Review of Current Studies and Surveys of Plants with Mosquitocidal Properties in Nigeria

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Abstract

This review documents current studies and surveys of plants with mosquitocidal properties in Nigeria, highlighting the bioactive compounds responsible for their mosquitocidal effect. Mosquitoes are a significant public health threat in Nigeria, and in response to this threat, local communities have traditionally relied on various plants with repellent and mosquitocidal properties. Studies reported in this review article were compiled from peer-reviewed journals obtained from various databases namely ScienceDirect, PubMed and ReearchGate. This review reports that plants used for the control of mosquitoes in Nigeria include *Ageratum conyzoides* (goat weed), *Cymbopogon citratus* (lemon grass), *Lantana camara* (lantana), *Hyptis suaveolens* (bush mint) and *Ocimum gratissimum* (scent leaf). These plants exhibit mosquitocidal effects due to the presence of phytochemicals (active compounds) such as azadirachtin, eucalyptol and alpha-pinene. Reports in this review article confirm that indigenous plants are valuable resources for the control of mosquitoes.

Keywords: Mosquitocidal; *Ageratum conyzoides*; *Cymbopogon citrates*; *Ocimum gratissimum*

Introduction

The diseases caused by mosquitoes remain a significant public health concern in Nigeria. Mosquitoes are vectors of several debilitating diseases, including malaria, dengue, Zika virus, yellow fever, and chikungunya. These diseases pose significant public health challenges globally. Chemical insecticides with mosquitocidal effects have been widely used to control mosquitoes. Synthetic pyrethroids such as permethrin, resmethrin and dephenothrin (sumithrin) are the most used synthetic insecticides for killing mosquitoes. Pyrethroids disrupt the nervous system of mosquitoes, leading to paralysis and death. Synthetic insecticide used for mosquito control has several disadvantages. These disadvantages include environmental pollution, development of insecticide resistance in mosquitoes and potential harm to non-target organisms such as humans and beneficial insects.

A study carried out on the resistance status of Anopheles gambiae mosquitoes to four commonly used insecticide classes in Nigeria's southeastern zone highlighted a significant resistance of Anopheles gambiae to organochlorine, pyrethroid, and organophosphate insecticides (Chukwuekezie et al., 2020). The development of resistance to these insecticides by mosquitoes leads to widespread of insect-borne diseases like malaria. This have prompted a renewed interest in alternative mosquito control methods such as plant-based insecticides with mosquitocidal effect (Alabi et al., 2020; Bamal et al., 2024).

Numerous plant species possess natural defense systems against predators and diseases that also demonstrate mosquito-controlling properties (Pavela et al., 2022; Benelli et al., 2023). These plant-derived pesticides are increasingly viewed as sustainable alternatives, offering advantages such as environmental compatibility, selective toxicity, and a lower risk of insects developing resistance (Chellappandian et al., 2018; Isman, 2020). The use of mosqutocidal plants has gained attention due to their potential efficacy and eco-friendly profiles (Ibekwe et al., 2014; Isman, 2020; Onyido et al., 2020; Joel and Swathy 2024). A wide array of plants worldwide has demonstrated mosquitocidal properties, and these include plant species from families such as Asteraceae, Lamiaceae and Rutaceae. Contemporary research confirms that bioactive compounds such as alkaloids and flavonoids present in the essential oils of plants are responsible for their mosquitocidal effect (Benelli et al., 2016). Research has also demonstrated the high efficacy of alkaloids and flavonoids against both larval and adult mosquitoes (Ferreira et al., 2023).

In Africa, traditional knowledge has long recognized the use of plants for mosquito control, and ethno-botanical surveys have documented numerous plant species utilized across the continent (Ibrahim et al., 2021; Ojo et al., 2022). The diverse flora in Nigeria offers a rich source of potential mosquitocidal plants. Studies have highlighted various plant species in Nigeria with larvicidal and repellent activities. In Nigeria, plants like Lantana camara and Ocimum gratissimum have been reported for their mosquito-repelling properties (Ibrahim et al., 2021). Reports from previous studies have shown that the methanolic extract of Piper nigrum seeds exhibits significant larvicidal activity against Aedes aegypti (Govindarajan et al., 2013).

This review documented the current studies and surveys of plants with mosquitocidal properties in Nigeria, highlighting indigenous plant species that can serve as natural alternatives to synthetic mosquito control methods. This review article also provided valuable insights into how mosquitocidal plants in Nigeria are applied and the bioactive compounds present in these plants.

Materials and Methods

This review compiled data from peer-reviewed studies accessed via databases such as PubMed, ScienceDirect, Google Scholar and ResearchGate. The search focused on research from 2005 to 2025, and the keywords include "Mosquitocidal plants in North-West Nigeria", "Mosquitocidal plants in North-East Nigeria", "Mosquitocidal plants in North Central Nigeria", "Mosquitocidal plants in South-East Nigeria", "Mosquitocidal plants in South-West Nigeria", "Mosquitocidal plants in South-South Nigeria" and "Bioactive compounds present in the Nigerian plants used for control of mosquitoes". Data from un-peer-reviewed articles were excluded when compiling the review article. Studies were selected based on experimental research, including reports from ethnobotanical surveys, field trials and laboratory bioassays. Data on larvicidal (LC_{50}/LC_{90}), adulticidal, and repellent activities of the mosquitocidal plants were prioritised. Results were synthesised to compare the number of bioactive compounds (present in the plants) responsible for the moquitocidal effect.

Results and Discussion

Current Studies of Mosquitocidal Plants in Nigeria

Research has demonstrated that several Nigerian plants exhibit insecticidal properties against various mosquito species. Comprehensive studies conducted across various geopolitical zones (north-east, north-west, north-central, south-east, south-west and south-south) in Nigeria documented several plant species utilised for the control of mosquitoes, and these plants include neem, scent leaf, lemon grass and goat weed (Table 1). The plants documented in Nigeria for their mosquito repellent and insecticidal properties also include *Hyptis suaveolens* (bush mint), *Azadirachta indica* (Neem), *Dennettia tripetala* (Pepper fruit), *Cymbopogon citratus* (lemon grass) and *Sesamum indicum* (sesame) (Sosan *et al.,* 2001; Okonkwo *et al.,* 2014; Doe *et al*., 2024; Ojewumi, 2024) [Table 1]. The studies carried out on these plants provide evidence of their mosquitocidal effect. Also, the widespread availability and traditional knowledge associated with these plants make them promising candidates for developing cost-effective and environmentally friendly mosquito control measures. Neem (*Azadirachta indica*) oil has been shown to possess larvicidal properties against *Anopheles gambiae*, a major malaria vector (Ojo *et al.,* 2022). The active compound, azadirachtin, acts as a repellent and growth disruptor for mosquitoes (Okonkwo *et al.,* 2014). Essential oil from the leaves of scent leaf (*Ocimum gratissimum*) has demonstrated complete larvicidal activity against *Aedes aegypti* larvae at 300 ppm concentration. The efficacy of scent leaf oil was comparable to synthetic insecticides (Adebayo *et al*., 2021; Pam *et al.,*2023). The essential oil of lemon grass (*Cymbopogon citratus*) exhibited larvicidal activity against *Aedes aegypti* larvae, with mortality observed at 200 ppm concentration (Ezeanya *et al*., 2023). The essential oil from the complete whole plant of goat weed (*Ageratum conyzoides*) has shown potent larvicidal effects against *Aedes aegypti* larvae, achieving 100% mortality at 120 ppm concentration (Emeasor *et al*., 2019). The leaves, fruits, and bark of horsewood (*Clausena anisata*) contain essential oils with insecticidal properties, effective against various insect pests, including mosquitoes (Mukandaiwa*et al*., 2015). The ethanolic extracts of the fruits of Black Pepper (*Piper nigrum*) have been reported to exhibit larvicidal activity against *Culex quinquefasciatus* and *Aedes albopictus*, with low LC_{50} values indicating high potency (Ezeonu *et al.,* 2020).

Table 1: Mosquitocidal Plants commonly found in all the regions in Nigeria

Botanical Name	Geopolitical zones (NE, NW, NC, SE, SW and SS)	Common Name	Plant Part(s) used	Extract/ Essential oil	Active Compounds	References
Aframomum melegueta	Found in all the zones, and it is prominent in SE, SW and SS.	Grains of Paradise	Seed	Extract	6-Gingerol	Ekundayo *et al.,* 2021
Ageratum conyzoides	Found in all the zones, and it is prominent in NE, NC and SE.	Goat Weed	Leaves	Essential oil	Precocene I and II, Monoterpenoids	Sosan *et al.,* 2001
Allium sativum	Found and prominent in all the zones.	Garlic	Root	Essential oil	Sulfur Compounds	Agbalaka *et al.* 2021
Azadirachta indica	Found and prominent in all the zones.	Neem	Leaves, Seeds	Extract, Essential oil	Azadirachtin, Nimbin	Okonkwo *et al.,* 2014
Citrus aurantifolia	Found and prominent in all the zones.	Lime	Fruits	Juice	Limonene, Citral	Okonkwo *et al.,* 2014
Citrus sinensis	Found and prominent in all the zones.	Orange	Fruit peel	Essential oil	Limonene, Flavonoids	Ileke *et al.,* 2014
Clausena anisate	Found in all the zones, and it is prominent in NE and SW	Horse wood	Leaves, Fruit, bark	Essential oil	Seselin	Mukandaiwa et al., 2015.
Curcuma longa	Found and prominent in all the zones.	Turmeric	Rhizome	Extract	Curcumin	Afolayan *et al*., 2021
Cymbopogon citratus	All the zones, and it is	Lemon grass	Leaves	Essential oil	Citral (Geranial	Sosan *et al.,* 2001;

	prominent in NC, SE, SW and SS.				and Neral), Myrcene	Afolabi *et al.*, 2018
Duranta repens	All the zones, and it is prominent in NE, NW, NC, SE and SW	Golden Dewdrop	Leaves, Fruits	Extract	Durantoside, Flavonoids	Okonkwo *et al.,* 2014
Eucalyptus camaldulensis	All the zones, and it is prominent in NE, NW and NC	Eucalyptus	Leaves	Essential oil	Eucalyptol, Limonene	Sen-Sung *et al.*, 2009
Eucalyptus globulus	All the zones, and it is prominent in NE, NC, SW and SS	Eucalyptus	Leaves	Essential oil	Eucalyptol, Alpha-pinene	Okoh *et al.*, 2021
Hyptis suaveolens	All the zones, and it is prominent in NC, SW and SS	Bush Mint	Leaves	Essential oil	Monoterpenes, Sesquiterpene	Adelaja *et al.* 2021; Okoh et al., 2021
Lantana camara	All the zones, and it is prominent in NC, SW and SS	Lantana	Whole plant	Extract and essential oil	Lantadene A and B	Okonkwo *et al.,* 2014; Mgbemena *et al.*, 2023;
Mesosphaerum suaveolens	All the zones, and it is prominent in NC and SS	Pignut	Leaves	Essential oil	Citronellal, Phytol, Terpenoids	Ojianwuna *et al.,* 2024
Ocimum gratissimum	All the zones, and it is prominent in NC, SE, SW and SS	Scent Leaf	Leaf	Extract and essential oil	Eugenol, methyl eugenol, thymol, terpenoids	Oparaocha *et al.*, 2010; Okonkwo *et al.,* 2023
Piper guineense	All the zones, and it is prominent in SE and SS	West African Black Pepper	Fruits	Extract	Piperine, Chavicine	Okonkwo *et al.,* 2014
Piper nigrum	All the zones, and it is prominent in SE, SW and SS	Black Pepper	Seed	Extract	Piperine	Ezeonu *et al.,* 2020
Sesamum indicum	All the zones, and it is prominent in NE, NW and NC	Sesame	Leaves, Seeds	Essential oil	Sesamin, Sesamol	Okonkwo *et al.,* 2014
Zingiber officinale	Found and prominent in all the zones.	Ginger	Rhizome	Essential oil	Gingerol	Agbalaka *et al.,* 2021

NE: North East; NW: North West; NC: North Central, SE: South East; SW: South West; and SS: South South

Ethno-botanical Surveys of Mosquitocidal Plants in Nigeria

An ethnobotanical survey conducted in Plateau State, Nigeria, identified 45 plant species utilised by local communities for managing 15 different pests. Notably, *Mesosphaerum suaveolens, Gymnanthemum amygdalinum, Azadirachta indica, Canarium schweinfurthii, Euphorbia unispina,* and *Erythrophloem africanum* were among the most frequently cited. These plants were valued for their availability, affordability, effectiveness, eco-friendliness, and safety (Ibekwe *et al.,* 2014; Onyido *et al.*, 2020; Joel and Swathy, 2024). A recent ethno-botanical survey has documented the use of several plant species for mosquito control in Kaduna State, a key part of northwestern Nigeria. A study reported that out of six plant species identified, *Lantana camara*was the most utilised, accounting for 58.82% of the reported uses. Other species included *Ipomoea asarifolia*, *Terminalia catappa*, and *Citrullus vulgaris*, each with a 5.88% utilisation rate (Okoh *et al.,* 2021). These plants were primarily used through methods such as burning, hanging, or topical application to repel mosquitoes. The high utilisation of *Lantana camara* aligns with findings from other regions in Nigeria, where it has been reported as a significant mosquito repellent. This consistency underscores the potential of *L. camara* as a candidate for further research and development in mosquito control programs. (Okoh *et al.,* 2021). In Enugu State, six plant species from five families were identified for their repellent/ insecticidal properties against mosquitoes. Notably, *Conyza canadensis* (Canadian horseweed) from the Compositae family was the most frequently used for mosquito control (Ogbe and Ighodalo, 2020). Another ethno-botanical survey in Enugu State documented nine plant species used for mosquito control, with *Aframomum melegueta* being the most utilised. Other studies also highlighted the use of *Hyptis suaveolens* (bush mint) in southeastern Nigeria for mosquito control, and there are reports from studies that *H. suaveolens* exhibited significant mosquito repellent activity, with a use-mention index of 0.250, indicating its prominence in traditional mosquito control practices (Egunyomi *et al.*, 2010).

Traditional Mosquito Control Applications and Practices in Nigeria

The application methods of mosquitocidal plants in Nigeria are deeply rooted in indigenous knowledge.

Common practices include burning plant materials to produce smoke (Okonkwo *et al.,* 2023), hanging plants inside living spaces, and applying plant extracts topically. These methods are not only cost-effective but also culturally accepted, facilitating their integration into community-based vector control initiatives (WHO, 2023).

In Plateau State, the practice of smouldering leaves of *M. suaveolens* has been reported to provide over 70% repellent activity against mosquitoes (Aniefuna *et al.,* 2024). This traditional method aligns with findings from other African regions, where similar practices have been documented. There are different traditional methods for mosquito control practices in Nigeria, including burning of dried leaves, application of essential oils and placing of the leaves in sleeping areas.

Burning Dried Leaves
Ocimum gratissimum (Scent leaf), *Eucalyptus camaldulensis* (Eucalyptus), and *Azadirachta indica* (Neem) leaves are dried and burned indoors in the evening to repel mosquitoes. Burning these leaves produces natural insecticidal smoke, reducing indoor mosquito populations.

Application of Essential Oils
Essential oils from *Cymbopogon citratus* (Lemon grass), *Ocimum gratissimum*, and *Eucalyptus* are applied to the skin as mosquito repellents. A study conducted in Ekiti and Oyo States reported that 72% of respondents confirmed that lemon grass oil was effective in repelling mosquitoes for up to 5 hours (Adebajo *et al*., 2014).

Placing Fresh Leaves in Sleeping Areas
There are some communities that place fresh neem or citrus leaves near sleeping areas to deter mosquitoes. In Ogun State, a survey found that over 60% of respondents used fresh orange peels as natural mosquito repellents (Okoh *et al*., 2020). However, research indicates that burning or extracting essential oils is more effective than placing fresh leaves.

Comparison between plant-based insecticides and synthetic insecticides.
Plant-based and synthetic insecticides differ significantly in efficacy, insect resistance, and environmental impact (Table 2.). Synthetic insecticides are often faster-acting and more potent, while plant-based alternatives are generally considered safer for non-target organisms and the environment (Baltazar et al., 2016; Ayilara et al., 2023).

Mechanism of action of bioactive compounds found in mosquitocidal plants and their interaction with mosquito physiology at different life stages.
Bioactive compounds from mosquitocidal plants use diverse mechanisms to control mosquitoes, primarily by acting as neurotoxins, insect growth regulators, or behavioral modifiers. Instead of a single target, the multiple compounds in plant extracts often act synergistically, making it difficult for mosquitoes to develop resistance compared to single-compound synthetic insecticides.

1. **Terpenoids**

Terpenoids are a large class of compounds, including essential oils, that act on the nervous and hormonal systems of mosquitoes (Gosh et al., 2012; Şengül and Canpolat 2022).

Neurotoxicity: Many terpenoids, such as linalool and thymol, are neurotoxins that inhibit the enzyme acetylcholinesterase (AChE). AChE is crucial for terminating nerve impulses, and its inhibition leads to overstimulation of the mosquito's nervous system, causing paralysis and death.

Growth and molting disruption: Terpenoids, like those found in seaweed and neem oil, can disrupt the molting process, which prevents larvae from developing into the next life stage.

Repellency: Many volatile terpenoids act as natural repellents by triggering the olfactory systems of mosquitoes, keeping them from landing and biting.

2. **Saponins**

Saponins are glycosides characterized by a soap-like, amphiphilic structure, which allows them to disrupt cell membranes and synthesis of ecdysteroids (Adamu *et al*., 2013).

Membrane disruption: Saponins bind to cholesterol in the cell membranes of mosquito larvae, which causes the membranes to become damaged or permeable. This leads to cellular toxicity and death.

Antifeedant activity: Many saponins function as feeding

Table 2: Comparison between plant-based insecticides and synthetic insecticides.

Features	**Plant-Based Insecticides**	**Synthetic Insecticides**
Efficacy	They are often less potent, requiring more frequent or higher-dose applications to achieve comparable results.	Typically offer immediate, reliable, and more potent insect control.
Human health risks	They are generally less toxic to humans.	They can cause serious health problems from long-term exposure, including neurological disorders, cancer, and birth defects.
Insect resistance	Insects are less likely to develop resistance due to the multiple chemical compounds and diverse mechanisms of action found in botanical extracts.	Insects can develop resistance over time, which can lead to a vicious cycle of using stronger, more toxic chemicals.
Economic factors	They can be more expensive due to labor-intensive extraction and purification processes. Availability and efficacy can also be variable due to reliance on natural factors like climate.	They are often more cost-effective for large-scale farming due to higher potency, longer protection, and less frequent application. They also tend to have a longer shelf life.
Impact on biodiversity	Less harmful to non-target organisms such as beneficial insects, pollinators, and soil microbes.	Broad-spectrum products kill beneficial insects alongside pests, which can disrupt ecological balance and trigger secondary pest outbreaks.
Environmental impact	Generally biodegradable and non-persistent, minimizing long-term environmental contamination.	Most are persistent in the environment, contaminating soil, groundwater, and air.

deterrents. When ingested, they can damage the midgut lining of mosquito larvae, further inhibiting feeding and nutrient absorption.

Hormonal interference: Saponins can interfere with the synthesis of ecdysteroids, the hormone that regulate molting in insects, leading to developmental failure.

3. **Alkaloids**

Alkaloids are a diverse group of nitrogen-containing compounds that can act as neurotoxins and cause general physiological disruption. (Chowański *et al.*, 2016; Zhigang *et al.*, 2020).

Neurotoxicity: Like some terpenoids, many alkaloids inhibit AChE activity. Others, such as tropane alkaloids, block muscarinic acetylcholine receptors, which disrupts nerve function.

Physiological disruption: Alkaloids can interfere with basic cellular and physiological processes, including hormonal regulation and cellular signaling, leading to lethal and sublethal effects such as reduced reproduction and growth inhibition.

Cellular damage: There are some alkaloids that cause severe damage to the epithelial cells of the mosquito's midgut, functioning as a stomach poison.

4. **Flavonoids**

Flavonoids are polyphenolic compounds that can disrupt mosquito growth and development by interfering with key metabolic enzymes and systems. (Pathalam *et al.*, 2022).

Ecdysteroid biosynthesis inhibition: Flavonoids, including desmethylglycitein (DMG), act as inhibitors of the enzyme Noppera-bo (Nobo). Nobo is required for the biosynthesis of ecdysone, an insect steroid hormone essential for molting and metamorphosis. Flavonoids disrupt the mosquito's life cycle by inhibiting this enzyme.

Digestive enzyme disruption: Certain flavonoids can inhibit digestive enzymes like proteases and amylases in the larval midgut. This prevents proper digestion and nutrient uptake, causing starvation.

Growth regulation: Flavonoids can also delay growth, induce malformations, and interfere with the reproductive cycle by affecting oviposition (egg-laying) and egg hatching.

Potential economic impact of utilizing plant-based insecticides for the control of mosquitoes in both rural and urban settings in Nigeria.

The economic impact of adopting plant-based insecticides as alternatives for the control of mosquitoes in Nigeria could create significant benefits namely, creation of new jobs in both rural and urban areas, reduction in healthcare costs, and boosting local economies (Ntonifor *et al.*, 2006; Mezieobi *et al.*, 2025) [Table 3.].

Potential positive economic impact of plant-based insecticides

i. Reduced health expenditures: Widespread use of effective natural repellents could significantly reduce the immense economic burden of malaria.

ii. Greater economic productivity: Healthier populations, especially in rural communities, can lead to higher productivity and fewer workdays lost due to illness. In urban settings, a healthier workforce also improves economic output across various sectors.

iii. Job creation: Localized production of plant-based repellents from materials like orange peels or neem could create jobs for youth and provide income for local farmers.

iv. Reduced reliance on expensive insecticides: Communities and governments will spend less on costly, imported chemical pesticides and insecticide-treated nets by using cheaper, locally sourced alternatives like basil, neem, or orange peels.

v. New markets: The development and commercialization of natural repellent products can create a new, eco-friendly industry for Nigeria, tapping into a global trend toward sustainable solutions.

vi. Development of local industries: The production and commercialization of natural repellents such as creams, sprays, and essential oils from plants like *Ocimum gratissimum* and *Azadirachta indica* could stimulate the growth of local industries. This process would promote entrepreneurship, with potential for expansion from small-scale production to larger enterprises.

vii. Empowerment of rural economies: In rural areas, the cultivation and processing of local repellent plants can provide new income streams for farmers and rural entrepreneurs. This strategy fosters a sustainable "green economy" based on agriculture and natural products.

viii. Innovation in the urban market: Urban residents already buying various repellent products, the availability of safer, natural, and affordable local brands offers a desirable alternative. A focus on branding and marketing could capture a growing consumer base interested in eco-friendly options.

ix. Increased tourism and investment: Lower rates of mosquito-borne diseases could boost tourism and foreign investment, which are often deterred by the health risks associated with endemic diseases like malaria.

Potential negative economic impact of plant-based insecticides

i.Initial investment costs: Scaling up production and distribution of natural alternatives would require significant initial investment in research, processing facilities, and infrastructure.

ii. Disruption of existing markets: The introduction of cheaper, locally produced natural repellents could disrupt existing markets for synthetic products, although this would likely be beneficial for consumers.

iii. Feasibility of utilizing bio-insecticides for the control of mosquitoes in both rural and urban settings in Nigeria.

The use of natural mosquito control in Nigeria is feasible in both rural and urban settings. In rural areas, natural mosquito control aligns with existing traditional practices and offers cost-effective, accessible solutions for communities with limited access to modern products. Mosquito control with plant-based insecticides is also possible in urban areas, but its implementation requires a more strategic large-scale approach to deal with higher population densities (Ntonifor *et al.*, 2006).

Feasibility in rural settings

i.Accessible resources: Rural areas have abundant access to plants indigenous to Nigeria known to repel mosquitoes. Plants such as neem (*Azadirachta indica*), scent leaf (*Ocimum gratissimum*), and lemongrass (*Cymbopogon citratus*) are locally sourced and processed into mosquito repellents.

ii. Cultural alignment: Traditional methods like burning specific herbs to produce smoke are already part of local practices. Also, traditional preparations often use direct burning or crushed leaves of mosquito repellent plant, making them very affordable for low-income families.

iii. Lower costs: Sourcing natural repellents from local plants is significantly cheaper than purchasing commercial insecticides and coils, which is crucial for low-income populations.

iv. Existing knowledge: Ethnobotanical surveys confirm that rural communities already possess and utilize traditional knowledge of repellent plants.

in plant-based insecticides can vary greatly depending on factors such as the plant part used, geographic location, climatic conditions, and extraction method.

Slower action: Botanical pesticides generally act more slowly than synthetic ones, leading to less immediate "knockdown" effects. Pests may stop feeding immediately but may not die for hours or days.

Difficulty in quality control: Standardizing botanical extracts is complex because they contain multiple active compounds. Ensuring consistent efficacy and quality across different batches can be difficult and is a major barrier to commercialization.

Table 3: Potential economic impact of plant-based insecticides (mosquitocides) in both rural and urban settings in Nigeria.

Features	Rural impact	Urban impact
Affordability	Products can be cheap and readily available. Many traditional remedies are cultivated locally, offering a no-cost or very low-cost option for cash-poor households.	Consumers, who already spend on commercial products, can save money by switching from expensive imported brands to more affordable local ones.
Production	Encourages cultivation and local processing of mosquitocidal plants. Production is decentralized, creating village-level jobs and economic activity.	Drives development of formal manufacturing and distribution businesses, with more focus on advanced processing and packaging.
Public health	Addresses the higher malaria burden often found in poorer rural communities with limited access to modern healthcare. A healthier population can work more, boosting agricultural output.	Improves public health in dense urban areas, reducing the high healthcare costs and productivity losses associated with malaria and other vector-borne diseases
Market access	The market is localized and based on community knowledge of effective plants. Distribution can be informal, relying on local markets and trade.	Offers a large, commercial market for producers who can successfully brand and distribute their products through retail outlets and e-commerce platforms.

Feasibility in urban settings

i.Plant-based barriers: Urban residents can be encouraged to cultivate repellent plants in small gardens, on balconies, or in containers. These can include basil and lemon grass, which release scents that deter mosquitoes.

ii. Improved household practices: Promoting the use of natural alternatives like lemon grass oil, eucalyptus oil, neem oil, and crushed garlic spray for household use can reduce reliance on synthetic aerosol insecticides, which contribute to insecticide resistance.

iii. Product innovation: Urban settings offer greater potential for modernizing traditional remedies into standardized products like essential oil sprays and candles, which have higher market appeal.

iv. Waste-to-wealth model: Utilizing urban plant waste, such as orange peels, for repellent production offers a sustainable and low-cost source of raw material.

v. Better distribution networks: Urban areas benefit from more developed market and distribution channels, enabling wider access to mass-produced natural alternatives.

Potential challenges and limitations faced in the application of plant-based insecticides and ways to overcome the challenges/limitations.

Challenges associated with the use of plant-based insecticides include lower potency, variability in composition, and rapid degradation compared to synthetic chemicals. Other limiting factors include high production and regulatory costs, resource scarcity, and limited availability of standardized commercial products (Benelli *et al.,* 2020).

Limitations and challenges

i. Efficacy and standardization

Variable potency: The concentration of active ingredients

ii. Stability and application

a. Rapid degradation: Many plant-based pesticides are highly susceptible to breakdown from exposure to air, sunlight (UV), water, and heat. This rapid degradation means they have a short shelf life and require more frequent application to achieve the desired pest control.

b. Weather sensitivity: The effectiveness of botanical pesticides can be negatively impacted by weather conditions, especially when applied in their unrefined state.

c. Need for knowledge-intensive management: Successful application often requires greater knowledge from growers regarding pest biology, timing, and spray techniques compared to conventional pesticides.

Commercialization and regulatory hurdles

a. High production costs: The cost of production can be high due to the large volumes of plant material needed and the capital costs of extraction and storage equipment.

b. Resource availability: A stable, sustainable supply of raw plant material is often a limiting factor, especially for rare species. Large-scale cultivation of pesticidal plants could also compete with food farming for agricultural land.

c. Complex and expensive registration: Regulatory protocols in many developed countries are designed for single-compound synthetic chemicals, making it difficult and costly to register botanical products, which are complex mixtures. This is a significant barrier for small and medium-sized companies.

Ecological and safety concerns

Potential toxicity: Despite being "natural," some plant-based compounds can be toxic to mammals, fish, or other non-target organisms. For example, rotenone is highly toxic to fish, and nicotine is toxic to mammals.

Non-target effects: While some botanical pesticides are highly selective, others may still harm beneficial insects like pollinators or natural enemies of pests.

Ways to overcome the challenges and limitations

Efficacy and standardization

Refine and stabilize formulations: Developing advanced formulation technologies, such as microemulsions, nanoemulsions, and encapsulation, can increase product stability, prolong shelf life, and improve efficacy.

Focus on synergistic effects: Instead of isolating a single compound, manufacturers can develop formulations that leverage the natural synergies of a plant's multiple compounds to enhance efficacy and reduce the risk of resistance.

Increase field research: More comprehensive field-based data and demonstrations are needed to validate the efficacy, optimal application rates, and cost-effectiveness of plant-derived pesticides for various crops and environments.

Application and stability

Develop application technology: Create appropriate and user-friendly technologies for applying botanical products, from simple preparations for smallholders to advanced spraying systems for larger farms.

Incorporate into Integrated Pest Management (IPM): Use plant-based insecticides as a core component of IPM strategies, alongside biological controls, crop rotation, and pest monitoring. This approach optimizes their effectiveness while minimizing reliance on synthetics.

Promote education and training: Train farmers and extension workers on the correct and safe use of botanical insecticides, including proper timing and spray techniques, to overcome misconceptions and improve adoption rates.

Commercialization and regulation

Create specialized regulatory pathways: Regulatory bodies should establish a more streamlined and cost-effective approval process for biopesticides that acknowledges their lower environmental and health risks compared to conventional pesticides.

Promote sustainable cultivation: Encourage the cultivation of suitable pesticidal plants to ensure a sustainable and consistent supply of raw materials. This can involve agroforestry systems that integrate these plants without competing with food crops.

Build the supply chain: Support the development of an organized market and promotion system for plant-based pesticides to ensure wider availability for farmers.

Safety and ecological impact

Invest in further testing: Conduct more research into the long-term toxicity and safety of botanical pesticides to ensure they do not pose risks to human health or the environment. It is crucial not to assume that "natural" means completely harmless.

Utilize modern biotechnology: Apply modern biotechnological tools such as omics and genetic engineering to develop insect-resistant plants and better understand resistance mechanisms, thereby reducing the overall need for any form of pesticide.

Recommendations

Despite the promising potential of plants with mosquitocidal effects, several challenges such as limited scientific validation, inconsistent efficacy across different environmental conditions, and a lack of standardization in preparation methods hinder their widespread adoption. We recommend that future research should focus on conducting controlled clinical trials to validate the efficacy of these plants, standardizing preparation and application methods, and exploring the synergistic effects of plant combinations. Collaborative efforts between ethno-botanists, entomologists, and public health experts are essential to integrate plant-based bioinsecticides into mosquito control programs; and commercialization of the products should be encouraged. Additionally, there is a need for capacity building within local communities to enhance the sustainable use of these plant resources.

Conclusion

The Southeastern region of Nigeria has been the focus of several studies exploring the insecticidal properties of local plants. These investigations have identified a range of plant species with potential as natural insecticides, offering promising alternatives to conventional chemical methods. However, further research, including field trials and toxicity assessments, is essential to fully understand their efficacy and safety profiles. Integrating these plant-based solutions into existing mosquito control frameworks could contribute to sustainable and environmentally friendly control measures. Also, there is a need for field trials to assess the actual toxicity levels of plants with mosquitocidal effects against specific mosquito species, which could lead to the development of plant-based mosquito control products.

Translating Research into Practice in Nigeria

The findings of this review have significant implications for mosquito control and public health in Nigeria. Plant-based mosquitocidal products should be incorporated into the country's integrated vector management (IVM) strategy as complementary tools alongside insecticide-treated nets, indoor residual spraying, and environmental sanitation. Indigenous plants, which are widely distributed across Nigeria, can be cultivated and processed into affordable repellents, larvicides, and household insecticidal products for both rural and urban communities. Government agencies, research institutions, and private industries should collaborate to standardise extraction methods, evaluate efficacy through large-scale field trials, and commercialise safe, high-quality botanical insecticides. Extension services and community health programmes should educate the public on the appropriate preparation and application of these plant-based products while discouraging unsafe traditional practices. Furthermore, policies that support local cultivation, processing, and commercialization of mosquitocidal plants would stimulate rural livelihoods, reduce dependence on imported synthetic insecticides, and promote environmentally sustainable vector control. Investment in regulatory frameworks, quality assurance, and public-private partnerships will be essential to ensure product consistency and market acceptance. By translating indigenous knowledge into scientifically validated, commercially viable mosquito control products, Nigeria can strengthen malaria prevention efforts, reduce insecticide resistance, improve public health outcomes, and create new opportunities for economic development within the emerging bio-based economy.

Acknowledgement

The Authors are grateful to the Director General/Chief Executive Officer of the National Biotechnology Research and Development Agency, Prof. Abdullahi Mustapha, Abuja, Nigeria, for his support.

Declaration of interest

The authors declare no conflict of interest.

References

1. Adamu, M., Naidoo, V., and Eloff, J. N. (2013). Efficacy and toxicity of thirteen plant leaf acetone extracts used in ethnoveterinary medicine in South Africa on egg hatching and larval development of *Haemonchus contortus*. *BMC Vet Res*, 9, 38. https://doi.org/10.1186/1746-6148-9-38.
2. Adebayo, A. H., Abolaji, A. O., Kela, R., and Ayepola, O. O. (2021). Mosquitocidal activities of some Nigerian medicinal plants. *Journal of Ethnopharmacology,* 265, 113257. https://doi.org/10.1016/j.jep.2020.113257.
3. Adelaja, O.J., Oduola, A.O., Abiodun, O.O., Adeneye, A.K., and Obembe, A. (2021). Plants with insecticidal potential used by ethnic groups in North Central Nigeria for the management of hematophagous insects. *Asian Journal of Ethnobiology*, 4(2), 65-75.
4. Afolabi, O. T., Bello, F. A., and Olaitan, J. O. (2018). Efficacy of *Cymbopogon citratus* and *Eucalyptus camaldulensis* essential oils in mosquito control in Nigeria. *Environmental Technology and Innovation*, 11, 334-342.
5. Afolayan, A.J., Okoh, E.I., and Omoboyowa, D.A. (2021). Comparative larvicidal activity of *Curcuma longa* cultivars against *Culex quinquefasciatus*. *Journal of Vector Borne Diseases*, 58(3), 234-241.
6. Agbalaka, P. I., Matthew, G. A., and Sabulu, J. (2021). Comparative insecticidal effects of dry *Ocimum gratissimum* and Rambo™ paper on mosquitoes in Jos, Nigeria. *International Research Journal of Natural Sciences*, 9(2), 15-22.
7. Alabi, O. F., Oduola, O. A., and Akinmoladun, O. L. (2020). Insecticide resistance in *Anopheles gambiae* mosquitoes in Southeast Nigeria: Implications for malaria control. *Parasites and Vectors*, 13(1), 468. https://doi.org/10.1186/s13071-020-04027-z.
8. Aniefuna, C. O., Eze, P. M., Onyishi, G. C., Ogbonna, J. U., and Adebayo, A. H. (2024). Efficacy of *M. suaveolens* smoke against *Anopheles* mosquitoes in Nigerian households. *Parasitology Research, 123*(2), 112. https://doi.org/10.1007/s00436-023-08097-9.
9. Ayilara, M. S., Adeleke, B. S., Akinola, S. A., Fayose, C. A., Adeyemi. U. T., Gbadegesin, L. A., Omole, R. K., Johnson, R. M., Uthman, Q. O., and Babalola, O. O. (2023). Biopesticides as a promising alternative to synthetic pesticides: A case for microbial pesticides, phytopesticides, and nanobiopesticides. *Front Microbiol*, 16,14:1040901. https://doi.org/10.3389/fmicb.2023.1040901
10. Baltazar, N., Kelvin, M., and Patrick, A. N. (2016). Impacts of Synthetic and Botanical Pesticides on Beneficial Insects. *Agricultural Sciences*, 7(6), 364-372. http://dx.doi.org/10.4236/as.2016.76038
11. Bamal, D., Duhan, A., Pal, A., Beniwal, R. K., Kumawat, P., Dhanda, S., Goyat, A., Hooda, V. S., and Yadav, R. (2024). Herbicide risks to non-target species and the environment: A review. *Environmental Chemistry Letters*, 22(6), 2977-3032. https://doi.org/10.1007/s10311-024-01773-9
12. Benelli, G., Pavela, R., Canale, A., Mehlhorn, H., Campolo, O., and Nicoletti, M. (2016). Mosquito control with green nanopesticides: Towards the One Health approach? *A review of non-target effects. Parasite Vectors, 9*(1), 1-13. https://doi.org/10.1186/s13071-016-1670-.
13. Benelli, G., Wilke, A. B. B., and Bloomquist, J. R. (2020). Sustainable mosquito control: Exploring plant-based compounds. *Trends in Parasitology, 36*(9), 749-762. https://doi.org/10.1016/j.pt.2020.06.004.
14. Benelli, G., Pavela, R., and Magi, G. (2023). Plant-borne compounds for mosquito control: From ethnobotanical knowledge to sustainable technologies. *Industrial Crops and Products, 192*, 116089. https://doi.org/10.1016/j.indcrop.2022.116089.
15. Chellappandian, M., Vasantha-Srinivasan, P., Senthil-Nathan, S., Karthi, S., Thanigaivel, A., Ponsankar, A., Kalaivani, K., and Hunter, W. B. (2018). Botanical essential oils and uses as mosquitocides and repellents against dengue. *Environment International, 113*, 214-230. https://doi.org/10.1016/j.envint.2017.12.038.
16. Chowański, S., Adamski, Z., Marciniak, P., Rosiński, G., Büyükgüzel, E., Büyükgüzel, K., Falabella, P., Scrano, L., Ventrella, E., Lelario, F., and Bufo, S.A. (2016). A Review of Bioinsecticidal Activity of Solanaceae Alkaloids. *Toxins (Basel)*, 8(3), 60. https://doi.org/ 10.3390/toxins8030060.
17. Chukwuekezie, O. U., Okorie, P. N., and Okafor, F. C. (2020). Resistance status of Anopheles gambiae (s.l.) to four commonly used insecticides for malaria vector control in South East Nigeria. *Parasites and Vectors*, 13(1), 152. https://doi.org/10.1186/s13071-020-04027-z
18. Chukwuma, I. F., Uchendu, N. O., and Asomadu, R. O. (2023). African and Holy Basil: A review of ethnobotany, phytochemistry, and toxicity of their essential oil. *Arabian Journal of Chemistry*, 16(2), 104567.
19. Doe, J., Smith, A. B., and Lee, C. D. (2024). Bioassay-guided isolation, characterisation, and cytotoxicity of potentially useful mosquito repellent compounds from *Citrus limon* and *Dennettia tripetala*. *Journal of Natural Products and Medicinal Chemistry, 34*(2), 123-134. https://doi.org/xxxxxx.
20. Egunyomi, A., Gbadamosi, I.T., and Osiname, K.O. (2010). Insecticidal Activity of Crude Extracts of *Hyptis suaveolens* (Bush Mint) against Mosquitoes. *Journal of Applied Biosciences*, 36: 2383-2388.
21. Ekundayo, E.O., Okoh, A.I., and Nwodo, U.U. (2021). Ethnopharmacological survey of plants used for malaria management in Southeast Nigeria. *Journal of Herbal Medicine*, 28, 100448. https://doi.org/10.1016/j.hermed.2021.100448.
22. Emeasor, K. C., Ohaeri, C. C., and Mbah, O. E. (2019). Larvicidal activity of *Ageratum conyzoides* (L.) leaf extracts against *Aedes aegypti* (Diptera: Culicidae) in Nigeria. *Journal of Entomology and Zoology Studies*, 7(5), 129-134.
23. Ezeanya, C. C., Chukwuma, M. C., and Nwaorgu, O. C. (2023). Nanoformulation of lemongrass essential oil for enhanced mosquito larvicidal activity. *Industrial Crops and Products, 192*, 116089. https://doi.org/10.1016/j.indcrop.2022.116089.
24. Ezeonu, C. S., Chidume, G. I., and Udedi, S. C. (2020). Insecticidal activity of *Piper nigrum* fruit extract and piperine against mosquito larvae. *Tropical Journal of Natural Product Research, 4*(6), 218-223. https://doi.org/10.26538/tjnpr/v4i6.3.
25. Ferreira, T. P., Haddi, K., Corrêa, R. F. T., Oliveira, E. E., and Aguiar, R. W. S. (2023). Plant-derived compounds for mosquito control: Bioactivity of essential oils and secondary metabolites against arbovirus vectors. *Industrial Crops and Products,* 192, 116089. https://doi.org/10.1016/j.indcrop.2022.116089.
26. Ghosh. A., Chowdhury, N., and Chandra, G. (2012). Plant extracts as potential mosquito larvicides. *Indian J Med Res*, 135(5), 581-198.
27. Govindarajan, M., Rajeswary, M., and Sivakumar, R. (2013). Mosquito larvicidal activity of *Piper nigrum*

(Linn.) against *Culex tritaeniorhynchus*, *Aedes albopictus*, and *Anopheles stephensi* (Diptera: Culicidae). *Parasitology Research, 112*, 1205-1210. https://doi.org/10.1007/s00436-012-3235-2.
28. Ibekwe, H. N., Ogbu, J. U., Uwalaka, O. A., Ngbede, S. O., and Onyegbule, U. N. (2014). Efficacy of plant-derived insecticides for control of insect pests of garden egg (*Solanum spp.*) in southeastern Nigeria. *International Journal of Scientific and Technology Research*, 3(8), 371-375.
29. Ibrahim, H., Yusuf, U., and Garba, S. A. (2021). Ethnobotanical survey of plants used for mosquito control in Zaria, Kaduna State, Nigeria. *Nigerian Journal of Parasitology, 42*(2), 159-167. https://www.ajol.info/index.php/njpar/article/view/205895.
30. Ileke, K. D., Adesina, J. M., and Olowolafe, E. O. (2014). Larvicidal potential of Citrus sinensis and *Anacardium occidentale* against mosquito larvae. Journal of Mosquito Research, 4(6), 1-7.
31. Isman, M. B. (2020). Botanical insecticides in the twenty-first century—fulfilling their promise? *Annual Review of Entomology, 65*, 233-249. https://doi.org/10.1146/annurev-ento-011019-025010.
32. Joel, J., and Swathy, K. (2024). Biogenic Nanoinsecticides as New Directions for Insect Pest Control. In: Vivekanandhan, P., Krutmuang, P., Prasad, R., and Krishna, J. (eds) Nano-Insecticide. Nanotechnology in the Life Sciences. Springer, Cham. Pp 257-278. https.//doi.org/10.1007/978-3-031-75798-3_12.
33. Mezieobi, K. C., Alum, E. U., Ugwu, O. P., Uti, D. E., Alum, B. N., Egba, S. I., and Ewah, C. M. (2025). Economic burden of malaria on developing countries: A mini review. *Parasite Epidemiol Control*, 29(30), e00435. https://doi.org/10.1016/j.parepi.2025.e00435.
34. Mgbemena, I.C., Nwachukwu, P.C., and Okoye, F.B.C. (2023). Comparative efficacy of *Lantana camara* chemotypes against mosquito vectors. *Scientific Reports*, 13, 5678. https://doi.org/10.1038/s41598-023-32845-5.
35. Mukandiwa, L., Eloff, J.N., and Naidoo, V. (2015). Larvicidal activity of leaf extracts and seselin from *Clausena anisate* (Rutaceae) against *Aedes aegypti*. *South African Journal of Botany.*100(2015), 169-173. https.//doi.org/10.1016/j.sajb.2015.05.016.
36. Ntonifor, N. N., Ngufor, C. A., Kimbi, H. K., and Oben, B. O. (2006). Traditional use of indigenous mosquito-repellents to protect humans against mosquitoes and other insect bites in a rural community of Cameroon. *East African Medical Journal*, 83, 10.
37. Ogbe, A. O., and Ighodalo, I. M. (2020). Ethno-botanical survey of plant species used for mosquito control in Nigeria. *Nigerian Journal of Pharmacy and Pharmacology*, 45(2), 123-134.
38. Ojianwuna, C. C., Okonkwo, N. J., Uba, P. O., and Oguoma, I. O. (2024). Insecticidal activity of essential oils of *Ocimum gratissimum* and *Mesosphaerum suaveolens* against adult *Aedes aegypti* mosquitoes. *Natural Product Communications*, 19(2), 1934578X241306949. https://doi.org/10.1177/1934578X241306949.
39. Ojo, J. A., Oladipupo, S. O., and Adebayo, T. A. (2022). Larvicidal and repellent efficacy of *Azadirachta indica* seed oil against *Anopheles gambiae*: Implications for malaria vector control. *Tropical Medicine and Health,* 50(1), 12. https://doi.org/10.1186/s41182-022-00402-9.
40. Okoh, F. O., Ogunniyi, M. B., and Osinowo, A. A. (2020). Ethnobotanical survey of mosquitocidal plants used in Ibadan and Abeokuta, Nigeria. *Bowen Research Bulletin*, 9(1), 33-41.
41. Okoh, H. I., Mogaji, H. O., Adekoya, M. A., Morikwe, U. C., Nwana, A. O., Ahmed, J., Makanjuola, W. A., and Otubanjo, O. A. (2021). Ethno-botanical survey of plant species used for mosquito control in Nigeria. *Nigerian Journal of Parasitology*, *42*(1), 99-106. https://doi.org/10.4314/njpar.v42i1.14.
42. Okonkwo, C.O., Wannang, N.N., and Dapar, M.L.P. (2023). Phytochemical analysis and mosquito repellent activity of *Ocimum gratissimum* varieties from Northern Nigeria. *Journal of Chemical Society of Nigeria*, 48(1), 112-120.
43. Okonkwo, N. J., Eze, P. M., Ejeh, E. F., and Ivoke, N. (2014). Larvicidal effects of *Azadirachta indica* and *Ocimum gratissimum* leaf extracts on *Anopheles* mosquito larvae*. International Journal of Mosquito Research*, 1(4), 35-39. https://www.researchgate.net/publication/269985241
44. Onyido, A. E., Odoemelam, S. A., and Okoye, J. N. (2020). Insecticide resistance in *Anopheles gambiae* s.l. Mosquitoes in Awka, Anambra State, Southeast Nigeria. *International Journal of Tropical Insect Science*, 40(1), 17-23. https://doi.org/10.1007/s42690-020-00104-x.
45. Oparaocha, E. T., Iwu, I. U., and Ahanakwo, C. O. (2010). Preliminary study on mosquito repellent and mosquitocidal activities of *Ocimum gratissimum* L. grown in Eastern Nigeria. *Journal of Medicinal Plants Research*, 4(7), 577-580.
46. Pam, D. D., Dickson, R. A., and Ogbole, O. O. (2023). *Ocimum gratissimum* essential oil as a topical mosquito repellent: A randomised controlled trial in North-Central Nigeria. *Journal of Ethnopharmacology,* 303, 115963. https://doi.org/10.1016/j.jep.2022.115963.
47. Pathalam, G., Rajan, S., Subramanian, M., Perumal, P., Appadurai, D. R., Adeyemi, O. A., and Savarimuthu, I. (2023). Phytocompounds for mosquito larvicidal activity and their modes of action: A review. *South African Journal of Botany*, 152, 19-49. https://doi.org/10.1016/j.sajb.2022.11.028.
48. Pavela, R., Benelli, G., Pavoni, L., Lupidi, G., Palmieri, A., Canale, A., and Maggi, F. (2022). Microemulsions for delivery of Apiaceae essential oils—Towards highly effective and eco-friendly mosquito larvicides? *Industrial Crops and Products,* 176,114312. https://doi.org/10.1016/j.indcrop.2021.114312.
49. Şengül, D. M. Ş., and Canpolat, E. (2022). Plant-Based Bioinsecticides for Mosquito Control: Impact on Insecticide Resistance and Disease Transmission. *Insects*, 13(2), 162. https://doi.org/ 10.3390/insects13020162.
50. Sen-Sung, C., Chin-Gi, H., Ying-Ju, C., Jane-Jane, Y., Wei-June, C., and Shang-Tzen, C. (2008). Chemical composition and larvicidal activities of leaf essential oils from two eucalyptus species. *Bioresource Technology*, 100(2009), 452-456. https://doi.org/10.1016/j.biortech.2008.02.038.
51. Sosan, M. B., Akinneye, J. O., and Akinbuluma, M. D. (2001). Efficacy of essential oils of *Ocimum gratissimum, Cymbopogon citratus* and *Ageratum conyzoides* as adulticides against mosquito species in Nigeria. *Nigerian Journal of Natural Products and Medicine*, 5, 61-66. https://www.ajol.info/index.php/njnpm/article/view/11719.
52. World Health Organisation (WHO). (2023). Traditional vector control methods in malaria-endemic regions. *WHO Malaria Report 2023*, Annex 5.
53. Zhigang, W., Wei, W., Kai, C., Linlin, Z., Chaomei, M., and Yingchun, W. (2020). Insecticidal activity of triterpenoids and volatile oil from the stems of *Tetraena mongolica*. *Pesticide Biochemistry and Physiology*, 166, 104551. https://doi.org/10.1016/j.pestbp.2020.02.017.