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A Review on Recent Advances of Natural Products as Larvicides in Vector Control Management

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ABSTRACT

The mosquito, a biological vector, is responsible for the transmission of serious and dreaded diseases worldwide. These diseases, which are chiefly endemic to tropical countries, cause millions of deaths each year. The significance of plant-based and environmentally friendly insecticides has increased in recent years. Due to their easy biodegradability and target selectivity, they can be used safely in aquatic environments. Despite their effectiveness in controlling target vector species, pesticide applications pose a threat as they can lead to increased chemical insecticide resistance, causing a rebound in vectorial capacity. This review explores the efficacy of phytochemicals in controlling mosquito populations. In mosquito control programs, phytochemicals play a significant role. Plants serve as an immense repository for primary and secondary metabolites. Various types of polar and nonpolar solvents can be used to extract the bioactive plant ingredient(s) from either the whole plant or a specific part of it. This literature review defines natural products and provides an overview of the different types of natural products that can be used to control mosquito larvae. Particularly, it examines the effectiveness of natural products in vector control without causing resistance or harm to non-target organisms. The purpose of this paper is to offer a comprehensive review of the use of natural products as mosquito larvicides and to underscore their potential as an alternative to traditional chemical methods. Ultimately, it encourages further research into the development and use of natural products for successful vector mosquito control.

Keywords: Vector Control, Traditional Method, Natural Products, Phytochemicals.

INTRODUCTION

The mosquito represents a severe threat to public health, transmitting several dangerous diseases like malaria, filaria, dengue, dengue fever, and Japanese encephalitis, primarily in the tropics and subtropics (WHO, 2012). A noticeable increase in these vectors' insecticide resistance has evolved into a global problem. To prevent the transmission of these deadly diseases, mosquito population control is necessary. Chemical insecticides were favored a decade ago, but due to their persistence in the environment and harm to non-target organisms, these have shifted researchers' focus toward the search for new, safer natural products [1]. Natural products, such as plant-based insecticides, have potential for use in mosquito control. These natural products, deemed potential sources of mosquito larvicides due to their low toxicity to non-target organisms and the mosquito's declining resistance to synthetic insecticides, have recently been reviewed [2]. Recent advances in this field include using essential oils derived from plants such as citronella, eucalyptus, and peppermint as larvicides. These oils have demonstrated promising larvicidal activity against different mosquito species. Chitosan, a

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polysaccharide derived from crustacean shells, represents another promising natural product; it has been found to possess strong larvicidal activity against Aedes and Anopheles mosquitoes. Several phytochemicals, such as alkaloids, steroids, terpenoids, essential oils, and phenolics, from various plant parts, have been reported to exhibit insecticidal activities [3,4]. Overall, the use of natural products as mosquito larvicides is a promising approach that could provide an alternative to synthetic insecticides. This review article places emphasis on collating and updating the use of various phytochemicals as mosquito larvicides.

Traditional methods of mosquito control:

Traditional methods of mosquito control have been utilized for many years and involve various techniques to reduce mosquito populations. Here are some examples of traditional mosquito control methods:

- **Source reduction:**

This method involves removing or modifying mosquito breeding sites, such as stagnant water, to prevent the development of mosquito larvae. This can be achieved using techniques such as filling in puddles, draining standing water, and cleaning up trash or debris that can collect water.
(https://www.cdc.gov/zika/vector/source-reduction.html).

- **Larvicidal:**

This method involves the use of insecticides to eliminate mosquito larvae in breeding sites, such as standing water. This can be achieved with a variety of chemicals, including Bacillus thuringiensis israelensis (Bti) and methoprene
(https://www.who.int/water_sanitation_health/resources/vector282to301).

- **Adulticiding:**

This method involves the use of insecticides to kill adult mosquitoes. This can be conducted by spraying insecticides from the ground or the air, or by using fogging or misting devices
(https://www.cdc.gov/zika/vector/mosquito-control.html).

- **Biological control:**

This method involves using natural predators or pathogens to control mosquito populations. For example, introducing fish that eat mosquito larvae into bodies of water can help reduce mosquito numbers (https://www.who.int/neglected_diseases/vector_ecology/vector-control/biological_control/en/).

- **Personal protection:**

This method involves using physical barriers or insect repellents to prevent mosquito bites. This can include wearing long sleeves and pants, using mosquito nets over beds, and applying insect repellents containing DEET or other chemicals (https://www.epa.gov/insect-repellents.).

Limitations of traditional methods:

Traditional methods of mosquito control, such as the use of insecticides and mosquito nets, have some limitations that can hinder their effectiveness in reducing mosquito populations.

Firstly, the repeated use of insecticides can lead to the development of insecticide resistance in mosquitoes, making them less susceptible to the effects of the insecticides [5]. This can reduce the effectiveness of insecticides as a means of controlling mosquito populations.

Secondly, mosquito nets may not be used consistently or correctly, reducing their effectiveness in preventing mosquito bites and the transmission of mosquito-borne diseases [6].

Thirdly, traditional mosquito control methods such as source reduction, larviciding, and adulticiding can be expensive, time-consuming, and require significant resources (World Health Organization, 2019). This can limit their implementation in resource-poor settings.

Finally, traditional mosquito control methods may have unintended environmental consequences, such as the potential to harm non-target species or disrupt ecosystems [7].

Definition of natural products:

Natural products refer to chemical compounds obtained from sources such as plants, microorganisms, and animals, which demonstrate larvicidal activity against mosquitoes. These compounds may act directly on mosquito larvae, disrupting their physiological processes, or indirectly by interfering with the larvae's growth and development.

One study by [8] defined natural products used as mosquito larvicides as "chemical substances obtained from natural sources that can kill or inhibit the growth and development of mosquito larvae." The authors emphasized the potential of these natural products as a sustainable and environmentally friendly approach to mosquito control.

Types of natural products used as mosquito larvicides:

Several natural products have been examined and employed as mosquito larvicides. We can categorize these natural products based on their chemical structure and origin.

Plant-derived natural products: Several essential oils, alkaloids, flavonoids, and other plant-derived compounds have shown potential as mosquito larvicides. For example, essential oils from plants such as Citronella, Eucalyptus, and Lemongrass have demonstrated larvicidal activity against mosquitoes [9].

Microbial metabolites: Bacteria and fungi produce a variety of secondary metabolites that have demonstrated larvicidal activity against mosquitoes. For instance, the bacterial metabolite Spinosad has been used as a larvicide in mosquito control programs [10].

Marine natural products: Compounds derived from marine organisms such as algae, sponges, and corals have also shown potential as mosquito larvicides. For example, extracts from the marine sponge Acanthella cavernosa have shown to have larvicidal activity against Aedes aegypti [11].

Other natural products: In addition to those already mentioned, other natural products such as neem oil, chitinase, and certain plant extracts have demonstrated larvicidal activity against mosquitoes [12].

Advantages of natural products as mosquito larvicides:

Natural products have attracted substantial attention as alternatives to chemical insecticides in mosquito control programs, due to their environmental friendliness, low toxicity, and cost-effectiveness. Several studies have highlighted the potential of natural products as mosquito larvicides. The advantages include:

- Biodegradability: Unlike synthetic insecticides, which can accumulate in soil and water bodies, leading to pollution and environmental hazards, natural products are biodegradable and do not persist in the environment.
- Selectivity: Natural products are usually more selective, targeting specific insect pests while minimizing the impact on non-target organisms, including humans and other beneficial insects.
- Resistance management: The incidence of resistance development is lower for natural products, compared to synthetic insecticides. Repeated use of synthetic insecticides has led to a rise in resistance amongst mosquitoes, making them less susceptible to chemical control. Natural products, on the other hand, have various modes of action.
- Sustainable: Natural products can be sustainably produced and procured from renewable resources, making them a viable option for long-term use in mosquito control programs.

Some examples of natural products with mosquito larvicidal activity include plant-derived compounds such as alkaloids, flavonoids, and essential oils. Other sources of natural larvicides encompass bacterial and fungal metabolites, as well as extracts from marine organisms.

One study conducted by [13] evaluated the larvicidal activity of essential oils from 20 plant species against Aedes aegypti and found that most of the oils exhibited significant larvicidal activity. Another study by [14] demonstrated the larvicidal potential of a fungal metabolite, cordycepin, against Aedes aegypti and Culex quinquefasciatus.

Below are examples of secondary metabolites of plant origin that have been reported to function as mosquito larvicides.

Alkaloids:

Alkaloids are a diverse group of naturally occurring organic compounds distinguished by their basic (alkaline) properties and nitrogen-containing heterocyclic structures. They are typically derived from about 15% of plant species, though some alkaloids can also be found in fungi and animals. Alkaloids exhibit a wide range of biological activities and are often recognized for their pharmacological effects [15].

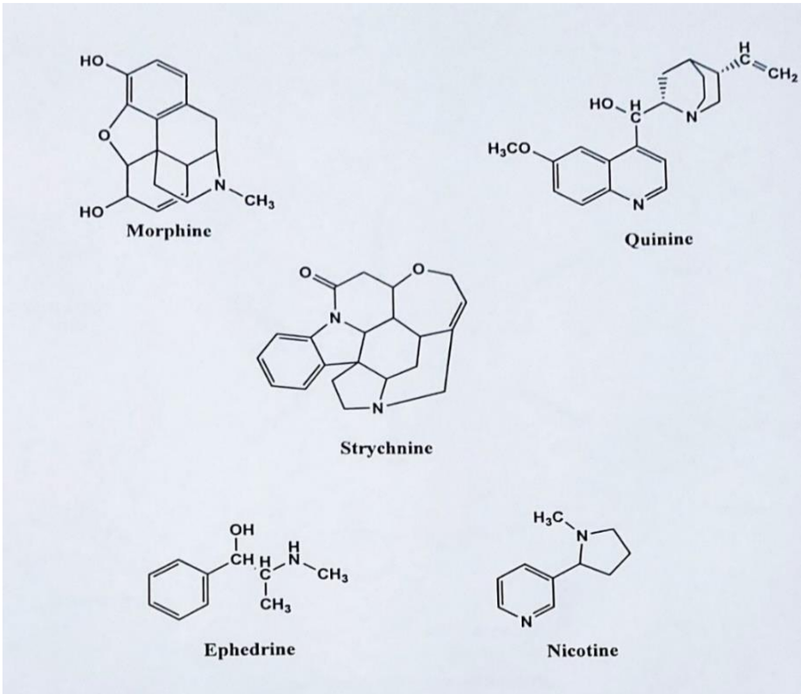

Figure 1: Structure of some alkaloids reported from the plant

Certain plant families among the angiosperms contain a higher concentration of alkaloid-rich species compared to others (Figure 1). Families such as Papaveraceae, Berberidaceae, Fabaceae, Boraginaceae, Apocynaceae, Asteraceae, Liliaceae, Gnetaceae, Ranunculaceae, Rubiaceae, Solanaceae, and Rutaceae are known to include a significant number of taxa that produce alkaloids. These alkaloid-rich plants have been recognized for their potential insecticidal properties, including their effectiveness as mosquito larvicides (Table 1).

Mechanism of action of plant alkaloids:

Plant alkaloids specifically act on microtubule proteins during the metaphase stage of the cell cycle, leading to mitotic arrest. Consequently, the affected cells become incapable of dividing, ultimately leading to their demise. These alkaloids primarily target the M phase of the cell cycle (Figure 2). Their major toxic effects are observed in the hematopoietic, integumentary, neurologic, and reproductive systems.

Quinolizidine alkaloids, on the other hand, impact insects by affecting the potassium channel and glutamate receptor, effectively halting protein synthesis in these organisms. Tetracyclic sparteine, which is derived from Cytisus scoparius, has particularly proven to have insecticidal action [15].

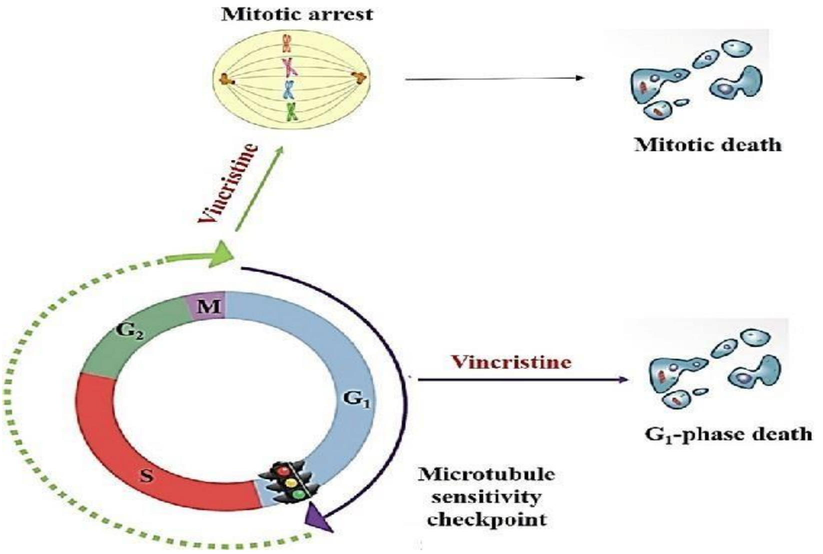

Figure 2: Mode of action of alkaloids [15]

Table 1: Some plant-based alkaloids with mosquito larvicidal properties, along with their respective plant name, family, mosquito species targeted, plant part used, LC50 value, and references

S.N.	Plant Name	Family	Mosquito Speciestargeted	Plant Part used	LC50 Value	References
1	*Zanthoxylum piperitum*	Rutaceae	*Culex pipiens and Aedes aegypti*	bark	0.006 and 0.009 mg/l respectively	[16]
2	*Mammea americana*	Calophyllaceae	*Aedes aegypti*	seeds	38.58 ppm	[17]
3	*CaricaPapaya*	Caricaceae	*Aedes aegypti*	seeds	At 10% concentraion	[18]
4	*Tinosporarumphii*	Menispermaceae	*Aedes aegypti*	leaf	10 mg/ml	[19]
5	*Murraya koenigii*	Rutaceae	*Aedes aegypti*	root	1.75 µg/ml	[20]
6	*Tridax procumbens*	Asteraceae	*Aedes aegypti*	leaves	219 µg/ml	[21]
7	*Tagetesminuta*	Asteraceae	*Anopheles stephensi*	Aerialpart	2.5 mg/l	[22]
8	*Ruta graveolens*	Rutaceae	*Culiseta longiareolata*	leaves	43.24 ppm	[23]
9	*Lantanacamara*	Verbenaceae,	*Anopheles stephensi*	leaves	36.65 ppm	[24]
10	*Solanum nigrum*	Solanaceae	*Cx. quinquefasciatus*	fruits	48.41µg/ml	[25]

Flavonoids:

Flavonoids are a class of plant compounds that are widely distributed in nature and are known for their diverse biological activities. These compounds have been extensively studied for their antioxidant and anti-inflammatory properties; their potential as mosquito larvicides has also been explored.

One of the mechanisms by which flavonoids exhibit larvicidal activity is through their interference with mosquito larvae's growth and development. Flavonoids can disrupt the molting process and inhibit chitin synthesis—an essential component of the larval exoskeleton. This disruption hampers the normal development of the larvae, leading to mortality [26].

The most popular solvents for extracting flavonoids include ethanol, combinations of water in various ratios, and natural deep eutectic solvents (NADES). These solvents are chosen for their ability to solubilize moderately polar flavonoids at a relatively low cost, and with minimal negative environmental impact.

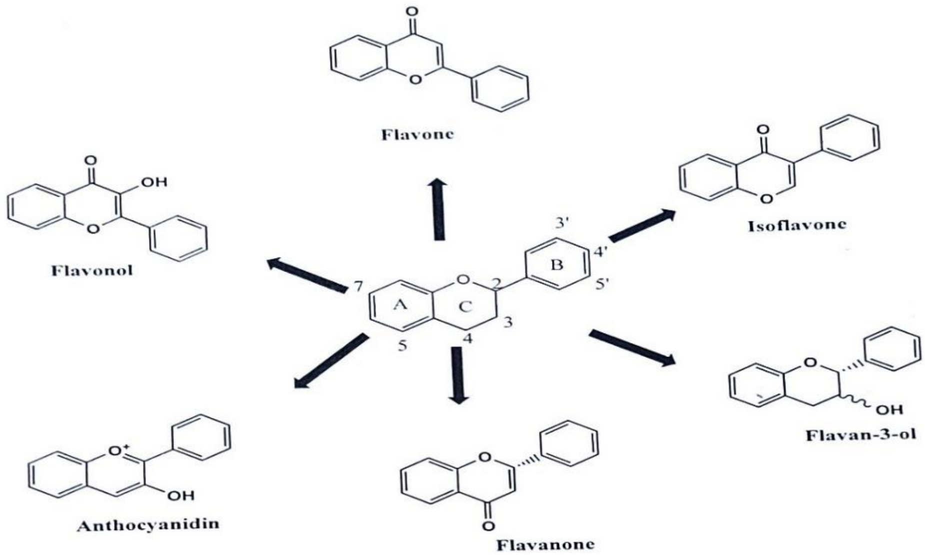

Figure 3: Basic structure of flavonoids

Table 2: Some plant-based Flavonoids with mosquito larvicidal properties, along with their respective plant name, family, mosquito species targeted, plant part used, LC50 value, and references.

S.N.	Plant Name	Family	Mosquito Speciestargeted	Plant Partused	LC50 value	Reference
1	*Vitex negundo*	Lamiaceae	An. Stephensi	root	83.17ppm	[27]
2	*Poncirustrifoliata*	Rutaceae	*Aedes aegypti*	leaves	0.082mg/l	[28]
3	Argemonemexicana	Papaveraceae	*Culex quinquefasciatus*	stem	10.61ppm	[29]
4	*Calotropis gigantea*	Apocynaceae	*Ae. Aegypti*	flower	0.21µg/ml	[30]
5	*Citrus grandis*	Rutaceae	*Ae. Aegypti*	fruit peel	236.70 µg/mL	[31]
6	Artemisia absinthium	Asteraceae	Cs. Longiareolata	leaves	97.74 ppm	[32]
7	*Cassia Occidentalis*	Fabaceae	*Anophelesstephensi*	leaves	64.76	[33]
8	Couroupitaguianensis	Lecythidaceae	*A. aegypti*	leaf	44.55 ppm	[34]
9	*Tagetes patula*	Asteraceae	*Aedes aegypti*	flower	15.74 µg/ml	[35]
10	Anacardium occidentale	Anacardiaceae	Ae. aegypti.	stem	1200 mg/L	[36]

Flavonoids are a group of phytochemicals commonly found in plants. They are known for their diverse biological activities and have been extensively studied for their potential health benefits. While flavonoids have been investigated for their insecticidal properties, their effects on mosquitoes are shown in Table 2.

Flavonoids are a diverse group of compounds found in various plant families, as depicted in Figure 3. Plant families reported to contain flavonoids include Fabaceae, Asteraceae, Rosaceae, Rutaceae, Solanaceae, among others.

Steroids:

Steroid phytochemicals are naturally occurring compounds found in plants and have been investigated for their potential use as mosquito larvicides. Mosquito larvicides are substances designed to control mosquito populations by targeting larvae in their aquatic breeding sites.

Primary plant steroids, known as phytosterols or plant sterols, are depicted in Figure 4. Phytosterols are found in various parts of plants, with the highest concentrations typically found in seeds and fruits [37].

The extraction of phytosterols from plant parts involves several steps, such as harvesting the plant material, crushing or grinding it to increase the surface area, followed by solvent extraction or other separation techniques to isolate phytosterols [38, 39].

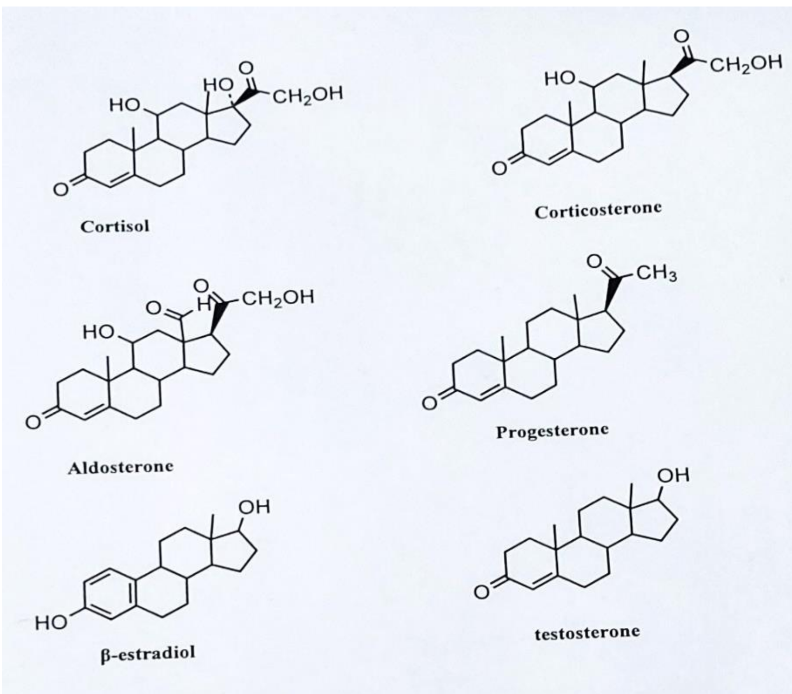

Figure 4: Basic structure of steroids.

Several plant families, including Solanaceae, Liliaceae, Fabaceae, Asperagaceae, Dioscoreaceae, and Poaceae, are known for producing steroids with mosquito larvicidal activity, as shown in Table 3.

Table 3: Some plant-based Steroids with their respective plant name, family, mosquito species targeted, plant part used, LC_{50} value, and references

S.N.	Plant Name	Family	Mosquitospecies targeted	PlantPart used	LC50 Value	References
1	*Jatropha curcas*	Euphorbiaceae	*Aedes aegypti*	leaf	88 mg/mL	[19]
2	*C. papaya*	Caricaceae	*Cx. quinquefasciatus*	seed	0.13µg/ml	[40]
3	*M. paniculata*	Rutaceae	*Cx. quinquefasciatus*	Leaf	0.08 µg/ml	
4	*C. collinus*	Phyllanthaceae	*Cx. quinquefasciatus*	leaf	0.09 µg/ml	
5	*Solanumvillosum*	Solanaceae	*Ae. aegypti*	berry	60 to 538 ppm	[41]
6	*Artemisia absinthium*	Asteraceae	*Aedes aegypti*	flower	694.3 ppm	[42]
7	*Indigofera arrecta*	Fabaceae	*Culex mosquito.*	leaf	2752.6 ppm	[42]
8	*Elytraria acaulis*	Acanthaceae	*Aedes aegypti*	leaf	124.25 mg/100ml	[43]
9	*Dregea volubilis*	Apocynaceae	*Cx. quinquefasciatus*	leaf	31.29 ppm	[44]
10	*Bombax malabaricum*	Bombacaceae	*Cx. quinquefasciatus*	leaf	23.55 ppm	

Tannins

Tannins are chemical compounds commonly found in various plant species. They have been explored for their potential as mosquito larvicides due to their insecticidal properties. The typical structures of hydrolyzable and condensed tannins are presented in Figure 5. Mosquito larvicides are substances used to control mosquito larvae in their aquatic breeding habitats, preventing them from maturing into disease-spreading adults. The efficacy of tannins as mosquito larvicides can vary based on several factors, including the tannin concentration, mosquito species, environmental conditions, and the presence of other organic matter in the water. Potential modes of action include disrupting the mosquito digestive system, interfering with nutrient absorption, and affecting the development of mosquito larvae [45]. Table 4 lists some plant-based tannins, their respective plant names and families, and their effectiveness as mosquito larvicides.

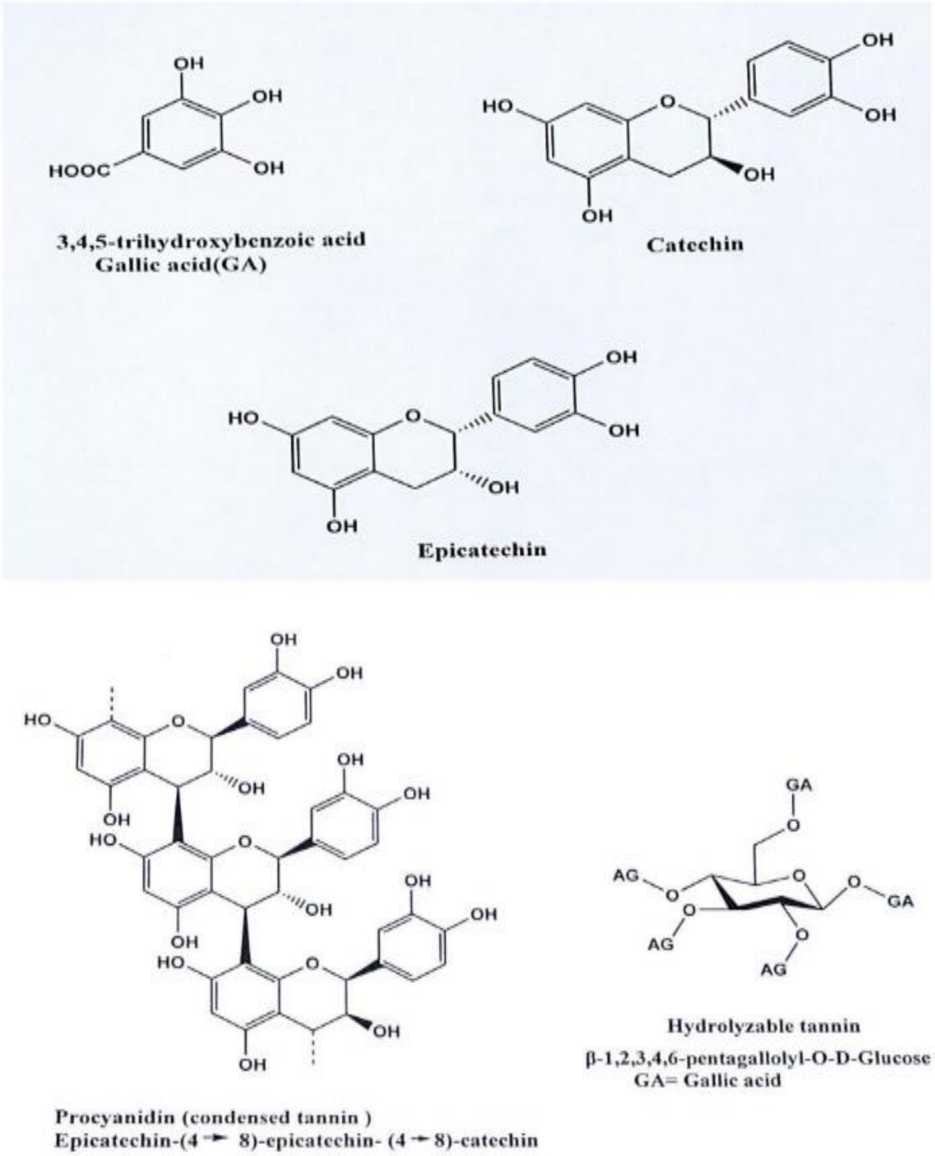

Fig 5: Typical Structures of hydrolyzable and condensed tannins.

Table 4: Some plant-based tannins along with their respective plant name, family, mosquitospecies targeted, plant part used, LC_{50} value, and references

SN	Plant Name	Family	Mosquito speciestargeted	Plant partused	LC_{50} value(mg/L)	References
1	*Rumex vesicarius*	Polygonaceae	*Aedes aegypti*	flower	19.99mg/l	[46]
2	*Prunus domestic*	Rosaceae	*Culex pipiens*	leaves	33.3mg/l	[47]
3	*Rhamnus cathartica*	Rhamnaceae	*Culex pipiens*	leaves	63.4 mg/l	
4	*Cassia fistula*	Fabaceae	*Culex Quinquefasciatus*	bark	50.27 mg/l	[48]
5	*Nicotiana tabacum*	Solanaceae	*Culex quinquefasciatus*	flower	17.77 mg/l	
6	*Reichardiatingitana*	Asteraceae	*Aedes aegypti*	flower	46.85 mg/l	[46]
7	*Argemone mexicana*	Papaveraceae	*Culex quinquefasciatus*	flower	18.61ppm	[47]
8	*Saracaindica*	Fabaceae	*Cx. quinquefasciatus*	leaves	228.9ppm	
9	*Clitoria ternatea*	Fabaceae	*An. stephensi*	leaves	65.2ppm	
10	*Clitoria ternatea*	Fabaceae	*Ae. aegypti*	roots	154.5ppm	[48]

Glycosides:

Glycosides are a diverse group of natural compounds found in many plants. They are characterized by their chemical structure, which consists of a sugar molecule (glycone) attached to a non-sugar molecule (aglycone) via a glycosidic bond. Plants produce glycosides for various reasons, including defense against herbivores and pathogens. The ideal structure of glycosides is depicted in Figure 6 below.

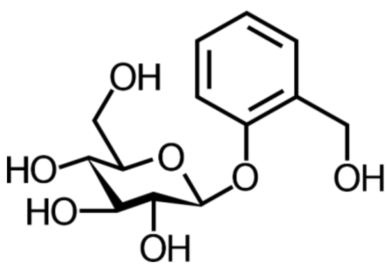

Fig 6: Structure of Glycosides

Glycosides may exert neurotoxic effects on mosquito larvae by impacting their nervous system, leading to paralysis and death. Certain glycosides can disrupt cellular processes and result in cell death in mosquito larvae [51]. Plant families known for the presence of glycosides include Araceae, Asteraceae, Gramineae, and Fabaceae - all of which have been reported for mosquitocidal activities (Table 5).

Table 5: Some plant-based glycosides along with their respective plant name, family, mosquito species targeted, plant part used, LC50 value, and references

SN	Name	Family	Mosquito species targeted	Plant part used	LC_{50} value (ppm)	References
1.	*Typhonium trilobatum*	Araceae	*Cx. quinq uefasciatus*	leaf	19.87 ppm	[52]
2.	*Cassia mimosoides*	Fabaceae	*Anophelesgambiae*	leaf	0.28 mg/ml	[51]
3.	*Duranta erecta*	Verbenaceae	*Anopheles gambiae*	leaf	10.037 ppm	[53]
4.	*Tridax procumbens*	Asteraceae	*Anopheles gambiae*	leaf	213.410 ppm	
5.	*Tridax procumbens*	Gramineae	*Anopheles gambiae*	leaf	214.417 ppm	
6.	*Ageratumconyzoide*	Asteraceae	*Anophelesgambiae*	leaf	423.520 ppm	[54]
7.	*Annona squamosa*	Annonaceae	*An. subpictus*	bark	93.80 mg/l	[55]
8.	*Chrysanthemum indicum*	Asteraceae	*Cx. tritaeniorhynchus*	leaf	39.98 mg/l	
9.	*Tridax* procumbens	Asteraceae	*Cx. tritaeniorhynchus*	leaf	51.57 mg/l	
10	*Stemona curtisii*	Stemonaceae	*Ae. aegypti*	aerial parts	358 mg/mL	[56]

Saponins:

Saponins are a class of naturally occurring compounds found in various plants, including some medicinal herbs. Known for their diverse biological activities, they have been extensively studied for potential applications in different fields, such as medicine and agriculture, due to their insecticidal properties. Given their amphipathic nature, saponins exhibit surfactant action, which may allow them to interact with phospholipids and cholesterol in cell membranes. This characteristic could potentially inform the development of medications and cosmetics. As a subclass of the larger terpenoid class of metabolites, saponins hold a specific place in plant biochemistry. Figure 7 depicts their basic structure.

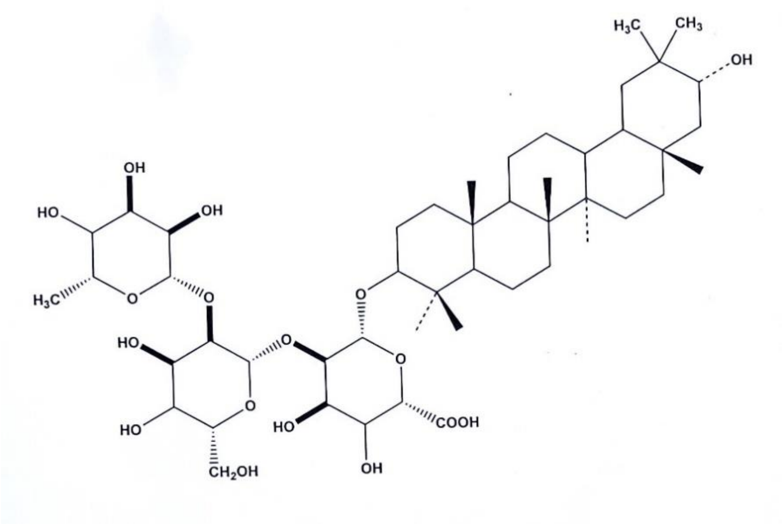

Fig 7: Basic structure of saponins

The larvicidal action of saponins involves disrupting the cell membranes of mosquito larvae, leading to cell lysis and ultimately causing their death [57]. Table 6 lists several plant-based saponins effective against different vector mosquitoes.

Table 6: Some plant-based Saponins along with their respective plant name, family, mosquitospecies targeted, plant part used, LC_{50} value, and references

S.N	Plant Name	Family	Mosquito species targeted	Plantpart used	LC_{50} value(ppm)	References
1	*Sapindusmukorossi*	Sapindaceae	*Aedes aegypti*	fruits	10.05 ppm	[58]
2	*Achyranthesaspera*	Amaranthaae	*Ae. aegypti*	leaf	18.20 ppm	[59]
3	*Tagetes minuta*	Asteraceae	*Anopheles stephensi*	flower	2.5 mg/l	[60]
4	*Gymnema sylvestre*	Apocynaceae	*Culex tritaeniorynchus*	leaves	34.75 mg/ml	[61]
5	*Solanum lycocarpum*	Solanaceae	*Culex quinquefasciatus*	fruit	75.13 mg/l	[62]
6	*Rhizophora mangle*	Rhizophoraceae	*Anopheles gambiae*	leaves	225 ppm	[63]
7	*Rhizophora racemosa*	Rhizophoraceae	*Anopheles gambiae*	leaves	175 ppm	
8	*Schinopsisbrasiliensis*	Anacardiaceae	*Aedes aegypti*	stem	313 µg/ml	[64]
9	*Annona muricata*	Annonaceae	*Anopheles gambiae*	leaf	36.64 mg/ml	[65]
10	*Lawsonia inermis*	Lythraceae	*Anopheles stephensi*	leaves	69.40 ppm	[66]

Phenols:

Phenols are a class of organic compounds widely distributed in the plant kingdom and known for their diverse chemical structures, as shown in Figure 8. Many phenolic compounds, identified in various plant species, exhibit mosquito larvicidal properties. Mosquito larvicides are substances capable of effectively killing mosquito larvae, an essential approach to controlling mosquito populations and reducing the spread of mosquito-borne diseases. Phenols may interfere with the crucial enzymatic processes within the mosquito larvae, disrupting their metabolic pathways and leading to death [67]. Plant families known for being rich sources of phenols include Rosaceae, Lamiaceae, Asteraceae, Fabaceae, Rutaceae, among others. Some of these, listed in Table 7, have proven effective against immature stages of mosquitoes.

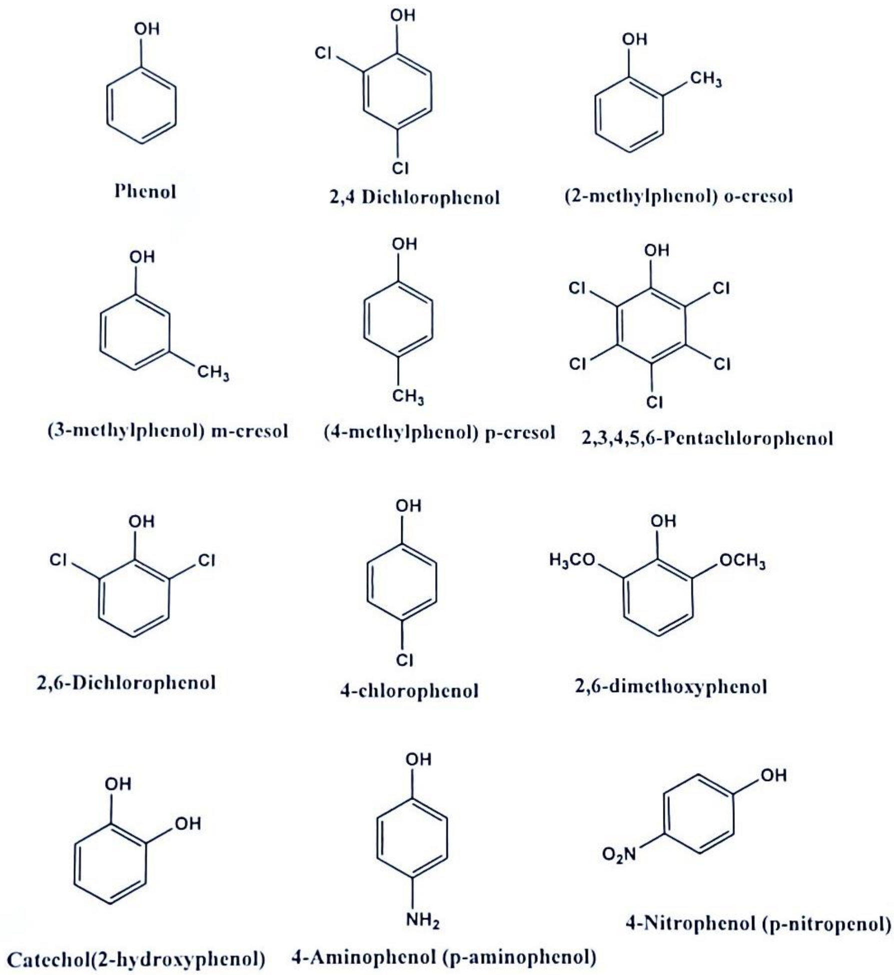

Figure 8: Structure of phenols

Table 7: Some plant-based Phenols along with their respective plant name, family, mosquito species targeted, plant part used, LC_{50} value, and references

S.N.	Plant Name	Family	Mosquito species targeted	Plant part used	LC_{50} value (ppm)	References
1.	*Anacardium occidentale*	Anacardiaceae	*Aedes aegypti and Culex quinquefasciatus*	leaves	5.4–22.6 mg/L	[68]
2.	*Kotschya thymodora*	Fabaceae	*Anopheles gambiae*	leaves	77.35 µg/mL	[69]
3.	*Salvia elegans*	Lamiaceae	*An. albopictus*	Aerial parts	46.4 ppm	[70]
4.	*Salvia splendens*	Lamiaceae	*Aedes albopictus*	Aerial parts	59.2 ppm	
5.	*Ricinus communis*	Euphorbiaceae	*An. stephensi*	leaves	0.75 ± 0.01 ppm	[71]
6.	*Callistemon rigidus*	Myrtaceae	*Cx. quinquefasciatus*	leaves	17.11 ppm	[72]
7.	*Eclipta prostrata*	Asteraceae	Cx. quinquefasciatus	Leaves	27.49 mg/l	[73]
8.	*Solanum trilobatum*	Solanaceae	*Cx. quinquefasciatus*	Leaf	265.69 ppm	[74]
9.	*Syzygium aromaticum*	Myrtaceae	*Ae. aegypti*	leaf	92.56 mg/l	[75]
10.	*Millingtonia hortensis*	Bignoniaceae	*Anopheles stephensi*	leaves	123 ppm	[76]

Essential oils

Essential oils have been studied for their potential use as mosquito larvicides due to their natural properties and the presence of certain phytochemicals. Phytochemicals are compounds derived from plants that often exhibit biological activity. Some essential oils have demonstrated larvicidal properties, as detailed in Table 8.

Compounds found in essential oils may induce oxidative stress within mosquito larvae, damaging their cells and tissues. Certain volatile compounds in essential oils may affect the respiratory processes of mosquito larvae, leading to suffocation and mortality [77].

Essential oils are prevalent in various plant families, and different plants within each family may yield essential oils with unique chemical compositions (Figure 9) and properties. Some plant families, famous for their essential oil production, include Apiaceae, Lauraceae, Pinaceae, Lamiaceae, and Myrtaceae.

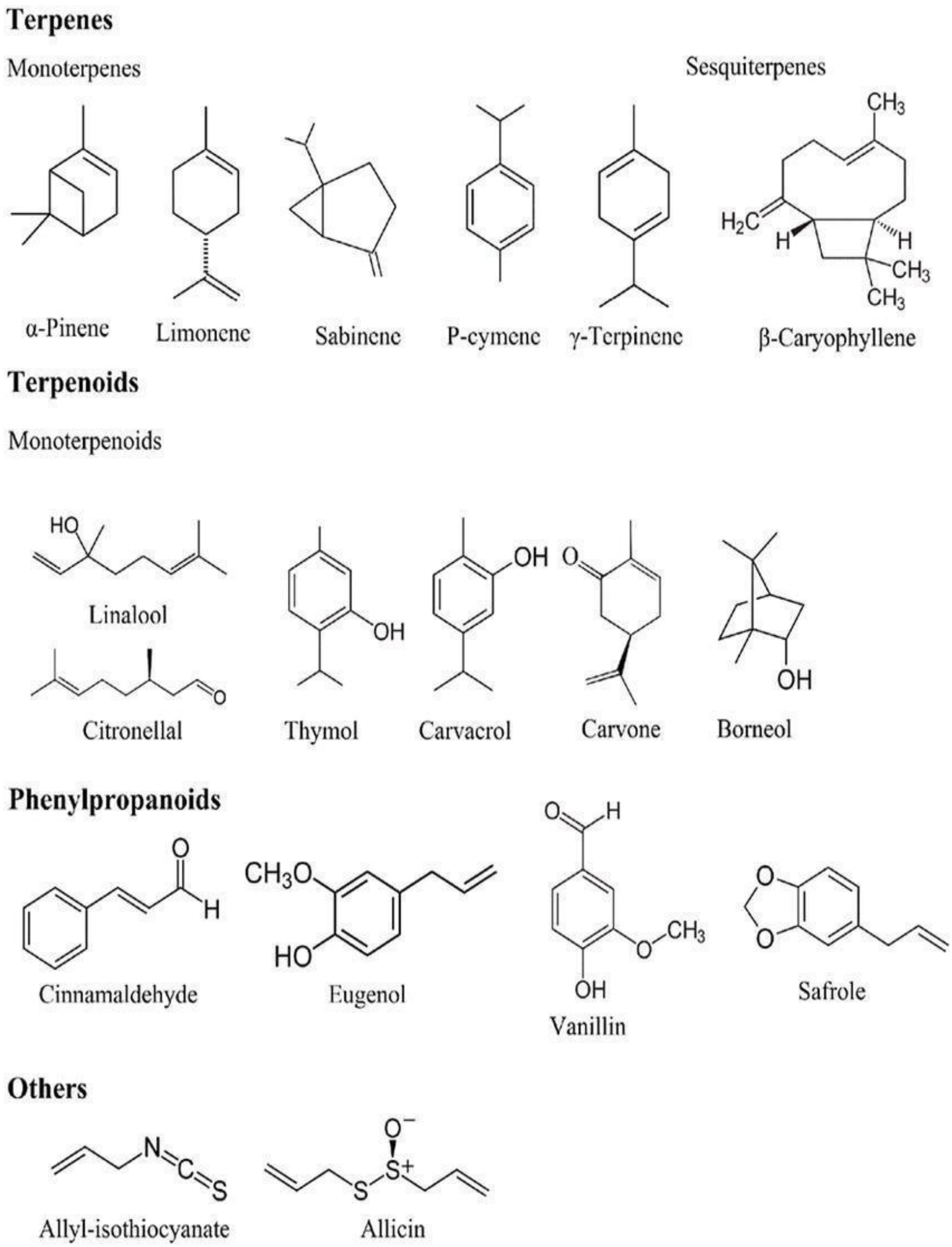

Fig 9: Structures of Essential oils

Table 8: Some plant-based Essential oils along with their respective plant name, family, mosquito species targeted, plant part used, LC_{50} value, and references

S.N.	Plant Name (Scientific Name)	Family	Mosquito species targeted	Plant part used	LC_{50} value (µg/mL)	References
1	*Tagetes patula*	Asteraceae	*Aedes aegypti*	flower	13.57 ppm	[78]
2	*Satureja bachtiarica*	Lamiaceae	*An. stephensi*	Leaves	24.27 ppm	[79]
3	*Satureja bachtiarica*	Lamiaceae	*Cx. quinquefasciatus*	leaves	44.96 ppm	
4	*Zingiber collinsii*	Zingiberaceae	*Ae. albopictus*	leaves	25.51 µg/mL	[80]
5	*Mentha spicata*	Lamiaceae	*Cx. quinquefasciatus*	leaf	62.62 ppm	[81]
6	*Ocimum americanum*	Lamiaceae	*A. aegypti*	*Leaves*	67 ppm	[82]
7	*Ocimum gratissimum*	Lamiaceae	*A. aegypti*	*Leaves*	60 ppm	
8	*Cinnamomum cassia*	Lauraceae	*A. aegypti*	Leaves	36 ppm	[83]
9	*Eucalyptus citriodora*	Myrtaceae	*Aedes aegypti*	Leaves	104.4 ppm	[84]
10	*Cymbopogon citratus*	Poaceae	*Aedes aegypti*	leaves	120.6 ppm	

Growth and reproduction inhibiting phytochemicals

Plant-based insecticides have the potential to significantly reduce the spread of vector-borne diseases by acting as repellents or insecticides. Plants primarily store phytochemicals in the form of secondary metabolites, facilitating the plant's defense mechanisms. Secondary metabolites such as alkaloids, steroids, terpenoids, tannins, and flavonoids, derived from various plants, have been reported above for their insecticidal properties. These phytochemicals are extracted from the entire body of small herbs or different parts of larger trees, including the fruits, leaves, stems, bark, and roots. In addition to serving as larvicides, these plant-derived phytochemicals can also be used as repellents, oviposition attractants, insect growth hormone regulators, and deterrents. Many regions globally have utilized plant products, either as extracts or whole plants, to either kill or repel mosquitoes [85].

Certain phytochemicals have a broad toxicant (insecticide/larvicide) effect on both mosquito larvae and adults. Others, known as growth inhibitors or chemosterilants, work by interfering with growth and development or reproduction, or they provide olfactory sensations that either attract or repel insects [86,87]. Factors such as the plant species, their geographic distribution, the extraction process, and the polarity of the solvent used during extraction all influence the insecticidal qualities of the phytochemicals. For mosquito control programs, extracts containing the active ingredient responsible for their mosquitocidal effect are extracted and utilized.

However, despite possessing favourable LC50 values, the majority of phytochemicals are ineffective due to the modest dose-response slope identified for most of them over a 24-hour period. Therefore, a phytochemical's ability to inhibit development may be crucial to the adoption of the substance by mosquito control businesses. The judicious use of extraordinary phytochemicals could not only result in novel strategies but also prevent the emergence of insect resistance [88].

Scope for future research: isolation of toxic larvicidal active ingredients

Multiple research studies have demonstrated the effectiveness of plant extracts as a reservoir of bioactive toxic compounds against mosquito larvae. However, few have been extensively used in vector control regimens and commercially produced. Factors such as poor characterization and inefficiency in determining the structural configuration of active toxic components responsible for larvicidal action have contributed to the unsuccessful transition of bioactive toxic phytochemical discoveries from laboratory to practical applications. Any research design involving phytochemicals could consider the following stages for the manufacture of a green biopesticide [89,90,91]:

- Perform screening of floral biodiversity for crude plant extracts with potential to kill mosquito larvae;
- Prepare plant solvent extracts, starting with non-polar compounds and progressing to polar chemicals to identify the most effective solvent extract;
- Conduct a phytochemical analysis of the solid residue and apply column chromatography and thin-layer chromatography to purify and isolate the toxic phytochemical with larvicidal potential;
- Determine the lethal concentration (LC50/LC100 values);
- Evaporate the liquid solvent to obtain solid residue;
- Perform a phytochemical analysis of the solid residue; and
- Identify the structure of the active principle using infrared (IR) and nuclear magnetic resonance (NMR).

CONCLUSION

In conclusion, controlling mosquito populations is crucial in preventing the spread of lethal diseases such as malaria, dengue fever, and the Zika virus. Traditional mosquito control methods come with several limitations, including potential environmental impacts and the development of insecticide resistance. The use of natural products, such as mosquito larvicides, has gained attention as an alternative approach to controlling mosquito populations. Derived from plants, animals, and microorganisms, natural products offer several advantages, including low toxicity, biodegradability, and a reduced risk of resistance development. Therefore, the use of natural products like mosquito larvicides could offer a sustainable and effective solution to mosquito control. Further research is needed to explore the potential of natural products in mosquito control and identify new natural products with mosquito larvicidal properties.

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Conflicts of interest/Competing interests

The authors declared that they have no conflicts of interest.

Fig 10: Solanum nigrum (Alkaloids extracts from fruits)

Fig 11: *Tagetes patula* (Flavonoids reported from the flowers)

Fig 12: *Solanum villosum* (Steroid reported from berry)

Fig 13: *Clitoria ternatea* tannins reported from leaves and roots

Fig 14: ***Cassia mimosoides*** **(Glycosides from leaf)**

Fig 15: Saponnins reported from flowers of ***Tagetes minuta***

Fig 16: ***Salvia elegans*** **(Phenols from aerial parts)**

Fig 17: ***Ocimum americanum*** **(essential oil reported from leaves)**

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مراجعة للتطورات الحديثة للمنتجات الطبيعية كمبيدات لليرقات في إدارة مكافحة ناقلات الأمراض

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ملخص

البعوض، وهو ناقل بيولوجي، مسؤول عن نقل بعض الأمراض الخطيرة والمخيفة في العالم كله. هذه الأمراض مستوطنة في البلدان الاستوائية بشكل رئيسي وتتسبب في وفاة الملايين كل عام. أصبحت المبيدات الحشرية ذات الأصل النباتي والصديقة للبيئة أكثر أهمية في السنوات الأخيرة. ونظرًا إلى قابليتها في التحلل البيولوجي وانتقائية الأهداف، يمكن استخدامها بأمان في البيئات المائية. على الرغم من أن تطبيقات المبيدات الحشرية فعالة للغاية في السيطرة على أنواع النواقل المستهدفة، إلا أنها تسبب خطرًا لأن مقاومة المبيدات الحشرية الكيميائية آخذة في التزايد، مما يؤدي إلى انتعاش القدرة الناقلية. تستكشف هذه الورقة فعالية المواد الكيميائية النباتية في مكافحة مجموعات البعوض الناقل. وفي برامج مكافحة البعوض، يكون للمواد الكيميائية النباتية تأثيرا كبيرا. تعمل النباتات كمخزن ضخم للأيضات الأولية والثانوية. يمكن استخدام أنواع مختلفة من المذيبات القطبية وغير القطبية لاستخلاص المكونات النباتية النشطة بيولوجيًا من النبات بأكمله أو من جزء معين منه. تحدد هذه المراجعة الأدبية أيضًا المنتجات الطبيعية وتقدم نظرة عامة على الأنواع المختلفة من المنتجات الطبيعية التي يمكن استخدامها للسيطرة على يرقات البعوض. ويناقش بشكل خاص فعالية المنتجات الطبيعية في مكافحة ناقلات الأمراض دون التسبب في أي مقاومة أو ضرر للكائنات الحية الأخرى غير المستهدفة. الغرض من هذه الورقة هو تقديم نظرة شاملة عن استخدام المنتجات الطبيعية كمبيدات ليرقات البعوض وتسليط الضوء على إمكاناتها كبديل للطرق الكيميائية التقليدية. وهدف هذه الورقة هو تشجيع إجراء المزيد من البحوث في مجال تطوير واستخدام المنتجات الطبيعية لمكافحة البعوض الناقل للمرض بشكل فعال.

الكلمات الدالة: مكافحة ناقلة الأمراض، المنهج التقليدي، الإنتاجات الطبيعية، المواد الكيميائية النباتية.

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