

ORIGINAL ARTICLE

Open Access



Biocidal potential of *Chromolaena odorata* L. and *Ocimum gratissimum* L. against adult houseflies (*Musca domestica* Linnaeus 1758)

Fatai Olaitan Alao¹, Emmanuel Ajibola Olagunju^{1*} , Oladele Abiodun Olaniran¹, Saidat Yetunde Yusuf² and Timothy Abiodun Adebayo¹

Abstract

The use of plant extracts as insecticides against vector insects serves as a perfect alternative to conventional methods. This study was carried out to assess the chemical composition and efficacy of *Chromolaena odorata* L. and *Ocimum gratissimum* L. in the control of adult houseflies. *C. odorata* and *O. gratissimum* were extracted with cold water and applied at four concentrations (5, 10, 40 and 100% v/v) in different bioassays (contact, fumigant and feeding-deterrent). A synthetic insecticide (Lambdacyhalothrin) and an untreated control were included in the treatments. The treatments were arranged in a completely randomized design with three replicates. The phytochemical compositions of the tested plant extracts were determined via gas chromatography–mass spectrometry (GC–MS). Mortality data were recorded at the stipulated times (1, 2, 4, 6, 8 and 24 h), and the means were separated via Duncan's multiple range test at a 5% probability. GC–MS revealed different chemical compounds, and eugenol, n-hexadecanoic acid, caryophyllene, phytol, humulene, 9,12,15-octadecatrienoic acid, (Z,Z,Z)-, squalene, and stigmaterol compounds, among others, were identified as active insecticidal compounds. The tested plant extracts were effective against the studied insects, which suggested synergistic action of the observed natural chemicals in the plant extracts used. Moreover, the two plant extracts did not kill the studied insects faster than the synthetic insecticide did, but 100% mortality was observed after 12 h of exposure to the plant extracts. The mode of application and concentration played a significant role in the toxicity of the plant extracts, with the feeding mode of application resulting in greater toxicity effects than the fumigant and contact bioassays at the highest concentration. However, *O. gratissimum* exhibited better insecticidal control than *C. odorata* extracts did. Therefore, the use of crude plant extracts as insecticides could serve as substitutes for lambdacyhalothrin in the control of houseflies, especially in animal rearing facilities and in the human population.

Keywords Housefly, *Chromolaena odorata*, *Ocimum gratissimum*, Zoonoses, Botanical insecticides

Handling editor: Zhixin Lei.

*Correspondence:

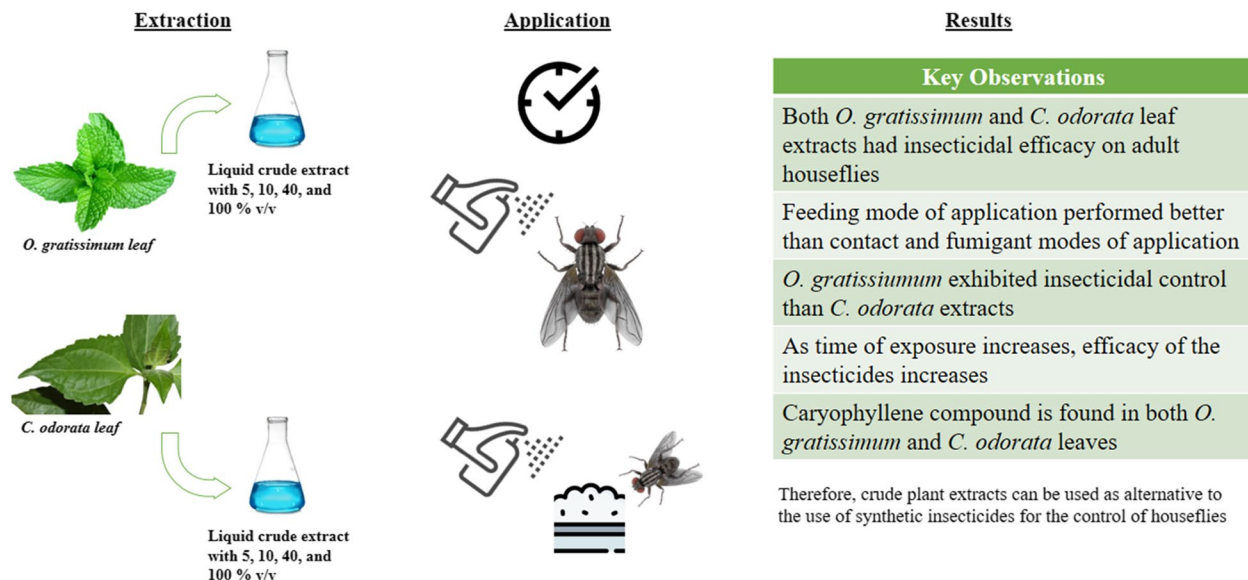
Emmanuel Ajibola Olagunju
olagunjuemmanuel7@gmail.com

Full list of author information is available at the end of the article



© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

Graphical Abstract



Introduction

The housefly (*Musca domestica* Linnaeus, 1758) cohabits with humans, presents numerous health hazards, and serves as a mechanical vector that can transmit a range of infections, including cholera, while also causing annoyance to people (Sankar and Jagadeeswaran 2020; Soyelu et al. 2020; Olagunju 2022). Houseflies thrive on a range of temporary food sources, including kitchen waste; dung from swine, goats, bovines, sheep, and horses; wet hay; fermenting organic matter; human excrement; cut grass; and urine. Dairy farms serve as optimal environments for the breeding of houseflies, presenting a significant challenge to dairy operations globally (Neupane et al. 2019; Soyelu et al. 2020). *M. domestica* not only transmits diseases but also contributes to food spoilage, stress, and irritation in livestock and poultry, ultimately resulting in decreased production efficiency (Kumar et al. 2011; Alghamdi 2021). Furthermore, it leads to substantial economic losses, unwarranted staff frustration, and a notable decline in the quality of animal management (Chantawee and Soonwera 2018; Freeman et al. 2019). Therefore, managing this insect becomes necessary.

Chemical insecticides, such as organochlorines, organophosphates, and pyrethroids, serve as primary methods for controlling house flies. However, chemical insecticides are widely recognized for their significant health and ecological drawbacks (Zhang et al. 2017; Singh et al. 2023). Consequently, alternative control strategies that are effective against insects, safe for humans, and

environmentally sustainable are urgently needed. An increasing number of people are looking to use plants to eliminate household pest insects. Botanical pesticides are good sources of safer and more eco-friendly pesticides, making them a better choice than conventional chemicals. Botanicals are more eco-friendly, economical, species specific, and biodegradable and have fewer or no harmful effects on nontarget organisms, including humans, making them a viable alternative to chemical pesticides (Sharma et al. 2011; Demirak and Canpolat 2022; Nteziyaremye et al. 2023).

Plant-derived products have surfaced as a prominent option for managing insect populations. Plant extracts contain bioactive compounds such as polyphenols, alkaloids, terpenoids, essential oils, steroids, lignins, fatty acids, and sugars. These compounds are secondary metabolites of plants and have a wide range of effects on various insect pests. Consequently, these products are regarded as effective alternatives to chemical insecticides for managing insect pests and have minimal impact on human health, the environment, and beneficial insects, such as predators, parasites, and pollinators, owing to their low residual activity (Regnault-Roger et al. 2012; Pandey 2022).

Ocimum gratissimum L. (Lamiaceae), commonly referred to as white wild basil, clove basil, or African basil, is an aromatic herb within the genus *Ocimum*, which is part of the *Lamiaceae* family (Dzoyem et al. 2017). This species is found across pantropical regions,

originally from southern Africa and Madagascar, and has become prevalent in all intertropical areas because of its ability to adapt ecologically (Lebrun and Stork 1997). This plant is often used in traditional medicine in tropical areas because it has pain-relieving, diabetes-lowering, muscle-spasm-relieving, expectorant, diuretic, antibacterial, calming, antidiarrheal, and asthma-relieving properties (Benelli et al. 2019). Additionally, it serves purposes such as treating snake bites, repelling mosquitoes, and controlling insects (Benelli et al. 2019).

Chromolaena odorata L., widely referred to as Siam weed, belongs to the *Asteraceae* family and is recognized for its pesticidal and medicinal properties in various regions (Sirinthipaporn et al. 2017). While it is not restricted to specific habitats, it is frequently found in wastelands (Rajmohan and Logankumar 2011). Globally, people acknowledge *C. odorata* as one of the most problematic tropical weeds because of its rapid proliferation (Mandal and Josh 2014). Researchers have identified alkaloids, cardiac glycosides, anthocyanins, tannins, and flavonoids in the leaf extracts of *C. odorata* (Ngozi et al. 2009). Several studies have illustrated the effectiveness of its leaf extract, highlighting its role as an antioxidant, anti-inflammatory, analgesic, antimicrobial, and cytoprotective agent (Ajao et al. 2011). *C. odorata* has been shown to be effective against adult mosquito vectors (Alam et al. 2011), and its leaf extract has been tested for its ability to control red flour beetle (Onumkum 2013). However, information on the effects of the two tested plant extracts against adult houseflies at different concentrations is lacking; therefore, the aim of this study was to evaluate the insecticidal effectiveness of *O. gratissimum* and *C. odorata* against adult houseflies.

Results

GC–MS analysis of the plants

GC–MS (Figs. 1 and 2) revealed 22 compounds in the leaves of *C. odorata* (Fig. 3) and 28 compounds in the leaves of *O. gratissimum* (Fig. 4). In *C. odorata* leaves, 4H-pyran-4-one, 1,2-benzenediol, hexanoic acid, α -terpineol, oleic acid, (Z,Z)-9,12-octadecadienoic acid-, 14-methyl-, methyl ester, 9,12,15-octadecatrienoic acid, methyl ester, n-hexadecanoic acid, caryophyllene, and octadecanoic acid were found to be insecticidal compounds. 2-Methoxy-4-vinylphenol, eugenol, n-hexadecanoic acid, caryophyllene, phytol, humulene, 9,12,15-octadecatrienoic acid, squalene, stigmasterol, and β -sitosterol are the insecticidal compounds found in *O. gratissimum* leaves. Both plants share the common compound caryophyllene.

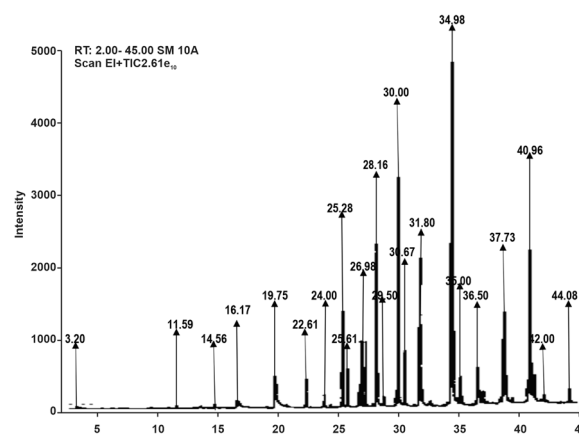


Fig. 1 Phytochemical analysis of *Chromolaena odorata* plants

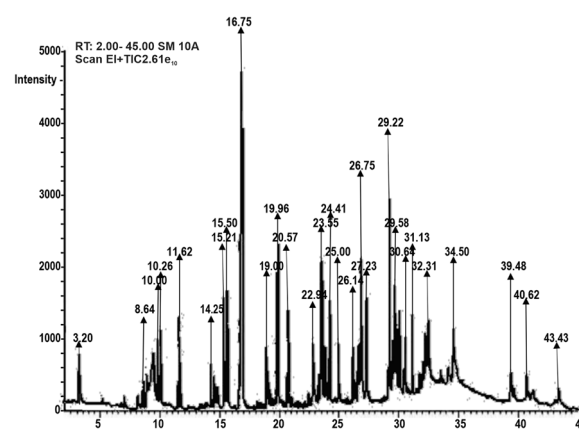


Fig. 2 Phytochemical analysis of *Ocimum gratissimum* plants

Effects of insecticides through contact toxicity on adult houseflies

Table 1 shows that *O. gratissimum* and *C. odorata* leaves presented insecticidal potential against adult houseflies when applied through contact. None of the developed botanicals resulted in mortality among the houseflies after 1 h of exposure, whereas the synthetic insecticide lambda-cyhalothrin eliminated all the insects within the same time frame. The concentration of *O. gratissimum* at 100% v/v had the most significant insecticidal potential after 8 and 12 h of exposure. All concentrations of *O. gratissimum* (5, 10, 40, and 100% v/v) and *C. odorata* (100% v/v) exhibited equivalent insecticidal efficacy to lambda-cyhalothrin after a 24 h exposure period. In addition, other concentrations of *C. odorata* (5, 10, and 40% v/v) demonstrated reduced insecticidal efficacy compared with *O. gratissimum* and lambda-cyhalothrin after a 24-h exposure period. Nonetheless, there is a progressive increase in the effectiveness of insecticides with prolonged exposure time. Compared with other

concentrations, the formulated insecticides, which were applied at a concentration of 100% v/v, demonstrated significant insecticidal potential.

Effects of insecticides through feeding toxicity on adult houseflies

The effects of insecticides on adult houseflies are reported in Table 2, with a focus on feeding toxicity. The insecticides tested resulted in mortality within the stipulated time, except for *C. odorata* leaves at 5 and 10% v/v, as did the control group, which showed no insecticidal effects on *M. domestica* adults after 1 h of exposure. In contrast, lambda-cyhalothrin resulted in a 100% mortality rate in the treated insect population. The efficacy of *O. gratissimum* at 100% was equivalent to that of lambda-cyhalothrin after a 4-h exposure period. The efficacy of *O. gratissimum* at all concentrations was statistically 100% mortality, as was observed for the synthetic insecticide-treated houseflies after 12 h of exposure. Moreover, *C. odorata* at 100% v/v demonstrated the highest insecticidal potential among its formulations, effectively eliminating 80% of the insect population. The rates of 10, 40, and 100% demonstrated the highest efficacy after a 24 h exposure period, according to the statistical analysis.

Effects of insecticides through fumigant toxicity on adult houseflies

According to our findings (Table 3), none of the botanical insecticides had insecticidal effects on adult houseflies after 2 h of exposure. In contrast, lambda-cyhalothrin effectively eliminated the entire insect population within 1 h of exposure via its fumigant application method. The application of *C. odorata* at concentrations of 5 and 10% v/v did not result in any mortality among the studied insects after an 8-h exposure period. In contrast, *C. odorata* at a concentration of 100% v/v presented the highest insecticidal efficacy among the concentrations tested, leading to a mortality rate of 46.7% in the insect population after the same duration of exposure. Following a 24 h exposure period, *O. gratissimum* at concentrations of 5, 10, 40, and 100% v/v and *C. odorata* at 10 and 100% v/v effectively competed with synthetic insecticides.

Discussion

The management of *M. domestica* depends on the application of chemical insecticides; however, the widespread application of insecticides has resulted in the emergence of resistance and tolerance among insect populations, leading to negative consequences for both consumers and the environment (Vasanth-Srinivasan et al. 2016; Jyoti et al. 2018; Richardson et al. 2019; Sánchez-Bayo 2021). Products derived from plants include bioactive compounds that can be utilized for

managing insect pests that affect animals, crops, and humans (Khater and Geden 2018; Wang et al. 2019; Lengai et al. 2020; Ayilara et al. 2023). Crude botanical extracts derived from plant leaves, roots, seeds, flowers, and bark have served as traditional pesticides for centuries (Alao et al. 2020, 2025; Cossetin et al. 2021). Furthermore, the use of crude or partially purified plant extracts is clearly a much more cost-effective and effective way to control *M. domestica* than the use of purified compounds or extracts (Fouda et al. 2017).

These observations indicate that both plant extracts, *O. gratissimum* and *C. odorata*, demonstrated insecticidal activity against *M. domestica*. This finding aligns with the findings of Udebuani et al. (2015), who reported that *C. odorata* leaf extracts were toxic to *P. americana*. Additionally, Mohammed (2018) noted that aqueous extracts from plants such as the leaves of *Nerium oleander*, *Myrtus communis*, and *Vachellia farnesiana* significantly impacted the mortality rates of adult houseflies. Additionally, a study conducted by Attaullah et al. (2019) demonstrated that extracts derived from *Azadirachta indica*, *Peganum harmala*, *Datura stramonium*, *Tribulus terrestris*, and *Chenopodium murale* exhibited insecticidal effectiveness against 2nd instar larvae of *M. domestica*. The mortality observed in adult *M. domestica* resulting from various plant extracts may be attributed to the varying toxicity levels of the active compounds present.

In *C. odorata* leaves, 4H-pyran-4-one, 1,2-benzenediol, hexanoic acid, α -terpineol, oleic acid, (Z,Z)-9,12-octadecadienoic acid, 14-methyl-, methyl ester, 9,12,15-octadecatrienoic acid, methyl ester, n-hexadecanoic acid, caryophyllene and octadecanoic acid are the insecticidal compounds found. This is corroborated by the findings of previous reports (Liu et al. 2012; García-Robles et al. (2013), Igwe and Udofia, 2015, Gurunathan et al. 2016, Khaleel et al. 2018, Jiang et al. 2018, Ali and Venugopalan 2019, Ma et al. 2020, Khamis et al. 2023, Abdullah et al. 2024).

Eugenol (Fernandes et al. 2020), 2-methoxy-4-vinylphenol (Jung et al. 2015), n-hexadecanoic acid (Abdullah et al. 2024), caryophyllene (Liu et al. 2012), phytol (Methew and Thoppil 2011), humulene (da Silva et al. 2015; Benelli et al. 2018), 9,12,15-octadecatrienoic acid (Rahman et al. 2014), squalene (Chauhan et al. 2015), stigmaterol (Gade et al. 2017), and β -sitosterol (Aguilar-Marcelino et al. 2022) are the insecticidal compounds found in *O. gratissimum* leaves. These compounds may contribute to the mortality of adult *M. domestica*. Stigmaterol causes mortality through the inhibition of *Aedes aegypti* acetylcholinesterase (Gade et al. 2017). Caryophyllene, on the other hand, acts as a nerve poison to pests through sodium channel modulators (Balar and Nakum 2010).

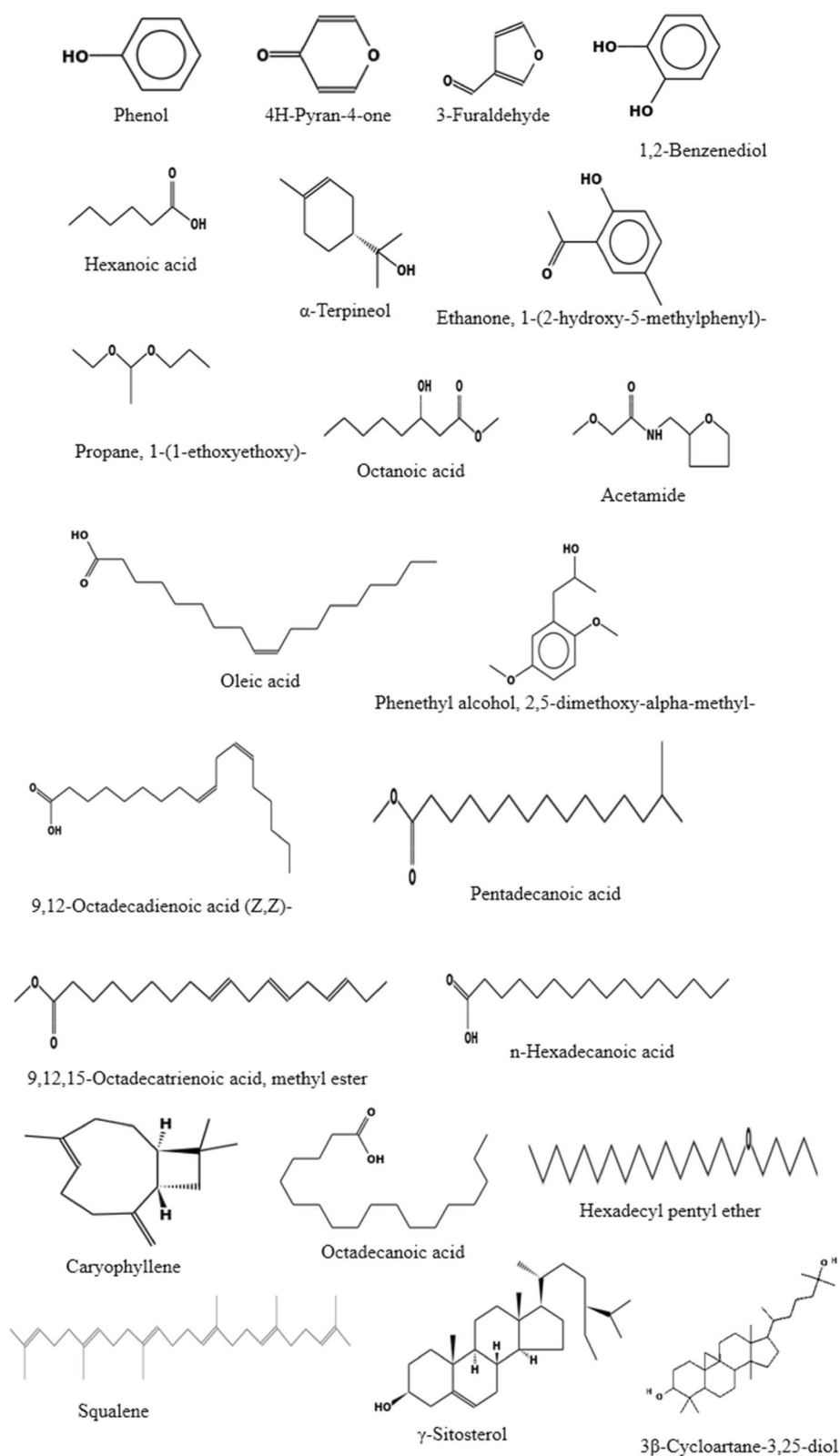


Fig. 3 Identified compounds in *Chromolaena odorata* leaves

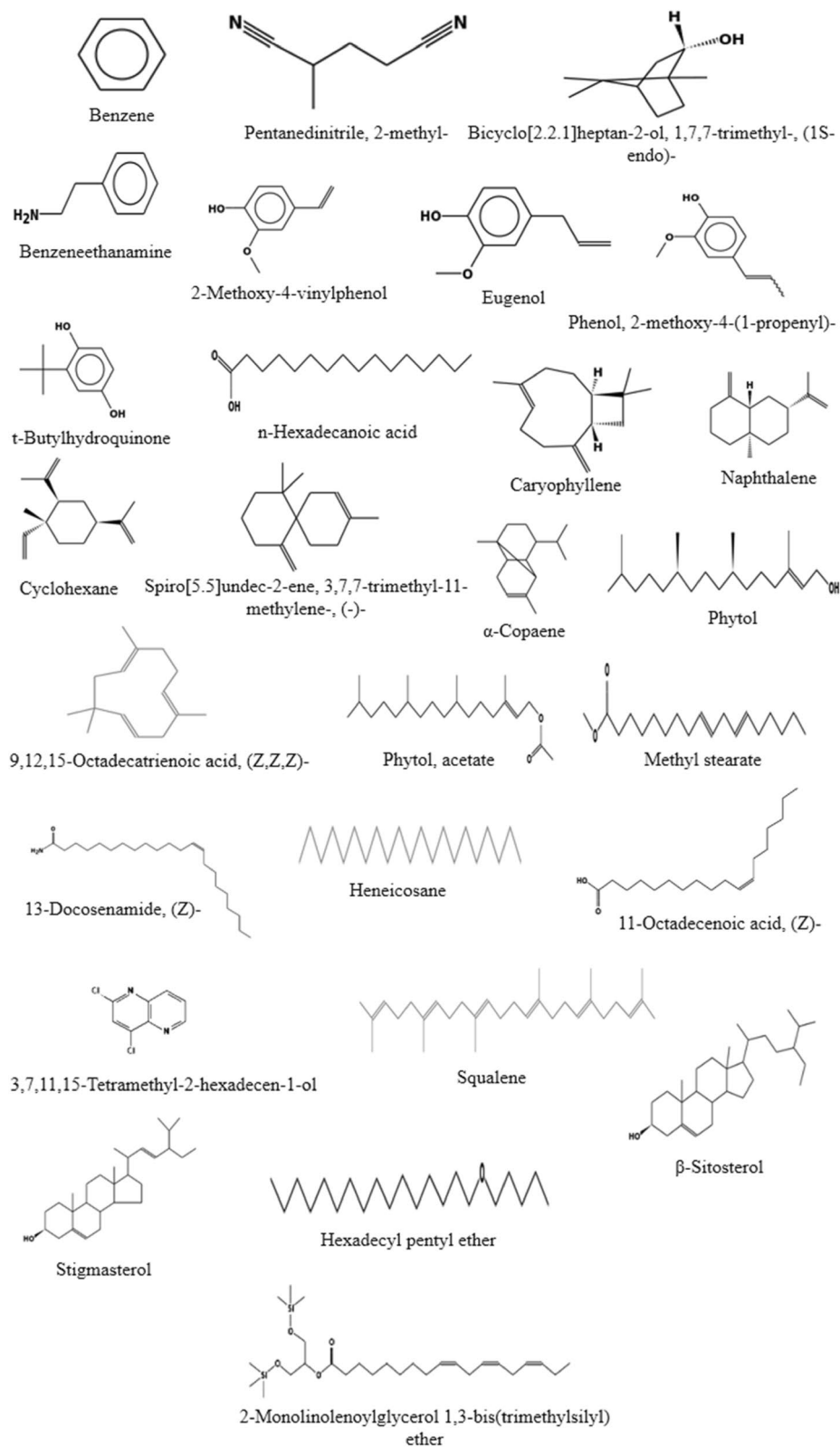


Fig. 4 Identified compounds in *Ocimum gratissimum* leaves

Table 1 Effects of contact toxicity on adult houseflies

Treatments	Rates	Hours of exposure					
		1	2	4	8	12	24
Lambdacyhalothrin		100 ^a	100 ^a	100 ^a	100 ^a	100 ^a	100 ^a
Control		0.00 ^b	0.00 ^d	0.00 ^f	0.00 ^e	0.00 ^e	0.00 ^d
<i>O. gratissimum</i> leaf	5	0.00 ^b	0.00 ^d	20.0 ^e	46.7 ^c	78.8 ^{bc}	100 ^a
<i>O. gratissimum</i> leaf	10	0.00 ^b	20.0 ^{bc}	33.3 ^{cd}	66.7 ^b	86.7 ^a	100 ^a
<i>O. gratissimum</i> leaf	40	0.00 ^b	26.7 ^b	40.0 ^{bc}	66.7 ^b	93.3 ^a	100 ^a
<i>O. gratissimum</i> leaf	100	6.67 ^b	26.7 ^b	53.3 ^b	73.3 ^b	100 ^a	100 ^a
<i>C. odorata</i> leaf	5	0.00 ^b	0.00 ^d	13.3 ^{ef}	26.7 ^d	46.7 ^d	66.0 ^c
<i>C. odorata</i> leaf	10	0.00 ^b	0.00 ^d	20.0 ^{de}	33.3 ^{cd}	60.0 ^{cd}	86.7 ^a
<i>C. odorata</i> leaf	40	0.00 ^b	13.3 ^{bcd}	26.7 ^{cde}	40.0 ^{cd}	53.3 ^{cd}	80.0 ^{bc}
<i>C. odorata</i> leaf	100	0.00 ^b	6.67 ^{cd}	26.7 ^{cde}	33.3 ^{cd}	60.0 ^{cd}	93.3 ^a
Rate	100	35.3 ^a	44.4 ^a	60.0 ^a	68.9 ^b	86.7 ^a	97.8 ^a
	40	0.00 ^b	20.0 ^b	33.3 ^b	58.3 ^b	73.3 ^a	93.3 ^a
	10	0.00 ^b	10.0 ^b	26.7 ^b	50.0 ^b	73.3 ^a	90.0 ^a
	5	0.00 ^b	0.00 ^c	11.1 ^c	24.4 ^c	40.0 ^b	55.6 ^b

Notes: Means with the same superscript (s) are not significantly different at the 5% probability level. *O. gratissimum*: *Ocimum gratissimum*; *C. odorata*: *Chromolaena odorata*

Table 2 Effects of insecticides through feeding toxicity on adult houseflies

Treatments	Rates	Hours of exposure					
		1	2	4	8	12	24
Lambdacyhalothrin		100 ^a	100 ^a	100 ^a	100 ^a	100 ^a	100 ^a
Control		0.00 ^e	0.00 ^e	0.00 ^f	0.00 ^c	0.00 ^c	0.00 ^c
<i>O. gratissimum</i> leaf	5	13.3 ^{de}	20.0 ^d	40.0 ^{cde}	53.3 ^{cd}	100.0 ^a	93.3 ^a
<i>O. gratissimum</i> leaf	10	20.0 ^{cd}	33.3 ^c	53.3 ^{bc}	73.3 ^a	93.3 ^a	100 ^a
<i>O. gratissimum</i> leaf	40	33.3 ^c	33.3 ^c	66.7 ^b	66.7 ^{cd}	100 ^a	100 ^a
<i>O. gratissimum</i> leaf	100	20.0 ^{cd}	66.7 ^b	86.7 ^a	93.3 ^a	100 ^a	100 ^a
<i>C. odorata</i> leaf	5	0.00 ^e	0.00 ^e	20.0 ^e	46.7 ^d	40.7 ^d	93.3 ^a
<i>C. odorata</i> leaf	10	0.00 ^e	13.3 ^{de}	26.7 ^{cd}	53.3 ^{cd}	46.7 ^{cd}	93.3 ^a
<i>C. odorata</i> leaf	40	20.0 ^{cd}	33.3 ^c	46.7 ^{cd}	53.3 ^{cd}	60.0 ^c	100 ^a
<i>C. odorata</i> leaf	100	20.0 ^{cd}	33.3 ^c	33.3 ^{cde}	53.3 ^{cd}	80.0 ^b	100 ^a
Rate	100	57.8 ^a	66.7 ^a	73.3 ^a	82.2 ^a	93.3 ^a	100 ^a
	40	26.7 ^b	33.3 ^b	56.7 ^b	60.0 ^b	80.0 ^a	100 ^a
	10	10.0 ^c	23.3 ^c	40.0 ^c	63.3 ^b	70.0 ^a	96.7 ^a
	5	4.44 ^c	6.67 ^c	20.0 ^d	33.3 ^c	42.2 ^b	62.2 ^b

Notes: Means with the same superscript (s) are not significantly different at the 5% probability level. *O. gratissimum*: *Ocimum gratissimum*; *C. odorata*: *Chromolaena odorata*

The results revealed that *O. gratissimum* and *C. odorata* at 100% v/v presented superior insecticidal potential to the other concentrations (5, 10, and 40% v/v). This aligns with the findings of Sharma et al. (2011), who reported that the percentage mortality of adult houseflies increased with increasing concentrations of plant extracts, indicating a direct relationship between the dose and percent mortality. Additionally,

Mohammed (2018) noted that the maximum concentration of *Metarhizium anisopliae* fungus (1×10^0 spores/ mL) resulted in complete mortality (100%) of adult houseflies, which was significantly different from the mortalities induced by the other fungal concentrations. Similarly, the findings of Attaullah et al. (2019), Cossetin et al. (2021) and Alao et al. (2025) indicated that the mortality rate of *M. domestica* increased

Table 3 Effects of insecticides through fumigant toxicity on adult houseflies

Treatments	Rates	Hours of exposure					
		1	2	4	8	12	24
Lambdacyhalothrin		100 ^a	100 ^a	100 ^a	100 ^a	100 ^a	100 ^a
Control		0.00 ^b	0.00 ^b	0.00 ^b	0.00 ^d	0.00 ^d	0.00 ^c
<i>O. gratissimum</i> leaf	5	0.00 ^b	0.00 ^b	6.67 ^{cd}	13.33 ^c	20.0 ^{ef}	93.3 ^a
<i>O. gratissimum</i> leaf	10	0.00 ^b	0.00 ^b	13.3 ^c	20.0 ^c	40.0 ^{cd}	93.3 ^a
<i>O. gratissimum</i> leaf	40	0.00 ^b	0.00 ^b	40.0 ^b	40.0 ^b	53.3 ^{cd}	93.3 ^a
<i>O. gratissimum</i> leaf	100	0.00 ^b	0.00 ^b	38.3 ^b	40.0 ^b	66.7 ^{bc}	100 ^a
<i>C. odorata</i> leaf	5	0.00 ^b	0.00 ^b	0.00 ^d	0.00 ^d	13.3 ^{fg}	53.3 ^c
<i>C. odorata</i> leaf	10	0.00 ^b	0.00 ^b	0.00 ^d	0.00 ^d	60.0 ^{cd}	86.7 ^a
<i>C. odorata</i> leaf	40	0.00 ^b	0.00 ^b	0.00 ^d	13.3 ^c	33.3 ^{ef}	66.6 ^b
<i>C. odorata</i> leaf	100	0.00 ^b	0.00 ^b	0.00 ^d	46.7 ^b	73.3 ^b	86.7 ^a
Rate	100	33.3 ^a	33.3 ^a	44.5 ^a	62.2 ^a	80.0 ^a	95.6 ^a
	40	0.00 ^b	0.00 ^b	20.0 ^b	26.7 ^b	43.3 ^b	80.0 ^b
	10	0.00 ^b	6.67 ^c	10.0 ^c	10.0 ^c	33.3 ^b	80.0 ^b
	5	0.00 ^b	0.00 ^b	22.2 ^c	4.44 ^c	11.1 ^c	48.9 ^c

Notes: Means with the same superscript (s) are not significantly different at the 5% probability level. *O. gratissimum*: *Ocimum gratissimum*; *C. odorata*: *Chromolaena odorata*

significantly with increasing dose rates. The insecticidal effects of *O. gratissimum* extracts might be associated with eugenol, 2-methoxy-4-vinylphenol, n-hexadecanoic acid, caryophyllene, phytol, humulene, 9,12,15-octadecenoic acid, squalene, stigmasterol, and β -sitosterol in combination with these bioactive compounds; 4H-pyran-4-one, 1,2-benzene, hexanoic acid, α -terpineol, oleic acid, (Z,Z)-9,12-octadecadienoic acid, 14-methyl-, methyl ester, 9,12,15-octadecatrienoic acid, methyl ester, n-hexadecanoic acid, caryophyllene and octadecanoic acid can be attributed to *C. odorata*.

Compared with those of *C. odorata*, extracts of *O. gratissimum* demonstrated superior insecticidal effects on adult houseflies. This aligns with the findings of Suwannayod et al. (2019), who reported that *O. gratissimum* presented the second highest toxicity among the five plants tested against houseflies. These findings underscore the potential of *O. gratissimum* as an eco-friendly insecticide for fly management and provide fresh perspectives on the industrialization and commercialization of plant-derived fly control solutions. The variations in the effectiveness of the plant extracts utilized in this study could be attributed to the differences in their chemical compositions (Figs. 3 and 4), which significantly influence the mortality rates of the insect pests that were treated (Mohammed 2018). Furthermore, the differing toxicity levels present in the insecticidal components of each plant likely contributed to the discrepancies in the results (Monzon et al. 1994). A prior investigation corroborated these results, with Kazim (2013) indicating that the effectiveness of aqueous extracts from *Nerium*

oleander was notably superior to that of *Myrtus communis* and *Vachellia farnesiana* in combating the larval stage of houseflies.

An increase in the exposure of houseflies to insecticidal formulations results in an increased mortality rate. Raja and Suresh (2015) provided evidence that the mortality rate of *M. domestica* larvae increases proportionally with the duration of exposure to the hexane extract of *Sapindus emarginatus* seeds. In a related context, direct exposure to dry allicin residues resulted in a distinct dose-response, culminating in 100% mortality of adult houseflies 48 h after a 24 h exposure period, with an LD50 for allicin recorded at 32.6 mg/cm², as reported by Bell et al. (2015).

The application of the formulations through feeding had greater insecticidal efficacy on adult houseflies than the other modes of application, i.e., contact and fumigant (Tables 1–3). This is in contrast with the findings of Alao et al. (2025), who revealed that extracts of *M. oleifera* and *J. curcas*, when applied by direct contact, demonstrated greater efficacy in killing the targeted insect than other modes of application. Notably, the insecticides used as fumigants had the least harmful effects.

Compared with synthetic insecticides, botanical insecticides result in a lower level of harm and have minimal or no impact on nontarget organisms. Furthermore, these substances present little to no risk to the environment, as they do not accumulate in soil, air, or water and are inherently biodegradable (Lengai et al. 2020; Gupta et al. 2021). This study was carried out in a controlled laboratory environment; therefore, subsequent investigations

should emphasize the use of botanical insecticides in real-world field settings. Botanical insecticides are biodegradable; however, a significant challenge is their limited shelf life. Further investigation is necessary to enhance the development of bioactive formulations that exhibit improved shelf-life and efficacy.

The findings of this study could pave the way for creating more cost-effective and environmentally friendly alternatives to conventional organic insecticides, as the plants used in the present study for the formulation of the crude insecticides were readily available and were harvested with ease. Additionally, the technique and other materials used for the formulation of these insecticides are easy to adapt.

Conclusions

These observations clearly showed that crude extracts of *C. odorata* and *O. gratissimum* can effectively manage housefly populations. The findings of this study further support the conventional use of plant products and imply that the extracts contain compounds with insecticidal properties that can serve as lethal or repellent agents against medically important insects. To maximize the insecticidal potential of these native medicinal plants and develop a formulation that is both effective and economically viable, additional research is necessary.

Methods

Experimental site

The study was conducted at the Department of Crop and Environmental Protection, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Oyo State, Nigeria. The temperature has remained consistently elevated, with an annual variation of approximately 5°C. The average annual precipitation is approximately 1200 mm, with a typical range spanning from 786.2 mm to 1513 mm. The rainy season occurs between April and November. The monthly distribution exhibits a bimodal pattern, with an initial peak occurring in June and a subsequent peak in September, whereas July and August serve as breaks in this timeframe.

Experimental design

We used three modes of application: contact, feeding, and fumigant. The treatments were organized in a completely randomized design (CRD) and were replicated three times. Adult houseflies gathered in insect-holding boxes were removed and placed into the specified plastic containers (five insects per container), following which the treatments were applied. The treatments evaluated in this study consisted of *Chromolaena* leaves, *Ocimum* leaves, lambda-cyhalothrin (serving as the positive control), and water (acting as the negative control).

The mortality rates for each treatment were recorded at 1, 2, 4, 6, 8, and 24 h. The treatments were performed in triplicate.

Insect collection

Adult house flies were drawn into the insect wooden cage using meats in a well-known abattoir in Ogbomoso from September to October 2024. They were provided with a combination of meats and sugary substances diluted in water. The houseflies were permitted to adapt to their new surroundings for one week prior to the initiation of the experiment (Alao et al. 2025). Healthy adult houseflies were selected from the insect box without regard to sex for the study.

Plant collection and identification

Leaves of *C. odorata* and *O. gratissimum* were collected from the premises of LAUTECH in Nigeria during the rainy season, which spans from April to October. The plants were subsequently transported to the botany section of the Pure and Applied Biology Department of the institution for identification purposes.

Gas chromatography–mass spectrometry (GC–MS) analysis of phytochemical compounds

The samples' chemical compositions were analyzed via a Varian 3800/4000 gas chromatograph mass spectrometer (GC–MS), which was outfitted with an Agilent capillary column DB-1MS (30 mm×0.25 mm inner diameter×0.25 µm thickness). The carrier gas employed was nitrogen, which was maintained at a steady flow rate of 1.2 mL/min. The apparatus features an oven set to an initial temperature of 55°C for 3 min, followed by a ramp program that increases at a rate of 6°C/min until reaching 310°C, accompanied by an additional isothermal hold of 3 min, with a flow rate split ratio of 10:1. Two microliter volumes of samples were injected, and the injector temperature was maintained at 250°C. A specific component was identified via standard mass spectra from the National Institute of Standards and Technology (NIST-LIB 0.8) libraries, which were integrated within the software of the GCMS system (ChemStation), along with relevant literature data. The various phytochemicals found in the crude extract were isolated via a gas chromatography column. A single compound isolated through gas chromatography proceeds to the mass spectrometer, where it undergoes ionization. The mass spectrometry ionizing spectrum was documented and analyzed in relation to the mass spectrometry spectrum of established compounds found in the NIST library. Each compound underwent a comparative analysis on the basis of a percentage score derived from both the reverse and forward

spectra. The MS spectrum accurately reveals the molecular weights of individual molecules.

The chromatograms derived from the total ion count (TIC) were integrated without any adjustments for coeluting peaks, and the findings are reported as total abundance. All the peaks were identified through mass spectral matching, achieving a threshold of 90% or higher, utilizing both the NIST and Wiley libraries. Compounds were reported only when they exhibited a spectral matching accuracy of 90% or higher. No response factors were determined.

Preparation of plant extracts

The leaves of *C. odorata* and *O. gratissimum* were air-dried for 14 d, and each plant material was pulverized separately via a mortar and pestle (Alao and Adebayo 2011). Five hundred grams of the pulverized plant powder was weighed separately via a sensitive scale. Each paste was subsequently transferred to a separate 15-L plastic bucket that contained 1000 mL of water. The materials were permitted to remain in the solution for 24 h (Ezena et al. 2016). The filtrates were collected and stored in a 5-L plastic keg as a stock solution. The filtration was conducted via the muslin linen. A one-liter extract of each plant was extracted from the stock solution. Four concentrations (5, 10, 40, and 100% v/v) were subsequently prepared and diluted with an equivalent volume of distilled water (Alao and Adebayo 2015). For example, 50 mL of the extract was diluted with 950 mL of distilled water after 5% of the stock was added. For the estimation of the other concentrations, the procedure was followed for 10% and 40%, whereas 100% of the extract was not mingled with water. The bioassay was conducted using the same volume of the solution (5 mL).

Contact toxicity bioassay

The experiment commenced at 8 am in the morning. Each container was labeled with the corresponding treatments, namely, *Chromolaena* leaf, *Ocimum* leaf, lambda-cyhalothrin, and the control. The transparent plastic container was introduced to five active adult houseflies that were selected from housefly rearing crates with dimensions of 31.0 cm in length, 45.5 cm in width, and 30.5 cm in height. The investigated insects were sprayed with a 5 mL solution of each plant extract (5, 10, 40, or 100% v/v) via a medical syringe to ensure that the solution made contact with the housefly. The houseflies were checked for survival or death by introducing an external stimulus through a spatula (Alao et al. 2025). The failure or failure of the housefly to respond to stimuli was recorded as either dead or alive.

Fumigant toxicity assay

Five active adult houseflies were collected from insect wooden boxes and placed into a plastic container. The lid of the container was removed in a circular manner and fitted with mosquito netting to facilitate the exchange of oxygen within and outside the container. One gram of cotton wool was saturated with 10 mL of the various concentrations (5, 10, 40, and 100% v/v), which were subsequently placed into each designated plastic container (Alao et al. 2025). The subjects were assessed for viability by applying an external stimulus to the tested insect via a spatula. The response of the houseflies to stimuli was documented as either dead or alive.

Feeding toxicity detection

The cow meat, which weighed 0.5 g, was soaked in each treatment separately and allowed to stand for 5 min. The treated meat was introduced into plastic containers. The tested houseflies were checked for survival or death via an external stimulus to the larvae through a spatula. The failure or failure of the houseflies to respond to stimuli was recorded as either dead or alive (Alao et al. 2025).

Data collection and statistical analysis

The percentage mortality of dead houseflies was estimated via the formula described by Babarinde et al. (2018).

$$\% \text{ Mortality} = \frac{\text{Number of dead insects}}{\text{Total number of insects}} \times 100$$

However, percentage mortalities were subjected to analysis of variance (ANOVA), and means were separated via least significant difference (LSD) at 5% probability via the statistical analysis system (SAS) 2002 V.2.0.

Abbreviations

M. domestica	Musca domestica
C. odorata	Chromolaena odorata
O. gratissimum	Ocimum gratissimum
LSD	Least significant difference
ANOVA	Analysis of variance
SAS	Statistical analysis system
GCMS	Gas chromatography–mass spectrometry
LAUTECH	Ladoke Akintola University of Technology
v/v	Volume per volume
TIC	Total ion count
NIST	National Institute of Standards and Technology
ML	Milliliter
CRD	Completely randomized design

Acknowledgements

Not applicable.

Authors' contributions

Study conception, experimental design, and supervision: Fatai O Alao, Oladele An Olaniran, and Timothy A Adebayo. Data collection and experimentation: Fatai O Alao and Emmanuel An Olagunju. Data analysis and draft manuscript

preparation: Fatai O Alao, Emmamuel An Olagunju, and Saidat Y Yusuf. All the authors have read and consented to publish the manuscript.

Funding

We received no external funding for this research.

Data availability

All the data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

¹Department of Crop and Environmental Protection, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. ²Department of Crop Protection, University of Ilorin, Ilorin, Kwara State, Nigeria.

Received: 20 January 2025 Accepted: 20 May 2025

Published online: 10 June 2025

References

- Abdullah, R.R.H., A.H. Abd El-Wahab, and S.A. Abd El-Salam. 2024. Insecticidal activity and possible modes of action of secondary metabolites of some fungal strains and wild plants as natural pesticides against *Spodoptera frugiperda*. *Beni-Suef Univ J Basic Appl Sci* 13: 9 (2024). <https://doi.org/10.1186/s43088-024-00467-z>
- Aguilar-Marcelino, L., J. A. Pineda-Alegría, D. O. Salinas-Sánchez, V. M. Hernández-Velázquez, G. I. Silva-Aguayo, N. Navarro-Tito, and C. Sotelo-Leyva. 2022. In vitro insecticidal effect of commercial fatty acids, β -sitosterol, and rutin against the sugarcane aphid, *melanaphis sacchari* zehntner (Hemiptera: Aphididae). *Journal of Food Protection* 85 (4): 671–675. <https://doi.org/10.4315/JFP-21-329>.
- Ajao, A.T., T.S. Ajadi, and M.S. Oyelowo. 2011. Evaluation of multiplicative killing effect of *C. odorata* extracts and β -lactam antibiotics against β -lactamase producing bacteria, isolated from selected hospitals in Ilorin Metropolis. *Annals of Biological Research Scholars Research Library* 2 (4): 76–84.
- Akram Ali Mohammed. 2018. Evaluation the efficacy of *Metarhizium anisopliae* and some plant extracts in controlling the housefly, *Musca domestica* in laboratory conditions. *Kufa Journal For Agricultural Sciences* 10 (1): 285–268. <https://doi.org/10.21276/kjas>
- Alam, M. F., M. M. Safhi, A. K. Chopra, and V. K. Dua. 2011. Toxicological properties of several medicinal plants from the Himalayas (India) against vectors of malaria, filariasis and dengue. *Tropical Biomedicine* 28 (2): 343–350.
- Alao, F. O., and T. A. Adebayo. 2011. Comparative toxicity of botanical and synthetic insecticides against major field insect pests of cowpea (*Vigna unguiculata* (L) Walp). *Journal of Natural Production and Plant Resources* 1 (3): 86–95.
- Alao, F.O. and T.A. Adebayo. 2015. Comparative efficacy of *Tephrosia vogelii* and *Moringa oleifera* against insect pests of watermelon (*Citrullus lanatus* Thumb). *International Letters of Natural Sciences* 35: 71–78. <https://doi.org/10.18052/www.scipress.com/ILNS.35.71>
- Alao, F.O., T.A. Adebayo, and O.A. Olaniran. 2020. Bioactivity and effects of spraying interval of selected plant extracts for control of preflowering insect pests of watermelon (*Citrullus lanatus* [Thunb.] Matsum. & Nakai). *Acta Agric Slov* 116/1: 107–14. <https://doi.org/10.14720/aas.2020.116.1.1583>
- Alao, F.O., E.A. Olagunju, O.A. Olaniran, T.A. Adebayo, S.Y. Yusuf. 2025. Laboratory evaluation of *Moringa oleifera* and *Jatropha curcas* extracts on adult housefly (*Musca domestica* L.). *Journal of Zoonotic Diseases* 9 (1): 690–696. <https://doi.org/10.22034/jzd.2024.18319>
- Alghamdi, T. S. 2021. Biological effect of two plant extracts against house flies (*Musca domestica* L) as a sustainable approach to vector disease control. *Entomological Research* 51:610–623. <https://doi.org/10.1111/1748-5967.12555>.
- Ali, S.I., and V. Venugopalan. 2019. Mosquito larvicidal potential of hydroxy-2-methyl-4H-pyran-4-one (MALTOL) isolated from the methanol root extract of *Seneciolaetus* Edgew. and its *in-silico* study. *Natural Product Research* <https://doi.org/10.1080/14786419.2019.1634712>
- Attaullah, M. K., M.A. Zahoor, Zahoor, et al. 2019. Insecticidal, biological and biochemical response of *Musca domestica* (Diptera: Muscidae) to some indigenous weed plant extracts. *Saudi Journal of Biological Sciences*. <https://doi.org/10.1016/j.sjbs.2019.05.009>.
- Ayilara, M. S., B. S. Adeleke, S. A. Akinola, C. A. Fayose, U. T. Adeyemi, L. A. Gbadegehin, R. K. Omole, R. M. Johnson, Q. O. Uthman, and O. O. Babalola. 2023. Biopesticides as a promising alternative to synthetic pesticides: A case for microbial pesticides, phytopesticides, and nanobiopesticides. *Frontiers in Microbiology* 14:1040901. <https://doi.org/10.3389/fmicb.2023.1040901>.
- Babarinde, S. A., A. K. Kehinde, A. A. Ifeoluwa, C. K. Funmilayo, and D. A. Ade-tayo. 2018. Synergistic effect of spinosad with selected botanical powders as biorational insecticides against adults of (*Tribolium castaneum*) Herbst, 1797 (Coleoptera: Tenebrionidae). *Journal of Agricultural Sciences* 63 (1): 39–51. <https://doi.org/10.2298/JAS1801039B>.
- Balar C., and A. Nakum. 2010. Application of natural compounds caryophyllene oxide, caryophyllene and limonene derived from plant in agriculture field as a pest repellent and insecticide. Appl. IN 2010MU01729 A 20100806. Indian Pat.
- Bell, H.A., A.G. Cuthbertson, and N. Audsley 2015. The potential use of allicin as a biopesticide for the control of the house fly, *Musca domestica* L. *International Journal of Pest Management*. <https://doi.org/10.1080/09670874.2015.1120363>
- Benelli, G., M. Govindarajan, M. Rajeswary, B. Vaseeharan, S. A. Alyahya, N. S. Alharbi, S. Kadaikunnan, J. M. Khaled, and F. Maggi. 2018. Insecticidal activity of camphene, zerumbone and α -humulene from *Cheilocostus speciosus* rhizome essential oil against the Old-World bollworm, *Helicoverpa armigera*. *Ecotoxicology and Environmental Safety* 148:781–786. <https://doi.org/10.1016/j.ecoenv.2017.11.044>.
- Benelli, G., R. Pavela, F. Maggi, J. G. N. Wandjou, D. Koné-Bamba, G. Sagratini, S. Vittori, and G. Caprioli. 2019. Insecticidal activity of the essential oil and polar extracts from *Ocimum gratissimum* grown in Ivory Coast: Efficacy on insect pests and vectors and impact on nontarget species. *Industrial Crops and Products* 132:377–385. <https://doi.org/10.1016/j.indcrop.2019.02.047>.
- Chantawee, A., and M. Soonwera. 2018. Larvicidal, pupicidal and oviposition deterrent activities of essential oils from Umbelliferae plants against house fly *Musca domestica*. *Asian Pacific Journal of Tropical Medicine* 11 (10): 621–629. <https://doi.org/10.4103/1995-7645.246338>.
- Chauhan, N., P. Kumar, S. Mishra, et al. 2015. Insecticidal activity of *Jatropha curcas* extracts against housefly, *Musca domestica*. *Environmental Science and Pollution Research* 22:14793–14800. <https://doi.org/10.1007/s11356-015-4686-1>.
- Cossetin, L. F., E. M. T. Santi, Q. I. Garlet, A. F. I. M. Matos, et al. 2021. Comparing the efficacy of nutmeg essential oil and a chemical pesticide against *Musca domestica* and *Chrysomya albiceps* for selecting a new insecticide agent against synanthropic vectors. *Experimental Parasitology* 225 : 108104. <https://doi.org/10.1016/j.exppara.2021.108104>.
- da Silva, R. C., P. Milet-Pinheiro, B. P. C. da Silva, A. G. da Silva, M. V. da Silva, D. M. Navarro, and N.H., and da Silva. 2015. (E)-Caryophyllene and α -Humulene: *Aedes aegypti* oviposition deterrents elucidated by gas chromatography-electrophysiological assay of Commiphora leptophloeos leaf oil. *PLoS ONE* 10 (12) : e0144586. <https://doi.org/10.1371/journal.pone.0144586>.
- Demirak, M. ŞS., and E. Canpolat. 2022. Plant-based bioinsecticides for mosquito control: Impact on insecticide resistance and disease transmission. *Insect* 13 (2): 162.
- Dzoyem J.P., L.J. McGaw, V. Kuete, and U. Bakowsky. 2017. Chapter 9 - Anti-inflammatory and anti-nociceptive activities of African medicinal spices and vegetables, Editor(s): Victor Kuete, Medicinal Spices and Vegetables from Africa. Academic Press, 239–270. <https://doi.org/10.1016/B978-0-12-809286-6.00009-1>.

- Ezena, G.N., C. Akotsen-Mensah, and K.O. Fening. 2016. Exploiting the insecticidal potential of the invasive siam weed, *Chromolaena odorata* L. (Asteraceae) in the management of the major pests of cabbage and their natural enemies in southern Ghana. *Adv. Crop Sci. Technol.* 4: 1000230. <https://doi.org/10.4172/2329-8863.1000230>
- Fernandes, M. J. G., R. B. Pereira, D. M. Pereira, A. G. Fortes, E. M. S. Castanheira, and M. S. T. Gonçalves. 2020. New eugenol derivatives with enhanced insecticidal activity. *International Journal of Molecular Sciences* 21 (23): 9257. <https://doi.org/10.3390/ijms21239257>
- Fouda, M. A., M. I. Hassan, A. Z. Shehata, A. I. Hasaballah, and M. E. Gad. 2017. Larvicidal and antifeedant activities of different extracts from leaves and stems of *Lantana camara* (Verbenaceae) against the housefly, *Musca domestica* L. *Egypt. Acad. J. Biolog. Sci* 9 (1): 85–98.
- Freeman, J. C., D. H. Ross, and J. G. Scott. 2019. Insecticide resistance monitoring of house fly populations from the United States. *Pesticide Biochemistry and Physiology* 158:61–68. <https://doi.org/10.1016/j.pestbp.2019.04.006>
- Gade, S., M. Rajamaniyam, V. Vadlapudi, K. M. Nukala, et al. 2017. Acetylcholinesterase inhibitory activity of stigmasterol and hexacosanol is responsible for the larvicidal and repellent properties of *Chromolaena odorata*. *BBA - General Subjects*. <https://doi.org/10.1016/j.bbagen.2016.11.044>
- García-Robles, I., C. Ochoa-Campuzano, E. Fernández-Crespo, G. Camarines, A. C. Martínez-Ramírez, C. González-Bosch, P. García-Agustín, C. Rausell, and M. D. Real. 2013. Combining hexanoic acid plant priming with *Bacillus thuringiensis* insecticidal activity against Colorado potato beetle. *International Journal of Molecular Sciences* 14 (6): 12138–12156. <https://doi.org/10.3390/ijms140612138>
- Gupta N., N. Sharma, S. Ramniwas. 2021. Botanical pesticides: use of plants in pest management. *CGC International Journal of Contemporary Technology and Research*. 4 (1): 271–275. <https://doi.org/10.46860/cgcijctr.2021.12.31.271>
- Gurunathan, A., J. Senguttuvan, and S. Paulsamy. 2016. Evaluation of mosquito repellent activity of isolated oleic acid, eicosyl ester from *Thalictrum javanicum*. *Indian Journal of Pharmaceutical Sciences* 78 (1): 103–110. <https://doi.org/10.4103/0250-474x.180259>
- Igwe, O., and D. Udofia. 2015. Secondary metabolites of the cuticular abdominal glands of variegated grasshopper (*Zonocerus variegatus* L.). *International Journal of Spectroscopy* 4:1–6. <https://doi.org/10.1155/2015/901386>
- Jiang, H., J. Wang, L. Song, X. Cao, X. Yao, F. Tang, and Y. Yue. 2018. Chemical composition of an insecticidal extract from *Robinia pseudacacia* L. seeds and its efficacy against aphids in oilseed rape. *Crop Protection* 104:1–6. <https://doi.org/10.1016/j.cropro.2017.10.004>
- Jung, J. Y., H. C. Lee, and J.-K. Yang. 2015. Insecticidal activity of *Coptis chinensis* extract against *Myzus persicae* (Sulzer). *Journal of Korean Wood Science and Technology* 43 (2): 274–285. <https://doi.org/10.5658/WOOD.2015.43.2.274>
- Jyoti, M. C., A. D. Mudasir, and S. P. Radhakrishna. 2018. Evaluation of some essential oils against the larvae of house fly, *Musca domestica* by using residual film method. *Advances in Biotechnology and Microbiology* 9 (1): 1–8.
- Kazim, S. M. 2013. Effect of some plant extracts on the larvae of aquatic insects fly home (*Musca domestica*) (Diptera: Muscidae). *Magazin of Al-Kufa University for Biology* 5:15–20.
- Khaleel, C., T. Nurhayat, and B. Gerhard. 2018. α-Terpineol, a natural monoterpene: A review of its biological properties. *Open Chemistry* 16:349–361. <https://doi.org/10.1515/chem-2018-0040>
- Khamis, W. M., S. I. Behiry, S. A. Marey, A. A. Al-Askar, G. Amer, A. A. Heflish, Y. Su, A. Abdelkhalek, and M. K. Gaber. 2023. Phytochemical analysis and insight into insecticidal and antifungal activities of Indian hawthorn leaf extract. *Science Reports* 13 (1): 17194. <https://doi.org/10.1038/s41598-023-43749-9>
- Khater, H., and C. J. Geden. 2018. Potential of essential oils to prevent fly strike and their effects on the longevity of adult *Lucilia sericata*. *Journal of Vector Ecology* 43 (2): 261–270. <https://doi.org/10.1111/jvec.12310>
- Kumar, P., S. Mishra, A. Malik, and S. Satya. 2011. Repellent, larvicidal and pupicidal properties of essential oils and their formulations against the housefly, *Musca Domestica*. *Medical and Veterinary Entomology* 25 (3): 302–310. <https://doi.org/10.1111/j.1365-2915.2011.00945.x>
- Lebrun, J.P., and A.L. Stork. 1997. Énumération des plantes à fleurs d'Afrique tropicale. Gamopétales: Ericaceae à Lamiaceae. Énum. Pl. Fleurs Afr. Trop. 4: 626.
- Lengai, G. M. W., J. W. Muthomi, and E. R. Mbega. 2020. Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. *Scientific African* 7 : e00239. <https://doi.org/10.1016/j.sciaf.2019.e00239>
- Liu, P., X. C. Liu, H. W. Dong, Z. L. Liu, S. S. Du, and Z. W. Deng. 2012. Chemical composition and insecticidal activity of the essential oil of *Illicium pachyphyllum* fruits against two grain storage insects. *Molecules* 17 (12): 14870–14881. <https://doi.org/10.3390/molecules171214870>
- Ma, S., R. Jia, M. Guo, K. Qin, and L. Zhang. 2020. Insecticidal activity of essential oil from *Cephalotaxus sinensis* and its main components against various agricultural pests. *Industrial Crops and Products* 150 : 112403. <https://doi.org/10.1016/j.indcrop.2020.112403>
- Mandal, G., and S. P. Josh. 2014. Invasion establishment and habitat suitability of *Chromolaena odorata* (L) king and Robinson overtime and space in the western Himalayan forests of India. *Journal of Asia Pacific Biodiversity* 7 (4): 319–400.
- Methew, J., and J. E. Thoppil. 2011. Chemical composition and mosquito larvicidal activities of *Salvia* essential oils. *Pharmaceutical Biology* 49:456–463. <https://doi.org/10.3109/13880209.2010.523427>
- Monzon, R. B., J. P. Alvior, L. L. Luczon, A. S. Morales, and F. E. Mutuc. 1994. Larvicidal potential of five Philippine plants against *Aedes aegypti* and *Culex quinquefasciatus*. *South East Asian J. Trop. Med. Pub. Health* 4:755–759.
- Neupane, S., D. Naydich, and L. Zurek. 2019. House flies (*Musca domestica*) pose a risk of carriage and transmission of bacterial pathogens associated with bovine respiratory disease (BRD). *Insects* 10:358. <https://doi.org/10.3390/insects10100358>
- Ngozi, M., C. J. Ikewuchi, and C. C. Ikewuchi. 2009. Chemical profile of *Chromolaena odorata* (L) Leaves. *Pakistan Journal of Nutrition* 8 (5): 521–524. <https://doi.org/10.3923/pjn.2009.521.524>
- Nteziyaremye, P., J. Cherutoi, J. Makatiani, and T. Muhizi. 2023. Insecticidal potential of essential oils from *Cupressus lusitanica* growing in ecological zones of Rwanda against adult housefly, *Musca domestica* L. *International Journal of Tropical Insect Science* 43.
- Olagunju E.A. 2022. Housefly: Common zoonotic diseases transmitted and control. *Journal of Zoonotic Diseases* 6 (1): 1–10. <https://doi.org/10.22034/jzd.2022.14378>
- Onumkum, O. 2013. Studies on the repellent activities of four common asteraceae in nigeria against red flour beetle, *Tribolium Castaneum*. *The International Journal of Engineering and Science* 2 (12): 90–93.
- Pandey, R.S. 2022. *Calotropis procera* and *Annona squamosa* ethanol extracts' insecticidal efficacy against *Musca domestica*. *Agricultural Science and Food Technology*. <https://primepubmed.com/agricultural-science-and-food-technology/>
- Rahman, M. M., S. H. Ahmad, M. T. Mohamed, and M. Z. Ab Rahman. 2014. Antimicrobial compounds from leaf extracts of *Jatropha curcas*, *Psidium guajava*, and *Andrographis paniculata*. *The Scientific World Journal* 2014 : 635240. <https://doi.org/10.1155/2014/635240>
- Raja, M., and M. Suresh. 2015. Extraction and evaluation of *Sapindus emarginatus* seed against the housefly, *Musca domestica* Linn. *J. Chem. Bio. Phy. Sci. Sec.* B5 (4): 3877–3884.
- Rajmohan, D., and K. Logankumar. 2011. Studies on the insecticidal properties of *Chromolaena odorata* (Asteraceae) against the life cycle of the mosquito, *Aedes aegypti* (Diptera: Culicidae). *Journal of Research in Biology* 4:253–257.
- Regnault-Roger, C., C. Vincent, and J. T. Arnason. 2012. Essential oils in insect control: Low-risk products in a high-stakes world. *Annual Reviews in Entomology* 57:405–424. <https://doi.org/10.1146/annurev-ento-120710-100554>
- Richardson, J. R., V. Fitsanakis, R. H. S. Westerink, and A. G. Kanthasamy. 2019. Neurotoxicity of pesticides. *Acta. Neuropathology* 138 (3): 343–362.
- Sánchez-Bayo, F. 2021. Indirect effect of pesticides on insects and other arthropods. *Toxics* 9 (8): 177.
- Sankar, P., and A. Jagadeeswaran. 2020. Fly control efficacy of neem products in comparison with methoprene against the house fly (*Musca domestica*) in experimental broilers farm. *Journal of Entomology and Zoology Studies* 8 (5): 2171–2175.
- Sharma, P. P., A. B. Pardeshi, and D. Vijigiri. 2011. Bioactivity of some medicinal plant extracts against *Musca domestica* L. *Journal of Ecobiotechnology* 3 (9): 14–16.
- Singh, J., A. Singh, and S. Singh. 2023. Entomotoxic potential of plant lectins as an environment friendly tool to control insect pests. *Environ Sci Arch* 2 (2): 205–212.

- Sirinthipaporn, A., and W. Jiraungkoorskul. 2017. Wound healing property review of siam weed. *Chromolaena Odorata. Pharmacogn Rev* 11 (21): 35–38. https://doi.org/10.4103/phrev.phrev_53_16.
- Soyelu, O.J., B.A. Oluwamakinde, and R.E. Okonji. 2020. Effect of neem, siam weed and vetiver oils on physiological reactions and fitness of house fly, *Musca domestica* L. *J Appl Sci Environ Manage.* 24 (3): 519–523.
- Suwannayod, S., K. L. Sukontason, B. Pitasawat, A. Junkum, K. Limsopatham, and M. K. Jones. 2019. Synergistic toxicity of plant essential oils combined with pyrethroid insecticides against blow flies and the house fly. *Insects* 10 (6): 178. <https://doi.org/10.3390/insects10060178>.
- Udebuani, A. C., P. C. Abara, K. O. Obasi, and S. U. Okuh. 2015. Studies on the insecticidal properties of *Chromolaena odorata* (Asteraceae) against adult stage of *Periplaneta Americana*. *Journal of Entomology and Zoology Studies* 3 (1): 318–321.
- Vasanth-Srinivasan, P., S. Senthil-Nathan, A. Thanigaivel, E. S. Edwin, and A. Ponsankar. 2016. Developmental response of *Spodoptera litura* Fab. to treatments of crude volatile oil from *Piper betle* L. and evaluation of toxicity to earthworm. *Eudrilus Eugeniae Kinb. Chemosphere* 155:336–347. <https://doi.org/10.1016/j.chemosphere.2016.03.139>.
- Wang, Z., P. Dai, X. Yang, C. C. Ruan, A. Biondi, and N. Desneux. 2019. Selectivity of novel and traditional insecticides used for management of whiteflies on the parasitoid *Encarsia formosa*. *Pest Manage Sci.* 75 (10): 2716–2724. <https://doi.org/10.1002/ps.5380>.
- Zhang, Z. L., Y. J. Xie, Y. Wang, Z. F. Lin, L. H. Wang, and G. Y. Li. 2017. Toxicities of monoterpenes against the housefly *Musca domestica* L. (Diptera: Muscidae). *Environmental Science and Pollution Research* 24:24708–24713. <https://doi.org/10.1007/s11356-017-0219-4>.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.