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Effectiveness of Moringa (*Moringa oleifera* Lam) extracts in controlling insects and mites on tomato plants

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Abstract: **This study was to determine the effectiveness of Moringa (*Moringa olefera* Lam) extracts in controlling insects and mites on tomato plants. The study was conducted in Cape Coast in the Central Region of Ghana Three different concentrations of *Moringa oleifera* leaf, bark and root as well as water and a chemical insecticide were used in spraying tomato plants. Treatments were applied on plots of land laid in randomized complete block design. Insects and mites found on the tomato plants were observed at between 7 and 11 am every six days on each sub-plot and the number counted. Graphs were drawn and interpreted. Means were compared with analysis of Variance. Results showed that there were significant differences among the treatments ($p<0.05$) but insignificant for concentrations as well as between treatments and concentrations ($p>0.05$). Synthetic insecticide was the most effective against all the species studied. Reduction of species populations were treatment and concentration dependent. In all, Moringa root extract appeared to be the most promising in controlling four of the species studied. It is suggested that further research using Moringa extracts in reducing species numbers be carried out using higher concentrations of the extracts. Furthermore, the mechanism of the effect of the extracts in reducing the species populations should be studied.**

Keywords: **Moringa, effectiveness, population, roots, bark, leaf, tomato plants.**

1. INTRODUCTION

Tomato (*Lycopersicon esculentum*. Mill), a sprawling herbaceous plant (Peralta & Spooner, 2001) is one of the most important vegetables in the world (Asiedu *et al.*, 2020). It is considered as the most widely cultivated vegetables in Ghana (FAOSTAT, 2019, cited by Asiedu *et al.*, 2020). In Ghana, its production is seasonal and depends on the rains (Robinson & Kolavalli, 2010). It can be grown in every ecological zone in the country (Asiedu *et al.*, 2020). Because of its nutritional value, tomato is used by several people in preparing different types of meals. For example, it contains high levels of vitamins, minerals, folic acid, other trace elements, protein and dietary fibre (Hedges & Lister, 2005; Singh & Goyal, 2008), amino acids (leucine, threonine, valine, histidine, lysine, arginine), monounsaturated fatty acids (linoleic and linolenic acids), carotenoids (lycopene and β-carotenoids) and phytosterols (β-sitosterol, camp sterol and stigmasterol) (Hedges & Lister, 2005). Common varieties grown in Ghana are Roma VFN, Power, Lauren, Power Rano, Pectomech VF, Tropimech, Rio Grande, Woso woso, Jaguar, Lindo, Titao Derma, and Ada Cocoa (Melomey *et al.*, 2019).

Despite the many values and benefits of tomatoes, farmers at Cape Coast in the Central Region of Ghana complain of low yields from their farms due to a number of factors including negative effects of chemical pesticides on the land, the health of farmers and consumers as well as the invasion of insects pests on their farms. Generally, insect pests of tomato usually suck plant nutrients and transmit a number of viruses that cause problems such as leaf curl (Osei *et al.*, 2010), wilting and shedding of leaves, fruit falls associated with very heavy infestations. These at times result in decrease in yield. In West-

Africa, tomatoes are attacked by many insects including flea beetles and aphids which are responsible for heavy defoliation (Odebiyi, 1980). Heavy yield losses are reported in Nigeria and Ghana (Obeng-Ofori & Sackey, 2003, Ahmed *et al*., 2007).

Tomato plants in gardens are badly infested and injured by flea beetle. In most tomato production systems, including Cape Coast, farmers almost entirely rely on the use of chemical pesticides to combat insect pests and diseases (Biney, 2001, Berlin & Eitrem, 2005, Gianessi, 2009). Such chemical pesticides safeguard crops and improve farm productivity. As a result farmers continue using them. For example, the annual pesticide usage in Akumadan was estimated at 500 tons, of which 4% was made up of organochlorine compounds (Ntow, 2008). In many cases, unapproved pesticides are used. For example, out of the several pesticide formulations used by tomato farmers in the Upper East Region of Ghana (Biney 2001) only two were registered for use in Ghana. Studies in Ghana suggest that some farmers mix cocktails of two or more insecticides including obsolete insecticides (Ntow *et al*,, 2008, Wintuma, 2009).

The main contributing factor for farmers in resource-poor smallholder farms in Africa for that matter Cape Coast area in Ghana to use unapproved or banned pesticides is that such pesticides are affordable and effective in pest control (Williamson, 2003). A cursory observation of pesticide control practices of tomato farmers of Cape Coast area points to similar phenomena. However, there are increased concerns about potentially dangerous residues of chemical pesticides and their effects on the ecosystem (Cooper & Dobson, 2007). These chemicals can also have adverse effects on the applicators, the environment and consumers. It can also have other harmful effects such as toxicity to beneficial and other non-target organisms, pollution of the environment, tainting of produce, among others. Therefore, the sole reliance on synthetic insecticides to protect crops is not the best.

If tomato plants are left untreated with synthetic pesticides yield will greatly be affected. Meanwhile, application of the synthetic pesticides if continued with no healthier alternative it can lead to serious environmental problems and health issues. Therefore, there is the need to research into the use of alternative pesticides in controlling insect pests on tomato plants in Ghana including Cape Coast. Meanwhile, botanical insecticides such as Moringa (Nisar *et al*., 2021); neem tree (*Azadirachta indica*) (Erenso & Berhe**,** 2016; Hordzi, 2024); *Datura stramonium* L. (Jawalkar *et al*., 2016); *Securidaca longepedunculata* (Burkhill, 1997); *Zanha africana* (Radlk.) Exell (Sapindaceae) ((Swanepoel, 2013), garlic (*Allium sativum*) (Plata-Rueda *et al*., 2017) and others have been reported to control insects pests.

The health (Razis *et al*., 2014; Pareek *et al*., 2023), functional food and natural food additive functions (Hodas *et al*., 2021) and insecticidal functions (Nisar *et al*., 2021) of *Moringa olefera* (Family Moringaceae) have been trumpeted. In Ghana for that matter in Cape Coast area much is known about the medicinal/health and food additive benefits of Moringa, whereas very little if any insecticidal functions of Moringa is known. This necessitates the need to investigate the insecticidal effects of Moringa on insects and mites found on crops such as tomatoes in the Cape Coast area where tomato plants suffer drastic effects of pests. A favourable result would help the farmers to use Moringa to control tomato pests. This has the advantage of doing environmentally friendly tomato farming and production of healthy tomato fruits for human consumption.

Considering the above, the purpose of the study therefore was to determine the effectiveness of Moringa (*Moringa olefera* Lam) extracts in controlling insects and tomato mites on tomato plants. The specific objectives were to:

1. Assess the extent to which different Moringa extracts were able to reduce the number of insects and tomato mites on tomato plants in Cape Coast.
2. Determine the most effective Moringa concentration in reducing species numbers on tomato plants.

The research questions answered by the study were:

1. To what extent were different Moringa extracts able to reduce the number of insects and tomato mites on tomato plants in Cape Coast?
2. What was the most effective Moringa concentration in reducing species numbers on tomato plants?

The hypotheses tested were:

Null hypotheses:

H_{01}. There is no significant statistical difference among the mean numbers of insects and tomato mites affected by the different treatments.

H_{02}. There is no significant statistical difference among the mean numbers of species affected by the different concentrations of Moringa extracts.

Alternate hypotheses:

$H_{a1.}$ There is significant statistical difference among the mean numbers of insects and tomato mites affected by the different treatments.

H_{a2}There is significant statistical difference among the mean numbers of species affected by the different concentrations of Moringa extracts.

2. MATERIALS AND METHODS

Setting: The study was conducted in Cape Coast. Cape Coast is the capital city of Central Region of Ghana. It is situated between latitude 5°06'N and longitude 1°15'W (Ghana Statistical Service, 2012). It takes up around 122 square kilometers of space. The city is about 75 miles (120 km) southwest of the Ghanaian capital of Accra. The Gulf of Guinea borders the Metropolis on the south, the Komenda Edina Eguafo/Abrem Municipal on the west, the Abura Asebu Kwamankese District on the east, and the Twifo Hemang Lower Denkyira District on the north. The predominant vegetation cover is secondary forest, with thickets and bushes reaching average heights of 4.5 meters. (Ghana Statistical Service, 2012).

Raising seedlings: Two nursery beds measuring four meters by four meters were raised in a fine soil with small particles to the height of about 15cm (Greenlife: Crop Protection Africa, 2023). Power Rano and Pectomech are tomato varieties ideal for industrial processing because they contain high dry matter, have good colour, high brix, low pH or lower number of seeds (Asiedu *et al.*, 2020). Therefore, Pectomech tomato variety seeds were obtained from seed sellers in the Cape Coast Metropolis. The nursery beds were watered and after three days, the seeds were nursed. The nursery was covered by a shed to reduce sunlight effects. The beds were watered every day at 4.00pm until the seeds emerged after the eighth day. Watering continued up to one month.

Land preparation for transplanting: A plot of land measuring 55m by 55 m was prepared in the school farm of Holy Child Senior High School in Cape Coast**.** The plot was divided into 11 blocks and each block divided into 11 sub-blocks. One meter was left between two blocks and two sub-blocks respectively. This was to reduce the effect of each of the treatments blown by wind from influencing the results on untargeted block and sub-block. Thus, each sub-block measured four (4) meters by four (4) meters.

Transplanting of seedlings: When the seedlings were one month old, the nursery beds were watered to soften the soil. The seedlings were then uprooted and transplanted on the prepared field. On each subplot, the seedlings were planted in holes with a spacing of 60cm by 45cm (Greenlife: Crop Protection Africa, 2023). Therefore, on each sub-plot there were 48 stands of plants and one plant per stand.

Preparation of *Moringa* extracts: *Moringa oleifera* leaves, the bark and the roots were collected from a backyard garden in Cape Coast and dried in the open sun for one week. Fifty (50) grammes each of the dried leaves, bark and the root were weighed using a weighing scale. The weighed leaves, bark and root were pounded and ground into powder using pestle, mortar and grinding stone. Three different concentrations of the leaves, bark and root were prepared by weighing 20 grams of each of them placed into two liters (2L or 0.1kg/l)), four liters (4L or 0.05kg/l) and six liters (6L or 0.03kg/l)) of distilled water respectively. The 0.1kg/l was designated as concentration one (C1), which was the most concentrated, 0.05kg/l as concentration two (C2), which was less concentrated than C1 and 0.03kg/l as concentration three (C3) being the lowest concentration respectively.

Treatments and experimental design: The three *Moringa* extracts (leaf, bark and root), a chemical pesticide and control (only water) constituted the five treatments. Each of the extracts (leaf, bark and root) had three replicates (C1, C2 and C3) whereas control and chemical pesticide had a replicate each. However, for the sake of comparison they were also repeated and designated as C1, C2 and C3 respectively. An insecticide with commercial name Lambda containing the active ingredient Lambda-cyhalothrin is commonly used in Ghana by tomato farmers in pest control (Bandanaa *et al.*, 2024). Therefore, Lambda was the synthetic chemical pesticide used. The treatments were applied using randomized complete block design.

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Applications of the treatments: Each concentration of each treatment was sprayed directly on the tomato plants on each sub-plot two weeks after transplanting. The subsequent applications were done in two weeks intervals up to week 8. The spraying was done early in the morning.

Data collection and analysis: Type of insects and tomato mites on the tomato plants were observed at between 7 and 11 am every six days on each sub-plot. The number of each species was counted during the observation. The observation and counting started three days after the first spray and ended 20 days after the last spray. So, observation and counting was done for six times. In all, there were 11 sub-plots for each replicate. Number of each species counted was collated using SPSS Version 26. Means were calculated and graphs drawn and interpreted. Means were compared using two way analysis of variance (ANOVA).

3. RESULTS AND DISCUSSIONS

The insects found on the tomato plants were *Aphis* (Hemiptera, Aphididae), flea beetle: [*Altica* spp. (Insecta: Coleoptera: Chrysomelidae)], butterflies (Order Lepidoptera), ladybugs (Insecta: Coleoptera: Coccinellidae), and parasitic wasps (Hymenoptera). Also found on the plants were tomato mites commonly known as tomato russet mites (*Aculops lycopersici*) in the Class Arachnida; Family Eriophyidae.

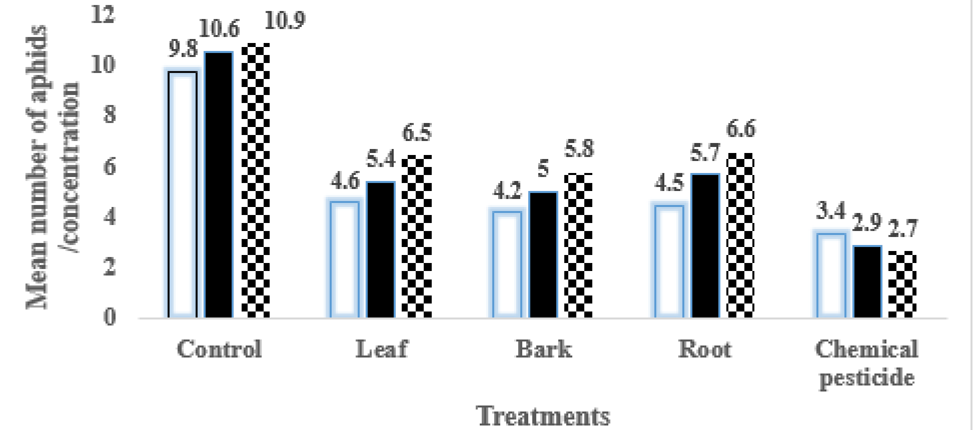

Figure 1. Mean number of aphids per treatment/concentration

The findings presented in Figure 1 highlight the efficacy of various Moringa extracts (leaf, bark, and root) and a chemical pesticide in controlling aphid populations on tomato plants. As expected, the control treatment (water) exhibited the highest aphid populations ranging from 9.8 to 10.9 per tomato plant. The absence of any deterrent or toxic agent in this treatment might have allowed aphid populations to increase, confirming the need for effective intervention in pest management strategies for tomato crops. A study by Osman and Elsobki (2019) also documented high pest populations in untreated control groups, emphasizing the vulnerability of crops to pest infestations without appropriate interventions.

The leaf, bark and root extracts of Moringa, at all concentrations, demonstrated notable reduction in aphid populations compared to the control. The insect populations on the plants were lowest for C1, followed by C2 and C3 respectively for all the extracts. This suggests a concentration-dependent efficacy of Moringa extract. On average aphid populations with regard to plants sprayed with water (control) was 10.43, bark extract was 5, leaf extract was 5.5, root extract was 5.6 and for synthetic insecticide was 3. This suggests that synthetic insecticide was the most effective in reducing aphid population, followed by bark extract, leaf extract, root extract and then control.

As expected, the synthetic or chemical pesticide provided the most significant reduction in aphid populations, with counts ranging from 2.7 to 3.4 aphids across the three concentrations. This aligns with findings of Idrees *et al*. (2022) proving the effectiveness of synthetic insecticides in controlling pest populations in agricultural systems. However, the potential environmental and health risks associated with chemical pesticide use, including soil contamination, non-target species impact, and pesticide resistance, cannot be overlooked. The relatively close efficacy of the Moringa extracts, particularly the bark extract, suggests that these natural alternatives could offer a more sustainable solution to pest control in tomato farming, reducing reliance on chemical inputs while mitigating environmental impacts.

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Table 1. ANOVA results of the efficacy of treatments on aphids

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Treatment	448.053	4	112.013	19.290	0.00
Concentration	19.227	2	9.613	1.656	0.20
Treatment * Concentration	12.107	8	1.513	0.261	0.98
Error	348.400	60	5.807		
Total	827.787	74			

The mean difference is significant at p = 0.05 level.

From Table 1, there is a significant difference between the various treatments ($p<0.05$) but not between their concentrations ($p>0.05$). This indicates that the treatments applied had a significant effect on reducing the aphid populations. The insignificance of the concentration factor could imply that the active compounds present in the Moringa extracts reach their maximum efficacy even at the lowest concentration, and increasing the concentration does not proportionally enhance their insecticidal properties. It is worth noting that there was no interaction between the treatments and their concentrations. The absence of a significant interaction implies that the effects of the treatments are independent of the concentration levels. In other words, regardless of whether a high or low concentration of Moringa extracts or chemical pesticide is applied, the type of treatment itself is the predominant factor for reducing aphid populations. This could further support the notion that natural treatments like Moringa extracts exhibit strong insecticidal effects at even low concentrations, making them both cost-effective and environmentally sustainable for pest management (Race *et al.*, 2012).

Since there was a significant difference between the treatments, a multiple comparison test was carried out (Table 2).

Table 2. Multiple comparison test amongst treatments based on their efficacy on aphids

Treatments		Mean Diff. (I-J)	Std. Error	Sig.
Control	Leaf	4.933*	0.880	0.00
Control	Bark	5.467*	0.880	0.00
Control	Root	4.800*	0.880	0.00
Control	Chemical pesticide	7.400*	0.880	0.00
Leaf	Bark	0.533	0.880	0.97
Leaf	Root	-0.133	0.880	1.00
Leaf	Chemical pesticide	2.467	0.880	0.05
Bark	Root	-0.667	0.880	0.94
Bark	Chemical pesticide	1.933	0.880	0.20
Root	Chemical pesticide	2.600*	0.880	0.04

The mean difference is significant at p = 0.05 level.

With p-values of 0.00 (Table 2), all of the comparisons between the treatment groups (chemical pesticide, leaf, bark and root) and the control group show statistically significant differences. These values indicate that all treatments, whether botanical (Moringa extracts) or chemical, significantly reduced aphid populations compared to the control plants.

The comparisons among the different Moringa extracts (leaf, bark, and root) show no statistically significant differences, suggesting that the insecticidal efficacy of the leaf, bark, and root extracts is relatively similar. While the bark extract was identified as the most potent treatment in Figure 1, the multiple comparison test suggests that the efficacy differences among the Moringa extracts are not statistically significant. In support of Salem *et al.* (2020), the bark extract did have the highest mean difference from the control, indicating that the bark extract is slightly more potent than the leaf or root extracts. The lack of significant differences between the leaf, bark, and root extracts shows that different parts of the Moringa plant can be used interchangeably with similar outcomes in aphid reduction.

There were significant differences between the chemical pesticide and the leaf extract ($p=0.05$) and also the root extract ($p<0.05$). This indicates that the chemical pesticide tends to be more effective than the leaf extract for reducing aphid populations, but the margin of difference is smaller than anticipated. As compared to root extract, the chemical pesticide is significantly more effective in controlling aphids. This aligns with the finding of Idrees *et al.* (2022) which highlights the superior efficacy of chemical pesticides due to their highly concentrated synthetic active ingredients that provide quicker and more consistent pest control. In contrast, the comparison between the bark extract and the chemical pesticide shows no significant difference (p = 0.20). The bark extract performed nearly as well as the chemical pesticide, making it a strong contender as an alternative aphid control agent.

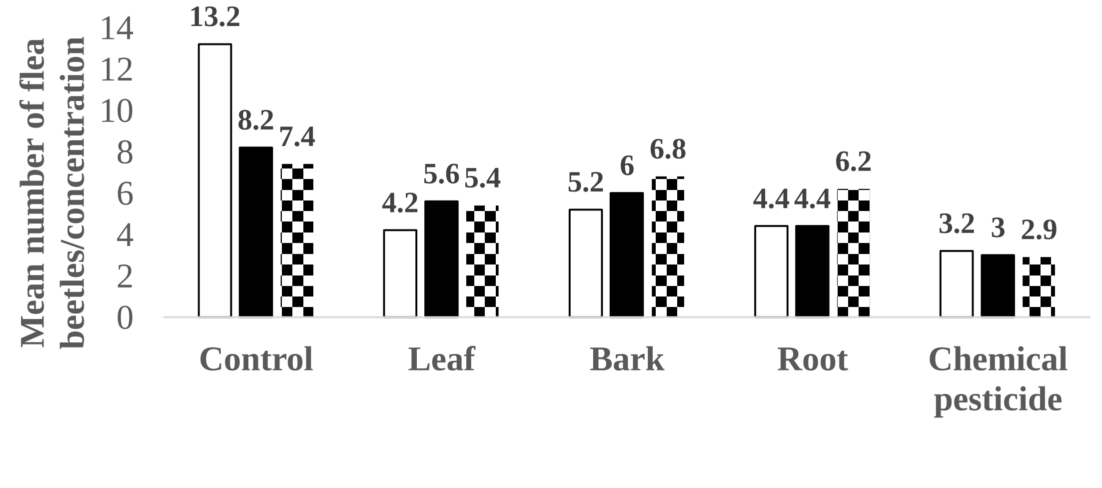

Figure 2. Mean number of flea beetles per tretment /concentration

Figure 2 presents the efficacy of Moringa extracts (leaf, bark, and root) and a chemical pesticide, on the number of flea beetles observed on tomato plants. The extracts were relatively effective in reducing the flea beetle population compared to the control group. These findings are consistent with studies of Ismael and Mohammed (2017) who found that leaf extract of *Moringa oleifera* was repellent against khapra beetle. Babarinde *et al* (2011) reported that *Moringa oleifera* leaf powder was effective on both the larvae and adults of *Trogoderma granarium* and showed repellent properties. Ojo *et al.* (2013) submitted that *Moringa oleifera* root powder was significantly effective against *C. maculates* in cowpea seed but mortality was dependent on the concentration of extract. In this study, the chemical pesticide consistently outperformed the Moringa extracts in reducing flea beetle populations. This is not surprising given the nature of synthetic pesticides, which are designed to target specific physiological pathways in pests with high efficacy. However, the environmental and health risks associated with chemical pesticides (Shah *et al.*, 2009) make plant-based alternatives like Moringa extracts a valuable area of research.

Table 3. ANOVA results of the efficacy of treatments on flea beetles

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Treatment	349.947	4	87.487	5.084	0.00
Concentration	4.667	2	2.333	0.136	0.87
Treatment * Concentration	122.533	8	15.317	0.890	0.53
Error	1032.400	60	17.207		
Total	1509.547	74			

The mean difference is significant at p = 0.05 level.

The ANOVA results on flea beetles have been presented in Table 3. There was a significant difference between the treatments only (p<0.05). This indicates that the different treatments (Moringa leaf, bark and root extracts, chemical pesticide, and control) differently impacted the number of flea beetles, suggesting that the treatments differently reduced flea beetle populations to varying degrees. The insignificant effect of concentration (p>0.05) on the flea beetle population suggests that varying the concentration of the treatments did not produce significant differences in the number of flea

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beetles. While one might expect higher concentrations of Moringa extracts or chemical pesticides to yield greater efficacy, the lack of significance implies that even lower concentrations were similarly effective. The interaction effect between treatment and concentration was also found to be insignificant (p>0.05), indicating that the combined influence of treatment type and concentration does not significantly affect the number of flea beetles. In other words, the effectiveness of each treatment (whether the Moringa leaf, bark, root extracts or the chemical pesticide) in controlling flea beetles does not change when you use different concentrations of the treatment. Whether you use a little or a lot of the treatment, it works the same.

The multiple comparison test results of the treatments have been presented in Table 4.

Table 4. Multiple comparison test amongst treatments based on their efficacy on Flea beetles

Treatments		Mean Diff. (I-J)	Std. Error	Sig.
Control	Leaf	4.467*	1.515	0.04
Control	Bark	3.533*	1.515	0.01
Control	Root	4.533*	1.515	0.03
Control	Chemical pesticide	6.600*	1.515	0.00
Leaf	Bark	-0.933	1.515	0.97
Leaf	Root	0.067	1.515	1.00
Leaf	Chemical pesticide	2.133	1.515	0.63
Bark	Root	1.000	1.515	0.96
Bark	Chemical pesticide	3.067	1.515	0.27
Root	Chemical pesticide	2.067	1.515	0.65

The mean difference is significant at p = 0.05 level

There were statistically significant differences between the effects of control and all Moringa extracts.as well as chemical pesticide. This suggests that there were differential effects among these treatments on flea beetles where the control had the least effect and the chemical pesticide the highest effect.

Amongst the Moringa extracts (leaf, bark and root), no significant differences were observed (p>0.05). This means the various parts of the Moringa plant (leaf, bark, and root) have similar insecticidal properties/abilities against flea beetles (Manzoor *et al*., 2015). Comparison between the Moringa extracts with the chemical pesticide revealed no statistically significant differences (p>0.05). Although the chemical pesticide produced the greatest reduction in flea beetle populations, the p-values suggest that its superiority over Moringa extracts was not statistically significant. This outcome supports the notion that botanical pesticides can serve as viable alternatives to synthetic chemicals (Shah *et al*., 2013). While the chemical pesticide was the most effective treatment for reducing flea beetle populations, Moringa extracts (leaf, bark, and root) provide competitive alternatives.

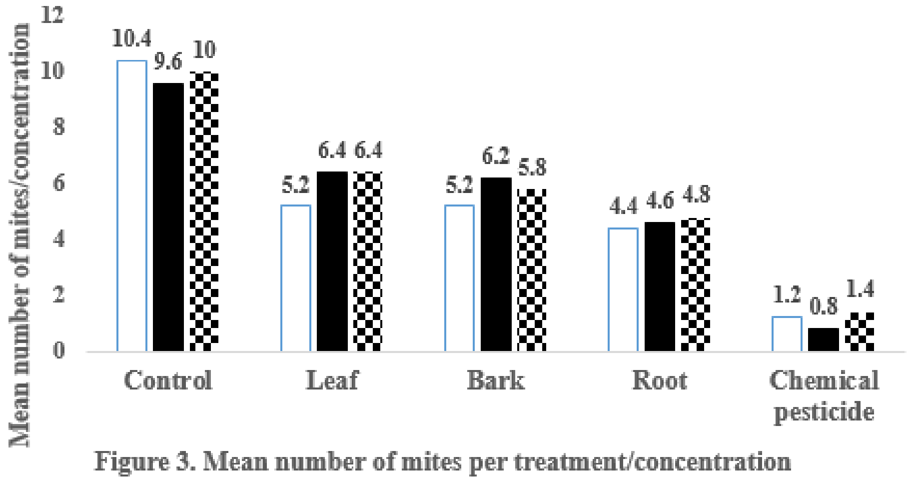

Figure 3. Mean number of mites per treatment/concentration

The results from Figure 3 demonstrate the efficacy of the treatments in reducing the number of mites on tomato plants. The chemical pesticide showed the lowest number of mites, with mean values of 1.2, 0.8, and 1.4 across. This highlights the efficacy of the chemical pesticide in controlling the mite population. The chemical pesticide, as expected, was the most zzzzzzzrthe development of pesticide resistance in pests, toxicity to non-target organisms, and contamination of soil and water (Kumar, 2012).

Among the Moringa extracts, the root extract appeared to be the most effective for reducing the mite population. The root extract yielded mean mite counts of 4.4, 4.6, and 4.8 across the three concentrations. This is a significant reduction compared to the control group. The bark extract followed closely with mean values of 5.2, 6.2, and 5.8 mites, indicating moderate efficacy. Leaf extract showed slightly higher mite counts, with values of 5.2, 6.4, and 6.4 mites, suggesting that it was the least effective of the three extracts but still substantially reduced the mite population compared to the control. The variation in effectiveness across the different plant parts may be due to differences in the bioactive compounds present in the leaves, bark, and roots of *Moringa oleifera.* Previous research has indicated that Moringa contains various bioactive compounds, such as isothiocyanates and alkaloids, which possess insecticidal properties (Saini *et al*., 2016). These compounds could be responsible for the reduction in mite populations. However, the varying concentrations of these compounds in different plant parts might explain why root extract was more effective than leaf or bark extract.

Table 5. ANOVA results of the efficacy of treatments on tomato mites

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Treatment	606.480	4	151.620	9.025	0.00
Concentration	2.027	2	1.013	0.060	0.94
Treatment* Concentration	8.240	8	1.030	0.061	1.00
Error	1008.000	60	16.800		
Total	1624.747	74			

The mean difference is significant at p = 0.05 level

The results from Table 5 show that there were significant differences in the effect of the different treatments on the mite population ($p < 0.05$). This indicates that there were differential effects of the treatments where the control was the least effective and the chemical pesticide the most effective in reducing the number of mites on the tomato plants. However, concentration as a factor did not have a statistically significant effect on mite reduction ($p>0.05$). Also, the interaction between treatment and concentration was found to be non-significant ($p = 1.00$).

The results of the multiple comparison test among the treatments have been presented in Table 6.

Table 6. Multiple comparison test amongst treatments based on their efficacy on tomato mites

Treatments		Mean Diff. (I-J)	Std. Error	Sig.
Control	Leaf	4.200*	1.497	0.04
Control	Bark	4.267*	1.497	0.04
Control	Root	5.400*	1.497	0.01
Control	Chemical pesticide	8.867*	1.497	0.00
Leaf	Bark	0.267	1.497	1.00
Leaf	Root	1.400	1.497	0.88
Leaf	Chemical pesticide	4.867*	1.497	0.02
Bark	Root	1.133	1.497	0.94
Bark	Chemical pesticide	4.600*	1.497	0.03
Root	Chemical pesticide	3.467	1.497	0.15

The mean difference is significant at p = 0.05 level

From Table 6, there are significant differences between the control and the other treatments ($p<0.05$). The control was ineffective; thus, it showed significantly higher mite counts compared to all the other treatments. Hence, all the other treatments were more effective for reducing mite counts on the tomato plants than the control.

In comparing the Moringa extracts to one another, the results show no statistically significant differences between the leaf, bark, and root extracts in terms of efficacy. This suggests that while there are observable differences in mean mite counts, with root extract generally performing best, these differences are not extreme enough to be statistically significant at the 0.05 level. In other words, all three Moringa extracts are equally effective and can be considered viable options for reducing mite populations.

There were significant differences between the chemical pesticides and the leaf extract (p=0.02), and chemical pesticides and the bark extract (p=0.03). This indicates that the chemical pesticide was significantly more effective than the leaf and bark extracts for reducing mite counts. However, the root extract did not show a statistically significant difference when compared to the chemical pesticide (p = 0.15), suggesting that root extract is equally as effective as the chemical pesticide for reducing mite counts. This outcome once again supports the notion that botanical pesticides can serve as viable alternatives to synthetic chemicals (Shah *et al*., 2013).

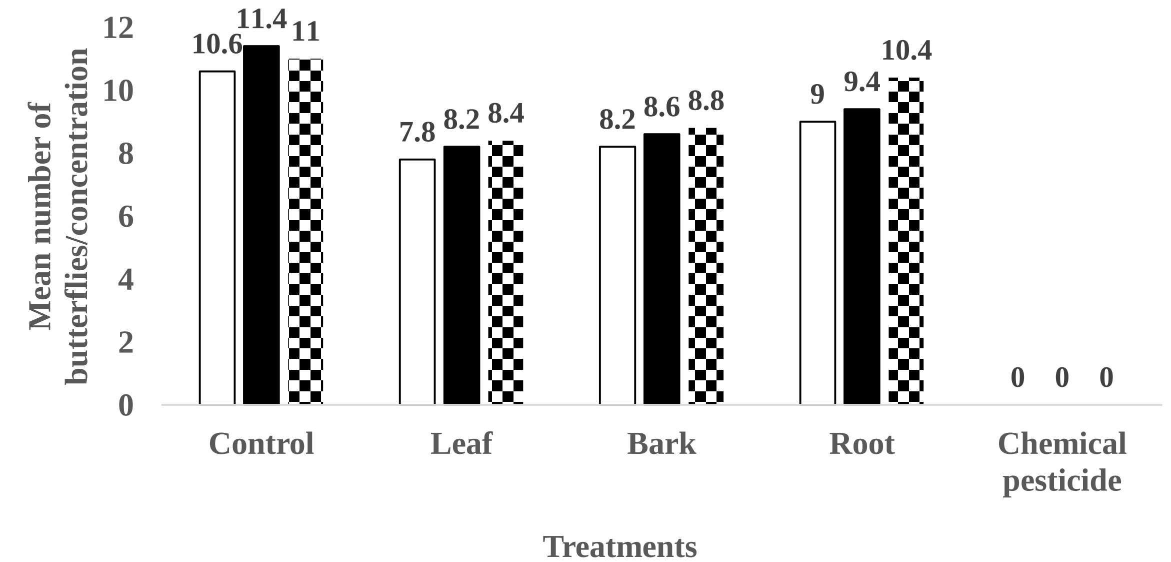

Figure 4. Mean number of butterflies per treatment/concentration

□ Con. 1 ■ Conc. 2 Conc. 3

From Figure 4, the control treatment consistently showed a high number of butterflies, with mean number of butterflies ranging from 10.6 to 11.4. This indicates that water, used as a control, did not influence the insect population on the tomato plants, as expected. This finding confirms the results of the study by Osman and Elsobki (2019) showing documented high pest populations in untreated control groups, emphasizing the vulnerability of crops to pest infestations without appropriate interventions.

All the Moringa extracts reduced the number of butterflies on tomato plants compared to the control, though to varying extents. Notably, the root extract at all concentrations was the least effective among the Moringa extracts and the chemical pesticide. The leaf and bark extracts were the most potent among the Moringa extracts. Both showed reductions in the mean number of butterflies (leaf: 7.8 to 8.4, bark: 8.2 to 8.8) across the concentrations. Previous studies have demonstrated that Moringa leaves possess alkaloids, flavonoids, and saponins, which have been associated with insecticidal activity (Saini *et al*., 2016).

On the other hand, the chemical pesticide completely eliminated butterflies, highlighting its superior insecticidal efficacy against butterflies. This outcome is expected given the potency of synthetic chemical pesticides, which are designed to target a broad range of insect pests effectively.

Table 7. ANOVA results of the efficacy of treatments on butterflies

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Treatment	1115.520	4	278.880	13.089	0.00
Concentration	4.667	2	2.333	0.110	0.90
Treatment * Concentration	4.000	8	0.500	0.023	1.00
Error	1278.400	60	21.307		
Total	2402.587	74			

The mean difference is significant at p = 0.05 level

The ANOVA results from Table 7 reveal high significant differences in effect of the treatments on butterfly numbers (p=0.00). This suggests that the various treatments affected the butterfly population differently, where water (control) was the worst and the chemical pesticide was the best. However, there were no significant differences among the concentrations of treatments (p=0.90) and also there were no significant statistical differences among the treatments and their concentrations (p=1.00). This implies that the efficacy of the treatments is independent of the concentration applied.

Since there was a significant difference between the treatments, a multiple comparison test was carried out (Table 8).

Table 8. Multiple comparison test amongst treatments based on their efficacy on butterflies

Treatments		Mean Diff. (I-J)	Std. Error	Sig.
Control	Leaf	2.867	1.685	0.44
Control	Bark	2.467	1.685	0.59
Control	Root	1.400	1.685	0.92
Control	Chemical pesticide	11.000*	1.685	0.00
Leaf	Bark	-0.400	1.685	1.00
Leaf	Root	-1.467	1.685	0.91
Leaf	Chemical pesticide	8.133*	1.685	0.00
Bark	Root	-1.067	1.685	0.97
Bark	Chemical pesticide	8.533*	1.685	0.00
Root	Chemical pesticide	9.600*	1.685	0.00

The mean difference is significant at p = 0.05 level

The results from Table 8 show that there were no significant differences between the effects of Moringa extracts (leaf, bark, or root) and the control group. This suggests that the Moringa extracts, while somewhat effective for reducing butterfly numbers compared to the control, did not achieve a level of reduction substantial enough to be considered significant. A study by Ojiako *et al.* (2013) elaborates that Moringa extracts have insecticidal properties against a wide range of insects. However, butterflies, in this study, have proven not to be part of insects that can be easily controlled by Moringa extracts. In any case, this sounds good because, to large extent butterflies are useful insects that need to be conserved.

When comparing the Moringa extracts against each other, no significant differences were observed. These results suggest that, in terms of efficacy, the different parts of the Moringa plant (leaf, bark, and root) performed similarly for reducing butterfly populations.

The chemical pesticide showed a significant reduction in butterfly numbers compared to the control (p = 0.00), leaf extract (p = 0.00), bark extract (p = 0.00) and root extract (p = 0.00). The superior performance of the chemical pesticide is consistent with its design as a synthetic, broad-spectrum insecticide.

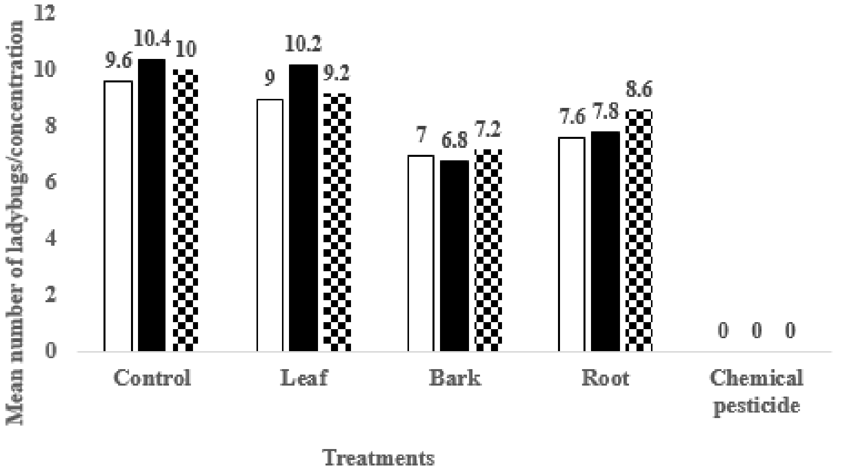

Figure 5. Mean number of ladybugs per treatment/concentration

From Table 5, the control group showed consistently higher mean numbers of ladybugs, ranging from 9.6 to 10.4. This suggests that in the absence of any active treatment, ladybug populations remained relatively high, confirming the susceptibility of tomato plants to insect infestations in untreated conditions (Osman & Elsobki, 2019). The leaf extract demonstrated a noticeable reduction in the mean number of ladybugs compared to the control, particularly at higher concentrations. Concentrations 2 and 3 of the leaf extract recorded mean ladybug populations of 10 and 9.2, respectively. Though these numbers are still relatively high, they do suggest a marginal improvement over the control. This indicates that leaf extracts may have some insecticidal properties (Ismael & Mohammed, 2017) but may require higher concentrations or longer treatment durations to achieve significant reductions in ladybug populations.

In contrast, the bark extract proved to be the most effective among the Moringa treatments, with a marked reduction in the mean number of ladybugs across all concentrations. The second highest concentration (C2) reduced the ladybug population to a mean of 6.8, which is significantly lower than the control group. This suggests that bark extracts possess stronger insecticidal properties than leaf extracts and may be more suitable for reducing ladybug counts at moderate to high concentrations. The root extract also reduced the ladybug population more effectively than the leaf extract but was not as effective as the bark extract. Moringa contains various bioactive compounds, such as isothiocyanates and alkaloids, which possess insecticidal properties (Saini *et al.*, 2016). These compounds could be responsible for the reduction in ladybug populations. However, the varying concentrations of these compounds in different plant parts might explain why bark extract was more effective than leaf or root extract.

The chemical pesticide treatment was the most effective, reducing the mean number of ladybugs to zero across all concentrations. This stark contrast highlights the superior efficacy of chemical pesticides in eliminating insects compared to Moringa extracts, despite the fact that they have negative sides (Fountain &Wratten., 2013). Therefore, exploring natural alternatives such as Moringa extracts is essential, particularly for organic farming and sustainable agriculture.

Table 9. ANOVA results of the efficacy of treatments on ladybug

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Treatment	975.413	4	243.853	89.872	0.00
Concentration	2.427	2	1.213	0.447	0.64
Treatment * Concentration	6.507	8	0.813	0.300	0.96
Error	162.800	60	2.713		
Total	1147.147	74			

The mean difference is significant at p = 0.05 level

From Table 9, there is a significant difference among the various treatments ($p<0.05$) but not between their concentrations ($p>0.05$). This indicates that different treatments might have differently affected the population of ladybugs. The insignificance of the concentration factor could imply that the active compounds present in the Moringa extracts reach their maximum efficacy even at the lowest concentration, and increasing the concentration does not proportionally enhance their insecticidal properties. It is worth noting that there was no interaction between the treatments and their concentrations. The absence of a significant interaction implies that the effects of the treatments are independent of the concentration levels.

Significant differences among the treatments led to multiple comparison test and results presented in Table 10.

Table 10. Multiple comparison test amongst treatments based on their efficacy on ladybug

Treatments		Mean Diff. (I-J)	Std. Error	Sig.
Control	Leaf	0.533	0.601	0.90
Control	Bark	3.000*	0.601	0.00
Control	Root	2.000*	0.601	0.01
Control	Chemical pesticide	10.000*	0.601	0.00
Leaf	Bark	2.467*	0.601	0.00
Leaf	Root	1.467	0.601	0.12
Leaf	Chemical pesticide	9.467*	0.601	0.00
Bark	Root	-1.000	0.601	0.46
Bark	Chemical pesticide	7.000*	0.601	0.00
Root	Chemical pesticide	8.000*	0.601	0.00

The mean difference is significant at p = 0.05 level

From Table 10, it can be observed that there is no significant difference between the control and the leaf extract (p>0.05). This means that the leaf extract was as ineffective as the control for reducing ladybug counts, although Babarinde *et al*. (2011) reported that *Moringa oleifera* leaf powder was effective on both the larvae and adults of *Trogoderma granarium* and showed repellent properties.

The significant difference between the control and the other Moringa extracts (bark and root) indicates that both bark and root extracts are more effective than the control. Ojo *et al*. (2013) intimated that *Moringa oleifera* root powder was significantly effective against *C. maculates* in cowpea seed but mortality was dependent on the concentration of extract. It can also be deduced from Table 10 that amongst the Moringa extracts, the most effective treatment for reducing ladybug populations was the bark extract. Significant differences were observed between the chemical pesticide and all the Moringa extracts (p<0.05). This indicates that the chemical pesticides were vastly more effective than all the Moringa extract, reducing ladybug populations to a far greater extent. Once more, this finding depicts the chemical pesticide as the most suitable treatment for reducing ladybug populations.

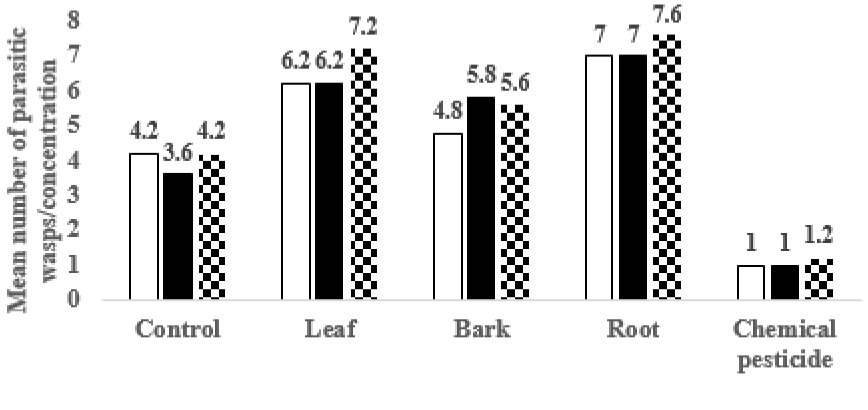

Figure 6. Mean number of parasitic wasps per treatment/concentration

The results from Figure 6 illustrate the mean number of parasitic wasps observed on tomato plants subjected to various treatments. Interestingly, despite being just water, the control treatment did reduce the parasitic wasp population. The mean numbers of parasitic wasps were 4.2, 3.6, and 4.2 respectively. While this reduction may not be as significant as that of the chemical pesticide, it indicates that either body physiological factors of the insect or external factors, such as water application or other environmental conditions, might have played a role in the decline in the parasitic wasp population.

The bark extract proved to be the most effective Moringa extract for reducing the parasitic wasp population compared to leaf and root. The mean numbers of parasitic wasps observed were 4.8, 5.8, and 5.6 for concentrations 1, 2, and 3, respectively. These values are consistently lower than those observed with the leaf extract, indicating that the bark contains more effective parasitic wasps-reducing compounds. The bark extract's ability to significantly reduce the wasp population suggests its potential as a natural insecticide (Nwachukwu *et al*., 2014), particularly when considering its greater efficacy compared to the leaf extract. The Moringa leaf extract was the second most effective among the natural treatments, followed by the root extract. The number of parasitic wasps observed was 6.2 for both concentrations 1 and 2, and slightly higher at 7.2 for concentration 3. While this extract reduced the wasp count compared to the root extract, the overall effect was less pronounced than the bark extract. The moderate effectiveness of the leaf extract suggests that while it contains compounds that may reduce wasp numbers, it is not the most potent part of the Moringa plant for this purpose.

As anticipated, the chemical pesticide treatment resulted in the lowest mean number of parasitic wasps, with values of 1, 1, and 1.2. This once again demonstrates its superior ability to reduce insect populations compared to all other treatments. However, as usual, given the environmental and health concerns surrounding synthetic pesticides (Fountain & Wratten, 2013), natural alternatives such as Moringa extracts remain valuable, despite their slightly lower efficacy. Meanwhile, since ordinary water appeared to have reduced parasitic wasps numbers in this study, it can be suggested that in the absence of chemical pesticides, application of water may help reduce numbers to a large extent.

Table 11. ANOVA results of the efficacy of treatments on parasitic wasps

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Treatment	355.413	4	88.853	34.618	0.00
Concentration	3.920	2	1.960	0.764	0.47
Treatment * Concentration	4.747	8	0.593	0.231	0.98
Error	154.000	60	2.567		
Total	518.080	74			

The mean difference is significant at p = 0.05 level

Results from Table 11 show a significant difference between the various treatments (p<0.05) but not between their concentrations (p>0.05). This indicates that the treatments applied had a significant differential effects on reducing the parasitic wasp population. The insignificance of the concentration factor could imply that the active compounds present in the Moringa extracts reach their maximum efficacy even at the lowest concentration, and increasing the concentration does not proportionally enhance their insecticidal properties. It is worth noting that there was no significant interaction between the treatments and their concentrations. The absence of a significant interaction implies that the effects of the treatments are independent of the concentration levels.

Results of multiple comparison test for the treatments have been presented in Table12.

Table 12. Multiple comparison test amongst treatments based on their efficacy on parasitic wasps

Treatments		Mean Diff. (I-J)	Std. Error	Sig.
Control	Leaf	-2.533*	0.585	0.00
Control	Bark	-1.400	0.585	0.13
Control	Root	-3.200*	0.585	0.00
Control	Chemical pesticide	2.933*	0.585	0.00
Leaf	Bark	1.133	0.585	0.31
Leaf	Root	-0.667	0.585	0.79
Leaf	Chemical pesticide	5.467*	0.585	0.00
Bark	Root	-1.800*	0.585	0.03
Bark	Chemical pesticide	4.333*	0.585	0.00
Root	Chemical pesticide	6.133*	0.585	0.00

The mean difference is significant at p = 0.05 level

When comparing the control treatment (water) to the Moringa extracts, there are significant differences in efficacy, particularly with the leaf and root extracts (p=0.00), indicating that water reduced the parasitic wasp population more effectively than the leaf and root extracts. On the other hand, the comparison between the control and bark extract does not yield a statistically significant result (p = 0.13). This implies that the efficacy of the bark extract in reducing wasp count is similar to that of water.

There was no significant difference between the Moringa leaf extract and the bark extract (p=31). This suggests that both leaf and bark extracts have similar effects in controlling parasitic wasp populations (Ismael & Mohammed, 2017), though the bark extract is marginally more effective. The comparison between the bark extract and root extract reveals a statistically significant difference (p = 0.03), indicating that the bark extract is more effective in reducing parasitic wasps than the root extract.

As usual, the chemical pesticide showed a significant reduction in parasitic wasp numbers compared to the control (p = 0.00), leaf extract (p = 0.00), bark extract (p = 0.00) and root extract (p = 0.00). The superior performance of the chemical pesticide is consistent with its design as a synthetic, broad-spectrum insecticide (Idrees *et al*., 2022). Therefore, the most effective treatment for reducing wasp counts on tomato plants was the chemical pesticide.

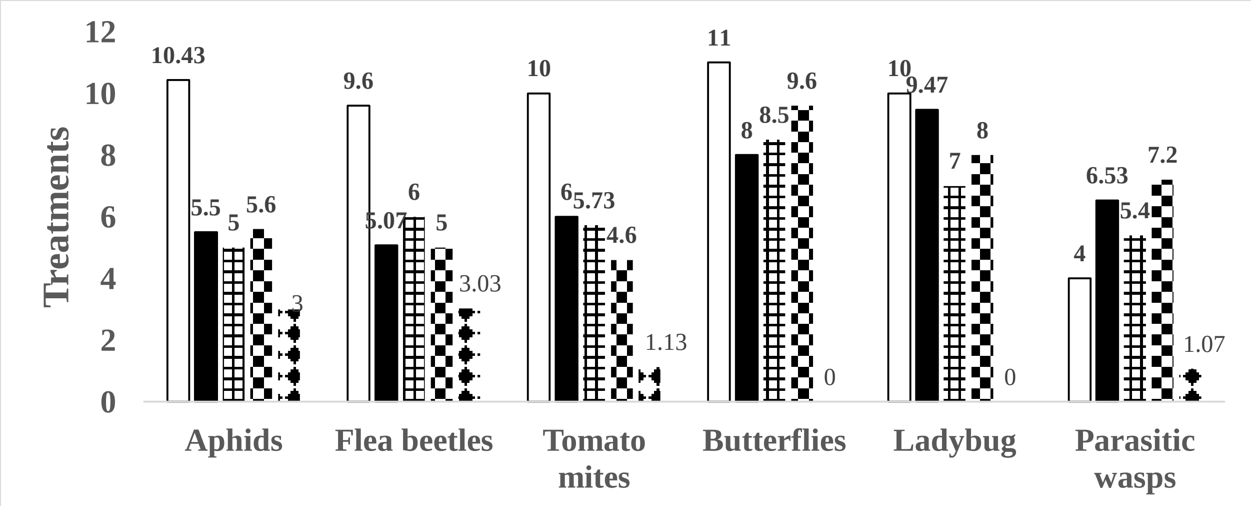

Figure 7. Mean number of insects/treatment

From Figure 7, it is evident that apart from parasitic wasps, the control group (water) consistently exhibited the highest number of insects across all categories, which is expected as no treatment was applied. For instance, aphids in the control group numbered 10.43, significantly higher than in the treated groups, where numbers ranged from 5.0 to 5.6 for the natural extracts and 3.0 for the chemical pesticide. This trend persists across all species measured, indicating that all treatments, whether natural Moringa extracts or chemical pesticides were effective to some degree in reducing insect populations compared to the control (Ojiako *et al*., 2013).

When comparing specific species, aphids, flea beetles, tomato mites, butterflies, ladybugs, and parasitic wasps exhibited varying responses to the treatments. Notably, the chemical pesticide performed best in reducing the population of tomato mites, parasitic wasps, and flea beetles, with numbers reduced to as low as 1.13, 1.07, and 3.03, respectively. Moringa extracts, while generally effective, showed some variations. For example, root extract seemed to perform consistently well across all species except butterflies and ladybugs. The leaf and bark extracts, however, showed mixed efficacy, with leaf extracts particularly effective against aphids and parasitic wasps, reducing their populations to 5.0 and 4, respectively. This variation in performance suggests that different insect species respond differently to the bioactive compounds in each Moringa extract (Saini *et al*., 2016). For example, aphids were most effectively controlled by the bark and root extracts, while tomato mites were more susceptible to the chemical pesticide, with natural treatments like root extract still offering competitive efficacy.

The results indicate that Moringa root extract may have the greatest overall efficacy among the natural treatments, as it significantly reduced insect numbers for most of the species studied. The leaf extract, while effective for some species (such as aphids and parasitic wasps), did not perform as well against tomato mites or butterflies. Similarly, the bark extract's effectiveness varied across species, performing relatively well against tomato mites and parasitic wasps but less so against aphids and butterflies.

Table 13. ANOVA results of the test of between-subjects effects (mean number of insects per treatment)

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Treatments	195.405	4	48.851	15.969	0.00
Insects	22.408	5	4.482	1.465	0.25
Error	61.184	20	3.059		
Total	1376.587	30			

The mean difference is significant at p = 0.05 level

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The ANOVA results from Table 13 indicate a highly significant treatment effect (p = 0.00). This suggests that the treatments, which includes the leaf, bark, and root extracts of Moringa, the chemical pesticide, and the control, had significantly different effects on reducing the insect populations. The large sum of squares for the treatments (195.405) compared to the error (61.184) further reinforces that the treatments accounted for a substantial proportion of the variation in insect numbers across the different experimental groups. This means that the differences in insect populations are primarily attributable to the effects of the treatments rather than random variation.

In contrast to the significant treatment effect, the variation in species (aphids, flea beetles, tomato mites, butterflies, ladybugs, and parasitic wasps) was not significant (p=0.25). This indicates that the treatments had relatively uniform effects across the different species.

Results of multiple comparison test among the treatments have been presented in Table 14.

Table 14. Multiple comparison test amongst treatments based on mean number of insects per treatment

Treatments		Mean Diff. (I-J)	Std. Error	Sig.
Control	Leaf	2.410	1.010	0.16
Control	Bark	2.900	1.010	0.06
Control	Root	2.505	1.010	0.14
Control	Chemical pesticide	7.800*	1.010	0.00
Leaf	Bark	0.490	1.010	1.00
Leaf	Root	0.095	1.010	1.00
Leaf	Chemical pesticide	5.390*	1.010	0.00
Bark	Root	-0.395	1.010	1.00
Bark	Chemical pesticide	4.900*	1.010	0.00
Root	Chemical pesticide	5.295*	1.010	0.00

The mean difference is significant at p = 0.05 level

The comparison between the control and the Moringa extracts (leaf, bark, and root) shows no statistically significant differences (p>0.05). This means that the reductions in insect populations for these natural treatments were not statistically significant compared to the untreated control group. This lack of significance suggests that while the Moringa extracts did reduce insect numbers, their effects were not large enough to show a clear distinction from the control group. However, the bark extract (p = 0.06) was relatively close to the significance threshold, indicating that with a larger sample size or more concentrated treatment, it might yield significant results. In contrast, the chemical pesticide showed a highly significant reduction in species populations compared to the control, with a p-value of 0.00. Again, this highlights the chemical pesticide's strong efficacy in controlling pests (Idrees *et al*., 2022), clearly outperforming both the control and the Moringa extracts.

When comparing the three Moringa extracts, the differences in mean species populations were not statistically significant (p>0.05). This suggests that all three Moringa extracts performed similarly in terms of their ability to reduce species numbers, and none of them was significantly more effective than the other. The chemical pesticide consistently outperformed all three Moringa extracts in reducing species numbers, with highly significant mean differences observed in each comparison. All of these comparisons had p-values well below 0.05, indicating that the chemical pesticide was significantly more effective at reducing species populations than the Moringa extracts. This finding reinforces the strength of the chemical pesticide in insect pest management, as it achieved a markedly greater reduction in species populations than the natural treatments.

4. CONCLUSIONS

- The various species generally exhibited varying responses to the treatments, where the chemical pesticide performed best in reducing the population of tomato mites, parasitic wasps, and flea beetles.

- The significant statistical differences among the treatments go a long way to show that the treatments accounted for a substantial proportion of variation in species numbers across the different experimental groups. Thus, the differences in species populations are primarily attributable to the effects of the treatments rather than random variation.

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- Different insect species and the mite responded differently to the bioactive compounds in each Moringa extract showing that there were some variations such that root extract seemed to perform consistently well across all species except butterflies and ladybugs. Therefore, despite the fact that Moringa treatments had relatively uniform effects across the different species, root extract may have the greatest overall efficacy among the natural treatments, as it significantly reduced the numbers for most of the species studied.

- Though there were no significant statistical differences among the effects of the different concentrations of Moringa extracts on the various species, concentration 1, which is the most concentrated extract seemed most promising followed by concentration 2. Thus, it is possible that higher concentrations of Moringa extracts may be more efficacious in reducing numbers of species and subsequently pests on tomato plants.

- Since there were no significant differences between the leaf, bark, and root extracts, different parts of the Moringa plant can be used interchangeably with similar outcomes in aphid population reduction.

- Though the differences among the effects of the three extracts on aphids were not statistically significant, but the bark extract performed nearly as the chemical pesticide, bark extracts showed most promising control effects on aphids among the three extracts.

- Although the chemical pesticide produced the greatest reduction in flea beetle populations, its superiority over Moringa extracts was not statistically significant, suggesting that Moringa extracts (leaf, bark, and root) provide competitive alternatives.

- All three Moringa extracts were equally effective and can be considered viable options for reducing mite populations. However, despite the fact that the chemical pesticide produced the best population reduction effect on tomato mites, the fact that the root extract did not show a statistically significant difference when compared to the chemical pesticide ($p = 0.15$) suggests that root extract is equally as effective as the chemical pesticide for reducing mite counts. Thus, root extract could be used in controlling tomato mites in place of the chemical pesticide.

- In general terms, though the chemical pesticide was more effective than all the Moringa extracts in reducing ladybug populations, bark extract could be used if Moringa extract should be used instead of chemical pesticide.

- It can be deduced from the results that in order to effectively reduce the population of parasitic wasps on tomato plants it is more advisable to use chemical pesticide. In the absence of that water can be used.

Implications of the findings

The main implication therefore is that *Moringa oleifera* is a promising botanical insecticide against Aphids, flea beetles, tomato mites, butterflies, ladybug and parasitic wasps. What is important is that further research into the use of *Moringa oleifera* should use higher concentrations of the extracts and further investigate how the extracts affect the species in order to reduce their numbers.

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