

Efficacy of varying concentrations of agroforestry-derived botanical extracts on aphid (*Brevicoryne brassicae*) populations and yield performance in rape (*Brassica napus* L.)

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Abstract

Synthetic herbicides are becoming unaffordable for many smallholder farmers in southern Africa. In controlling pesticides, most resource-poor farmers use plant extracts, which are less expensive and environmentally friendly. The objective of this study was to evaluate the use of agroforestry crude plant extracts in the control of aphids, and growth and yield performance of *Brassica napus* Linnaeus. The experiment was performed in a randomized complete block design with seven treatments replicated three times. The results revealed no significant effect ($p > 0.05$) on aphid number per plant from the use of various concentrations of the botanical extracts and Dimethoate. However, the use of 30 g L^{-1} *Tephrosia vogelii* or 30 g L^{-1} *Tagetes minuta* decreased the number of aphids per plant over time. The use of *T. vogelii* or *T. minuta* for 2–8 weeks had a significant effect on *Brassica napus* yield at different concentrations. The highest fresh yield ($9.26 \pm 0.02 \text{ t ha}^{-1}$) of rape was obtained from the 30 g L^{-1} *T.v.* concentration, and the lowest fresh yield ($0.80 \pm 0.64 \text{ t ha}^{-1}$) was recorded from the 10 g L^{-1} *T. vogelii* concentration but was not significantly different from that of dimethoate ($8.85 \pm 0.12 \text{ t ha}^{-1}$). The *T. vogelii* and *T. minuta* concentrations reduced the aphid population and improved fresh rape yield. However, farmers are encouraged to use *T. vogelii* and *T. minuta* botanical extracts at 30 g L^{-1} concentration or higher, as an economically viable aphid management strategy.

1 Introduction

Rape (*Brassica napus* L.), commonly referred to as rapeseed mustard, is a significant oilseed crop cultivated in Zimbabwe, yielding high-quality oil rich in fatty acids suitable for culinary applications. The vegetable crop's residual cake serves as a nutritious feed supplement for livestock. Rape's green foliage is utilized as a vegetable ingredient in traditional relishes, while its vegetative biomass provides a valuable source of green fodder for animal nutrition, thereby contributing to sustainable agricultural practices and diversified crop utilization [8, 25]. Brassicas are crucial, as they are a key component of the local diet and are nutritionally important for people who cannot afford alternative vegetables [14]. Rape, in particular, is an important smallholder subsistence crop in southern Africa. It is grown for its leaves, which are rich in vitamin A, thiamine and ascorbic acid; it has high levels of glucosinolates, which, during preparation, form compounds with antioxidants and induce anticancer treatment chemicals [18, 46]. Aphids, particularly cabbage aphids (*Brevicoryne brassicae*), are major pests that cause economic damage to rape production in Zimbabwe [42]. Under favorable conditions, damage caused by many aphids can kill seedlings and young transplants. In addition, on larger plants, feeding by aphids resulted in curling and yellowing of rape leaves, stunted plant growth and damage to flowers [34].

The cultivation of *Brassica napus* in Zimbabwe is hindered by suboptimal yields, primarily attributed to biotic stresses caused by insect pests and diseases, as well as abiotic factors. Notably, pest management strategies, particularly among smallholder farmers, remain largely reliant on chemical pesticides, which have far-reaching deleterious consequences. The excessive application of these pesticides has led to the development of resistance in target species while also causing collateral

damage to beneficial insects and natural enemies [41]. The overreliance on chemical pesticides has resulted in significant yield losses in oilseed crops, with reports indicating substantial reductions in productivity due to pest and disease pressure in Zimbabwe. Farmers predominantly use synthetic pesticides such as dimethoate to control aphids; however, these methods are expensive, especially for poor smallholder farmers. Many pests, including aphids, have also developed resistance to organophosphates, carbamates and pyrethroid insecticides [5, 18]. The increase in aphid populations as a result of reduced populations of natural enemies due to routine insecticidal sprays has also been observed in many studies. The use of natural pesticides is increasingly recognized as an option for addressing yield losses due to pest attacks as well as reducing the degree of environmental degradation associated with the use of synthetic pesticides [41]. This challenge has made it imperative to explore the possible utilization of biological pesticides that are relatively cheap, accessible, safer and environmentally friendly. These biological pesticides have little impact on the natural enemies of pests [42] and are easily biodegradable; hence, their use in crop protection has been seen as the most sustainable alternative [23].

Cabbage aphids (*Brevicoryne brassicae* Linnaeus) are the most notorious pests of vegetables because of their ability to cause substantial plant and economic losses and are resistant to a wide range of insecticides. Their feeding causes wilting, yellowing and stunted plant growth [46]. They are also known to transmit viral diseases and secrete honey dew, which attracts sooty molds and a number of insects [1]. Most farmers have continually used different types of synthetic pesticides that are systemic and broad spectrum to manage aphids, including methomyl, emamectine benzoate, rotenoids, pyrethroids, and neonicotinoids that are toxic to insects [16, 26]. *Tephrosia vogelii*, also known as the fish bean plant, and *Tagetes minuta*, commonly referred to as Mexican marigold, have been used traditionally as natural pest control agents because of their ability to repel or even kill insects [9, 28]. However, these insecticides have resulted in the development of pest resistance and negative side effects on humans and the environment, including beneficial insects. Furthermore, they have high costs, which make them unaffordable to many farmers. On the other hand, botanical plants are readily accessible to smallholder farmers and have low toxicity levels to mammals, fish and pollinators [30]. This would help minimize the negative effects of synthetic pesticides. Nevertheless, there is very little information about the effective active ingredients, preparations and application rates of agroforestry pesticide powder. Therefore, the objective of the current study was to evaluate the efficacy of botanical plant extracts for the control of vegetable aphids and their effects on fresh yield.

2 Materials and methods

2.1 Description of the study site

A field experiment was conducted at Gweshe Agritex Demonstration plot (17°10'0"S and 31°0'0"E, 1217 m above sea level) in ward 12 of Mazowe District, Zimbabwe. The experimental site is in agroecological zone IIb, which receives 950–1000 mm of rainfall annually. The site is associated with cold winters and

hot summers with temperatures ranging from 18–33°C. The site is characterized by deep and well-drained red clay soils.

2.2 Experimental design and procedure

The experiment was carried out in a completely randomized block design with seven treatments replicated three times. The experiment had three blocks each, with seven plots, resulting in 21 plots, and the plot size was 2x1 m². The land was plowed via an ox-drawn plow to a depth of 20 cm on the 18th of July 2023, and a spike toothed harrow was used to produce a fine tilth. Cattle manure was applied at a rate of 10 t ha⁻¹ to each plot and incorporated into the soil via a garden fork, and four *B. napus* (English giant) seeds were sown on the 30th of July 2023 in each pit. The seedlings were sown at a spacing of 20 cm between plants and 30 cm between rows, with each experimental unit consisting of 15 plants. Watering was initially performed twice daily and then twice a week after seedling emergence. One week after emergence, the other three seedlings were uprooted, leaving one healthy seedling in each pit. Ammonium nitrate was applied as a top-dressing fertilizer at a rate of 300 kg ha⁻¹ in the third week after emergence. Weeding was performed when the weeds appeared. The most prevalent weeds were black jack (*Bidens pilosa* L.) and black night shades (*Solanum nigrum* Mill).

2.3 Preparation of agroforestry plant extracts

Tephrosia vogelii Hook f. and *Tagetes minuta* leaves were harvested and subjected to sun drying under shaded conditions until complete desiccation was achieved. The dried leaves were then pulverized into a fine powder via a wooden hand crusher. Aqueous solutions of agroforestry pesticide powder were prepared at concentrations of 10, 20, and 30 g L⁻¹ in deionized water. The powders were thoroughly dissolved through vigorous agitation, followed by a 24-hour equilibration period to ensure complete solubilization. Subsequent filtration of the solutions was performed to prevent nozzle clogging during application. Concurrently, a solution of Dimethoate 40% EC was prepared at a concentration of 80 ml DM¹ 100 L of water and applied on the same day as the pesticide powders.

2.4 Data collection

The two outer rows were discarded, and the two center rows represented the net plot. Three plants in each row in the net plots were randomly selected for sampling. Systematic random sampling was used to select plants with a 3-k factor. In the first and second rows, plant numbers 1, 4, and 7 and 3, 6, and 9 were selected, resulting in a total of six plants per plot.

2.4.1 Number of aphids

Aphid counting started at two weeks after emergence and continued at two-week intervals until the eighth week. This was accomplished by counting all aphids that were present on the selected plants. All the plants in the bed were sprayed, but 15 plants were selected per bed for assessing aphid mortality. Spraying was performed early in the morning, recordings started 2 hours after spraying, and recordings

were taken at 2-hour intervals. The study was carried out over 2 months, and spraying commenced at 3 weeks after transplanting.

2.4.2 Number of leaves

The total number of active green leaves per plant was quantified through weekly manual counts, commencing at two weeks' post-emergence and continuing until eight weeks' post-emergence. This methodology enables the systematic monitoring of leaf development and growth dynamics over a six-week period, providing a comprehensive dataset for subsequent analysis.

2.4.3 Plant height (cm)

The plant height was determined by measuring the linear distance from the soil surface in the bed to the tip of the tallest leaf via a precision-calibrated ruler. This measurement was executed weekly, coincident with leaf number enumerations, to facilitate direct temporal correlations and minimize variability. The measurement procedure was rigorously standardized to ensure accuracy, precision, and reliability.

2.4.4 Leaf length (cm)

To account for the inherent variability in leaf morphology, a standardized measurement was employed to quantify the leaf length of *Brassica napus*. Specifically, at each harvest interval, the maximum leaf length was measured for both plants within each pot via a calibrated ruler. The average value was subsequently calculated to provide a representative measure of leaf length. Leaf length was defined as the distance from the apex of the lamina to the point of petiole detachment, ensuring consistency in the measurement methodology across all the samples.

2.4.5 Leaf width (cm)

The maximum leaf width was quantified via the same largest leaves previously utilized for the leaf length measurements. The width was measured at the broadest point of the lamina, perpendicular to the midrib, employing a calibrated standard ruler. The measurements were taken at the widest lobes of the lamina, and the average value was calculated to provide a representative measure of leaf width.

2.4.6 Fresh rape yield (g)

Leaf harvesting was performed on mature foliage at three consecutive intervals spaced 14 days apart. Following each harvest event, the freshly severed leaves were subjected to immediate weighing to determine their fresh biomass. The cumulative fresh weight of all the leaves harvested from each treatment across the three harvest events was subsequently calculated to derive the total leaf biomass yield per treatment.

2.5 Data analysis

A statistical analysis of variance (ANOVA) was performed on all measured parameters using Genstat software (version 21.1). The significance of differences between treatment means was evaluated via

Tukey's honest significant difference (HSD) test at a probability level of $p < 0.05$, allowing for multiple comparisons.

3 Results

3.1 Effects of different application rates of agroforestry botanical extracts on the mean aphid count

The results revealed no significant difference ($p > 0.05$) in the biweekly aphid counts among the treatments. In weeks 2, 4, 6 and 8, the mean aphid count in response to the agroforestry botanical extract was not significantly different ($p > 0.05$). Most importantly, there were no significant differences ($p > 0.05$) among the different concentrations of the botanical extract and the control treatment (Table 1). The application of 20 g L⁻¹ *Tm* was effective in week two, with the highest mean number (13.87) of aphids/plant, whereas 30 g L⁻¹ *Tm* resulted in the lowest mean number of aphids per plant (10.12). The results also revealed that as the number of weeks after transplanting progressed, all the agroforestry botanical extracts presented a decrease in the number of aphids up to the eighth week (Table 1). In the eighth week, the effects of the 30 g L⁻¹ *Tm* concentration botanical extract was similar to those of dimethoate but differed from those of the 30 g L⁻¹ *Tv* concentration. The application of 30 g L⁻¹ *T. vogelii* effectively controlled aphids, as indicated by low aphid numbers per plant from weeks 2 to 8 (Table 1). The 30 g L⁻¹ *Tv* treatment resulted in the greatest decrease in aphid percentage (72.88%), whereas the 10 g L⁻¹ *Tv* treatment resulted in the least decrease in aphid percentage (59%). The use of different concentrations of *B. napus* was sensitive to aphids, and the efficacy of agroforestry and crude plant extracts was noted. The effects of various concentration rates on the control aphids differed with time (weeks). This was caused by the composition of the agroforestry botanical species used and the use of dimethoate as the control.

Table 1. Mean number of aphids per plant at biweekly intervals

Botanical extract concentration	Biweekly interval aphid count using the square root ($\sqrt{x}$) * factor 12				Aphid % decrease
	2	4	6	8	
10 g L ⁻¹ <i>Tv</i>	13.00±0.23 ^d	13.33±0.12 ^d	7.33±0.23 ^c	5.33±0.54 ^a	59.00
10 g L ⁻¹ <i>Tm</i>	13.67±0.10 ^d	13.05±0.19 ^d	6.54±0.31 ^c	5.84±0.49 ^a	57.28
20 g L ⁻¹ <i>Tv</i>	13.22±0.11 ^d	13.67±0.17 ^d	7.56±0.19 ^{cf}	4.22±0.61 ^a	68.08
20 g L ⁻¹ <i>Tm</i>	13.87±0.08 ^d	13.06±0.21 ^d	6.32±0.26 ^a	4.64±0.52 ^a	66.55
30 g L ⁻¹ <i>Tv</i>	9.44±0.37 ^e	10.11±0.39 ^e	4.67±0.52 ^a	2.56±0.74 ^b	72.88
30 g L ⁻¹ <i>Tm</i>	10.12±0.13 ^e	10.25±0.28 ^d	5.35±0.28 ^a	3.24±0.56 ^a	67.98
80 ml DM ⁻¹ 100 L of water	10.33±0.18 ^d	10.22±0.42 ^e	5.39±0.36 ^a	3.22±0.44 ^a	68.83
P value	0.532	0.267	0.375	0.154	
LSD	ns	ns	ns	ns	

Means without common superscripts within each column are significantly different ($p < 0.005$). LSD= Least significant difference, ns means not significant

3.2 Effects of different application rates of agroforestry botanical extracts on the number of rape leaves

The data presented in Figure 1 demonstrate that varying application rates of agroforestry botanical extracts significantly impacted the number of leaves on rape plants over time, with a positive correlation observed between the botanical concentration and leaf production. The highest mean leaf count (8.19) was observed at 30 g L⁻¹ Tv at 8 weeks, whereas the lowest mean leaf count (2.79) was recorded at 10 g L⁻¹ Tv at 2 weeks. Although 30 g L⁻¹ Tv yielded the highest leaf count, this value was not significantly different from those obtained at 30 g L⁻¹ Tm and 80 ml DM⁻¹ 100 L of water ($p > 0.05$). No significant increase in leaf count was noted between the 10 g L⁻¹ and 20 g L⁻¹ concentrations biweekly. Furthermore, the botanical plant extract treatment influenced the leaf growth trends at various developmental stages (Figure 1). Notably, 20 g L⁻¹ Tv resulted in a relatively lower leaf count between weeks 2 and 8, followed by a positive growth trend over the subsequent two-week interval.

Fig 1. Effects of varying application rates of agroforestry botanical extracts on the number of rape leaves

3.3 Effects of different application rates of agroforestry botanical extracts on plant height

The results of the analysis revealed a statistically significant impact of agroforestry botanical plant extracts and biweekly time intervals on the accuracy of rape height estimation ($p < 0.05$). As illustrated in Figure 2, the interaction between the botanical plant extracts and biweekly intervals yielded significant differences in rape height. Specifically, the mean tallest plants (20.24 cm) were observed at 30 g L⁻¹ Tm, which did not differ significantly from those at 30 g L⁻¹ Tv (19.63 cm) and those in the control treatment (80 ml DM⁻¹ 100 L of water, 19.74 cm). Conversely, the mean shortest plants (6.7 cm) were recorded at 10 g L⁻¹ Tv, which was significantly shorter than those in the other treatments. Notably, no significant differences in plant height were observed across weeks 2, 4, 6, and 8. However, a significant decline in plant height occurred at week 6, from 13.76 cm to 13.06 cm, at the 20 g L⁻¹ botanical concentration. Furthermore, the treatment levels of the botanical plant extracts influenced the growth trend of plant height across different weekly growth stages, which tended to increase over time. The most pronounced increase in plant height was observed at 20 g L⁻¹ Tm (5.18 cm), whereas the least pronounced increase in growth was recorded at 10 g L⁻¹ Tm (4.43 cm) between weeks 4 and 6.

Fig 2. Effects of varying application rates of agroforestry botanical extracts on plant height

3.4 Effects of different application rates of agroforestry botanical extracts on leaf length and width (cm)

The concentrations of the botanical plants used in the present study are shown in Figure 3a. An investigation into the effects of the botanical plant concentration on leaf length during rape production revealed a statistically significant positive correlation over time ($p < 0.05$). Biweekly leaf length growth measurements indicated that 10 g L⁻¹ Tm resulted in the greatest percentage increase (51.71%) from weeks 6-8, whereas 30 g L⁻¹ Tv resulted in the lowest percentage increase (39.36%). The mean maximum leaf length (17.81 cm) was observed for the 30 g L⁻¹ Tm botanical extract, whereas the mean minimum leaf length (4.34 cm) was recorded for the 10 g L⁻¹ Tm extract (Figure 3). Although the 30 g L⁻¹ Tm botanical extract yielded the longest leaves, its leaf length did not differ significantly from those of 20

g L⁻¹ Tv (17.70 cm) and 80 ml DM⁻¹ 100 L of water (17.47 cm). In contrast, the leaf length at 30 g L⁻¹ Tv (17.07 cm) differed significantly from that at 20 g L⁻¹ Tv, 30 g L⁻¹ Tm, and 80 ml DM⁻¹ 100 L of water. A significant difference in leaf length was observed across concentrations ranging from 10 g L⁻¹ to 30 g L⁻¹, as was the case for 80 ml DM⁻¹ 100 L of water, the control treatment. While the results suggest that leaf length is influenced by the botanical extract concentration, 30 g L⁻¹ Tm produced relatively high leaf length values, which were statistically similar to those of plants treated with 80 ml DM/100 L.

The present study revealed a significant trend ($p < 0.05$) in leaf width in response to increasing botanical concentration and biweekly interval measurements (Figure 3b). At two weeks postemergence, the narrowest mean leaf width (3.65 cm) was observed at 10 g L⁻¹ Tv, whereas the widest leaf width (4.05 cm) was recorded at 80 ml DM⁻¹ 100 L of water. Notably, the leaf width at 80 ml DM⁻¹ 100 L of water varied significantly with the 10 g L⁻¹ and 20 g L⁻¹ concentrations but not with the 30 g L⁻¹ Tv (3.61 cm) and 30 g L⁻¹ Tm (3.63 cm) concentrations. Biweekly measurements yielded leaf widths that differed significantly from each other and from those at 10 g L⁻¹ Tv, 10 g L⁻¹ Tm, 20 g L⁻¹ Tv, and 30 g L⁻¹ Tv. The narrowest leaves were recorded at two weeks across all the botanical concentrations, which were not statistically similar to the measurements at four weeks. Conversely, the widest leaves, which were not statistically identical to the leaf width at six weeks, were observed at eight weeks postemergence. At eight weeks, the treatments with 30 g L⁻¹ Tv (12.1 cm) and 30 g L⁻¹ Tm (11.83 cm) produced significantly wider mean leaf widths than those with 10 g L⁻¹ Tv (7.95 cm) and 10 g L⁻¹ Tm (7.58 cm). However, the leaf widths at the 30 g L⁻¹ concentration at eight weeks were not significantly different from those at six weeks.

Fig 3. Effects of application rates of the botanical extracts on leaf length (a) and width (b)

3.5 Effects of different application rates of agroforestry botanical extracts on cumulative rape yield (t ha⁻¹)

The results revealed a significant difference ($p < 0.05$) in the effects of different application rates of agroforestry plant extracts on *B. napus* yield. The effects of the agroforestry botanical extract concentration on yield were not significantly different at biweekly intervals (Table 1). The mean highest fresh rape yield (9.26 ± 0.02 t ha⁻¹) of rape was obtained from the 30 g L⁻¹ Tv treatment, which was not significantly different from that of the 30 g L⁻¹ Tm treatment (9.18 ± 0.07 t ha⁻¹) during the eighth week after sowing. During the second week after sowing, the lowest rape yield (0.80 ± 0.64 t ha⁻¹) was recorded from 10 g L⁻¹ Tv, which was not significantly different from that of 80 ml DM⁻¹ 100 L of water (1.53 ± 0.43 t ha⁻¹) and 30 g L⁻¹ *T. minuta* (1.62 ± 0.38 t ha⁻¹), although the yield varied from 30 g L⁻¹ Tv (1.77 ± 0.33). The use of *T. vogelii* and *T. minuta* in controlling aphids has shown greater rape yield benefits at 30 g L⁻¹ than any other pesticide powder concentration and/or dimethoate. A significant difference was also noted in the yield of rape among the different concentrations. The highest mean cumulative fresh rape yield was recorded at the 30 g L⁻¹ Tm botanical extract concentration (6.34 ± 0.16), and this value did not significantly differ among all the botanical extract concentrations.

Table 2. Mean rape yield at biweekly intervals

Botanical extract concentration	Biweekly rape fresh yield (t ha ⁻¹)				Cumulative fresh rape yield (t ha ⁻¹)
	2	4	6	8	
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
10 g L ⁻¹ Tv	0.80±0.64 ^a	4.83±0.32 ^b	6.73±0.24 ^d	8.68±0.20 ^e	5.44±0.36 ^d
10 g L ⁻¹ Tm	1.54±0.52 ^a	4.96±0.23 ^c	7.07±0.16 ^d	8.59±0.11 ^e	5.87±0.27 ^d
20 g L ⁻¹ Tv	1.61±0.40 ^b	5.49±0.38 ^c	6.81±0.22 ^d	8.11±0.24 ^e	5.84±0.34 ^d
20 g L ⁻¹ Tm	1.38±0.53 ^a	5.37±0.23 ^c	7.10±0.19 ^d	8.87±0.07 ^e	6.01±0.26 ^d
30 g L ⁻¹ Tv	1.77±0.33 ^b	5.21±0.42 ^c	7.55±0.16 ^d	9.26±0.02 ^f	6.28±0.31 ^d
30 g L ⁻¹ Tm	1.62±0.38 ^a	5.74±0.36 ^c	7.48±0.10 ^d	9.18±0.07 ^{ef}	6.34±0.16 ^d
80 ml DM ⁻¹ 100 L	1.53±0.43 ^a	5.64±0.39 ^c	7.83±0.08 ^e	8.85±0.12 ^e	6.29±0.23 ^d
P value	0.453	0.372	0.279	0.141	0.201
LSD	ns	ns	ns	ns	ns

Means without common superscripts within each column are significantly different ($p < 0.005$). LSD= Least significant difference, ns means not significant

4 Discussion

4.1 Effects of different application rates of agroforestry botanical extracts on the mean aphid count

The results revealed no significant difference ($P > 0.05$) in the mean aphid populations after foliar spraying (Table 1). This finding is in accordance with Dube & Maleka [10], who reported that the botanicals *A. absinthium*, *T. minuta* and *A. sativum* had some reductive effects on aphid populations even though their effects were lower than those of synthetic chemical insecticides. The decrease in the population of aphids on rape plants could have been caused by repellent and pesticide effects on both *T. vogelii* and *T. minuta*. This could have a similar effect, which caused garlic and chilli to be successful in the control of blights in tomatoes, as indicated by Ngaufe and Kugedera [38]. *Tephrosia vogelii* and *T. minuta* have strong smells, which are responsible for the effectiveness of the extracts in controlling aphids. This finding was similar to the observations of Karani et al. [19], who reported success in controlling aphids with garlic. The results of this study are also similar to those of Mollaei et al. [32] in the control of cabbage aphids (*Brevicoryne brassicae* L.) in canola (*Brassica napus* Linnaeus), with a mean aphid cabbage count of 12.86 ± 3.24 in the intercropping of 3 Canola: 3Faba beans and 14.60 ± 3.55 in the intercropping of 3 Canola: 3Faba peas. *Tephrosia vogelii* and *Tagetes minuta* contain various compounds with insecticidal properties that can help reduce aphid populations in rape. *Tephrosia vogelii* contains rotenoids, which are known for their insecticidal and acaricidal properties, which can disrupt aphid hormone systems and prevent reproduction; isoflavones exhibit insecticidal and antifeedant activities, deterring aphids from feeding on treated plants, and alkaloids can disrupt the aphid nervous system, leading to mortality or reduced reproduction [47]. *Tagetes minuta* contains pyrethrum, a natural insecticide that affects aphid nervous systems, causing paralysis and death; terthienyls, compounds that

exhibit insecticidal and antifeedant activities, reduce aphid populations; and flavonoids, which display insecticidal and growth-inhibiting properties, affecting aphid development and reproduction [9].

This study revealed a greater decrease in aphid percentage across all the botanical concentrations and was similar to the results of a study by Peris and Kiptoo [43], who reported that the Mexican marigold extract resulted in 52.8% mortality of aphids by the third week. The chemical composition of the plant species, spray droplets and distribution patterns caused differences in the effectiveness of the chemicals. The increase in aphid numbers per plant with the time interval from transplanting could be caused by the resistance of aphids to the chemicals used. Mudzingwa et al. [35] reported that methods used in extracting active ingredients from plants can also cause variation in chemical concentration, affecting their efficacy. The use of *T. vogelii* and *T. minuta* at 30 g L⁻¹ resulted in greater efficacy than the use of low concentrations in controlling aphids. This can be an inexpensive option for smallholder farmers, as the performance of the botanical extracts was better than that of dimethoate with time from sowing. The reduced number of aphids could be due to the repellent, toxic and antifeedant effects of the extracts, since they contain essential oil and alkaloid constituents with pesticidal properties [28, 47]. Similarly, Mkindi et al. [30] reported that the use of indigenous insecticidal plants has beneficial effects on pest populations and can be adopted by smallholder farmers to control insect pests.

The results of the present study are similar to those reported by Mpumi [33], although a notable discrepancy exists regarding the effect of the botanical concentration. Conversely, Mpumi [33] reported a significant negative correlation between the percentage concentration of *T. vogelii* (1%, 5%, and 10%) and the mean population per crop over time (weeks 2–4). Specifically, the lowest *T. vogelii* concentration (1%) yielded the highest mean population, with values of 0.60 ± 0.08 and 0.58 ± 0.08 in weeks 2 and 4, respectively. In contrast, the highest concentration (10%) resulted in substantially lower mean population values, with values of 0.25 ± 0.05 and 0.20 ± 0.05 in weeks 2 and 4, respectively. These findings suggest a concentration-dependent effect of *T. vogelii* on the mean population per crop. Similarly, the results of this study are in agreement with those reported by Lekamoi [22], who investigated the effects of *T. vogelii* on the population dynamics of *A. catalaunalis* and *A. bimaculata*. Specifically, Lekamoi [22] reported that the mean populations of *A. catalaunalis* cooccurring with *T. vogelii* at a concentration of 10% were 1.20 ± 0.00 and 0.66 ± 0.14 in the second and fourth weeks' post-emergence, respectively. In contrast, the mean populations of *A. bimaculata* cooccurring with *T. vogelii* at the same concentration (10%) were 1.06 ± 0.14 and 0.80 ± 0.00 in the second and fourth weeks' post-emergence, respectively. These findings suggest that *T. vogelii* has a species-specific effect on the population dynamics of *A. catalaunalis* and *A. bimaculata*.

4.2 Effects of different application rates of agroforestry botanical extracts on the number of rape leaves

The results revealed no significant difference in the mean number of leaves at each botanical concentration (Fig. 1). A positive trend was observed in the number of rape leaves over time and with increasing concentrations of the botanical extract. The increasing concentration of botanical extract

used to control aphids triggers nutrient levels, which increase the enlargement of plant cells and hence lead to vigorous growth. The results of this study revealed that 30 g L⁻¹ Tv botanical extract at 8 weeks had the greatest effect on increasing the number of rape leaves. At 2 weeks, both 10 g L⁻¹ botanical extract concentrations resulted in a minimal number of leaves, which could be attributed to a lower nutrient supply and less repellent effects. The 30 g L⁻¹ botanical extract concentrations of both *Tephrosia vogelii* and *Tagetes minuta* may stimulate plant growth, leading to an increase in the number of leaves by more than 40% and improved leaf retention by reducing aphid stress and promoting healthy growth. A relatively high botanical extract concentration could optimize nutrient uptake and promote branching, leading to an increased number of leaves with improved plant architecture and healthy leaf growth and development [48]. These results are consistent with the findings of Tembo et al. [45] on legume crops and Jang & Kuk [17] on lettuce (*Lactuca sativa* L. var. Crispa). Similarly, the *L. esculentum* leaf number reportedly increases with the application of botanical extracts to tomato (*Lycopersicon esculentum* Mill.) [3]. The number of leaves increased with increasing botanical extract concentration, and these results are consistent with the findings of Merwad [27] on peas and Elzaawely et al. [11] on snap bean (*Phaseolus vulgaris* L.).

Studies have shown that spraying rape crops with *Tephrosia vogelii* can reduce pest populations and increase the number of healthy leaves on the plants, while *Tagetes minuta* is known for its ability to repel pests with a strong aroma, and farmers can deter insect pests and protect their plants from damage [21, 47]. This can result in increased leaf production and overall health of the plant. These results are in agreement with those reported by Lekamoi [22], who investigated the effects of *T. vogelii* on sesame (*Sesamum indicum*) leaf production. Specifically, Lekamoi [22] reported a significant increase in the mean number of leaves in sesame plants treated with *T. vogelii* at a concentration of 10% over a two-week period. The mean number of leaves increased from 17.93 ± 0.18 in the second week to 20.93 ± 0.27 in the third week, indicating a progressive increase in leaf production over time. These findings suggest that *T. vogelii* has a positive effect on sesame leaf morphogenesis and development. In a study by Musara & Chitamba [36], the *A. angustissima* application rate (0.5, 1.0 and 1.5 t ha⁻¹) had no significant effect ($p > 0.05$) on the mean rape leaf number per plant in any of the treatments at any of the harvesting periods. A continued increase in the mean number of leaves for all the treatments was observed.

4.3 Effects of different application rates of agroforestry botanical extracts on plant height

The tallest rape plants were noted at a 30 g L⁻¹ *T. minuta* concentration during the eighth week, and the shortest rape plants were observed at 10 g L⁻¹ Tv two weeks after emergence (Fig. 2). These results corroborate the findings of Hemati et al. [15] on canola (*Brassica napus* L.) and Gonfa & Shiberu [13] on cabbage (*Brassicae oleracea*). The observed increase in the height of rape plants in response to increased concentrations of the botanical extracts may be attributed to the synergistic effects of the auxins, cytokinins, and alkaloids present in these extracts. These phytochemicals are known to regulate plant growth and development by promoting cell elongation, cell expansion, and cell division. Auxins, in particular, are involved in cell elongation and cell division, whereas cytokinins regulate cell growth and

differentiation [31]. Alkaloids, on the other hand, have been shown to modulate plant growth by influencing hormone regulation and signaling pathways. The combined action of these phytochemicals likely contributes to the enhanced plant growth and increased height observed in response to the botanical extracts [24, 29]. Lekamoi [22] reported a significant temporal increase in the height of sesame plants (*Sesamum indicum*) in response to treatment with *T. vogelii* at a concentration of 10%. Specifically, the mean plant height increased from 30.60 ± 0.35 cm in the second week to 71.00 ± 0.31 cm in the fourth week, indicating substantial growth enhancement over time. This observation suggests that *T. vogelii* had a positive effect on sesame plant growth and development, particularly in terms of height increase.

The study results are also consistent with findings reported by Allison [4] regarding plant height. Specifically, compared with the various Neem and Papaya extract treatments (6.5 v: v, 7.5 v: v, and 8.5 v: v), the control treatment yielded a significantly shorter mean plant height of pepper (13.0 cm). Among the treatments, Neem 8.5 v: v consistently presented the highest mean values for plant height (16.2 cm), leaf length (6.8 cm), and leaf width (4.5 cm), indicating a potential synergistic effect on plant growth promotion and insect repellency. These findings suggest that Neem extract at a concentration of 8.5 v: v may have a positive effect on plant morphometric parameters, warranting further investigation into its potential applications in sustainable agriculture.

4.4 Effects of different application rates of botanical extracts on leaf length and width (cm)

The present study revealed a significant trend ($p < 0.05$) in leaf length and width in response to increasing botanical concentration and biweekly interval measurements (Fig. 3a, 3b). These results were consistent with findings of Bosekeng [6] in rape (*Brassica napus* L.) and Çavusoglu & Karaferiyeli [7] in barley. Spraying rape plants with natural pesticides such as *Tephrosia vogelii* and *Tagetes minuta* can have various effects on leaf length and width. When natural pesticides are sprayed on rape plants, they can help protect the plants from damage caused by insects and reduce the need for synthetic pesticides [39]. The botanical extracts may help stimulate leaf growth, hormonal regulation, nutrient uptake enhancement and pest stress reduction. These may contain plant growth promoters or auxins that can increase leaf growth, leading to increased leaf length (by 5–10%) and leaf width (by 3–8%) [20]. The botanical extracts might influence the hormone balance in the plant, resulting in slightly increased leaf length and unchanged or slightly decreased leaf width and improved nutrient uptake, leading to increased leaf length and width (by 5–12%) [37]. By controlling aphid populations, these extracts may reduce stress on plants focused on growth and development, resulting in healthy leaf growth, with minimal changes in length and width. Musara & Chitamba [36] reported no significant differences ($p > 0.05$) in rape leaf length or width with different *A. angustissima* application rates (0.5, 1.0 and 1.5 t ha⁻¹) or placement methods (broadcasting and spot) in all periods of leaf measurement.

4.5 Varying effects of application rates of agroforestry botanical extracts on cumulative rape yield (t ha⁻¹)

The mean highest rape yield was recorded at the 30 g L⁻¹ concentration, as was the cumulative rape yield (Table 2). The increase in the concentration of botanicals was directly related to an increase in yield. This can be attributed to the reduction in aphid populations on rape leaves caused by the crude botanical extracts. The results of this study are in accordance with observations by Ganya et al. [12], who reported rape yields ranging from 8–25 t ha⁻¹; Ahlawat et al. [2] reported the control of aphids by Dimethoate 30% EC (1.79 t ha⁻¹) and Neem seed extract (1.56 t ha⁻¹) after 14 days of spray. Similarly, these results are comparable to those of Bosekeng [6], who reported the highest mean rape yield (0.040 g) at 75% vermicompost in Northeast China, Botswana. A similar trend was obtained by Araya et al. (2023), who reported a mean yield of 26.72 t ha⁻¹, and Nyakudya et al. [40], who reported a mean rape yield of 1.718 g plot⁻¹. In comparison, Pahla et al. [42] reported a greater rape yield of at least 55 t ha⁻¹ with 2.5 g of garlic and 2.5 g of chili for controlling aphids on rape. The nymph stage and adult stage damage plants by sucking sap from tender leaves, twigs, stems and inflorescences by piercing and sucking [19]. Aphids, if in large numbers, remove sufficient sap to kill the leaves and growing tips. Infected seedlings become stunted and distorted; continual feeding on mature plants causes wilting, yellowing and general plant stunting [35, 42], curling and subsequent drying of leaves, hence reducing yields [44]. Aphids also produce honey dew, which predisposes an affected plant to develop a black sooty mold, making the leaves age faster and reducing the photosynthetic surface area [19]. The highest pod yield (kg ha⁻¹) (493.25 ± 86.765) was observed in plots treated with *T. diversifolia*, whereas the highest seed yield (kg ha⁻¹) (289.35 ± 36.938) was observed in both plots treated with *T. diversifolia* and those treated with *T. vogelii*.

Conclusion

The results obtained from this study show that botanical extract pesticides have the potential to control pests in *Brassica napus* production. *T. vogelii* had better pesticidal effects on aphids at an application rate of 30 g L⁻¹ than at 30 g L⁻¹ *T. minuta*/L. Similar growth characteristics, including comparable leaf lengths, with all three groups displaying equivalent expansion rates, similar leaf widths, indicating analogous rates of lateral growth, and equivalent plant heights, suggest uniform vertical development and identical numbers of leaves, indicating comparable foliage production. Furthermore, an assessment of yield potentials revealed that *T. minuta*, *T. vogelii*, and plants treated with 80 ml DM⁻¹ 100 L of water also demonstrated substantially similar productivity levels, suggesting that these species and treatment concentrations may share comparable growth habits and output capacities. The use of synthetic pesticides can be completely substituted by the use of agroforestry botanical extracts, as shown in this study. Smallholder farmers are encouraged to adopt agroforestry plant extracts, which are far better, cost effective and ecologically friendly than the use of dimethoate in the control of aphids in rape, growth and yield potential.

Declarations

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Author contributions: All the authors contributed to the study conception and design. Experimental preparation, data collection and analysis were performed by Mango L., Nhete M. and Kugedera A.T. Manuscript drafting was performed by Nhete M., Kugedera A.T. and revised to the present form by Mango L. All the authors read and approved the final manuscript.

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Data availability: The manuscript contains all pertinent data necessary to substantiate the research findings. Nevertheless, if supplementary data are needed, they may be accessed by contacting the corresponding author upon reasonable request.

Ethics approval and consent to participate: Before commencing the experiment, all necessary permissions and approvals were formally obtained from the relevant authorities at the Agriculture Demonstration Plot, in accordance with prevailing regulations and guidelines. Moreover, comprehensive measures were taken to safeguard the welfare and rights of the plant species employed in the research, including adherence to stringent ethical protocols and adherence to established best practices for plant research, thereby minimizing potential risks or harm to the plant species.

Competing interests: The authors declare that they have no conflicts of interest/competing interests to disclose.

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Figures

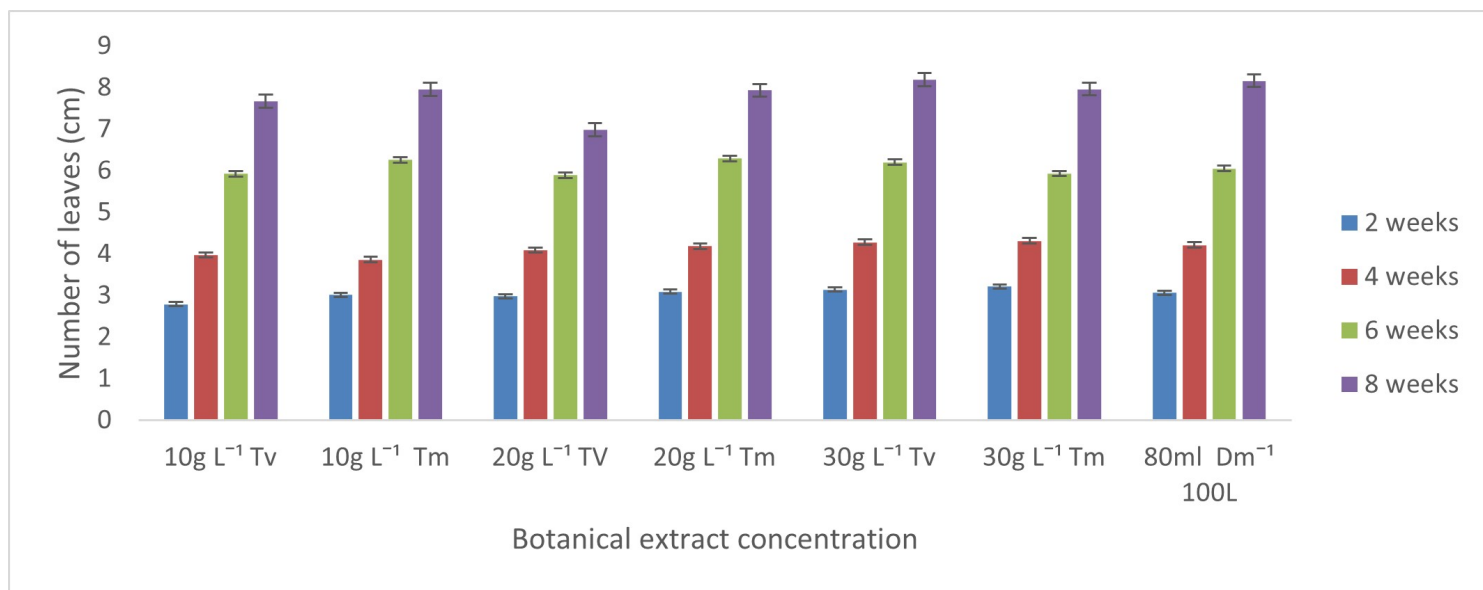


Figure 1

Effects of varying application rates of agroforestry botanical extracts on the number of rape leaves

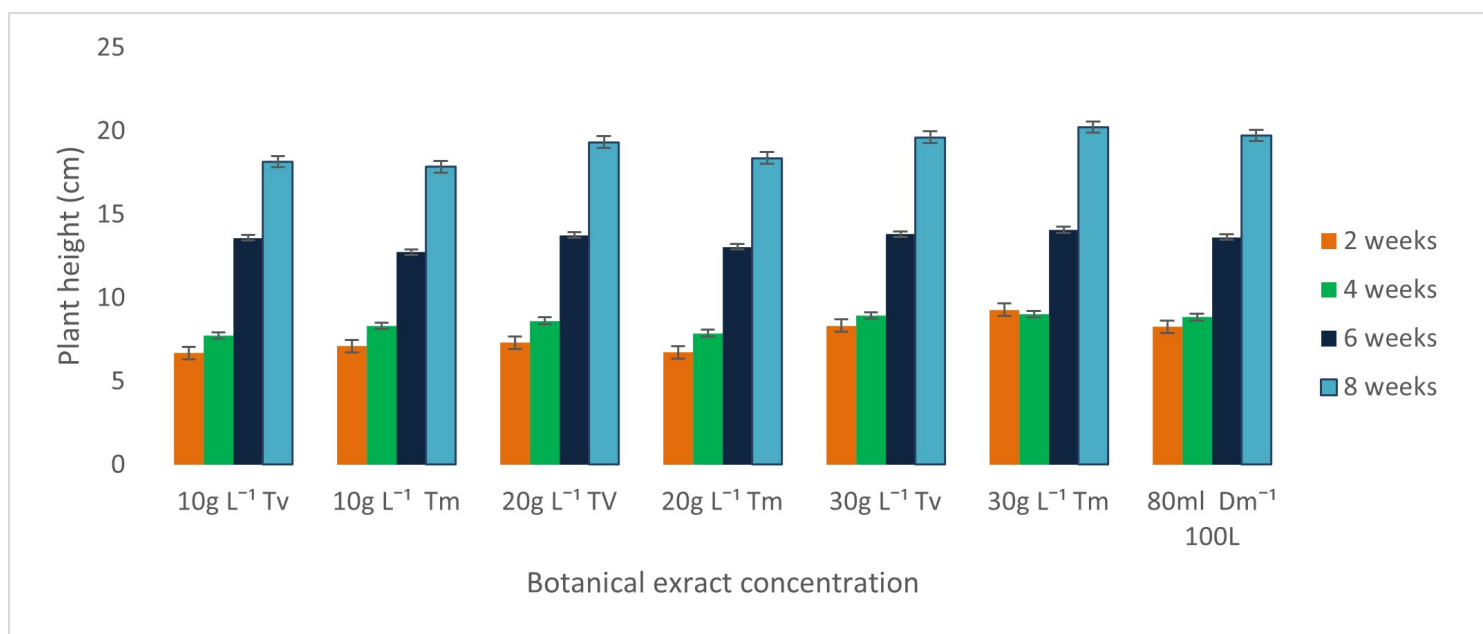


Figure 2

Effects of varying application rates of agroforestry botanical extracts on plant height

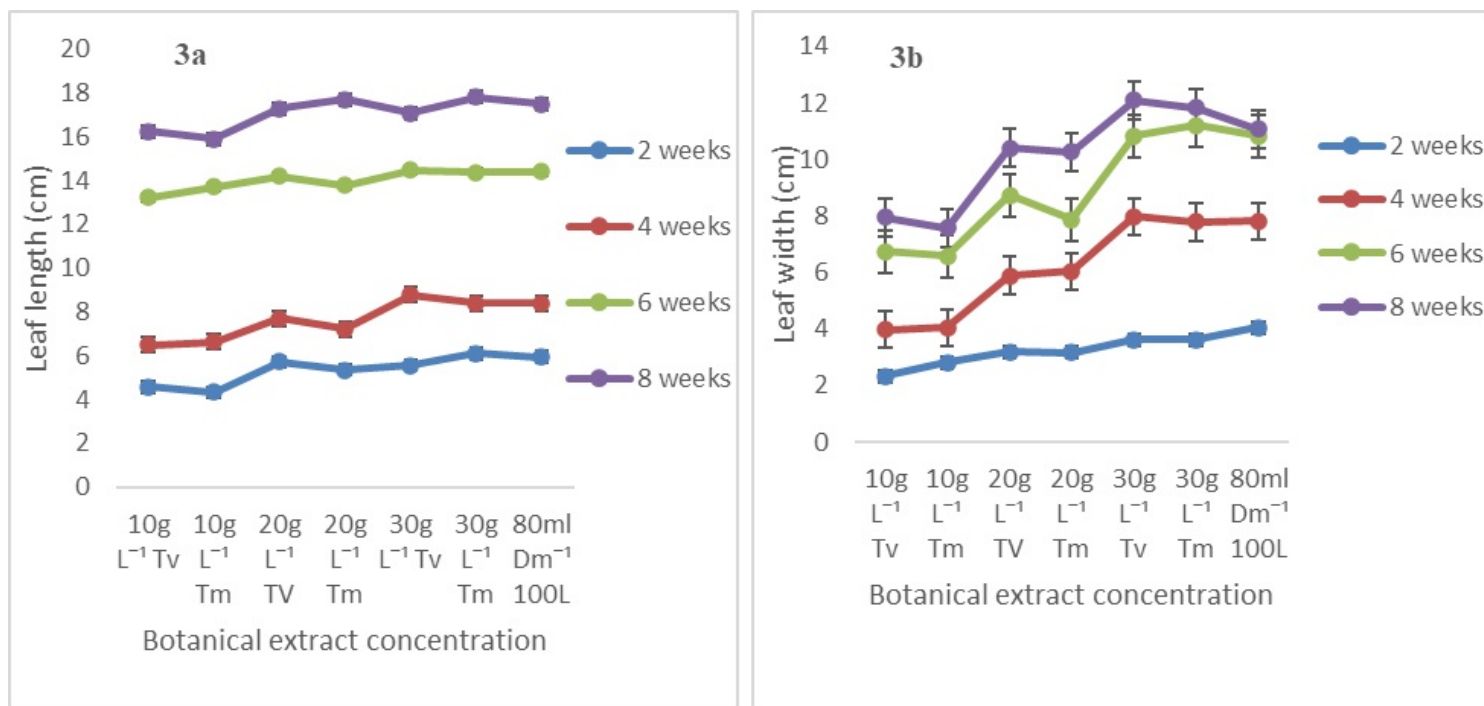


Figure 3

Effects of application rates of the botanical extracts on leaf length (a) and width (b)