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Green Approaches to Mosquito Control: A Comprehensive Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Mosquito-borne diseases pose significant health risks to humans and animals worldwide. Traditional methods of mosquito control often rely heavily on chemical pesticides, which not only harm the environment but also lead to the development of pesticide-resistant mosquito populations. In response to these challenges, there has been a growing interest in exploring eco-friendly approaches to mosquito control. This review paper aims to examine various green strategies for combating mosquitoes, focusing on their effectiveness, environmental impact, and feasibility for large-scale implementation and discuss methods such as biological control using natural predators and pathogens, habitat modification, utilization of botanical repellents, genetic manipulation of mosquito populations, and community-based interferences. Additionally, highlight the importance of integrated pest management (IPM) strategies that combine multiple tactics for sustainable mosquito control. By exploring these alternative methods, this review provides insights into promoting environmentally responsible practices while effectively managing mosquito populations and reducing the spread of mosquito-borne diseases.

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1. INTRODUCTION

Mosquitoes are derived from the Spanish word "Musketas," which means "small fly," and these arthropods have a worldwide distribution. Species are classified into genera based on their physical traits. Mosquitoes are one of the deadliest insects in the world, there are over 3500 species all over the earth except in antarctica [1]. Temperature and species characteristics determines the life cycle from 1 to 20 days. Its life cycle consists of four main stages: Eggs last 2-3 days, larvae 8-9 days, pupae 1-2 days, and adults 10 days. The adult is active and lives on land, whereas the larvae and pupae live only in water [2]. Globally, malaria cases and mortality increased dramatically in 2022 compared to 2019 before the COVID-19 epidemic. Malaria incidences worldwide decreased from 243 million in 2000 to 233 million in 2019. In 2022, the number of cases reached approximately 249 million. The COVID-19 pandemic led to an increase of 55,000 deaths in 2020, bringing the total to 631,000 [3]. Vectors are living organisms that can spread infections or diseases between humans and animals. Vectors, such as arthropods, spread disease-causing germs by feeding on the blood of infected hosts (animal or human) and then spreading to new victims with their next meal. The mosquito is humanity's deadliest animal, causing over a million deaths each year by carrying malaria, Zika, yellow fever and a variety of other diseases [1] with the bulk of mortality happening in underdeveloped countries [4]. Mosquito-borne diseases, such as human malaria, *Dengue* fever, C*hikungunya* fever, *Zika* virus (ZIKV) sickness, and lymphatic filariasis, (Table 1) pose a significant threat to global health [5,6].

Vector control tactics have historically concentrated on killing mosquitos with a variety of insecticides. As insecticide resistance spreads across mosquito species, there is an increasing demand for safe, new, low-cost, and dependable mosquito control tactics [7]. Insecticide resistance in mosquitos is endangering the efficiency and sustainability of malaria control efforts around the world. Biological approaches present interesting alternatives to chemical control. They include natural mosquito killers, plant-based insecticides, releasing mosquitoes that are either sterile or unable to transmit disease, and erecting protective barriers against them [8].

There are 404 mosquito species identified in India, divided into 50 genera [9]. The major species that transmits diseases are *Anopheles culicifacies, A. minimus, A. philippinensis, A . stephensi, Aedes aegypti, A. albopictus, Culex tritaeniorhynchus, C. annulirostris, C. tarsalis, C. quinquefasciatus, Mansonia indiana, M. uniformis* and *M. annulifera* etc [10].

Present day vector control programs are focused on spraying chemicals. Despite the environmental and health problems, mosquitoes develop resistance to chemicals. In order to encompass these adversities it is better to choose eco-friendly green approaches. The green approaches include biological control (pathogens and predators), botanical insecticides, insect sterile techniques, physical methods and mechanical methods of control [12].

Table 1. Species transmitting diseases in India

Vector	Disease	Pathogen transmitted	References
A. aegypti	*Dengue* fever (DHF) *Chickungunya* *Zika* Yellow fever	Virus	10,11
Anopheles *Culex*	Malaria Filariasis	Round worms *Plasmodium* sp.	10,11
Culex spp.	*West nile* virus	Virus	10,11
C. tritaeniorhynchus	*Japanese encephalitis*	Virus	10,11
C. annulirostris *A.vigilax*	*Ross river* fever	Virus	11

2. GREEN METHODS TO COMBAT MOSQUITOES

The methods include, role of pathogens including, entomopathogenic bacteria and fungi. Role of predators which covers, dipterans, coleopteran, hemipterans, odonatan, larvivorous fishes, frogs and toads. Incompatible insect technique, sterile insect technique, nano technological approach and role of botanicals (*Lantana camara,* marigold and periwinkle).

2.1 Role of Pathogens

2.1.1 Entomopathogenic bacteria

2.1.1.1 Bacillus thuringiensis (Bt)

B. thuringiensis (Bt) is a gram-positive, spore-forming, aerobic bacteria found in a wide range of environments. Bt serovarieties with larvicidal activity for Lepidoptera, Coleoptera, Diptera, and other insects have been isolated from a variety of habitats around the world, including dead insects, soil, the phylloplane, grain dust, aquatic, and other environments [13]. The mosquitocidal bacteria *B. thuringiensis* subsp. *israelensis* is more efficient than *B. sphaericus* as a larvicide against a wide range of mosquitoes and has been used consistently in various pest and vector management programs for over 20 years [14]. This bacterial bio-pesticide appears to last longer in the environment, especially in unclean water, and hence could be a feasible choice for long-term mosquito control [15,16].

The main insecticidal component of *B. thuringiensis* subsp*. israelensis* is a spherical parasporal body formed during sporulation and made up of four primary endotoxin proteins: Cyt1Aa, Cry4Aa, Cry4Ba, and Cry11Aa. This parasporal body is one of the most insecticidal known, with an LC50 value of 10 ng mL-1 against several mosquito species' fourth instars. *Bacillus thuringiensis* (Bt) causes damage to insect guts when swallowed by vectors. Shortly after ingestion, these proteins bind to and lyse insect midgut epithelial cells, resulting in death. Ingestion of activated toxic protein (granular formulation) of Bti was extremely toxic to *Anopheles*, *Culex*, and *Aedes* larvae, causing cell membrane lining disintegration in the midgut (Fig. 1). *Bt israelensis* at 0.006 - 0.662 mg L-1 (LC50) caused 50% mortality of *A. gambiae* [17].

2.1.1.2 Bacillus sphaericus

B. sphaericus is a gram-positive, spore-forming, aerobic bacterium found in a wide range of soil and aquatic environments. The moiety that causes mosquito larvicidal activity in serovar. 5a5b isolates of *B. sphaericus* are binary toxins [16]. Proteins are essential for complete toxicity in the host. Similarly to Bti, ingested poisons are solubilized in the alkaline midgut and cleaved to the active moiety by proteases. The toxin's two component proteins, Bin A (42k Da) and Bin B (51k Da), bind to specific receptors on the brush border of epithelial cells in the gastric caecum and midgut, causing pore formation (permeabilization), disrupting osmotic balance, cell lysis, and, ultimately, insect death. *B. sphaericus* at 0.002-0.342 mg L-1 (LC50) caused 50% death, while *A. gambiae* at 0.018-1.807 mg L-1 (LC95) caused 95% mortality [19]. *B. sphaericus* is completely safe for humans, animals, wildlife, and the environment, and is ideal for communal use [20]. Unlike Bti, which has no known field resistance, *B. sphaericus* crystal toxin resistance has been observed in *Culex* larvae [21]. As a result, the recent rise of resistance has complicated mosquito control efforts.

Mazigo [22] conducted an experiment to evaluate the time of application of a biolarvicide, *Bacillus thuringiensis israelensis* (Bti), and fertilizer (di-ammonium phosphate-DAP or urea), and to analyze their effect on mosquito larval density and rice crop yields. The findings of this study indicate that applying Bti and fertilizer at 7-10 day intervals reduces mosquito larvae density in rice fields. This suggests that the Bti was only effective for 7–10 days.

2.1.2 Entomopathogenic fungi

Recent research has highlighted the potential of entomopathogenic fungus in suppressing malaria vectors. These fungi do not induce immediate death, but instead have sublethal and late-life lethal effects on various phases of the mosquito life cycle. Because of these features, fungi have the potential to be utilized as "evolution proof" agents, overcoming mosquito resistance in contrast to the currently used fast-acting chemical insecticides [22]. *Beauveria*, *Pythium*, *Metarhizium*, *Leptolegnia*, *Coelomomyces*, *Lagenidium* and *Conidiobolus* are the most regularly reported genera to have an effect on mosquitos.

In adult mosquitos, the conidia connect to the host cuticle, forming an appressorium before entering the cuticle via a penetration peg (Fig. 2). After entering the hemocoel, hyphae develop and release toxins, killing the host within 4-16 days of exposure. In aquatic insects, fungal conidia enter the spiracles, germinate, and pierce the respiratory siphon, releasing poisons by impeding the breathing mechanism [23]. When applied to water bodies, the hydrophobic conidia float on the surface and come into contact with mosquito larvae via the siphon's tip and head. When floating conidia come into touch with larvae, their peri spiracular valves allow them to breathe by breaking the water tension. Plugging the spiracles usually results in death before major invasion of the hemocoel occurs, therefore hyphal body production is limited [24,25].

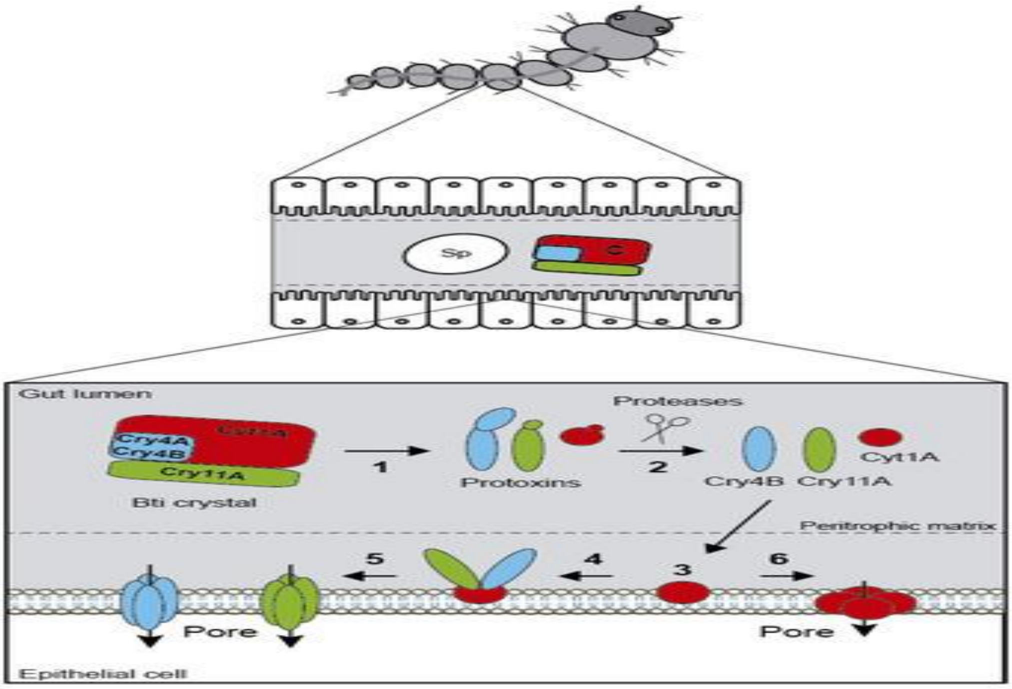

Fig. 1. Mode of action of *Bacillus thuringenesis* [18]

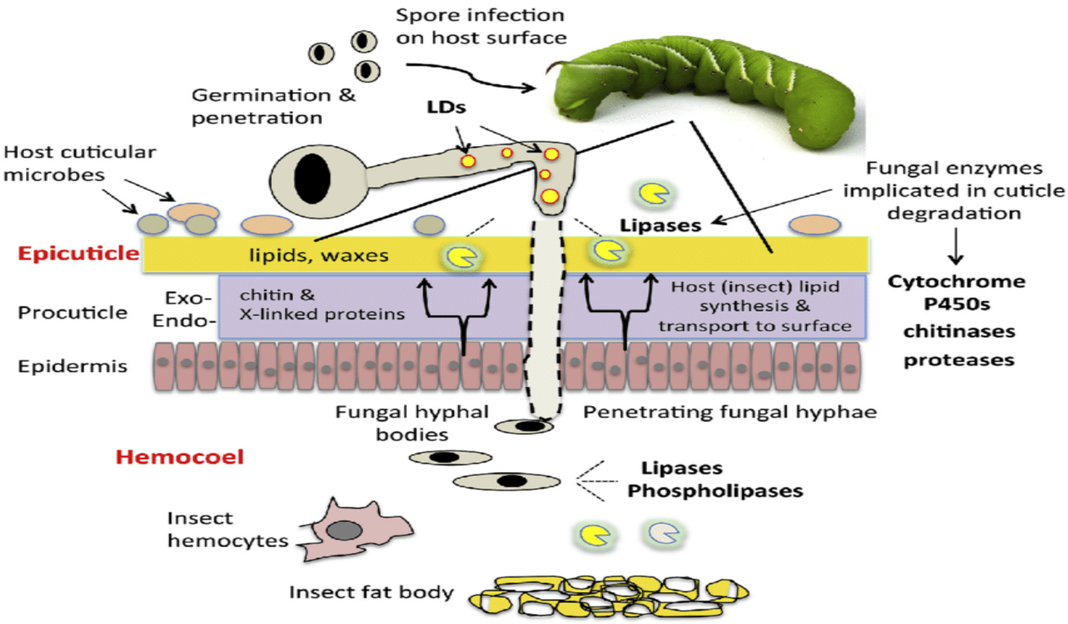

Fig. 2. Mechanism of infection of entomopathogenic fungi [26]

2.1.3 Microbial formulations used in mosquito control

One of the key components to the commercial success of a biological control agent is formulation. The development of a good formulation is important for the successful utilization of commercial biopesticides.
Commercial Bt formulations used to control mosquitos (Table 2) [27].

1. Water Dispersible Granules (WDG)
2. Aqueous Suspensions (AS)
3. Granules (G) Briquets
4. Icy granules.

2.2 Role of Predators in Mosquito Control

Predatory insects that feed on mosquito larvae and pupae in aquatic situations can help reduce Culicidae populations [31]. A variety of aquatic creatures prey on young instars, including mosquito larvae from other species, copepods, odonate young instars, water bugs, amphibians, and fish [30].

2.2.1 Dipteran predators

Toxorhynchites spp., also known as the "elephant mosquito" or "mosquito eater", is a big, worldwide mosquito genus that does not swallow blood [32]. While the adults consume sugar-rich items such as honeydew, fruit, and nectar, the larvae feed on the larvae of other mosquitos and other nektonic (free swimming) creatures. *Toxorhynchites* adults are larger than *Aedes* and thought to be harmless to humans [33].

2.2.2 Coleopteran predators

Dytiscidae and Hydrophilidae are coleopteran families that have been studied as mosquito larvae predators. Dytiscidae and Hydrophilidae adults and larvae are common predators in ground pools, ponds (both permanent and temporary), and artificial mosquito breeding areas. Aditya [34] identified *Laccophilus*, *Agabus*, and *Rhantus* as possible biological control agents for mosquitos. A recent field study [35] found that *Acilius sulcatus* (Family: Dytiscidae) larvae have a considerable impact on mosquito larvae *C. quinquefasciatus, C. vishnui, C. bitaeniorhynchus, C. gelidus, C. tritaeniorhynchus, Anopheles annularis, A. subpictus, A. barbirostris and Armigeres subalbatus* that prevail in cement tanks.

2.2.3 Hemipteran predators

Predaceous Hemipteran bugs are classified into three major families: Belostomatidae, Nepidae, and Notonectidae. Back swimmers (Family: Notonectidae) are the most prevalent bugs that feast on mosquito larvae, making them an essential component in reducing young mosquito populations and considered promising for mosquito control [36].

2.2.4 Odonatan predators

Odonata larvae are fierce predators of mosquito larvae in watery settings. Dragonfly larvae are known to eat significantly on bottom feeder mosquitoes, such as *Aedes* larvae. Sebastian [37] discovered that using dragonfly larva, *Labellula* sp., full elimination of all *A. aegypti* larvae and pupae was obtained between days 4 and 9, depending on the density of aquatic stages of mosquitoes present per container [38].

2.2.5 Larvivorous fishes

Biological mosquito control with vertebrates has been focused on the role of larvivorous fish, which consume mosquito larvae in the aquatic stage [31]. Fish predation on mosquito larvae has been seen in a variety of habitats, ranging from small plastic containers to complex natural ecosystems, including coastal wetland environments [39]. *Gambusia* and *Poecilia* (Poeciliidae) have been introduced to more than 60 nations for mosquito control. Salim [40] discovered that the quantity of larvae was reduced in the intervention ponds. The greatest reduction in *Anopheles* larvae devoured by *G. affinis* was 100% after one month, followed by 83.3% in a fortnight.

2.2.6 Frogs and toads

Tadpoles with varying life histories actively hunt on *A. aegypti* eggs. It has been demonstrated that this mosquito species prefers to lay eggs in tadpole water, and that tadpoles from the *Polypedates cruciger*, *Bufo*, *Ramanella*, *Euphlyctis*, and *Hoplobatrachus* genera prey on the eggs [41].

2.3 Incompatible Insect Technique

Cytoplasmic incompatibility (CI) is a situation in which sperm and eggs are unable to produce viable progeny. The effect is caused by alterations in the gametes of *Wolbachia*-infected males. *Wolbachia* changes sperm prior to spermatogenesis and interferes with the parental chromosomes during the initial mitotic divisions, causing them to split out of sync. Because of the sensitive relationship between mosquito survival and vectorial capacity, interventions aimed at reducing adult mosquito daily survivorship, such as residual insecticide spraying in homes and insecticide-treated bed nets for malaria control, result in significant reductions in pathogen transmission rates. A strain of the obligatory intracellular bacteria *Wolbachia pipientis*, wMelPop, has been identified that shortens the adult life span of its natural fruit fly host, *Drosophila melanogaster*. It has been hypothesized that life-shortening *Wolbachia* strains, such as wMelPop, might be employed to shift the age structure of the mosquito population toward younger individuals, lowering pathogen transmission but not destroying the population. *Wolbachia* are maternally inherited bacteria that exploit processes including cytoplasmic incompatibility (CI), a type of embryonic mortality caused by crosses between infected males and uninfected females, to rapidly spread throughout insect communities. Evidence from other *Wolbachia* insect [42] interactions suggests that CI may allow *Wolbachia* strains, such as wMelPop, to infect mosquito populations even if they impose a fitness penalty, such as increased mortality. Current simulations.

suggest that this method could lead to considerable reductions in disease transmission. However, life-shortening *Wolbachia* strains are not found naturally in mosquitos. Stable introduction of a life-shortening *Wolbachia* infection into the mosquito *Aedes aegypti* resulted in a shorter life span for all mosquitos and induced cytoplasmic incompatibility, resulting in non-viable offspring when crossed with an infected male, reducing mosquito populations [42].

Table 2. Commercial formulations of *Bacillus* sps.

Bt sub sp.	Commercial Formulation	Producer	Dose	References
Bt israelensis	VectoBac [AS]	Abbott Laboratories	0.3-6.0 l/ha	[28]
	Vectobac [WDG]	Valent Biosciences corporation	@ 300 g/ha	[29]
	Culinex tablets		1 tablet/2000 l	[30]
	Vectobac [G]	Abbott Laboratories	2-20 kg/ha	[28]
	FourStar™ briquets	Best chemical Co(s) Pte Ltd	1 briquette/100 ft^2	[19]
B. sphaericus	Vectolex WDG	Valent Biosciences corporation	400 g/ha	[19]
	VectoBac 12AS	ADAPCO, Azelis company	0.5 – 1L /ha	[19]

Abbreviations: Bti, Bacillus Thuringiensis var. *israelensis; Bs, Bacillus sphaericus; AS, Aqueous Suspension; G, Granules; WDG, Water-Dispersible Granules*

Table 3. *Wolbachia* strains infect mosquitos

Strain	Original host	Transinfected host	Effect on host Insect	References
wMelPop-CLA	*Drosophila melanogaster*	*A. aegypti*	Cytoplasmic In compatability, Life shortening, Blood-feeding alteration Bendy proboscis	[42]
wMelPop	*Drosophila melanogaster*	*A. albopictus*	life shortening, embryo mortality	[42]
wPip	*Culex pipiens*	*A. albopictus*	CI, lower hatch rate, reduced fecundity	[43]

2.4 Sterile Insect Technique

There are no specific treatments or licensed vaccines for *Dengue,* thus attempts to limit transmission rely primarily on vector management [44]. The current control measures are jeopardized by the actual or potential spread of resistance in the vector population. As a result, new ways must be developed expeditiously. The introduction of transgenic vectors may open up new avenues for lowering the density or vectorial capacity of vector populations [45]. Insect Technique (SIT) is a genetic control approach that involves the release of a large number of radiation-sterilised insects. These mate with wild insects of the same species, reducing the reproductive capacity of the wild pest population by producing no or fewer viable offspring as a result of radiation-induced lethal mutations in their gametes [46, 47]. Although successful against certain agricultural pests, attempts against mosquitos have been less successful. This is due in part to the somatic damage and performance loss in sterile insects that unavoidably occurs with radiation sterilization. Interestingly, one effective case of SIT in mosquitos used a chemosterilant instead of radiation [48].

Modern genetics has the potential to overcome this problem, for example, by using an engineered self-limiting gene that is both repressible by an antidote provided in a managed rearing facility and, when expressed in the absence of the repressor, causes mortality before the insect reaches functional adulthood, which could be used in place of radiation [49]. Operationally, the system would be quite similar to SIT, with the same clean, species-specific qualities and benefiting from the released males' female-seeking abilities. However, the insects would not be irradiated; rather, they would be homozygous for a transgene, which, when passed to an embryo via sperm, would cause the zygote to die at some stage in development [50]. In addition to minimizing the requirement for radiation, altering the timing of death can improve efficiency versus target populations with high density dependence. Simulation modeling reveals that such an approach could potentially be successful and economical against *Aedes aegypti* [48].

According to Carvalho [48], SIT with self-limiting genetic technology is a promising strategy. OX513A, a self-limiting strain of *Aedes aegypti,* has previously been field evaluated. In 2010, sustained releases of OX513A *A. aegypti* males resulted in an 80% suppression of the target wild *A. aegypti* population in the Cayman Islands. Sustained release of OX513A males has the potential to be a practical and efficient strategy for inhibiting the primary *Dengue* vector*, A. aegypti*. In the tested locality and other areas with comparable or lower transmission, the reported degree of suppression would probably be adequate to stop *Dengue* epidemics [48].

2.5 Nano Technological Approach

Over the last decade, nanocomposite (NCs) has gained popularity in a variety of commercial products due to its several advantages over nanoparticles. There are several types of NCs based on the combination, such as metal/polymer, metal/metal oxide, and Bio-NC, which combines a metal nanoparticle with bio-compounds as a solid supporting matrix [51]. Despite the fact that a wide range of solid supportive matrixes, such as porous carbon material, inorganic clay, silica, and zeolite, have been used to synthesize silver nanocomposite to take advantage of their surface functional group and anchor nanoparticles to exploit their novel potential [52]. As a result, the development of novel biodegradable, environmentally friendly, and targeted larvicides is critical for future control tactics. In this regard, the scientific community strongly supports the bio-synthesis of Ag-NC using low-value biowaste as a solid support material and crystallizing metal by hydrothermal treatment. Hydrothermal synthesis is typically performed at high vapor pressure levels and with a high-temperature aqueous solution, hence the name 'Hydro' + 'Thermal' = Hydrothermal technique.

Sundaramahalingam [53] produced silver nanoparticles (AgNPs-RH) and impregnated them on the surface of rice husk, which was then molded into a clay coin for the steady-state release of Ag ions from a porous terracotta disc (PTD) against mosquito larvae in water. They concluded that 24 hours of exposure to the intended PTD resulted in 100% larvicidal death, and the amount of silver released from the porous disc was 0.0343 ppm. Furthermore, histological investigations of dead larvae demonstrated that silver ions from the PTD had significantly damaged the larvae's exoskeleton.

2.6 Role of Botanical Insecticides in Mosquito Control

Plant-based mosquito larvicides have been shown to outperform synthetic insecticides in mosquito control programs, reducing environmental risks. To date, 344 species have been documented to show substantial activity against mosquitos [54]. Common mosquito control plants include *Acacia nilotica*, *Lantana camera*, *Catharanthus roseus* G., *Clerodendrum phlomidis*, *Curcuma longa*, *Tagetes patula*, *Cymbopogon citrates* etc.

2.6.1 *Lantana* (*Lantana camara L.)*

Lantana oil and crude extract are natural fumigants that repel a variety of insects and mosquitos. Lantana leaves contain primarily (triterpenoids), Oleanonic acid, icterogenin, Lantadene A, Lantadene B, Lantanilic acid and 4,5-dihydroxy3,7-dimethoxyflavone-4-o-beta Dglucopyranoside, Camaroside. These chemicals were responsible for the repellent property [54].

2.6.2 Marigold (*Tagetes patula* Linn.)

Tagetes' chemical contents include β-karyophyllene, terpenes, hydrocarbons, alcohols, ethers, aldehydes, ketones, esters, carotenoids, flavonoids, and thiophenes. They offer insect repellents, antiseptics, diuretics, blood purifiers, and cancer treatments [55]. The extract of *T. patula* is effective over the larvae and pupae of *A. aegypti* at lower concentations [55].

2.6.3 Periwinkle (*Catharanthus roseus* L.)

Its leaves contain two secondary metabolites, vincristine and vinblastine, which have larvicidal activity against *Culex* spp. [56].

Kokila [55] investigated the insecticidal and biological effects of three plant extracts on the dengue vector, *A. aegypti* (Diptera: Culicidae). They found that Periwinkle (*Catharanthus roseus* L.) leaves showed larval and pupal mortality of *A. aegypti* after treatment with methanol extract of *C. roseus* leaf extract at various concentrations (2 mg L -1, 4 mg L -1, 6 mg L -1, 8 mg L -1, and 10 mg L -1). At a dosage of 10 mg L-1, 89 percent of the larvae died in the first instar.

Mortality varied significantly throughout the concentrations tested. The lowest measured LC50 was 5.89 mg L-1 for the I instar, while the highest was 6.87 mg L-1 for the IV instar. In comparison to *A. aegypti's* III and IV instars, the pupae were more sensitive [55]. Agnimantha (*Clerodendrum phlomidis*) flowers contain secondary metabolites such as tannins, alkaloids, polyphenols, terpenoids, and essential oils, which have larvicidal effect against mosquitos. *A. aegypti* larval and pupal death rates ranged from 12 to 85% [55]. Marigold (*Tagetes patula* Linn.) is effective against larvae and pupae at low concentrations ranging from 5 mg L -1 to 7 mg L-1. Early instars were more vulnerable to *T. patula* than later instars [55]. *T. patula* extract had a little greater death rate when compared to *C. phillomedis* and *C. roseus*, but there was no significant difference between the three test plants.

2.6.4 Botanical formulations used for mosquito control

2.6.4.1 Neo-Innova®

Neo-Innova® is a repellent with a long-lasting effect. "NEO-PART®" (Prolonged Action Release Technology) is a formulation containing 40% Citriodiol®. It comprises the chemical para-menthane 3,8-diol (PMD) at 25% w/v. In A. aegypti, the full protection period (CPT; 14.2 h) was around two to three times longer than that reported in other formulations sold in the United States, including a 25% deet and a 20% PMD ethanolic formulation [57].

2.6.4.2 ME 750

Smyrnium olusatrum contains isofuranodiene and essential oils with larvicidal properties. Isofuranodiene synthesized in ME 750 was effective against *C. quinquefasciatus* at an LC50 of 18.6 µL L-1, resulting in considerable larval mortality over time and a marked decrease in adult emergence [58].

3. PHYSICAL METHODS

It is the change of physical components in the environment to reduce or eliminate mosquito populations, which includes changing the water in birdbaths, pools, fountains, and rain barrels once a week. Screening doors and windows to defend against mosquito attacks. Mosquito net These nets are regarded as more protective than coils and other repellents because their use poses no health risk (59). There are two types of nets: medicated and non-medicated [60].

a)Mosquito trap b) Mosquito magnet c) Electric mosquito zipper

Fig. 3. Mechanical methods of mosquito control [62]

4. MECHANICAL METHODS

4.1 Mosquito Traps

These traps mimic numerous mosquito attractants, including body heat and exhaled carbon dioxide. They are powered by electricity, therefore their operation is safe. When a mosquito is drawn to an impeller fan, it attaches to the sticky surface of the trap and is shocked [61].

4.2 Electric Mosquito Zipper

This device operates by emitting UV light, which kills mosquitos when they interact with a deadly electric charge [62].

4.3 Mosquito Magnet

Its approach is based on mimicking mammal features such as emitting heat, moisture, and carbon dioxide. When a mosquito gets close to the gadget, it draws in and dies [62].

5. CONCLUSION

Eco-friendly mosquito control measures are required to limit the long-term administration of insecticides, which is currently the dominant strategy for mosquito control. Safe and sustainable approaches for targeting various mosquito species, including bioagents, predators, insect sterile techniques, physical and mechanical methods, should be developed such that they are accessible to the general public. The need-based production of biocontrol formulations such as tablets, capsules, ice granules, and so on should be promoted.

COMPETING INTERESTS DISCLAIMER

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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