

ORIGINAL RESEARCH ARTICLE

Biopesticidal Activity of Balanites, Nigella, and Neem Essential Oils against *Callosobruchus maculatus* L. on Stored Cowpea (*Vigna unguiculata* L Walp) in Sudan Savanna, Nigeria

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ABSTRACT

An experiment was conducted to assess the oviposition deterrence effect and identify bioactive compounds in some essential oils (EOs) on cowpea weevil (*Callosobruchus maculatus* L.) infesting stored cowpea (*Vigna unguiculata* L Walp). Three EOs, obtained from balanite, black seed, and neem; a synthetic insecticide; and a control were tested alongside three local cowpea cultivars (*Dan Misra*, *Kwankwasiya*, and *Kananado*). The treatments were applied at a rate of 2.5 mL per 50 g of cowpea (equivalent to 0.05 mL/g v/w). Treatments were arranged in a Completely Randomized Design (CRD) and were replicated three times. Data were collected on adult mortality, oviposition, and progeny emergence. Bioactive compounds with pesticidal properties were also analyzed. The data were subjected to analysis of variance (ANOVA), and significant means were separated using Duncan's Multiple Range Test (DMRT) at 5% probability. Adult mortality was significantly ($P < 0.05$) higher in insecticide-treated cowpeas 24 hours after infestation, followed by balanite oil. Black seed and neem oils performed similarly and were significantly more effective than the control. Complete oviposition deterrence was observed in insecticide-treated cowpeas, but the effects were not significantly different ($P > 0.05$) from those of the EOs. Balanite oil recorded the lowest number of eggs among the EOs. Progeny emergence was significantly ($P < 0.05$) lower in the EOs, but was comparable to the insecticide treatment and significantly different from the control. Bioactive compounds with insecticidal and repellent properties were identified using Gas Chromatography-Mass Spectrometry (GC-MS), which included tetradecane, oleic acid, octadecanoic acid, tetradecanoic acid, 2,4-di-tert-butylphenol, and tetradecanoic acid in black seed and balanite oils, respectively. Based on these findings, essential oils, particularly balanite and black seed oils, could serve as environmentally friendly alternatives to synthetic insecticides for controlling bruchids in sustainable cowpea storage in the study area.

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INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp.; Fabaceae) is a vital legume in tropical and subtropical regions, often called a “poor man’s meat” due to its high protein content and affordability (Larweh *et al.*, 2025). Beyond its use as food, feed, and fodder, cowpea enhances soil fertility through nitrogen fixation (Kalpna *et al.*, 2022). It is a dietary staple in Sub-Saharan Africa (SSA), particularly in Nigeria, where millions rely on it as a source of protein (AATF, 2014). However, pest infestations significantly degrade its nutritional quality, reducing protein content and limiting its value as a food and feed source (Akinola *et al.*, 2020). This deterioration has serious implications for food security, especially in low-income households dependent on cowpea-based diets. Infested seeds are often discarded due to odor, discoloration, and contamination, leading to

food loss and increasing vulnerability to hunger and malnutrition (Singh and Kang, 2021).

Cowpea storage faces a major threat from the cowpea seed bruchid, *Callosobruchus maculatus* L. [Coleoptera: Chrysomelidae], a destructive post-harvest pest responsible for severe losses in germination, weight, and nutritional quality (Sanon *et al.*, 2018; Kéita *et al.*, 2000). Bruchid infestation causes both quantitative and qualitative losses, undermining grain quality and market value (Ekoja *et al.*, 2022). Infestation can lead to complete seed loss within months (Tchouassi *et al.*, 2020). The pest’s larvae develop inside the seed, making early detection difficult, and leave characteristic exit holes and powdery residues after adult emergence (Tchouassi *et al.*,

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2020; Adegbite *et al.*, 2020). These damages exacerbate food insecurity and reduce farmers' income (Singh and Kang, 2021).

Although chemical insecticides are widely used for bruchid control, there are serious concerns regarding health risks, environmental pollution, and pest resistance (Jallow *et al.*, 2020). Their high cost also limits access for resource-poor farmers. Residues from synthetic insecticides contaminate stored seeds, soil, and water, posing hazards to humans and ecosystems (Muhammad and Bashir, 2017; Ekoja *et al.*, 2022; Kumar *et al.*, 2021; Prakash and Rao, 2019). These challenges have intensified interest in safer, sustainable pest management alternatives.

Environmentally friendly solutions, particularly plant-derived essential oils (EOs), are being explored as substitutes for synthetic insecticides. EOs from aromatic plants exhibit insecticidal, repellent, and oviposition-deterrent properties, effective against *C. maculatus* and other storage pests, as reported by previous researchers (Ngonadi, 2025; Ati *et al.*, 2024; Muhammad *et al.*, 2024; Ekoja *et al.*, 2022; Ileke *et al.*, 2020). Examples include oils from neem (*Azadirachta indica*), clove (*Syzygium aromaticum* L.), garlic (*Allium sativum* L.), citronella (*Cymbopogon citratus* L.), and eucalyptus (*Eucalyptus globulus* L.) (Prieto-Rodríguez *et al.*, 2025; Ripoll-Aristizabal *et al.*, 2025). These aromatic plants produce bioactive compounds with insecticidal, antifeedant, repellent, and growth-regulating effects (Adimas *et al.*, 2024).

For instance, eugenol in clove oil is highly toxic to *C. maculatus*, reducing adult mortality and egg-laying, and may serve as a sustainable alternative to chemicals (Kumar *et al.*, 2021; Kavallieratos *et al.*, 2024). EOs are biodegradable, safe for mammals, and environmentally benign (Ekoja *et al.*, 2022). Neem oil, containing azadirachtin, acts as an antifeedant, oviposition deterrent, and growth inhibitor, effectively suppressing bruchid populations while maintaining seed viability (Isman, 2019). Oils from balanite (*Balanites aegyptiaca*) and black seed (*Nigella sativa*) also showed strong insecticidal and repellent properties. Their bioactive compounds, such as thymoquinone, disrupt feeding and reproduction, reduce pest emergence, and leave minimal residue, ensuring safety for humans and the environment (Ahmed *et al.*, 2021; Albakry *et al.*, 2022; Kareem *et al.*, 2020).

EOs act through various mechanisms, including neurotoxicity, feeding inhibition, oviposition deterrence, and interference with insect development (Popescu *et al.*, 2024). The mode of action of EOs acts via fumigant toxicity, contact toxicity, and repellency, often targeting insect nervous systems (e.g., acetylcholinesterase inhibition) (Baghouz *et al.*, 2024; Mssillou *et al.*, 2022; Jumbo *et al.*, 2018). Their effectiveness varies among plant species due to differences in chemical composition. Recent advances include formulating EOs into nanoemulsions or encapsulated forms to improve stability, bioavailability, and efficacy (Maurya *et al.*, 2024; Gupta *et al.*, 2023). Synergistic blending of EOs from different plants is also being investigated to enhance insecticidal potency and minimize the development of

resistance (Et-Tazy *et al.*, 2025; Aslan *et al.*, 2024). Essential oils offer an environmentally friendly alternative to synthetic pesticides, with lower risk of resistance and minimal impact on seed quality (Baghouz *et al.*, 2024; Akami *et al.*, 2017; Rubasinghe *et al.*, 2006).

Given these advantages, this study aims to evaluate the efficacy of balanite, black seed, and neem seed oils, compared with a synthetic insecticide, in deterring oviposition and controlling *C. maculatus*. Research on the composition profiles of balanites and black seed oils is limited in the study area, especially during post-harvest storage. Such an investigation supports the search for cost-effective, safe, and sustainable pest management strategies for cowpea storage in the study area.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted in the Biological Science Laboratory at Federal University, Dutsin-Ma, located at latitude 12° 28' 24.378" N and longitude 7° 29' 9.48" E, at an elevation of 538 meters above sea level in the Sudan Savannah ecological zone of Nigeria. This zone typically experiences high temperatures, with mean annual temperatures ranging between 25°C and 35°C. Relative humidity varies significantly between the wet and dry seasons, from about 20% during the dry season to approximately 80% in the wet season. The area receives an average annual rainfall of 600-900 mm, with a short rainy season from May to September. Additionally, the region experiences strong seasonal winds, especially during the Harmattan period, when dry, dusty winds from the Sahara Desert dominate (Abaje *et al.*, 2014).

Treatments and experimental design

The experiment involved three essential oils (EOs): T1 *Balanites aegyptiaca* (L.) (Balanite oil); T2 *Nigella sativa* (L.) (Black seed oil); and T3 *Azadirachta indica* (L.) (Neem oil). The oils were purchased from Shamwal Herbal Products, Yahaya Madaki Way, Katsina. Treatment four (T4) was a synthetic insecticide (Pestox), a contact poison chemical containing cypermethrin (2.0%), talc (97.8%), and fragrance (0.2%), purchased from an agrochemical store in Dutsin-Ma town, and T6 was the control. The three cowpea cultivars were C1 (*Dan Misra*), C2 (*Kvankwasinyya*), and C3 (*Kananado*). The EOs were applied at 2.5 mL in 50 g cowpea [equivalent to 0.05 mls/g v/w] while 5 g of Pestox (insecticide) was used. Treatments were arranged on a laboratory bench in a Completely Randomized Design (CRD) and were replicated three times.

Balanites aegyptiaca (L.) oil

The seed of *Balanites aegyptiaca* (desert date) is a good source of oil containing bioactive compounds, such as saponins, alkaloids, and flavonoids, which exhibit insecticidal and antimicrobial activities (Raveau *et al.*, 2020). The saponins damage insect cell membranes and contribute to insect-repellent properties, as reported by Abu Zeid *et al.* (2019). Research shows that balanite oil acts as both a contact and ingestion insecticide by

disrupting the insects' digestive systems. Its active compounds suppress metabolic enzymes in pests, ultimately leading to death. The oil also prevents pests from feeding on and laying eggs on the treated seeds (Raveau *et al.*, 2020). Balanite oil has demonstrated strong potential for controlling stored-product pests such as *C. maculatus*. A study by Ahmad and Yousuf (2021) reported that the oil significantly reduced adult emergence and oviposition when applied to cowpea seeds. The oil is especially effective as a fumigant because of its fumigant properties, particularly in closed storage facilities, making it useful for harvest management. Balanite oil can be used as a fumigant or contact insecticide. However, due to its high volatility, reapplications may be needed to maintain effectiveness over long storage periods (Abu Zeid *et al.*, 2019). Despite this limitation, balanite oil is generally safe for seeds and causes minimal phytotoxicity, making it suitable for cowpea storage.

Black seed, *Nigella sativa* (L.) oil

Black seed oil derived from *Nigella sativa* is rich in thymoquinone, nigellone, and carvacrol, making it highly bioactive, as reported by Albakry *et al.* (2022). Thymoquinone is a beneficial compound that imparts antimicrobial and insecticidal properties to the oil (Asgarpanah and Ariamanesh, 2021). The oil contains thymoquinone, which disrupts pest cellular respiration, impairing energy metabolism and leading to death. Additionally, black seed oil acts as a repellent, reducing the number of pests in storage areas where it is applied (Akhigbe *et al.*, 2021). Research has shown high efficacy of black seed oil against *C. maculatus*. Malami and Usman (2022) found that black seed oil offers strong protection against pest oviposition and adult emergence in treated cowpea seeds. It is also highly effective as a fumigant, making it ideal for use in dry storage facilities. Fumigation: Black seed oil can be used as a fumigant or seed coating; however, due to its potent active constituents, application rates are low. Nevertheless, its strong smell can raise concerns about flavor contamination during storage, which should be considered (Akhigbe *et al.*, 2021).

Neem, *Azadirachta indica* (L.) oil

The most active component of neem oil is azadirachtin. It is highly insecticidal and growth-regulating for pests. Its multifunctional pest-killing ability is also due to other compounds, such as nimbin and salannin (Muhammad & Kashere, 2020; Khan & Mian, 2020). Neem oil affects insect development by disrupting growth through antifeedant, repellent, or disruptor actions. Azadirachtin mimics insect hormones, disrupting their molting and reproductive processes, thereby gradually reducing pest populations (Rattanapun & Shrestha, 2021). Khan *et al.* (2021) found that neem oil was highly effective at reducing oviposition and adult emergence of *C. maculatus* in stored cowpeas. It has a long-lasting residual effect that offers protection against infestation, though periodic applications may be necessary for optimal control. Neem seed oil is commonly used as a seed dressing or fumigant, as its properties are effective even at low concentrations. However, due to neem's strong smell, it can affect the

sensory qualities of stored cowpeas, limiting its use in consumer-oriented storage practices.

Seed collection and preparation

The cowpea seeds used in this study were sourced from Zaria. The seed variety used is *Kananado*, *Dan Misra*, and *Kwankwasiya*, and was carefully selected for uniform size and absence of visible damage. After selection, the seeds were sorted and kept under controlled conditions (25°C and 60% humidity) to maintain their natural physiological state. Prior to treatment with essential oils, a quarter (1/4) size phostoxin tablet was placed in the container to kill any living larvae and eggs (disinfest) on the beans' surfaces before commencement. After two weeks, the phostoxin residue was removed, and the beans were air-dried to eliminate any odour and residues, as described by Muhammad *et al.* (2020).

Insect culture, infestation, and treatment application

The culture of *C. maculatus* was established using a stock population obtained from an existing colony of infested cowpea purchased from Dutsin-Ma Market. The colony was kept in a laboratory kliner jar. The setup was maintained in the laboratory at $27 \pm 2^\circ\text{C}$, $70 \pm 5\%$ RH, and 13:11 (L:D) h for the duration of the experiment. The F1 progenies that emerged were used for the bioassays according to Hamzei *et al.* (2023); Ekoja *et al.* (2022). One hundred unsexed adult cowpea bruchids were introduced into a kliner jar filled with 500 g of *Kwankwasiyaa* cowpea cultivar. The jar was covered with a muslin cloth and secured with a rubber band to allow aeration and prevent bruchids from escaping, as described by Ati *et al.* (2024). The adult beetles were allowed to mate and oviposit freely on the seeds for two weeks. Both live and dead beetles were sieved out, and the emerged F1 from the parent stock was used in the bioassay experiment. Fifty grams (50 g) of cowpea cultivar were placed in transparent plastic containers measuring 4.5 cm in depth and with a lid diameter of 8.0 cm. The lid was cut in the center, and a piece of muslin cloth was placed to ensure complete aeration. In each container, 2.5 mL of EOs was introduced using a microtube. The insecticide was applied at a rate of 5 g. The containers were vigorously shaken to ensure complete coverage of the treatments on the bean surfaces. After about 30 seconds, 10 cowpea bruchids in a 1:1 male-to-female ratio were introduced into each experimental unit. The lid was tightly fastened as described by Muhammad *et al.* (2020). The F1 generation from the eggs laid by the parent stock was used for the research, as described by Ati *et al.* (2024), Oaya *et al.* (2023), Hamzei *et al.* (2023), Ekoja *et al.* (2022), and Muhammad *et al.* (2020).

Data collection

Mortality rates of *C. maculatus*

Mortality rates of *C. maculatus* were monitored by counting the number of dead beetles in each container at 24, 48, 72, and 96 hours. Bruchids that failed three probing attempts on their legs using a feather were considered dead, as described by Ati *et*

al. (2024), Muhammad *et al.* (2020), and Oaya *et al.* (2017).

Oviposition

The number of eggs laid by the bruchids was recorded 2 weeks after infestation. Five (5) cowpeas were randomly selected, and the number of eggs laid was observed with the aid of a hand lens. The total number of eggs laid was recorded, and the average was taken as described by Muhammad *et al.* (2023).

Number of exit holes

Exit holes were indicators of successful adult emergence and the extent of seed damage. At the expiration of the experiment (3 months), 5 seeds from each treatment unit were inspected for exit holes. The total number per seed and per treatment group was documented, and the average was taken.

Progeny emergence

Progeny emergence was recorded by counting the total number of adult bruchids that emerged from artificially infested seeds in each treatment group at the end of the study. This parameter provided insights into the reproductive success of *C. maculatus* and the inhibitory effects of the plant EOs used.

Gas Chromatography Mass Spectrometry (GC-MS) screening

Essential oils from desert date *Balanites aegyptiaca* (L.), black seed *Nigella sativa* (L.), were analyzed using GC-MS, following the standard procedure described by Abu Zeid *et al.* (2019) in the laboratory of the National Agency for Food Drug Administration and Control (NAFDAC) Kaduna, to identify bioactive compounds. The data reported include the compound name, chemical formula, retention index, and retention time. The volatile oil analysis was conducted with a gas chromatography-mass spectrometer (manufactured by Thermo Quest Finningan, TRACE MS model). A DB-5 column, 30 meters long with an inner diameter of 0.25 mm and a film thickness of 0.25 µm, was used. Helium served as the carrier gas at a flow rate of 1.1 ml/min. The injection temperature was set at 250°C, and the temperature program ranged from 40°C to 460°C, increasing at 5°C per minute. An injection volume of 0.2 microliters and an electron ionization detector with an ionization energy of 70 eV were employed (Sarrami *et al.*, 2023; Adamu *et al.*, 2022; Salisu *et al.*, 2017; Salisu *et al.*, 2025; Hamisu and Salisu, 2025; Mohammed *et al.*, 2017).

Data Analysis

Data collected from the experiment were analyzed using analysis of variance (ANOVA) in SAS version 26.0 (SAS, 2002). Before analysis, data with zero values were transformed using $\sqrt{n} + 0.5$ (Muhammad *et al.*, 2019). Significantly different means were separated using the Duncan Multiple Range Test at the 5% significance level.

RESULTS

Effect of essential oils and cowpea cultivars on *C. maculatus* mortality at 24, 48, 72, and 96 hours after infestation

Results of the effect of Balanites, black seeds, neem oils, and a synthetic insecticide on cowpea bruchids at different sampling periods are presented in Table 1. At 24 hours, black seed oil emerged as the most potent essential oil, producing the highest mortality (2.33), which was significantly ($p < 0.05$) more effective than Balanites and neem oils, which were statistically comparable. All the essential oils were significantly better than the control. The synthetic insecticide proved superior to all the treatments. At 48 hours, the effectiveness of black seed (1.67) and neem (1.33) oils increased, but they remained comparable. At 96 hours after infestation, all the essential oils' potency decreased, while the control recorded higher mortality.

Table 1: Effect of Essential oils and cowpea cultivars on *C. maculatus* mortality at 24, 48, 72, and 96 hours

Treatments	Means (Hrs.)			
	24	48	72	96
Essential Oils (EO)				
Balanite	1.83c	0.83abc	1.50	0.50bc
Black seed	2.33b	1.67a	1.00	0.33bc
Neem	2.00c	1.33ab	0.00	0.67b
Insecticide	10.00d	0.00c	0.00	0.00c
Control	0.50d	0.50c	1.33	1.33a
SE(±)	0.109	0.327	0.209	0.203
Cultivars (C)				
<i>Dan Misra</i>	3.80a	1.60a	1.90	0.20b
<i>Kwankwasiya</i>	3.20b	0.60a	0.60	0.60ab
<i>Kananado</i>	3.00b	0.40b	0.80	0.90a
SE(±)	0.085	0.254	0.161	0.157
Interaction (EO x C)	NS	NS	NS	NS

Means followed by the same letter(s) within the same column are not significantly different ($p \leq 0.05$) according to Duncan's Multiple Range Test (DMRT). NS = Not Significant

Table 2: Effect of Essential oils and cowpea cultivar on *C. maculatus* on oviposition in stored cowpea seeds

Treatments	Means
Essential Oils (EO)	
Balanite	0.08 ^b
Black seed	0.24 ^b
Neem	0.24 ^b
Insecticide	0.00 ^b
Control	1.88 ^a
SE(±)	0.0979
Cultivars (C)	
<i>Dan Misra</i>	0.41
<i>Kwankwasiya</i>	0.49
<i>Kananado</i>	0.57
SE(±)	0.0758
Interaction (EO x C)	NS

Means followed by the same letter(s) within the same column are not significantly different ($p \leq 0.05$) according

to Duncan's Multiple Range Test (DMRT). NS = Not Significant

The effect of cowpea cultivar on bruchid mortality showed that high mortality was recorded in *Dan Misra* (3.80), which was significantly higher than *Kwankevasiyya* and *Kananado*, which were statistically ($P > 0.05$) at par. A similar performance effect was recorded 48 hours after treatment application.

Effect of essential oils and cowpea cultivars on oviposition of *C. maculatus* in stored cowpea

Analysis of oviposition of *Callosobruchus maculatus* across treatments and cowpea cultivars is presented in Table 2. The control treatment recorded significantly ($p < 0.05$) the highest average number of eggs laid with the highest average oviposition rate of 1.88 as compared to other treatments. A statistically similar average number of eggs was recorded in EOs-treated cowpea. However, the least oviposition was recorded in Balanites (0.08). Complete oviposition deterrence was recorded in insecticide-treated cowpea (0.00), which was significantly ($p < 0.05$) different from the EOs. The treatment effect across cowpea cultivars was, however, not significant.

Table 3: Effect of Essential oils and Cowpea cultivars on *C. maculatus* progeny emergence in stored cowpea seeds

Treatments	Means Progeny emergence
Essential Oils (EO)	
Balanite	0.11 ^b
Black seed	0.00 ^b
Neem	9.67 ^b
Insecticide	0.00 ^b
Control	375.51 ^a
SE(±)	29.940
Cultivars (C)	
<i>Dan Misra</i>	72.07
<i>Kwankevasiyya</i>	100.20
<i>Kananado</i>	58.91
SE(±)	23.190
Interaction (EO x C)	
	NS

Means followed by the same letter(s) within the same column are not significantly different ($p \leq 0.05$) according to Duncan's Multiple Range Test (DMRT). NS = Not Significant

Effect of essential oils and cowpea cultivars on progeny emergence of *C. maculatus* in stored cowpea seeds

Table 3 presents the effect of treatments on bruchid progeny emergence. *C. maculatus* progeny emergence differed significantly ($p < 0.05$) among EOs and the control throughout the study. The untreated cowpea seeds (Control) had the significantly highest number of progeny across all treatments. Neem, balanite oils, as well as insecticide treatments, did not differ ($p > 0.05$) from one

another. However, black seed oil recorded the least (0.00), which is statistically at par with insecticide (0.00).

Bioactive secondary compounds identified in balanite and black seed oils

Gas Chromatography Mass Spectrometry (GC-MS) analysis of balanite oil presented in Table 4 revealed a total of twenty-five (25) bioactive compounds. The profile also indicated the presence of two significant phenolic compounds, namely 2,4-di-Tert butylphenol and 2,6-di-Tert butylphenol, with equal molecular composition of $C_{14}H_{22}O$ and molecular weights of 206. Such phenolic compounds are well known for their antioxidant and insecticide properties, suggesting that balanite oil contains chemical constituents that interfere with insect development and survival. Moreover, the oil contained a high amount of essential fatty acids, such as 9,12-octadecadienoic acid ($C_{18}H_{32}O_2$) and oleic acid ($C_{18}H_{34}O_2$). It contains fatty acid esters (such as 9,12-octadecadienoic acid methyl ester and hexadecanoic acid methyl ester), further signifying its potential to disrupt the membranes of insects. The other recognized compounds included pentadecanoic acid and tetradecanoic acid, which were unsaturated fatty acids that may be associated with the oil's chemical stability and bioactivity. The GC-MS analysis of black seed oil it revealed the presence of nineteen (19) bioactive compounds (Table 5). The predominant constituents were oleic acid ($C_{18}H_{34}O_2$), 9,12-octadecadienoic acid (*Z,Z*) ($C_{18}H_{32}O_2$), and octadecanoic acid ($C_{18}H_{36}O_2$). Oleic acid was detected multiple times, confirming its abundance in black seed oil. 9,12-octadecadienoic acid (linoleic acid) was also prominently identified. The GC-MS chromatograms of balanites and black seed oils are presented in Figures 1 and 2, respectively.

DISCUSSION

Effect of Essential oils on the activities of *C. maculatus* in stored cowpea seeds

The results from this study revealed the ovicidal effect of essential oils on the mortality of *Callosobruchus maculatus* at various exposure times. At all sampling periods (hours), black seed oil demonstrated the highest mortality as compared to balanites and neem oils. This indicates that black seed oil acts rapidly, likely due to the presence of thymoquinone, which impairs neural transmission and causes acute toxicity in insects as reported by Ebadollahi and Mahboubi (2020). It could also be attributed to the thin layer of oil that completely sealed the insects' spiracles. This stopped gaseous exchange, and as a result, the insect died due to respiratory failure. Neem oil's moderate effect is associated with azadirachtin, which interferes with moulting and feeding (Kariuki *et al.*, 2021). The mortality recorded for the insecticide 24 hours after infestation indicates its high effectiveness and remains the most immediate, on-the-spot control strategy. Also, the findings aligned with earlier observations where the bioactivity of essential oils improves with time due to cumulative exposure (Ngamo *et al.*, 2020).

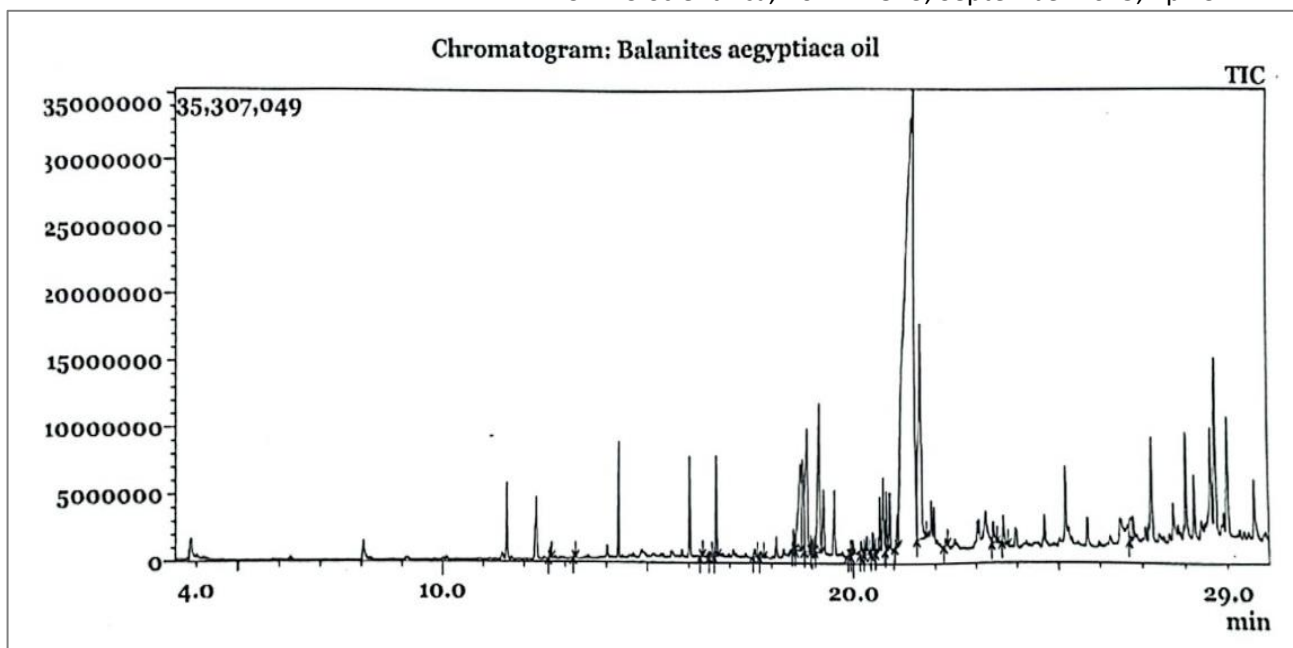


Figure 1: GC-MS chromatogram of desert date *Balanites aegyptiaca* oil

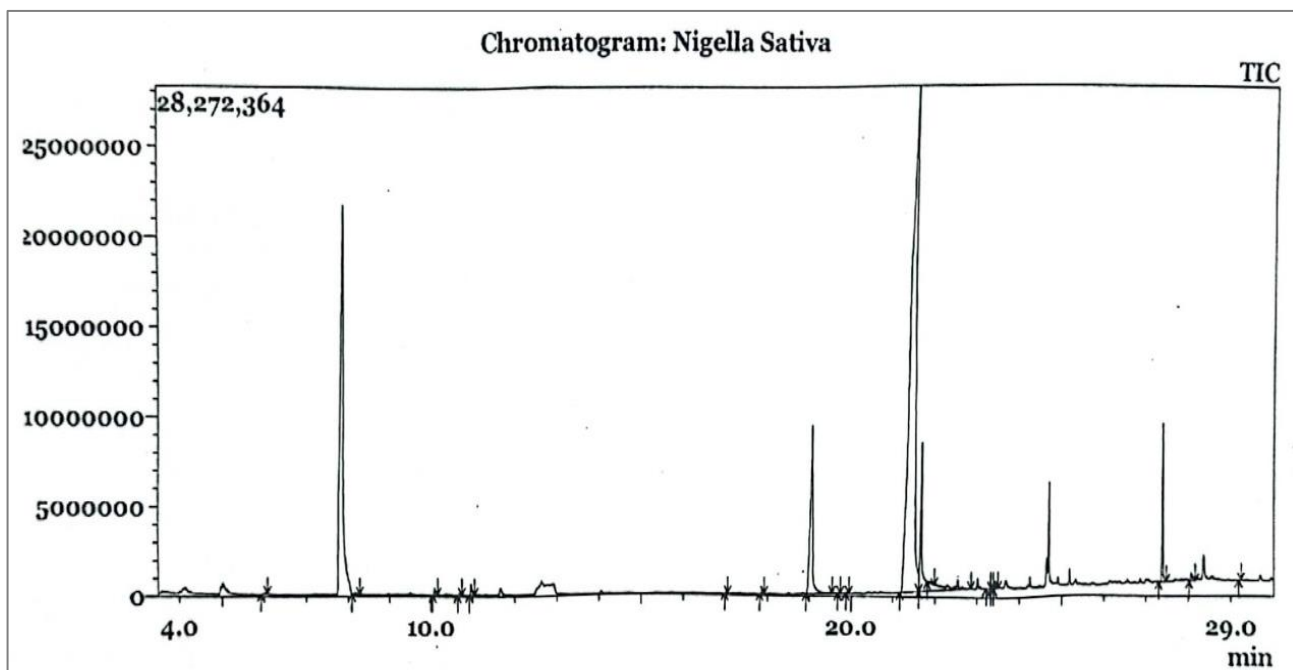


Figure 2: GC-MS chromatogram of black seed *Nigella sativa* oil

Regarding the effect of essential oils on the number of eggs laid, the results showed that EOs suppressed egg-laying in *C. maculatus*, and the control group recorded the highest oviposition value due to the absence of any deterrent effect. Among the oils, balanite oil was the most effective, showing strong repellency. Balanite is rich in saponins, which are known to act as insect feeding and oviposition deterrents, as observed by [Osipitan and Tijani-Eniola \(2020\)](#). The insecticide completely suppressed oviposition, demonstrating excellent short-term reproductive suppression, albeit with lower mortality efficacy. This suggested that it may act more as a sterilant or repellent rather than a toxicant. Exit holes in stored seeds and progeny emergence patterns reflect the complete reproductive success of *C. maculatus* and its successful development. The control recorded the highest

number of exit holes, indicating severe seed damage from unregulated infestation. Among essential oils, balanite oil completely suppressed exit holes, as did black seed oil and neem oil, revealing their strong efficacy in inhibiting adult emergence. This corroborates the reports of [Ghosh et al. \(2021\)](#), who found that essential oils disrupt larval development by altering physiological processes such as respiration and moulting.

Bioactive compounds identified in balanite and black seed oils

The GC-MS analysis revealed the presence of potent insecticidal compounds in both balanite and black seed oils. Balanite oil contained 2,4-di-tert-butylphenol, linoleic acid methyl ester, and oleic acid, which are known to possess strong insecticidal and antifeedant properties

Table 4: Gas Chromatography Mass Spectrometry (GC-MS) of bioactive compounds identified in balanite oil

SNo.	Compound name	Chemical Formulae	Molecular weight	Retention index	Retention time (sec.)
1	4a,7-Methano-4aH-naphth[1,8a-b]oxirene	C ₁₅ H ₂₄ O	220	1305	12.626
2	2,4-Di-tert-butylphenol	C ₁₄ H ₂₂ O	206	1555	13.222
3	Tetradecanoic acid	C ₁₄ H ₂₈ O ₂	228	1769	16.298
4	9-Tricosene	C ₂₃ H ₄₆	322	2315	16.516
5	1-Nonadecene	C ₁₉ H ₃₈	266	1900	16.665
6	Pentadecanoic acid	C ₁₅ H ₃₀ O ₂	242	1869	17.603
7	7,9-Di-tert-butyl-1-oxaspiro(4,5)deca-6,9-diene-2,8-dione	C ₁₇ H ₂₄ O ₃	276	2081	17.758
8	Hexadecanoic acid, methyl ester	C ₁₇ H ₃₄ O ₂	270	1878	18.549
9	n-Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	256	1968	18.716
10	Tetracosanoic acid	C ₂₄ H ₄₈ O ₂	368	2763	18.88
11	Dibutyl phthalate	C ₁₆ H ₂₂ O ₄	278	2037	19.007
12	n-Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	256	1968	19.179
13	9-Tricosene, (Z)	C ₂₃ H ₄₆	322	2315	19.91
14	Heptadecanoic acid, methyl ester	C ₁₈ H ₃₆ O ₂	284	1978	19.96
15	Palmitoleic acid	C ₁₆ H ₃₀ O ₂	254	1976	20.199
16	Tricosanoic acid	C ₂₃ H ₄₆ O ₂	354	2664	20.333
17	Heptadecanoic acid	C ₁₇ H ₃₄ O ₂	270	2067	20.483
18	Behenic alcohol	C ₂₂ H ₄₆ O	326	2451	20.575
19	Methyl stearate	C ₁₉ H ₃₈ O ₂	298	2077	21.095
20	Octadecanoic acid	C ₁₈ H ₃₆ O ₂	284	2167	21.668
21	9,12-Octadecadienoic acid (Z,Z)-	C ₁₈ H ₃₂ O ₂	280	2183	22.263
22	Oleic Acid	C ₁₈ H ₃₄ O ₂	282	2175	23.431
23	Eicosanoic acid	C ₂₀ H ₄₀ O ₂	312	2366	23.674
24	gamma-Sitosterol	C ₂₉ H ₅₀ O	414	2731	26.725

Bioactive compound identified in the laboratory of National Food Drugs Administration and Control in Kaduna, Nigeria.

Table 5: Gas Chromatography Mass Spectrometry (GC-MS) bioactive compounds identified in black seed oil

SN _o .	Compound name	Chemical Formulae	Molecular weight	Retention index	Retention time (sec)
1	Bicyclo[2.2.1]heptan-2-ol, 2,3,3-trimethyl	C ₁₀ H ₁₈ O	154	1088	6
2	3-Carene Bicyclo[4.1.0]hept-3-ene, 3,7,7-trimethyl-	C ₁₀ H ₁₆	136	948	8.172
3	Tetradecane	C ₁₄ H ₃₀	198	1413	10.082
4	Glycerol 1,2-diacetate 1,2,3-Propanetriol, 1,2-diacetate	C ₇ H ₁₂ O ₅	176	1230	10.681
5	Thymoquinone 2,5-Cyclohexadiene-1,4-dione,	C ₁₀ H ₁₂ O ₂	164	1340	10.966
6	Tetradecanoic acid	C ₁₄ H ₂₈ O ₂	228	1769	17.019
7	Cyclotetradecane	C ₁₄ H ₂₈	196	1679	17.866
8	n-Hexadecanoic acid	C ₁₆ H ₃₂ O ₂	256	1968	19.049
9	Acetic acid n-octadecyl ester	C ₂₀ H ₄₀ O ₂	312	2177	19.702
10	Isopropyl palmitate	C ₁₉ H ₃₈ O ₂	298	2013	19.898
11	Oleic Acid	C ₁₈ H ₃₄ O ₂	282	2175	21.48
12	Octadecanoic acid	C ₁₈ H ₃₆ O ₂	284	2167	21.662
13	9,12-Octadecadienoic acid	C ₁₈ H ₃₂ O ₂	280	2183	21.86
14	Erucic acid	C ₂₂ H ₄₂ O ₂	338	2572	23.25
15	Caryophyllene oxide	C ₁₅ H ₂₄ O	220	1507	23.363
16	Oleic Acid	C ₁₈ H ₃₄ O ₂	282	2175	23.45
17	2,3-Dihydro farnesyl acetate	C ₁₇ H ₃₀ O ₂	266	0	27.389
18	Octadecanoic acid, 2-hydroxy-1	C ₃₉ H ₇₆ O ₅	624	4395	28.066
19	Octadecanoic acid, 2,3-dihydroxypropyl ester	C ₂₁ H ₄₂ O ₄	358	2681	29.214

Bioactive compound identified in the laboratory of National Food Drugs Administration and Control in Kaduna, Nigeria.

(Popescu *et al.*, 2024). Black seed oil also contains fatty acids and esters, such as 9-octadecenamide and docosanoic acid, although with slightly lower toxicity. These compounds likely contributed to the observed variations in insecticidal activity between the oils. Overall,

the results suggest that neem and balanite oils are highly effective botanical insecticides that can be safely used in managing *C. maculatus* in stored cowpea. Their insecticidal efficacy, combined with their ability to preserve seed viability, makes them viable alternatives to synthetic

insecticides. Future research should focus on the long-term storage stability of treated seeds and on optimal application rates for commercial-scale storage solutions.

CONCLUSION

The findings of this research showed that essential oils obtained from desert date (*Balanites aegyptiaca* (L.)), black seed (*Nigella sativa* (L.)), and neem (*Azadirachta indica* (L.)) were lethal to adult *C. maculatus*, causing increased mortality, inhibiting egg laying, and strongly affecting adult emergence. It can therefore be used as a complement in stored cowpea control against infestation or as an alternative to synthetic insecticides, which pose a hazard to consumers and threaten the environment. It could also be incorporated into stored product Integrated Pest Management control.

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