 12° 22.19′, and 33° 87′, respectively, mostly dry with rainfall ranging from 600 to 1,000 mm annually. Nchenachena falls at an altitude of 1,213 m above sea level on southing 10° 45′ and easting 34° 02′, mostly cool with high rainfall (1,000–1,200 mm). Nchenachena is rich in rivers that flow all year round and contribute greatly to irrigating crops in the area. Furthermore, the Rumphi district is small with the lowest population density of 35 people per square kilometre, while the Mzimba district, which is considered the largest district, has more farming areas. This makes it possible for Mzimba farmers to own and cultivate slightly larger farms than in Rumphi.

2.2. Experimental Design. A randomized complete block design (CRBD) for field experiments and complete randomized design (CRD) for laboratory bioassay were replicated four and sixteen times, respectively, in this study. The seven treatments for field experiments consisted of *Tithonia diversifolia*, *A. indica*, *Tephrosia Vogelii, Solanum panduriforme*, *Vernonia adoensis*, Phoskill, and unsprayed with 5 and 10% weight per volume (w/v) doses. The experimental plots were measuring 5 m × 5 ridges. Beds were constructed 1 m by 5 m separated by the pathway of 0.5 m in between beds. Each experimental plot had four ridges gross with two middle ridges as a net plot. The laboratory bioassay had 12 treatments, namely *Solanum incanum*, *Cassia abbreviata*, *Vernonia amygdalina*, *T. diversifolia*, *Dolichos kilimandscarichus. Securidaca longepedunculata*, *T. vogelii*, *Bedotia madagascarensis*, *Agauria salicifolia*, *A. indica* (Control), *Euphorbia tirucalli*, and *Tagetes minuta.*

2.3. Collection of Pesticidal Plant Materials. The plants were collected from different sites in Mzuzu Agricultural Development Division (MZADD) and other areas in Malawi. Plant samples for use in laboratory experiments were appropriately coded, and all crude extracts were prepared with methanol. The plant materials were selected based on traditional knowledge concerning their application in vegetable pest control. All plant materials were dried under shade (Figure 1) at ambient temperature (23–27°C) for one week and stored under cool conditions in the laboratory. The dried plants were ground to a fine powder using a blender, mortar, and pestle. The ground materials were sieved in a 2 mm mesh and kept in a sealed plastic container ready for use.

2.4. Preparation of Plant Extracts. For all field experiments, 125 grams of dried *Vernonia* spp., *T. vogelli*, *A. indica*, *T. diversifolia* leaves, and dried *Solanum pandurifome* fruits were ground and mixed separately in 5 litres of water and allowed to stand for 12 h. The liquid was then filtered through a cloth and sprayed on plants using a knapsack sprayer [24–26]. Five millilitres of Phoskil/Dimethoate were dissolved in 5 litres of water and sprayed as a positive control for tomatoes and rapes, respectively. Sunlight dish oil was added to all treatments as a surfactant.

Figure 1: Pesticidal plant materials (neem) being dried under shade at Kasinthula Research Station.

2.5. Sowing and Transplanting. The seeds were sown at the nursery and later transplanted at a spacing of 40 cm for tomato and 20 cm for rape (between plants). The planting beds measured 5 m by 1 m (gross plot) and 4.8 m by 1 m wide (net plot). There were two rows per bed spaced 70 cm apart. Spacing between beds and replicates was 1.5 m in both cases. Basal dressing with 23:21:0 + 4 s was done at the rate of 40 kg N, 180 kg P_2O_5, and 150 kg K_2O per hectare. This was followed by top dressing with CAN at the rate of 50 kg N per hectare.

2.6. Insect Pests Sampling and Damage Assessment. Ten plants in the field were randomly selected and tagged from each plot for the assessment of insect pest abundance through actual insect counts on each plant on a fortnightly basis just before spraying. At harvest, tomato fruit and rape leaf damage were determined for insect pest damage using a three-score category where 1 = no damage, 2 = moderate damage, and 3 = severe damage (adapted from [27, 28]). Farmers were asked to rank the most preferred treatment during the vegetative growing season of the crop and at harvest in order of effectiveness.

2.7. Choice Test. The laboratory bioassay was conducted for antifeedant/repellency tests. Crude extracts of different plant materials were tested using the leaf disc choice test [25, 29]. Two alternate leaves of similar size were excised from a tomato plant and placed in a three-way 9 cm in diameter plastic Petri dish from Fisher, UK, and parafilmed to contain the pests in the Petri dishes. Five unsexed mites were introduced on the front part of the three-way (triplicate partitioned) Petri dish (Figure 2). Each treatment was replicated four times (total, $n = 20$). The number of mites present on each leaf disc was counted at various time intervals between 1, 12, and 24 h. The percentage repellency/repellency index (RI) was calculated from the following formula [30]:

$$\mathrm{RI} = \left[\frac{(C - T)}{(C + T)}\right] * 100, \quad (1)$$

where C is the number of mites found on the control leaf disc and T is the number of mites found on the treated leaf disc.

2.8. Toxicity of Selected Pesticidal Plants against Mites. Toxicity tests of ten pesticidal plant extracts against red spider mites (RSM) were conducted in the laboratory. Mites were collected from the tomato fields of Lunyangwa Experimental Farm, Mzuzu, Malawi, and were immediately transferred onto four-week-old potted tomato plants kept in a greenhouse at 27 ± 3°C and 65 ± 5% RH and used as stock culture. Test RSM was collected from this laboratory culture to ensure the use of a homogenous culture from tomato plants. Matured tomato leaves were then collected from separate uninfected tomato plants from the stock culture, and leaf discs of 2 cm diameter were cut from whole leaves.

The leaf discs were treated with a constant amount of spray solution for 5 seconds using a glass atomizer on both leaf surfaces. Treating both surfaces of the leaf disc was necessary to ensure exposure of adult mites because mites have the tendency to feed on the underside of the leaf. The treated leaf discs were left for about 5 minutes to let the extracts dry up; then five mites were separately introduced into each bioassay well and replicated sixteen times. The experiments were conducted at room temperature, 27 ± 3°C, and 65 ± 5% RH in our laboratory. The mortality of the mites and aphids was observed and recorded at 1, 12, and 24 h after treatment.

2.9. Toxicity of Selected Pesticidal Plants against Aphids. Aphid populations were reared on beans and brought to the laboratory for bioassays. The plant materials were dried under shade and later ground to dry powder. Pesticidal plant extracts were prepared in methanol and used for experiments. A 2 g of the powdered pesticidal plant materials were

Figure 2: Three-way Petri dishes for the choice test.

extracted with 20 ml of methanol for 24 h to prepare the stock solution. Each pesticidal plant extract was tested with four doses having four replications. The aphids were exposed to surface-coated glass vials with pesticidal plant extract solution. Each vial was coated with pesticidal plant extract by dispensing 2 ml of the pesticidal plant extract solution. The vials were rolled manually until the whole surface was coated with the solution and air-dried at room temperature for 30 to 60 minutes or until they were completely dry. The control vials were treated with 2 ml of distilled water containing 5 and 10% methanol. The aphids were placed individually in the surface-coated vials. Each vial was coated with 2 ml of each plant extract and left to dry for 5 minutes before introducing aphids. The plant extracts were assayed at 5 and 10% w/v to determine if the treatments were dose-dependent. The mortality of aphids was assessed at 1, 12, and 24 h after treatment application. Aphids were considered dead if they did not move when prodded with a fine brush. A total of eleven treatments comprising ten pesticidal plant extracts and control were used. In the experiment, treatments were laid in a randomized block design, and all bioassays were replicated four times.

2.10. Data Collection and Statistical Analysis. A sampling of the aphids and red spider mites was conducted visually by counting the attacked plants in each plot three weeks after planting (WAP). Usually, data collection took place either early in the morning between 7 and 9 a.m. or during afternoon hours from 3 to 5 p.m. About ten plants where data was collected were initially tagged in each plot to avoid subsequent changes in plants being sampled during each turn. Thus, ten plants were sampled in each plot for insect counts with the mean numbers of the insects recorded in each case. The mortality data were converted to Abbott's corrected mortality [31] as each treatment mortality effect was adjusted by factoring out mortality in the controls. SPSS (Statistical Package for the Social Sciences) was used to calculate the analysis of variance for the mortality of mites and aphids. The data were subjected to a one-way analysis of variance (ANOVA), while differences in treatment means were separated by Student Newman Keuls (SNK) and Tukey honestly significant difference (HSD) tests at a 5% level of significance.

3. Results

3.1. Choice Tests. As indicated in Table 1, the repellent activity of the plant extracts was time-dependent. There were no significant differences in plant extracts at 24 h after application. After application of crude extracts, *T. vogelii* (83.2%) significantly repelled mites more strongly than *B. madagascariensis* (77.5%), *A. indica* (75%), and *T. diversifolia* (67.5%) 48 h ($P < 0.001$). *S. incanum* showed an attractive effect of 25 and 45% at 24 and 48 h after application, respectively. *E. tirucalli* and *T. minuta* slowly lost their repellency effect with time. These two plant extracts displayed 100% effectiveness within the first 24 h period.

Plant extracts of all species caused a significant increase in mortality of *Trypanosoma evansi* after 24 h (Table 2) of the 10% (w/v) methanol crude extracts. At 1 h, only *T. vogelii* had a significantly greater effect against mites than control. *D. kilimandscarichus*, *T. vogelii*, *A. indica*, and *B. madagascarensis* had significantly greater mite mortality than control 12 h after crude extract application. All plant extracts displayed significantly ($P < 0.001$) higher mortality than control at 24 h after application with *T. diversifolia* recording over 50% mite mortality followed by *A. indica* and *B. madagascarensis*.

3.2. Toxicity Tests for Mites and Aphids. The plant extracts were further assayed at 5% (w/v) to determine their dose-dependent effects (Table 3). At 5% (w/v), all plant extracts had the same trend but with a significantly lower mortality effect against mites (Table 3). However, after 12 h, only *E. tirucalli*, *S. longependuncalata*, *A. indica*, *B. madagascarensis*, and *D. kilimandscarichus* were significantly ($P < 0.011$) greater than the control. Although there was some mortality 1 h after application of 5% (w/v) crude extract, this was not significant (Table 3).

An analysis of variance indicated that there were significant differences amongst the plant extracts treatments in their effects on mite and aphid mortality. The methanol

Table 1: Repellency (%) of methanol plant extracts on mites 24 and 48 h after application.

Plant extract	Repellency (%) against time	
	24 h	48 h
Solanum incanum	−25	−45^{b}
Cassia abbreviata	0	5^{ab}
Vernonia amygdalina	0	65^{ab}
Tithonia diversifolia	8.4	67.5^{a}
Dolichos kilimandscarichus	16.7	22.5^{ab}
Securidaca longepedunculata	25.8	50^{ab}
Tephrosia vogelii	41.7	83.2^{a}
Bedotia madagascarensis	50	77.5^{a}
Agauria salicifolia	50	63.3^{ab}
Azadirachta indica (control)	58.3	75^{a}
Euphorbia tirucalli	100	57.5^{ab}
Tagetes minuta	100	62.5^{ab}
F value	1.94	5.466
Sig.	0.066	0.001

Means with the same letters in the column indicate no significant difference, Tukey honestly significant difference (HSD), $P < 0.05$.

Table 2: Toxicity of methanol plant extracts (10% w/v) against *T. evansi* at 1, 12, and 24 h after application.

Plant extract	Mortality (%)		
	1 h	12 h	24 h
T. vogelii	15.0^{a}	26.25^{ab}	45.0^{ab}
E. tirucalli	10.0^{ab}	20.0^{abc}	37.50^{b}
S. longepedunculata	10.0^{ab}	12.5^{bc}	35.0^{b}
A. indica	8.75^{ab}	21.25^{ab}	51.25^{ab}
S. incanum	8.75^{ab}	11.25^{bc}	45.0^{ab}
C. abbreviata	6.25^{ab}	17.5^{abc}	37.50^{b}
T. diversifolia	6.25^{ab}	11.25^{bc}	50.0^{ab}
B. madagascarensis	3.75^{ab}	25.0^{ab}	52.5^{ab}
D. kilimandscarichus	3.75^{ab}	30.0^{a}	60.0^{a}
V. amygdalina	3.75^{ab}	18.75^{abc}	43.75^{ab}
Methanol (control)	1.25^{b}	3.75^{c}	6.25^{c}
Mean	6.9	18.0	42.2
F value	2.117	4.041	10.164
Sig.	0.026	0.001	0.001

Means followed by the same letters are not significantly different at $P < 0.05$ between treatments according to ANOVA and Student–Newman–Keuls test.

Table 3: Toxicity of methanol plant extracts (5% w/v) against *T. evansi* at 1, 12, and 24 h after application.

Plant extract	Mortality (%)		
	1 h	12 h	24 h
T. vogelii	7.5	18.75^{ab}	30.0^{a}
E. tirucalli	8.75	21.25^{a}	30.0^{a}
S. longepedunculata	11.25	21.25^{a}	32.5^{a}
A. indica	8.75	22.5^{a}	38.75^{a}
S. incanum	6.25	11.25^{ab}	30.0^{a}
C. abbreviata	6.25	17.5^{ab}	28.75^{a}
T. diversifolia	7.5	11.25^{ab}	28.75^{a}
B. madagascarensis	5.0	23.75^{a}	36.25^{a}
D. kilimandscarichus	8.75	22.5^{a}	38.75^{a}
V. amygdalina	8.75	15.0^{ab}	30.0^{a}
Control (methanol)	0	2.5^{b}	7.5^{b}
Mean	7.2	17.0	30.4
F value	0.946	2.40	4.69
Sig.	0.493	0.011	0.001

Means followed by the same letters are not significantly different at $P < 0.05$ between treatments according to ANOVA and Student–Newman–Keuls test.

Table 4: Yield components of tomatoes at Jenda (Malawi) during the first season.

Treatments	Total yield (kg ha^{-1})	Marketable fruits (kg ha^{-1})	Damaged fruits (%)
T. diversifolia	36,289	30,883^{b}	19.8^{bc}
A. indica	28,617	23,469^{d}	27.2^{ab}
T. vogelii	20,414	16,477^{f}	28.0^{ab}
S. panduriforme	24,414	20,055^{e}	26.8^{b}
V. adoensis	32,742	26,352^{c}	15.2^{bc}
Phoskil	38,320	36,406^{a}	5.5^{c}
Unsprayed	21,590	15,176^{g}	46.8^{a}
Mean	28,912	24,117	24.2
Sed	6,668.7	5,793.2	9.5
CV (%)	32.6	34.0	55.6
Sig.	ns	*	*

Means within the same column followed by the same letter are not significantly different ($P < 0.01$).

plant extracts had a significant ($P < 0.001$) toxic effect against aphids at both 2 and 5% w/v (Figures 3 and 4). A least aphicidal action (16.25–40.0%) was noticed after 24 h, and this was even lower at 2% of all the plant extracts. *E. tirucalli*, *B. madagascarensis*, and *C. abbreviata* had 40%, 32.2%, and 40% mortality after 24 h of application, respectively.

3.3. Mites and Aphid Count. The results from dried powdered products of the four botanicals *T. vogelii*, *V. amygdalina*, *T. diversifolia*, *S. panduriforme*, and *A. indica* were able to protect tomato and rape from aphids and mites with varying yield enhancement. The crude extract had a significant ($P < 0.001$) effect on the abundance of red spider mites and aphids at Jenda compared to the control (Table 5). Amongst the plant extracts, *T. diversifolia* recorded the lowest numbers of both red spider mites and aphids. However, Phoskil, the conventional pesticide used for red mite control, had the lowest number of both red spider mites and aphids, while the unsprayed recorded the highest levels of red spider mites and aphids.

The results on the prevalence of red spider mites and aphids (Table 5) in tomatoes at Jenda indicate that there was a significant effect ($P < 0.001$) amongst the treatments. Phoskil had the lowest number of both spider mites and aphids, while the unsprayed recorded the highest levels of spider mites and aphids. There were no significant differences amongst the biopesticides; however, *T. diversifolia* recorded the lowest numbers of both spider mites and aphids. Generally, the abundance of aphids and diamondback moths was lower at Nchenachena compared to Jenda.

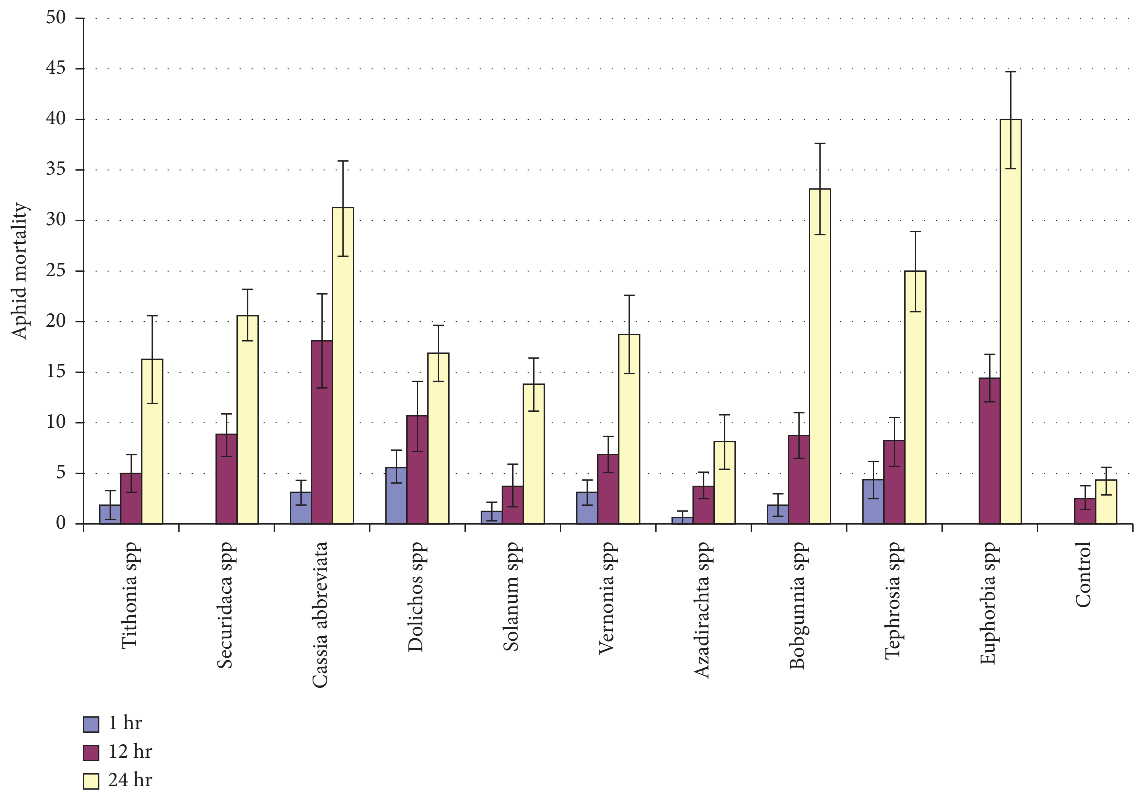

Figure 3: Aphid mortality for the 5% methanol plant extracts at 1, 12, and 24 h after application.

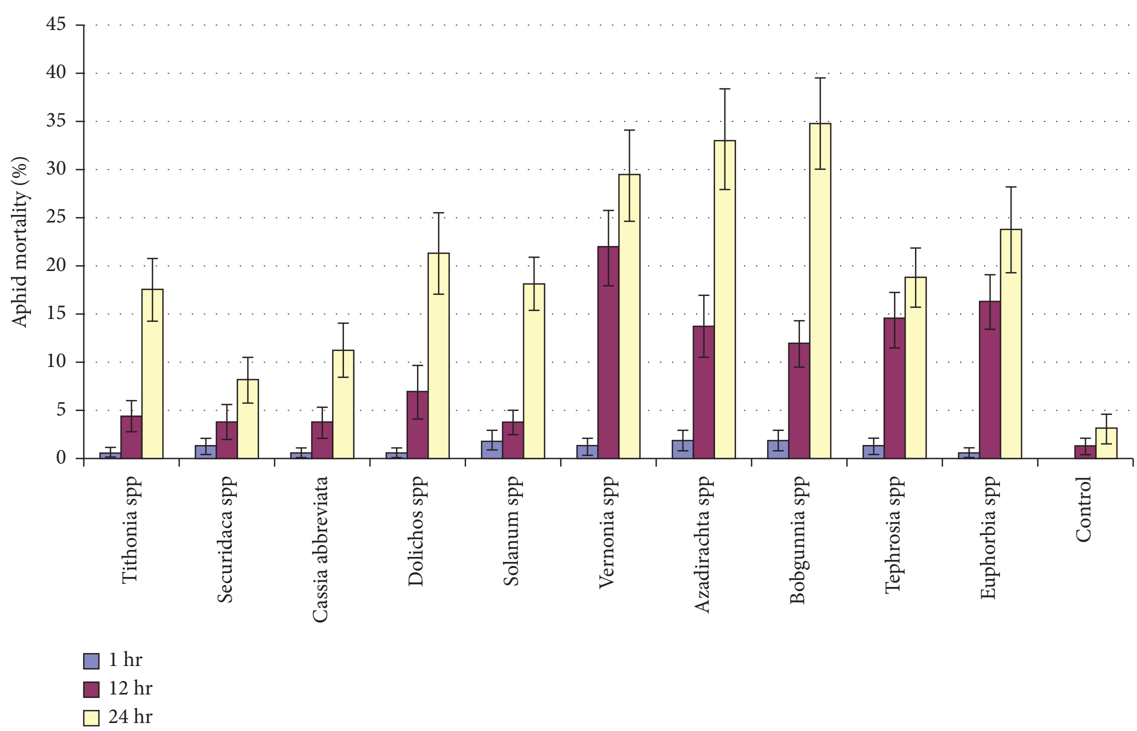

Figure 4: Aphid mortality for the 2% methanol plant extracts at 1, 12, and 24 h after application.

Plots treated with plant extracts had a significantly ($P < 0.05$) lower number of aphids and diamondback moths compared to the control at Jenda.

The results on tomato yields (Table 4) indicate that there were no statistically significant differences in total yield amongst the treatments. Nonetheless, Phoskil gave the

Table 5: Mean counts of red spider mites and aphids in tomatoes at Jenda (Malawi).

Treatments	Spider mites	Aphids
T. diversifolia	31.0^{b}	6.75^{b}
A. indica	31.2^{b}	7.00^{b}
T. vogelii	35.8^{ab}	8.75^{ab}
Solanum panduriforme	37.0^{ab}	8.25^{ab}
V. adoensis	31.5^{b}	7.00^{b}
Phoskil	11.8^{c}	1.5^{c}
Unsprayed	51.0^{a}	12.5^{a}
Mean	32.7	7.39
Sed	6.33	1.649
CV (%)	27.4	31.5
Significance	***	***

Means within the same column followed by the same letter are not significantly different ($P < 0.01$).

Table 6: Aphids and diamondback moth counts in rape at Jenda and Nchenachena.

Treatments	Jenda aphids	DBM	Nchenachena aphids	DBM
T. diversifolia	57.3^{b}	4.67^{b}	7.75	1.0
A. indica	51.7^{b}	3.67^{b}	9.0	1.0
T. vogelii	40.3^{bc}	3.33^{b}	9.0	1.0
S. panduriforme	44.0^{bc}	4.33^{b}	6.5	0.75
V. amygdalina	53.7^{b}	4.33^{b}	7.25	0.75
Phoskil	10.3^{c}	5.0^{ab}	2.5	1.0
Unsprayed	103.7^{a}	6.67^{a}	9.25	1.0
Mean	51.6	4.57	7.35	0.929
Sed	17.84	0.88	2.48	0.1942
CV (%)	42.4	23.6	48.0	29.6
Sig.	**	*	ns	ns

Means within the same column followed by the same letter are not significantly different ($P < 0.05$).

highest yields (38,320 kg/ha), while *T. diversifolia* gave the highest yield amongst the biopesticides (30,882 kg/ha). There were significant differences in the yield of marketable fruits ($P < 0.05$) and the percentage of fruits damaged ($P < 0.05$) by tomato fruit worm (*Helicoverpa armigera*). Phoskil gave the highest yield of marketable fruits (36,406 kg/ha) followed by *T. diversifolia* (30,882 kg/ha) and *V. adoensis* (26,352 kg/ha).

Amongst the biopesticides, *V. adoensis* gave the lowest percentage of nonmarketable fruits (15.2%), while *T. vogelli* gave both the least yield of marketable fruits (16,447 kg/ha) and the highest percentage of nonmarketable fruits (28.0%). Overall, the unsprayed treatment gave the lowest yield of marketable fruits (15,176 kg/ha) and the highest percentage of nonmarketable fruits (46.8%) amongst all treatments. The results from Table 3 show that there were no significant differences in plant height and canopy spread between the biopesticides and Phoskil. This shows that biopesticides did not have a negative effect on the growth and development of tomato plants.

The insect pest abundance results in rape (Table 6) indicate that there were statistically significant differences in the levels of aphids ($P < 0.01$) and diamondback moth ($P < 0.05$) at Jenda, while there were no significant differences in the levels of aphids and diamondback moth at Nchenachena. At Jenda, dimethoate and *T. vogelii* gave the lowest levels of aphids and diamondback moth, respectively. There were, however, no significant differences in levels of aphids and diamondback moths amongst the biopesticides. Overall, biopesticides had lower levels of diamondback moth than dimethoate. The unsprayed treatment gave the highest levels of aphids at both sites.

The results on yield (Table 7) indicate that there were no significant differences amongst the treatments in total fresh leaf yield and yield of marketable leaves at both Nchenachena and Jenda. Nonetheless, at Jenda, *S. pundurifome* gave the highest total fresh leaves yields (25,946 kg/ha) followed by *V. adoensis* (25,705 kg/ha) and *T. vogelli* (25,039 kg/ha). At Nchenachena, *T. vogelli* gave the highest total fresh leaf yields (32,475 kg/ha) followed by *T. diversifolia* (37,725 kg/ha) and *A. indica* (32,727 kg/ha). At both sites, biopesticide out yielded dimethoate, though dimethoate had lower percentages of damaged leaves compared to the biopesticides. Yields at Nchenachena were generally higher than at Jenda, which can be attributed to the differences in the levels of aphids and diamondback moths.

Towards the final stage of field experimentation, agricultural field days were organized where farmers were given an opportunity to choose the most effective treatments. Farmers' preferences for the different pesticidal plant treatments varied considerably (Figure 5). Generally, farmers preferred *T. diversifolia* and *V. amygdalina* treatments more than other pesticidal plant treatments. During the growing season of tomato and rape, 80% of the farmers preferred *T. diversifolia* due to low pest severity and high yields in terms of tomato, fruits, and vigorous rape growth in the treatment. Other treatments were not favoured since they displayed high pest pressure and low yield making them nonimpressive according to farmers.

4. Discussion

The present study indicated that different pesticidal plants screened having pesticidal properties able to control vegetable pests. Amongst the pesticidal plants tested, *T. vogelii and B. madagascarensis* extracts significantly repelled mites within 48 h after treatment. Similarly, *D. kilimandscarichus*, *T. vogelii*, *A. indica*, and *B. madagascarensis* had significantly greater mite mortality than the control 12 h after treatment application. This indicates that these pesticidal plants were either toxic to red spider mites or aphids feeding on the treated discs and directly reduced the population of mites and aphids. Therefore, these pesticidal plants may also be of use in the control of insect pests such as aphids and red spider mites. These findings agree with previous studies that had demonstrated that pesticidal plants have insecticidal properties against agricultural insect pests either as contact toxicity or repellent [24, 32].

The mortality of red spider mites was related to the activity of pesticidal plants as the mites were exposed to different concentration levels and exposure times. This indicates that higher dosages and longer exposure periods of insect pests to pesticidal plants are needed to achieve higher efficiency in the management of aphids and mites. The

Table 7: Yield (kg·ha^{-1}) of rape at Jenda and Nchenachena in Malawi during the second season.

Treatments	Jenda		Nchenachena	
	Total yield (kg·ha^{-1})	Marketable leaves (kg·ha^{-1})	Total yield (kg·ha^{-1})	Marketable leaves (kg·ha^{-1})
T. diversifolia	24,686	17,695	32,725	29,000
A. indica	23,002	16,835	32,475	29,250
T. vogelii	25,039	19,372	32,775	28,575
S. incanum	25,946	19,113	27,525	26,225
V. amygdalina	25,705	18,372	28,275	26,850
Phoskil	21,113	18,446	26,050	24,800
Unsprayed	20,710	13,877	24,800	20,275
Mean	23,743	17,695	29,232	24,425
Sed	2,424.5	2,489.5	5,474.9	5,458.5
CV (%)	12.6	19.7	26.5	29.2
Sig.	ns	ns	ns	ns

ns denotes not significant.

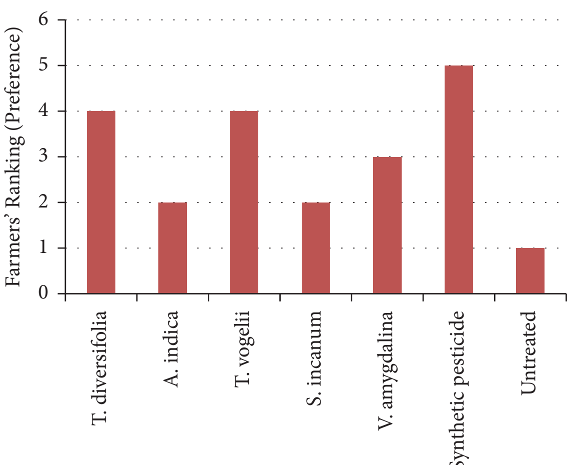

Figure 5: Farmers' preference for the different treatments evaluated at the two sites: Njenda and Nchenachena.

mortality of mites was a result of contact with toxic substances [33–35]. Similarly, in studies conducted by [36], *Capsicum* accessions (Solanaceae) were screened for their toxicity and repellency to the red spider mites. Crude extracts from fruits of *Capsicum chinense*, *Capsicum frutescens*, *Capsicum baccatum*, *Capsicum annuum*, and *Capsicum pubescens* were prepared in methanol and tested for their acaricidal properties. Similarly, in this study, a wide range of plant extracts proved to be toxic resulting in the death of pests as exhibited with red spider mite (RSM) using the leaf discs method with mortality ranging from 7.5 to 38.75% with 5% leaf extracts and 6.25–60% at the highest concentration of 10% leaf extract (Figures 3 and 4).

According to Isman [37], harmful effects associated with plant compounds can largely be alleviated by crude plant preparations that must range from 1 to 5% w/v; nevertheless, pesticidal plants can be effective against red spider mites causing complete mortality at a concentration of 5 and 10%. However, the dosage of 10% is too high from the economic point of view and may not be applicable at the field level. Methanol extracts of *A. indica*, *T. diversifolia*, *T. vogelii*, *B. madagascarensis*, *S. panduriforme*, and *V. amagdylina* showed significant toxicity and repellency to mites and aphids and have the potential for crop protection against the two target species. The results suggest that there are compounds in some of the plant extracts that are toxic or repellent to the target pest species. This shows that pesticidal plants also present many farmers with a large number of options for the control of insect pests that attack their vegetable crops as they are cheap and based on local plant materials. These results substantiate the traditional knowledge of pest control that farmers in many developing countries had been protecting food and fiber from insect pests [24, 38, 39].

The current findings agree with other studies that have shown that pesticidal plant extracts have significant lethal effects on red spider mites [40, 41]. It is, therefore, possible that some plant materials should be incorporated into integrated pest management to reduce the costs of purchasing synthetic pesticides. However, the efficacy of products varies with cultivars and families of the plant materials [24]. For instance, farmers in Malawi consider local cultivars of *Tephrosia* to be more effective compared to the improved cultivar that was introduced mainly for soil improvement [42]. These results also showed that the toxicity of plants increased according to the concentration of plant extract and the time the pests were exposed to the materials. Similarly, Ahmed et al. [43] stated that the toxicity and biological activity of methanol extracts of neem products against bean aphids increased with increasing concentration and time exposure of aphids to the products.

The results have demonstrated that two of the plant extracts evaluated (*T. vogelii* and *T. diversifolia*) exhibited contact toxicity to red mites and aphids (Figure 3). The results further showed that toxicity existed for 24 h and then toxic effects disappeared. Similarly, *T. diversifolia*, *B. madagariensis*, and *T. vogelii* extracts showed strong repellent effects against red spider mites during the initial 24 h after application (Table 5). This suggests that toxic and repellent compounds were very active within 24 h of the application period. The differences indicate variation in the content of the active components responsible for the insecticidal activities. These results are in agreement with [44, 45] that *T. diversifolia*, *B. madagariensis*, and *T. vogelii* have toxic and repellent compounds. However, the use of repellents as crop protectants is likely to be useful under limited circumstances. Plant extracts could only control insect pests if it is applied in such a way that it reaches its intended target insect at the correct life stage.

Likewise, when aphids were subjected to 7 ml vials, it was observed that they had their bodies fully elevated from the edge of the vials signifying a total dislike of the treated surface. Such behaviour was very unusual for aphids and was therefore typically related to unfavourable conditions on the vial. This suggests that aphids started detecting the presence of repellent compounds in the treatments. Consequently, if the aphids abandoned the treated surface, feeding or sucking of such plants may not occur. This is important because both aphids and red spider mites have a similar feeding behaviour [46]. Behavioral observations are crucial in determining the antifeedant effects [47–50]. Since aphids usually like to feed on succulent tissues such as new shoot tips, leaves, buds, and flowers, the prospects of antifeedant in pest management can have more successful practical application when insect behavioural effect leads to less damage to plants [51]. Through such behaviour, it would be easier to repel aphids upon spraying to effectively keep aphids out of the crops. It may show that aphids could have been detecting the odour of the pesticidal plants, which may deter feeding. Therefore, vegetable pests such as aphids and mites could leave treated plants because of the antifeedant effects of the pesticidal plant extracts.

Studies have indicated the potential ecological damage due to the widespread use of synthetic pesticides [52]. It is therefore important to encourage effective biorational control measures that are not detrimental to humans or the environment. If botanical pesticides are promoted to resource-poor farmers, it may be possible to satisfy the growing needs of farmers for pest control measures without resorting to the use of synthetic pesticides for crop protection [53, 54] without negative effects on the environment and mankind. Crude plant extracts often consist of complex mixtures of active compounds that act synergistically and may show greater overall biological activity compared to the individual constituents [55]. A wealth of literature has been published based on the effects of plant secondary chemicals on insects [34, 41, 56, 57] and indicates that certain plant extracts are more effective against insect pests. Studies on alternative control methods to ensure environmental and food safety have become an important task amongst researchers [58].

Especially, botanical insecticides have long been a subject of research to develop alternatives to conventional insecticides. These results are also in agreement with the ones obtained by other researchers that plant extracts are effective against crop pests [35, 38, 59]. This, therefore, provides a prerequisite for further future research to establish the efficacy of various traditionally used plant materials against insect pests on other crops. The plants are also readily available amongst resource-poor farmers and have extensively been used for medical, nutritional, and cosmetic purposes [60] and pose a minimal threat to humans and the environment. This study indicates that cheap, sustainable protection of vegetables against pests may be feasible using locally available pesticidal plant products.

5. Recommendations

The efficacy of crude extracts from several plant species such as *D. kilimandscarichus*, *T. vogelii*, *A. indica*, and *B. madagascarensis* that significantly increased mite mortality than control is recommended for pest control. It would therefore be essential that further work be conducted to investigate more plant materials and improve their efficacy. The current findings further confirmed that most of the pesticidal plants tested possess repellent and toxicity properties that can be used in the control of aphids and mites in vegetable production. The repellent activity of the pesticidal plants also revealed that the activity of plant extracts was time-dependent. Such studies could also be extended to cover the management of other vegetable pest species. The study has also demonstrated variations in bioassay mortality that can arise from many causes such as insect age, plant material, and temperature. These promising plant species should also be investigated further for their effect on natural organisms. There are a number of pesticidal plants known for their insecticidal activity, but there has been less progress in validating them for their efficacy. The use of pesticidal plants in pest management is considered ecologically viable to overcome the effects of insecticides.

6. Conclusion

In this study, *T. diversifolia* and *T. vogelii* pesticidal plants proved effective against aphids and mites. The results also showed that some pesticidal plant materials such *T. diversifolia* and *T. vogelii* significantly reduced the population of aphids, mites, and diamondback moths. *T. diversifolia* showed the strongest pest control effects compared to other plant materials. This suggests that not all pesticidal plants identified by farmers as potentially useful materials for pest control were effective against vegetable pests in comparison to standard synthetic pesticides but proved superior to untreated controls. In some cases, pesticidal plant extracts displayed a significant effect when used at higher concentrations. Based on these results, *T. diversifolia* and *T. vogelii* can be recommended for pest control against vegetable pests such as red spider mites, aphids, and diamondback moths.

Data Availability

The data used to support the findings of this study can be accessed from the corresponding authors upon request.

Disclosure

The contents of this document are the sole responsibility of the authors and can under no circumstances be regarded as reflecting the position of the SADC Secretariat or the European Union.

Conflicts of Interest

The authors take full responsibility for any errors, and the authors declare that there are no conflicts of interest in relation to the publication of this research paper.

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