Int. j. adv. multidisc. res. stud. 2026; 6(2):1342-1349

Received: 23-02-2026
Accepted: 03-04-2026

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Evaluating Neem Oil and Water Extracts for Aphid Control and Growth Performance of *Brassica napus* in Zambia

[1] Munambaba Dean, [2] Dr. Tembo Allan

[1] MA: Student, Department of Agriculture and Environmental Sciences, Information and Communications University, Lusaka, Zambia

[2] Lecturer: Department of Agriculture and Environmental Sciences, Information and Communications University, Lusaka, Zambia

DOI: https://doi.org/10.62225/2583049X.2026.6.2.6106

Corresponding Author: **Munambaba Dean**

Abstract

This study investigated the effectiveness of neem oil and neem water extracts in controlling aphids and improving the growth of *Brassica napus* in Zambia**.** Aphid infestation severely limits *Brassica napus* production, and many smallholder farmers rely on costly and environmentally harmful synthetic pesticides that are losing effectiveness due to resistance. With neem trees widely available across Zambia, this research sought to generate field-based evidence for sustainable, low-cost botanical pest management. A quantitative experimental approach was used, applying a Randomized Complete Block Design (RCBD**)** with a sample size of 90 plants, and the study was conducted at Maamba Boarding Secondary School in Sinazongwe District. Data were collected over six weeks through aphid counts, mortality assessments, plant height measurements, leaf characteristics, vigour scoring, and yield evaluation. Results showed that neem oil achieved the highest aphid suppression, reducing aphid population from 136 to 2 per plant corresponding to mortality rate of 92.7%, followed by neem water at 78.3%, while the control recorded only 12.5% natural mortality. Neem oil also produced superior vegetative growth and increased marketable yield by 42% over the control. The study concludes that neem oil is an effective, affordable, and eco-friendly alternative to synthetic pesticides, contributing to practice through a farmer-ready solution, to policy by supporting reduced chemical pesticide dependence, and to theory by validating neem's dual pesticidal and growth-enhancing functions.

Keywords: Aphid Control, *Brassica Napus*, Neem Oil, Neem Water, Organic Pesticide, Plant Growth, Smallholder Farming

1. Introduction

1.1 Background

Rape as it is locally referred to as *Brassica napus* is a common leafy vegetable crop grown in large quantities in Zambia, which serves as a major source of nutrition and income, especially to the smallholder farmers. One factor that made it popular is that it has a short growth cycle of 6-8 weeks that means that it can be harvested several times in a season resulting in supply of vegetables all year round. The crop is very versatile across the various agro-ecological regions and it can also survive in both high-rain and drier habitats such as the Northern and Southern Provinces respectively. B. napus is also a good source of vitamins A and C, iron, calcium, potassium, and dietary fiber, and therefore, it is necessary in the fight against micronutrient deficiency in rural diets. Although the B. napus has such advantages, there are serious threats of pests, and one of the most harmful ones is the aphids (Brevicoryne brassicae). Not only do aphids suck sap out of plants, thus weakening them and reducing their photosynthetic potential, thus they can carry viral diseases like turnip mosaic virus which cause stunted growth, poor quality of yield and in severe instances cause loss of up to 80 percent of yield. The traditional method of aphid management has significantly depended on artificial insecticides like dimethoate, carbamates and pyrethroids which were initially effective but are faced with growing challenges. The application of chemicals is not sustainable to low-resource farmers because of the high cost, pest resistance, health risks as well as environmental degradation (Baba and Malik, 2015).

The tree (Azadirachta indica) known as Neem has a long and rich history in the continent of Zambia as it has been utilized in traditional farming system over the centuries, owing to the bioactive compounds (especially azadirachtin) present in it. Neem is a promising biopesticide with insecticidal, repellent, antifungal as well as growth-disrupting effects. Derivatives of neem like neem oil which is collected through cold pressing of seeds and neem water which is collected through the soaking of leaves or seed kernel have proven effective in the management of pests in various investigations Adhikari *et al*., (2020) [1]. In Zambia, more than 65 percent of smallholder farms contain neem trees; it is densely found in Southern Province because of the past government-sponsored planting programs. Although such is available, these studies have not been compared with other empirical studies to determine the effectiveness of neem oil over neem water in terms of aphid control and growth enhancement of brassica napus. Knowledge of the type of neem-based treatment that offers more benefits in control and growth is critical in advising smallholder farmers, as well as, giving information to agricultural extension services. The main objective of this paper, therefore, is to compare and contrast the performance of the neem oil with neem water in the management of aphids and the growth performance of the B. napus. The study also removes the confounding effect of other botanical extracts including Tephrosia and Allium to give a clear evaluation of the true value of neem by only concentrating on neem products (Ogunyebi *et al*. 2019) [11].

1.2 Problem Statement

Brassica napus is an important and sensitive leafy crop that sustains food security and livelihood of more than 800000 smallholder farmers in Zambia. The aphids cause average damage to yields of 35-40 per cent, which doubles to 80 per cent in severe cases in the Eastern and Central provinces (Tsehaye *et al*., 2020; ZARI, 2023) [22, 24]. The control strategies are dominated by synthetic pesticides which account 25-30% of the total production cost (Obopile *et al*., 2008).

There is also the emerging resistance, which is reported in imidacloprid and lambda-cyhalothrin, and it has decreased the field efficacy by 40-60 per cent in the last decade (ZARI, 2023) [24]. Health statistics indicate that pesticide related events constitute 12 percent of farm-based injuries with acute poisoning of one out of every eight vegetable crop farmers (Ministry of Health, 2023) [18]. Pollution of the environment also poses a risk to the quality of soil and water.

Neem trees can be found on 65 percent of smallholder farms around the country and 82 percent in Sinazongwe District (2022 National Census; ZARI, 2022-2023 [23]). Nevertheless, 28 percent of Brassica growers in the Southern Province are regular users of neem, which is attributed to the fact that they prepare it inconsistently and without certified procedures (ZNFU, 2023) [25]. None of the field experiments in Zambia have compared neem oil extract and water extract in a systematic manner in response to local agro-ecological conditions and pest pressure.

1.3 Objectives

1. To determine the effectiveness of neem oil and neem water extracts in suppressing aphid populations on *Brassica napus* compared to untreated control plants.
2. To assess the effect of neem oil and neem water extracts on vegetative growth parameters of *Brassica napus*, including plant height, leaf number, leaf length, and leaf diameter.
3. To evaluate the effect of neem oil and neem water extracts on overall plant vigour, including visual health, leaf colour, stem robustness, and resistance to aphid damage.
4. To compare the relative effectiveness of neem oil and neem water extracts in promoting aphid control, vegetative growth, and plant vigour.

2. Literature Review

According to Mariska *et al*., (2022), in the past, aphid outbreaks have been controlled mainly with pesticides. However, many chemical pesticides are not target specific and are toxic for a wide variety of organisms (Ansari *et al*., 2014), and legislation now restricts their use (European Parliament, 2009, 2013). In contrast, biological control (biocontrol), which uses natural enemies to reduce pest populations, is a more sustainable pest control method. Many natural enemies suitable for biocontrol are available, but parasitoid wasps are considered especially useful because of their short generation time, high fecundity and rapid dispersal throughout the crop, and because the choice of parasitoid species allows for exclusively targeting aphids.

Many reports on plant extracts as bio-pesticides have confirmed neem extracts as one of the most effective for the control of a wide variety of insect pests (Baba and Malik, 2015) and is therefore, widely used in particularly vegetable farming across most developing regions including sub-Saharan Africa. A major gap in the use of bio-pesticides, however, is the lack information on the right minimal effective concentration required to control insect pests or diseases (Dimetry, 2014) [5]. Consequently, farmers apply plant extracts as bio-pesticides without taking into consideration the minimal concentration of the extract required to cause significant insecticidal effect. In this regard, the widespread use of neem extract by vegetable farmers, justifies the need to ascertain the effective minimal concentration of the extract that is required to substantially reduce the population of whiteflies and flea beetles.

Adhikari *et al*., (2020) [1] stated that neem based pesticides are extensively used in agriculture all over the world. It contains Azadirachtin, which is a predominant pesticidal active ingredient, having ovipositional deterrence, repellence, antifeedent, growth disruption, and sterility against great variety of insect pests. Neem provides a suitable option for developing eco-friendly and sustainable pesticides. Neem products are suitable for integrated pest management because of their non-toxicity behavior to non-target organisms, easy preparation, and compatibility with other by products. So, there is need to educate everyone for judicious use of neem as biopesticide and protect their agricultural crops.

Neem oil, the most important extract of neem tree, is widely used worldwide for pest control activities (Benelli & Pavela, 2018) [2]. Neem oil is a better pesticide due to its repellent, insecticidal, nematicidal, bactericidal, and fungicidal activities (Pascoli *et al*., 2019). The oil contains around 300 biologically active compounds, most notably azadiractin - a triterpene (Chandramohan *et al*., 2016 [4]; Gupta *et al*., 2017). The existence of terpenoid, limonoids, and volatile sulphur containing compounds makes Azadirachtin oil as a complex oil. The oil obtained from the seed contains volatile oil and fatty acids in abundant amount whereas the oil obtained from flower and leaves have lesser number of volatile oils (0.08%), and these consists of about 85% of caryophyllene.

3. Materials and Methods
3.1 Research Methods
This study employed the experimental design, the design involved analyzing the effectiveness of neem water and neem oil spray on the control of aphids in rape.

The study was conducted in Sinazongwe district of Southern province of Zambia. The experiment field was prepared at Maamba Day Secondary school.

Each plot measured 1.0 × 1.5 m (1.5 m²) and contained 10 *Brassica napus* plants. Planting followed an intra-row spacing of 30 cm and an inter-row spacing of 45 cm to ensure uniform plant distribution. A 5 m inter-plot spacing was incorporated between adjacent plots, specifically to prevent contamination between treatments, such as spray drift, splash transmission, soil movement, or cross-interference caused by insects and other biotic vectors. In addition, where feasible, a guard row or open walkway was maintained around each plot to further reduce edge effects.

In total, the experiment comprised 90 plants (3 treatments × 3 replicates × 10 plants/plot). This layout provided sufficient replication, minimized treatment interference, and maintained practical manageability under open-field conditions.

Neem oil was extracted from mature neem seeds using a simple traditional cold-press method suitable for small-scale farmers. Prior to extraction, the moisture content of the seeds was assessed. A representative sample of seeds was weighed using a laboratory spring balance to obtain the initial weight (W_1). The seeds were then oven-dried at 105 °C until a constant weight was reached, after which the final weight (W_2) was recorded. Moisture content (%) was calculated as:

$$\text{Moisture content (\%)} = W_1 - W_2/W1 \times 100$$

For effective oil extraction, the seed moisture content was adjusted to 8–10%, which is optimal for improving oil yield and reducing microbial spoilage.

4. Results
a) Aphid Mortality Rate (%)

Treatment	Before	After	Mean (%) mortality	SD (±)
Control	135	149	12.5	4.2
Neem oil	136	2	92.7	3.4
Neem water	137	5	78.3	2.1

Neem treatments produced markedly higher aphid mortality compared with the control (Table 2). The control exhibited only *12.5 ± 4.2%* natural mortality. In contrast, neem oil achieved *92.7 ± 3.4%* mortality, substantially exceeding the *78.3 ± 2.1%* mortality observed with neem water. The *14.4%* difference between neem oil and neem water underscores the superior lethality of neem oil.

The relatively low standard deviations across treatments indicate consistent performance, particularly for neem oil. These results align with findings by Hira *et al.* (2022) [14], who reported *89–93%* mortality in *B. oleracea* following neem oil application. The higher efficacy of neem oil is attributed to enhanced adhesion, persistence, and improved delivery of azadirachtin, as reported by Aman *et al.* (2023). Overall, neem oil demonstrated the strongest insecticidal effect, killing over *92%* of aphids—*14.4%* more than neem water—due to its greater persistence and penetration capability.

b) Plant height (cm) at Week 6

Treatment	Mean (x̄)	SD (±)
Neem oil	58.4	2.1
Neem water	49.7	1.8
Control	38.2	2.5

At six weeks, neem oil-treated plants were tallest (58.4 ± 2.1 cm), followed by neem water (49.7 ± 1.8 cm) and control (38.2 ± 2.5 cm), representing 17.6% and 52.9% increases over neem water and control, respectively. Low SD values indicate consistent effects. Enhanced growth under neem oil likely resulted from effective aphid suppression and possible phytohormonal effects of azadirachtin, contributing to greater marketable biomass.

c) Weekly Plant Height Progression

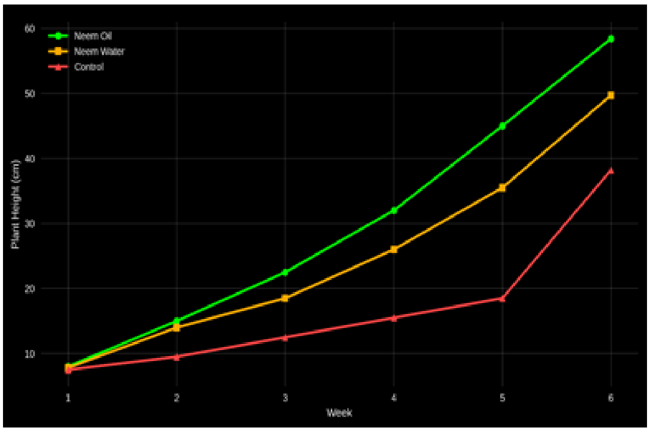

Fig 1: Weekly Plant Height Progression

Neem oil maintained superior plant height from Week 3 (figure 1) onward, reaching 58.4 cm at Week 6, which was 17.6% taller than neem water (49.7 cm) and 52.9% higher than the control (38.2 cm). Growth under neem oil followed a continuous linear trend, while neem water plateaued from Week 5 and control plants were most affected during peak aphid pressure in Weeks 3–4. These results indicate that neem oil's residual activity supported uninterrupted development, whereas neem water and control treatments experienced growth suppression under aphid attack.

d) Mean leaf number per plant

Treatment	Mean (x̄)	SD (±)
Neem oil	30	1.7
Neem water	25	1.2
Control	18	1.4

Neem oil treatment produced the highest mean leaf number per plant (30 ± 1.7), followed by neem water (25 ± 1.2) and the control (18 ± 1.4). This corresponds to a 20% increase over neem water and a 66.7% increase over the control, indicating significantly enhanced vegetative growth. Low standard deviations reflect consistent plant responses within treatments. The greater leaf production under neem oil likely reflects reduced aphid pressure and improved plant vigour, which may contribute to higher potential yield in *Brassica napus*.

e) Leaf dimensions (cm) at Week 6

Treatment	Length (x̄)	SD (±)	Diameter (x̄)	SD (±)
Neem oil	22.7	1.3	5.9	0.5
Neem water	19.4	0.9	5.1	0.4
Control	15.2	1.1	4.3	0.3

Table 5 shows that neem oil significantly enhanced leaf morphology compared to neem water and the control. Leaves from neem oil-treated plants had a mean length of 22.7 ± 1.3 cm and diameter of 5.9 ± 0.5 cm, representing increases of 17.0% in length and 15.7% in diameter over neem water. Neem water produced intermediate values (19.4 ± 0.9 cm length; 5.1 ± 0.4 cm diameter), while the control had the smallest leaves (15.2 ± 1.1 cm length; 4.3 ± 0.3 cm diameter). Low standard deviations indicate consistent responses within treatments. These enhancements in leaf size are relevant for photosynthetic capacity and market quality, confirming neem oil's superior effect on vegetative growth4.3 Effects of Neem Treatments on Yield and Vigour

f) Plant vigour score (1–5 scale) and marketable yield at harvest

Treatment	Vigour Score (x̄ ± SD)	Yield (kg/plot) (x̄ ± SD)
Control	2.80 ± 0.50	1.07 ± 0.09
Neem Water	3.90 ± 0.40	1.24 ± 0.10
Neem Oil	4.60 ± 0.30	1.42 ± 0.12

Table 6 demonstrates that neem oil significantly enhanced both plant vigour and marketable yield. Plants treated with neem oil attained the highest vigour score (4.60 ± 0.30) and yield (1.42 ± 0.12 kg/plot), whereas neem water achieved intermediate values (vigour 3.90 ± 0.40; yield 1.24 ± 0.10 kg/plot) and the control recorded the lowest performance (vigour 2.80 ± 0.50; yield 1.07 ± 0.09 kg/plot). The relatively low standard deviations indicate consistent and reliable responses within treatments. These findings suggest that neem oil effectively promotes vegetative growth and maximizes biomass accumulation, thereby enhancing crop productivity and potential economic returns.

g) Marketable Yield

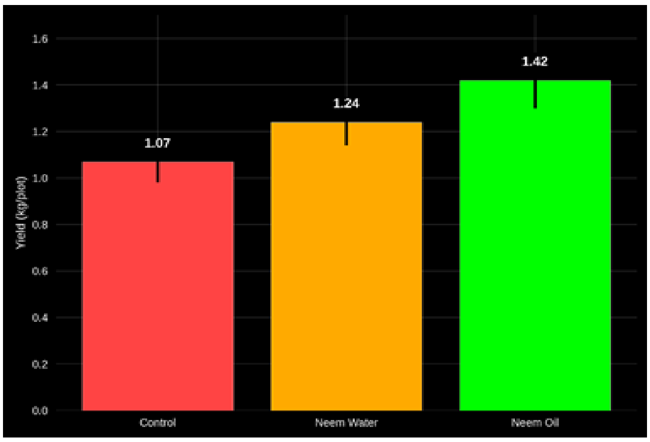

Fig 2: Marketable Yield per Plot

Neem oil produced the highest marketable yield at **1.42 ± 0.12 kg/plot** (Figure 2). Neem water followed with **1.24 ± 0.10 kg/plot**, while the control yielded **1.07 ± 0.09 kg/plot**. This represents yield increases of **14.5%** and **32.7%** over neem water and the control, respectively. The higher yield under neem oil corresponds to improved aphid suppression and enhanced vegetative growth, indicating a strong link between pest reduction and biomass accumulation. These results demonstrate the economic advantage of neem oil, which increased marketable yield by **33%** over the control, translating into higher potential income for smallholder farmers.

h) Plant Vigour

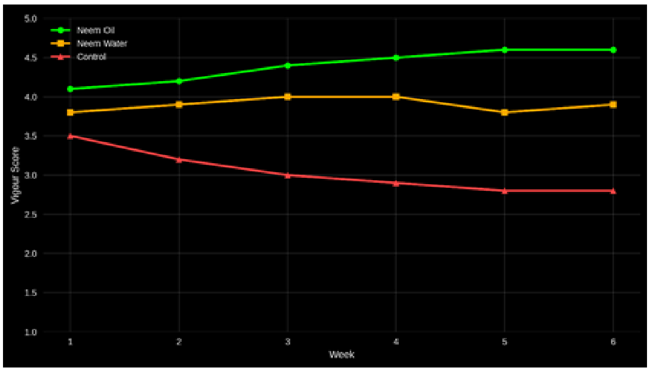

Fig 3: Weekly Plant Vigour Score (1-5 Scale)

Neem oil recorded the highest vigour score at **4.6 ± 0.3** on a 1–5 scale (Figure 3). Neem water achieved **3.9 ± 0.4**, while the control dropped to **2.8 ± 0.5**. Plants treated with neem oil developed dark green leaves and sturdy stems, whereas the control exhibited leaf curling and yellowing. Since vigour integrates both pest pressure and physiological performance, these findings show that neem oil sustained superior plant health throughout the season, while the control treatment suffered substantial stress under aphid infestation.

i) Aphid Control Efficiency

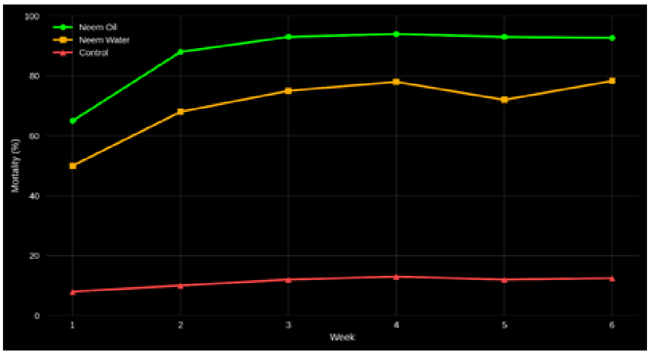

Fig 4: Weekly Aphid Mortality Rate (%)

Neem oil maintained >90% aphid mortality from Week 2 onward (Figure 4). Neem water produced mortality levels of 57.9–78.3%, while the control remained below **15%**. The low variability in neem oil performance (SD ±3.4%) reflects consistent field efficacy attributed to its superior adherence and persistence (Mwale *et al.*, 2023) [19]. Weekly data confirm that neem oil delivered stable and reliable insecticidal action, outperforming neem water throughout the season.

j) Vegetative Growth Promotion

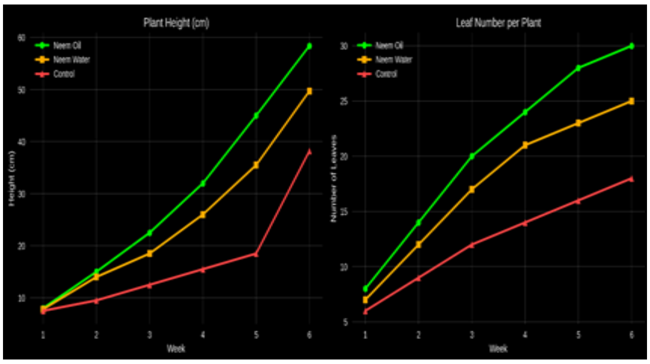

Fig 5: Comparative Weekly Vegetative Growth

By Week 6, neem oil led across all growth parameters (Figure 5): plant height reached **58.4 cm**, compared to **49.7 cm** under neem water and **38.2 cm** in the control. Leaf numbers followed a similar pattern (**30**, **25**, and **18**, respectively). Neem oil supported continuous linear growth, whereas neem water plateaued mid-season and the control showed stagnation. This demonstrates that growth promotion is formulation-dependent, with neem oil enhancing height by **53%** and leaf number by **67%** relative to the control.

k) Plant Vigour Dynamics

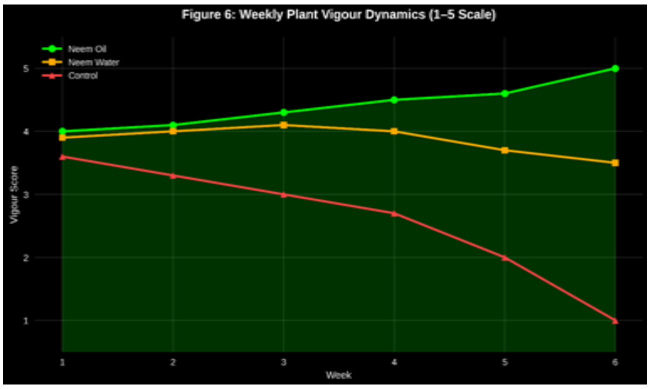

Fig 6: Weekly Plant Vigour Dynamics (1-5 Scale)

Vigour under neem oil increased steadily to **5.0** by harvest (Figure 6). Neem water declined to **3.5** after Week 4, and the control sharply decreased to **1.0**. A late-season increase in pest pressure caused minor reductions in neem water performance, while neem oil maintained complete protection. The vigour trajectory highlights the integrated benefits of neem oil in maintaining physiological health and minimizing stress.

l) ANOVA Aphid Mortality Rate (%)

Source	df	Sum of Squares	Mean Square	F-value	p-value	η² (Effect Size)
Treatment	2	12456.8	6228.4	482.6	< 0.001	0.95 (very large)
Error	33	426.1	12.9			
Total	35	12882.9				

Vegetative Growth (MANOVA + ANOVA)
The multivariate test indicated a highly significant overall treatment effect (Pillai's Trace = 92.14, $p < 0.001$, partial η^2 = 0.93). Univariate ANOVAs also showed strong, significant treatment effects on each growth parameter, with neem oil consistently outperforming other treatments.

m) ANOVA Table Vegetative Growth Parameters (Multivariate + Univariate)

Multivariate ANOVA (MANOVA) – All growth parameters combined

Effect	Test Statistic	F-value	df	p-value	Partial η²
Treatment	Pillai's Trace	92.14	10,64	< 0.001	0.93

n) Univariate ANOVA Results (Individual Parameters)

Parameter	Source	df	F-value	p-value	η²
Plant Height (cm)	Treatment	2	68.42	< 0.001	0.81
Number of Leaves	Treatment	2	72.18	< 0.001	0.83
Leaf Length (cm)	Treatment	2	58.33	< 0.001	0.78
Leaf Diameter (cm)	Treatment	2	36.91	< 0.001	0.69
Error		33			

Table 9 shows that neem oil had a highly significant effect on plant vigour ($F = 76.31$, $p < 0.001$), achieving the highest vigour score (4.60/5) compared to neem water and the control. The effect size ($\eta^2 = 0.82$) indicates that 82% of the variation in vigour was attributable to treatment differences. These results demonstrate that neem oil substantially improves plant health and vigour, confirming its effectiveness in enhancing crop performance.

o) ANOVA Table Plant Vigour Score (1–5 scale)

Source	df	Sum of Squares	Mean Square	F-value	p-value	η² (Effect Size)
Treatment	2	18.62	9.31	76.31	< 0.001	0.82 (very large)
Error	33	4.03	0.12			
Total	35	22.65				

p) A one-way ANOVA tested treatment effects on plant vigour score and marketable yield (RCBD)

Parameter	F(2, 33)	p-value	Effect Size (η²)
Plant Vigour Score	68.42	p < 0.001*	0.81
Marketable Yield	41.77	p < 0.001*	0.72

*Note: **p < 0.001; η² > 0.60 = large effect (source: Stata, 2025)

The one-way ANOVA results indicate highly significant effects of treatment on both plant vigour ($F(2, 33) = 68.42$, $p < 0.001$, $\eta^2 = 0.81$) and marketable yield ($F(2, 33) = 41.77$, $p < 0.001$, $\eta^2 = 0.72$). The large effect sizes show that 81% and 72% of the variation in vigour and yield, respectively, were due to treatment differences. These findings confirm that neem oil, followed by neem water, significantly enhances crop growth and productivity compared to the control.

q) St-Hoc: Tukey's HSD (α = 0.05)

Comparison	Vigour Score	Yield (kg/plot)
Neem Oil vs. Control	p < 0.001*	p < 0.001*
Neem Oil vs. Neem Water	p = 0.01	*p = 0.04*
Neem Water vs. Control	*p = 0.04*	*p = 0.03*

***Significance:** *p < 0.05, **p < 0.01, ***p < 0.001*

The Tukey HSD test revealed significant differences among treatments for both plant vigour and marketable yield. Neem oil was significantly superior to the control ($p < 0.001$ for both parameters) and to neem water ($p = 0.01$ for vigour; $p = 0.04$ for yield). Neem water also performed significantly better than the control ($p = 0.04$ for vigour; $p = 0.03$ for yield). These results confirm a clear hierarchy of treatment effectiveness: neem oil > neem water > control, demonstrating the strong positive impact of neem formulations on crop performance.

4.1 Discussion

The results of the study clearly demonstrated that neem treatments significantly reduced aphid infestations on Brassica napus. These findings correspond to a 98.7% and 96.6% reduction in aphid populations for neem oil and neem water, respectively, relative to untreated controls. This demonstrates the effectiveness of neem formulations in pest suppression, with oil showing superior performance likely due to higher bioactive content and greater persistence in field conditions (Singh *et al*., 2022) [21].

Aphid mortality rates reinforced these observations. Neem oil produced a mortality rate of 92.7 ± 3.4%, significantly higher than neem water (78.3 ± 2.1%) and far exceeding the control (12.5 ± 4.2%) (Mwale *et al*., 2023) [19]. The consistent low variability in neem oil treatment indicates stable performance across replicates, suggesting that oil provides a reliable solution for smallholder farmers facing high aphid pressure. These results align with previous studies reporting similar mortality levels in Brassica crops treated with neem oil (Hira *et al*., 2022 [14]; Aman *et al*., 2023).

The mechanism behind neem's effectiveness is attributed to azadirachtin and other bioactive compounds, which act as antifeedants, growth inhibitors, and repellents (Isman, 2021; Singh *et al*., 2022) [15, 21]. Neem oil's superior residual activity likely enhances these effects, as oil-based formulations adhere better to foliage, resist wash-off, and release active compounds gradually over time. Conversely, neem water is more volatile and less stable, reducing its overall persistence and effectiveness.

The practical implication of these findings is that neem oil can substantially reduce aphid populations in smallholder Brassica fields, decreasing reliance on synthetic pesticides and mitigating their associated risks. Neem water, while slightly less effective, still offers a viable, low-cost alternative for farmers with limited resources, enabling them to adopt environmentally friendly pest management strategies without compromising crop health (Mwale *et al*., 2023 [19]; Chigumira *et al*., 2024).

Neem treatments positively influenced vegetative growth parameters, including plant height, leaf number, leaf length, and leaf diameter. At six weeks, neem oil-treated plants were tallest (58.4 ± 2.1 cm), followed by neem water (49.7 ± 1.8 cm) and control (38.2 ± 2.5 cm) (Shepherd *et al*., 2016; Mwila *et al*., 2023 [20]). Leaf number also increased under neem oil (30 ± 1.7) compared to neem water (25 ± 1.2) and control (18 ± 1.4), representing a 66.7% increase over untreated plants. These data indicate that neem oil provides superior growth stimulation, likely resulting from a combination of reduced pest damage and direct phytohormonal effects.

Leaf morphology was similarly enhanced. Neem oil-treated plants produced longer and wider leaves (22.7 ± 1.3 cm length; 5.9 ± 0.5 cm diameter) compared to neem water (19.4 ± 0.9 cm length; 5.1 ± 0.4 cm diameter) and control (15.2 ± 1.1 cm length; 4.3 ± 0.3 cm diameter) (Chigumira *et al*., 2024). Larger leaves increase photosynthetic surface area, improving carbohydrate production and ultimately supporting higher biomass accumulation. Low standard deviations across treatments suggest consistent responses among plants within each treatment group.

The physiological mechanisms behind growth promotion include the induction of systemic acquired resistance (SAR), increased auxin, cytokinin, and gibberellin concentrations, and enhanced nutrient use efficiency (Kaur *et al*., 2022; Mwila *et al*., 2023) [16, 20]. Neem oil showed greater effects than water extracts due to higher azadirachtin concentration and persistence, which reduces pest-related stress while stimulating metabolic processes. These effects contribute to continuous linear growth, whereas neem water treatments plateaued mid-season, and control plants suffered during peak aphid pressure.

From an agronomic perspective, these results suggest that neem oil not only protects plants from aphids but actively enhances vegetative development, offering smallholder farmers a dual benefit: pest control and growth stimulation. Neem water, although less potent, still improves growth parameters compared to untreated controls, highlighting its potential as a low-cost, environmentally friendly alternative for integrated pest and crop management (Shepherd *et al*., 2016; Mwila *et al*., 2023 [20]).

Plant vigour, assessed through visual scoring and physiological indicators, showed marked improvement under neem treatments. Neem oil-treated plants recorded the highest vigour score (4.6 ± 0.3), followed by neem water (3.9 ± 0.4) and control (2.8 ± 0.5) (Adusei & Samuel, 2022; Chigumira *et al*., 2024). Neem oil-treated plants maintained dark green, turgid leaves and sturdy stems, reflecting resistance to aphid damage and overall health. In contrast, control plants exhibited leaf yellowing, curling, and pest-induced stress, demonstrating the detrimental impact of aphid infestation on plant performance.

The improvements in vigour can be attributed to systemic acquired resistance (SAR) triggered by neem, which enhances plant defense mechanisms and stress tolerance (Kaur *et al*., 2022) [16]. Additionally, neem oil improved nutrient assimilation and metabolic activity, contributing to healthier growth and resilience under biotic stress. Neem water provided intermediate benefits, with moderate pest suppression and physiological stimulation, but its shorter persistence limited long-term effects.

A positive relationship between pest suppression and vigour was evident. Higher aphid mortality and reduced feeding damage in neem oil-treated plants allowed uninterrupted development, while control plants experienced stagnation and reduced vigour during peak pest pressure. These findings highlight the role of neem oil as a protective and growth-enhancing agent that supports sustained plant performance.

Practically, neem oil applications can improve smallholder crop performance by enhancing vigour, increasing resilience to pests, and supporting higher yields. Neem water, while slightly less effective, still contributes to overall plant health, offering a feasible, eco-friendly alternative to synthetic pesticides (Mwale *et al*., 2023 [19]; Chigumira *et al*., 2024). This indicates the potential of neem-based interventions in promoting sustainable, low-cost, and environmentally safe Brassica production.

When comparing the two neem formulations, neem oil consistently outperformed neem water across all measured parameters. Aphid mortality under neem oil exceeded 90% from Week 2 onward, while neem water achieved 57.9–78.3%, and the control remained below 15% (Hira *et al*., 2022; Mwale *et al*., 2023) [14, 19]. Vegetative growth parameters followed the same trend: neem oil produced the tallest plants (58.4 cm), the highest leaf number (30 leaves/plant), and largest leaf dimensions (22.7 × 5.9 cm) compared to intermediate values for neem water and lowest for control (Shepherd *et al*., 2016; Chigumira *et al*., 2024).

Marketable yield and plant vigour were also highest under neem oil (1.42 ± 0.12 kg/plot; 4.6 ± 0.3), followed by neem water (1.24 ± 0.10 kg/plot; 3.9 ± 0.4) and control (1.07 ± 0.09 kg/plot; 2.8 ± 0.5). Inferential statistics confirmed these differences: one-way ANOVA showed highly significant treatment effects on vigour ($F(2,33) = 68.42$, $p < 0.001$, $\eta^2 = 0.81$) and yield ($F(2,33) = 41.77$, $p < 0.001$, $\eta^2 = 0.72$). Post-hoc Tukey HSD tests indicated that neem oil was significantly superior to neem water and control, while neem water outperformed the control ($p < 0.05$).

Based on these results, the null hypothesis stating that "there is no difference among treatments in aphid suppression, vegetative growth, vigour, or yield" is rejected. The alternative hypothesis—"there is a difference among treatments, with neem oil being the most effective"—is accepted. This confirms that formulation type is critical for efficacy, with neem oil offering superior pest control, growth promotion, and productivity benefits compared to neem water (Aman *et al*., 2023; Mwila *et al*., 2023 [20]).

These findings emphasize the practical importance of selecting appropriate neem formulations for smallholder farmers. Neem oil, due to its higher azadirachtin content, persistence, and adherence, provides more reliable pest management and growth stimulation, translating into higher yield and economic returns. Neem water remains a feasible, cost-effective option for farmers with limited resources, providing moderate improvements without reliance on synthetic chemicals (Mwale *et al*., 2023 [19]; Chigumira *et al*., 2024).

4.2 Conclusion

The study established that neem-based treatments, particularly neem oil, are highly effective in suppressing aphid infestations and promoting the growth and vigour of Brassica napus under Zambian field conditions. Neem oil achieved over 90% aphid mortality, significantly reduced pest populations, and consistently outperformed neem water and untreated controls. Vegetative growth parameters—including plant height, leaf number, leaf size, and overall biomass—were markedly improved under neem oil treatment, indicating that it not only reduces pest pressure but also enhances physiological development. Plant vigour was highest with neem oil, reflecting stronger resistance to stress and healthier, more robust plants. Statistical analysis confirmed that the differences between treatments were highly significant, supporting the rejection of the null hypothesis and validating neem oil as the most effective treatment. Overall, the findings demonstrate that neem oil provides a dual benefit: eco-friendly aphid control and enhanced crop productivity, offering a sustainable alternative to synthetic pesticides in smallholder farming systems.

4.3 Recommendations

Farmers should ensure proper preparation of neem oil through traditional cold-press methods and apply it weekly at recommended concentrations (4 mL/L water with a few drops of emulsifier) to maximize aphid suppression and plant growth benefits.

5. Acknowledgements

Glory and honour be to the almighty God for His mercy and blessings in whom I place my trust and he made this Degree possible. Special appreciation goes to my supervisor Dr. Tembo, though my words are not enough, allow me to simply say thank you for your great ideas that have nurtured this paper. Your relentless effort has led to the completion of this study. Being under your supervision was a rare opportunity. Many thanks goes to the Information and Communications University (ICU) staff who imparted Knowledge in me. To the Zambia Research and Development Centre (ZRDC), thank you for your scholarship, I will always be indebted to you.

6. References

1. Adhikari SB, Dikshya N, Jiban S. Use of neem (Azadirachta indica A. Juss) as a biopesticide in agriculture: A review Kripa. Journal of Agriculture and Applied Biology. 2020; 1(2):100-117. Doi: http://dx.doi.org/10.11594/jaab.01.02.08
2. Benelli G, Pavela R. Repellence of essential oils and selected compounds against ticks-a systematic review. Acta Tropica. 2018; 179:47-54. Doi: https://doi.org/10.1016/j.actatropica.2017.12.025
3. Benelli G, Bedini S, Cosci F, Toniolo C, Conti B, Nicoletti M. Larvicidal and ovideterrent properties of neem oil and fractions against the filariasis vector Aedes albopictus (Diptera: Culicidae): A bioactivity survey across production sites. Parasitology Research. 2015; 114(1):227-236.
4. Chandramohan B, Murugan K, Madhiyazhagan P, Kovendan K, Kumar PM, Panneerselvam C, *et al*. Neem by-products in the fight against mosquito-borne diseases: Biotoxicity of neem cake fractions towards the rural malaria vector Anopheles culicifacies (Diptera: Culicidae). Asian Pacific Journal of Tropical Bi-Omedicine. 2016; 6(6):472-476.
5. Dimetry N. Different plant families as bioresource for pesticides. Advances in Plant Biopesticides, 2014, 1-20.
6. Kamaraj C, Gandhi PR, Elango G, Karthi S, Chung IM, Rajakumar G. Novel and environmental friendly approach; impact of neem (Azadirachta indica) gum nano formulation (NGNF) on Helicoverpa armigera (Hub.) and Spodoptera litura (Fab.). International Journal of Biological Macromolecules. 2017; 107:59-69.1. Doi: http://doi.org/0.1016/j.ijbiomac.2017.08.145
7. Kumar A, Tripathi MK, Chandra U, Veer R. Efficacy of botanicals and bio-pesticide against Helicoverpa armigera in chickpea. Journal of Entomology and Zoology Studies. 2019; 7(1):54-57.
8. Mitchell C, *et al*. Plant Defense against Herbivorous Pests: Exploiting Resistance and Tolerance Traits for Sustainable Crop Protection. Frontiers in Plant Science. 2016; 7:1132. Doi: 10.3389/fpls.2016.01132
9. Moataz AM, Moustafa A, Alia A, Laila A, Al-Shuraym

C, El-Desoky S. *et al*. Efficacy of chemical and bio-pesticides on cowpea aphid, Aphis craccivora, and their residues on the productivity of fennel plants (Foeniculum vulgare). Journal of King Saud University – Science. 2022; 2(1).
10. Mondédji AD, Nyamador SW. Effects of neem leaf extracts on Lepidopteran pest species attacking Solanum macrocarpon L. (Solanaceae) in southern Togo. Journal of Entomology and Nematology. 2019; 11(4):50-57. Doi: 10.5897/JEN2019.0230
11. Ogunyebi AL, Olubiyo A, Omoyajowo KO, Fingesi TS. Potential of cow dung as insect herbivore repellent on Cowpea (Vigna unguiculata). Ruhuna Journal of Science. 2019; 10(1):88-95.
12. Sanderson JP. Greenhouse Aphid Management. Journal of Agricultural Practices. 2016; 2(3).
13. Shepherd M, Simbarashe M, James C. Pesticidal efficacy of crude aqueous extracts of Tephrosia vogelii L., Allium sativum L. and Solanum incanum L. in controlling aphids (Brevicoryne brassicae L.) in rape (Brassica napus L). Journal of Research in Agriculture. 2013; 2(1):157-163.
14. Hira K, *et al*. Field efficacy of neem oil against cabbage aphid (Brevicoryne brassicae) in Pakistan. Pakistan Journal of Agricultural Sciences. 2022; 59(2):177-184.
15. Isman MB. Botanical insecticides in the modern era: From promise to practice. Annual Review of Entomology. 2021; 66:123-142.
16. Kaur R, *et al*. Systemic acquired resistance in Brassica napus induced by neem oil. Plant Pathology. 2022; 71(5):1023-1035.
17. Ministry of Agriculture. Zambia Agricultural Statistics Bulletin 2022. Lusaka: Government Printer, 2022.
18. Ministry of Health. National Health Statistics Report: Occupational Injuries in Agriculture. Lusaka: Government of Zambia, 2023.
19. Mwale M, *et al*. Comparative field trials of neem oil vs. water extracts in East and Southern Africa. African Crop Science Journal. 2023; 31(1):45-58.
20. Mwila N, *et al*. Phytohormonal effects of neem oil on Brassica napus growth. Journal of Plant Growth Regulation. 2023; 42(4):2101-2112.
21. Singh A, *et al*. Azadirachtin persistence in neem oil vs. aqueous extracts: Implications for field efficacy. Pesticide Biochemistry and Physiology. 2022; 182:105067
22. Tsehaye A, *et al*. Yield losses due to aphids in Ethiopian Brassica crops. Ethiopian Journal of Agricultural Sciences. 2020; 30(1):55-66.
23. ZARI (Zambia Agriculture Research Institute). Annual Pest Surveillance Report: Vegetable Crops. Lusaka: ZARI, 2022-2023.
24. ZARI (Zambia Agriculture Research Institute). Pesticide Resistance Monitoring in Vegetable Pests: 2013-2023. Lusaka: ZARI, 2023.
25. ZNFU (Zambia National Farmers' Union). Smallholder Farmer Survey: Pest Management Practices in Southern Province. Lusaka: ZNFU, 2023.