



An approach to long-term eco-sustainable mosquito control measures

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Abstract

The mosquitoes are the most dominant species globally and act as a carrier of various human arboviral diseases like dengue, malaria, chikungunya, and others that are currently incurable as they cannot be completely treated through immunizations or medication. Prevention of these diseases relies mostly on the control of mosquito vectors in their immature as well as adult stages. The control strategies rely heavily on the use of synthetic insecticides. As a result, mosquitoes start developing resistance to these chemical insecticides. Indiscriminate use of these synthetic insecticides during peak seasons of outbreaks of mosquito borne disease also causes adverse effects on the environment and other beneficial insects. Thus, this study highlights an alternate tactic to control a wide range of mosquito species in an eco-friendly manner through biological means without harming the environment.

Keywords: Mosquito, environment, biological control, insecticide, insecticide resistance

Introduction

Worldwide mosquitoes have posed a serious threat to human health. Through international trade and travel, these insects can spread to new habitats and other geographic regions^[1], putting millions of people at risk of contracting the diseases they carry. Globally, there have been documented instances of 56 million dengue fever and an anticipated 229 million cases of malaria with 409 thousand deaths in 2019^[2,3].

According to a recent study, mosquito species will likely continue to expand over the world in the ensuing decades, putting 50% of people worldwide at risk of contracting a virus carried by mosquitoes by the year 2050^[4]. Despite continuous disease control initiatives, climate change is predicted to increase the burden of mosquito-borne diseases, posing an even more serious threat to human health^[5].

The most common way to keep mosquitoes away from human hosts is to use synthetic insecticides in mosquito nets, fabrics and indoor sprays. The use of chemical strategies brought hope to control the spread of disease in endemic areas, but the emergence of insecticide resistance was a major problem in reducing disease burden. Over the years, the uncontrolled use of pesticides has led to a resurgence and increase in the mosquito population. Between 2010 and 2019, about 28 malaria endemic countries (out of 82) identified resistance to all four of the most commonly used classes of insecticides, and 73 countries identified resistance to at least one class of insecticides. The problem continues to grow worldwide^[2]. Thus, insecticide resistance is now considered a major threat to controlling mosquito invasion and disease transmission. In order to improve the control of mosquitoes, it is important that the methods of monitoring mosquito populations with insecticides and the interpretation of results are carried out sufficiently, efficiently and in a timely manner^[6]. Current mosquito control research is now focused on understanding mosquito resistance to synthetic insecticides and developing new strategies to overcome resistance problems.

A number of environmentally friendly mosquito control methods have been investigated to reduce the selective

pressure of insecticide resistance. These versatile biocontrol technologies aim to be environmentally friendly and sustainable by targeting different stages of the mosquito life cycle. It contains natural organisms that kill mosquitoes, exploits mosquito behavior to improve mosquito mortality, and releases mosquitoes that are sterile or unable to transmit disease^[4, 7]. Environmental management by reducing or removing mosquito breeding sites in combination with chemical or biological ovicides, larvicides and pupicidal methods has often been used in areas with endemic mosquito infections^[8]. This review discusses the potential of these biological methods for mosquito control and as new tools to reduce the prevalence of insecticide resistance.

Biological control of mosquito

Biological control relies on the introduction of living organisms that target or otherwise reduce the population of the target organism. The use of toxins produced by natural pathogens, predators, competitors, parasites and microorganisms for biological control has traditionally been characterized as reducing populations of target pests and vector mosquitoes^[9]. Some of them are discussed in this study.

1. Virus

Viruses are first extracted from infected insects and then engineered and used in the field as bioinsecticides. Mosquito pathogenic viruses belong to four main groups: baculoviruses (NPV) (Baculoviridae: nucleopolyhedrovirus), densovirus (DNV) (Parvoviridae, Brevidensovirus), cytoplasmic polyhedroviruses (CPV) and iridoviruses (Iridoviridae) (MIV): Chlorovirus. *Baculoviridae*, *Pavoviridae* and *Iridoviridae* are DNA viruses and *Reoviridae* are RNA viruses that have effects on various mosquito species^[10, 11]. *Aedes aegypti* densovirus (Aae DNV), the first mosquito-specific densovirus (MDV), was discovered in *Ae. aegypti* larvae. MDVs have also been produced by several other mosquito species such as *Aedes albopictus*, *Anopheles sinensis*, *Anopheles gambiae*, and *Culex pipiens*^[12]. An entomopathogenic virus is effectively

transmitted in the first stage from one generation of insects to the next, causing paralysis and eventual death of mosquito larvae. As their host range is limited to insects so, they are harmless to other animals and plants, Furthermore, baculovirus treatment shows no evidence of long-term aggregation or atmospheric contamination [13].

2. Protozoa

Microsporids, or entomopathogenic protozoa, are a remarkably diverse class of parasites that target many insect species. Protozoan species that infect Ciliophora mosquitoes include: *Lambornella stegomyiae*, *Lambornella clarki*, *Chilodonella uncinata* and *Tetrahymena pyriformis*. All these species can cause the death of mosquitoes and thus have biocides. They are unicellular eukaryotic organisms between 30 and 75 µm long and most are described as microsporidia and ciliophoran (cilia). It has significant pathogenicity, desiccation resistance and reproductive ability when grown *in vitro*. They are usually gradual in onset and are host specific, resulting in permanent disease and general deterioration of the host. The ability of the host insect to ingest, develop, reproduce and survive for long periods is impaired, when the infectious stage, called a spore, germinates in the midgut of the insect host and releases the spore plasm. *Chilodonella uncinata*, a natural protozoan pathogen, has been investigated in a laboratory bioassay as a promising biological control agent against larvae of *Culex quinquefasciatus*, *Anopheles Stephens* and *Aedes aegypti* [14, 15].

3. Fungi

Fungi are also act as a mosquito biocontrol vectors. More than 700 species of fungi have been recognized as insect pathogenic fungi [16]. The most important mosquito pathogens include the genera *Coelomomyces*, *Beauveria bassiana*, *B. brongniartii*, *Pythium carolinianum*, *Entomophthora*, *Isaria fumosorosea*, *Lagenidium giganteum*, *Culicinomyces*, *Leptolegniacaudata* etc. In an intestinal infection, the fungus produces ruffles to pierce the epicuticle and then spreads subcutaneously to stop the infection and reproduces as blastospores that attack the insect's vital organs, expanding into its body cavity by hemolymphatic migration and eventually killing the insect by cutting off its blood supply. When the host dies, the fungus undergoes selective feeding, develops hyphae just outside the skin, and releases significant numbers of spores. By releasing mycotoxins, certain entomopathogenic fungi, including *beauvericin*, *destruxin*, *desmethyl destruxin*, and *cyclodepsipeptide*, can damage the host even more rapidly [17]. It was found that *Culex pipiens* can be successfully controlled by the entomopathogenic fungi *Metarhizium anisopliae* and *Ae. aegypti* biologically using 93 entomopathogenic fungal isolates from six B species [18]. The fungus has a huge effect on the survival of mosquito eggs. Larvae currently in diapause are susceptible to fungal infections that enter the eggs through the eggshell or damage the larvae [19]. Application in areas where mosquitoes rest or must pass through, including fungus-impregnated fabrics surrounding bed nets, attractive baits, adult mosquito traps and PET traps, shows promising in controlling mosquitoes [20].

4. Bacteria

Most pest control scientists focus on bacterial agents that target both aquatic and adult life forms [20]. During spore formation such bacteria produce protein crystals or some toxins with insecticidal activity [11]. Bacterial crystal proteins are very temperature-fast and crude proteins perform better than lightly purified exclusions for mosquito larvae. These bacterial toxins and other pathogenic agents, after consumption, damage the midgut epithelium of the host insect and then multiply in nutrient-rich hemocoel cells, causing septicemia and death of the insect host [21]. Cell death is caused by osmotic stress through the porous structure formed by oligomerization of the toxin monomer [11]. Among entomo bacteria, there are currently records of *Bacillus sphericus*, *Bacillus thuringiensis*, *Bacillus popilliae*, *Bacillus subtilis*, *Bacillus circulans*, *Bacillus laterosporus*, *Clostridium bif fermentans* and *Brevibacillus laterosporus* with possibilities for exercising control over insect dipterans [11, 22]. Most available microbial products are based on Gram-positive bacteria of the *Bacillus* genus due to their long-term reliability. *Bacillus thuringiensis* crystal and vegetative toxins are produced trans-genetically, making it the most effective antimicrobial agent to date. *Bti* kills mosquito larvae by releasing crystals and cytolitic proteins during the bacterial sporulation process.

5. Larvivorous fish

The use of larval fish is the oldest method of biological control of mosquitoes. *Gambusia affinis*, *Gambusia holbrooki*, *Esomus dandricus*, *Fundulus*, *Poecilia reticulata*, *Trichogaster lalia*, *Trichogaster fasciata* etc used to control larval mosquitoes. *Gambusia affinis*, a mosquito fish, was first discovered more than 100 years ago and was highly compatible with the simultaneous use of certain chemical or biological insecticides [23]. It is the most effective attacker of larvae of *Aedes aegypti* and *Anopheles stephens*, which mainly prey on larvae of the third instar. Larvivorous fishes can be chosen as they show least threat of resistance in mosquitoes, are cheap and easy to raise, eco-friendly to the environment and are used in small quantities [24].

6. Toxorhynchites mosquito species

Traditionally, larvae of the genus *Toxorhynchites* have been identified as clinically important predators of mosquito larvae and often exhibit cannibalism. They can eat up to 400 mosquito larvae as larvae, especially when enclosed in closed enclosures [25]. Toxorhynchids can enter the environment because they are autogenous and do not require a blood meal, making the mosquito species suitable for biological control, without increasing the potential for transmission of infection. Most of the species involved in biocontrol are: *Toxorhynchites splendens*, *Tx. moctezuma*, *Tx. brevipalpis*, *Tx. Amboinensis* and *Tx. noisy* If *Tx. Splendens* larvae were introduced into breeding areas of *Ae. aegypti*, *Ae. albopictus*, and *Culex quinquefasciatus*, these mosquito larvae were reported to be completely or almost destroyed within 3-4 days [26].

7. Arthropods

Arthropods, mainly mesocyclops and macrocyclops, are crustaceans used for the biological control of mosquitoes, feeding mainly on primarily on first instar larva. Several copepod species actively targeting mosquito early instars including *Cyclops vernalis*, *Megacyclops aspericornis*, *Mesocyclops formosanus*, *Mesocyclops guangxiensis*, *Mesocyclops edax* etc. Cyclopoids are self-reproducing, scavenging predators that can harm larger larvae than they actually consume, which is beneficial [27]. Since cyclopoid cephalopods had no known adverse effects on human well-being, it become an effective method of mosquito control.

8. Nematodes

The use of 14 genera and 5 species of nematodes for insect control has proven successful.

It has been established that the Mermitidae family is the most successful in reducing mosquito populations in their natural habitat [28]. However, eight other large nematode families are recognized in host or sterile contexts, including *Diplogasteridae*, *Allantonematidae*, *Heterorhabditidae*, *Rhabditidae*, *Neotylenchidae*, *Sphaerulariidae* and *Tetradonematidae*. Mermitids are the more resistant and preferred nematode species to control mosquito larvae because they affect the growth phase of the host, show host selectivity and have enormous reproductive capacity. Because they are free swimmers, they can easily spread to repel mosquitoes if they are infective. There are several newly discovered species of mermitids that control about 63 different types of mosquito larvae. The species attacks its host by penetrating through the spiracles, cuticle or anus, or after consuming the host insect.

9. Genetically modified mosquitoes and vector control

Since before the introduction of stably modifying mosquito strategies, biological control of arbovirus diseases using genetically modified mosquitoes has been introduced. This idea depends on the intention to replace the competent mosquito organism in the environment with modified mosquitoes. There are two main techniques, Sterile insect technique (SIT) and Release of insect carrying a dominant lethal gene (RIDL) have been developed as biological control mechanisms for genetically modified mosquitoes [29, 30].

Conclusion

Mosquito biological control is not only eco-friendly, but also a way to produce more lasting and effective control as compared to synthetic insecticides which cause greater harm to the environment as a whole. The insect predators must demonstrate positive preference for mosquitoes and act as an efficient biological mosquito control agent.

Eliminating aquatic larval phases is a preventative intervention as it helps to control adult mosquito population. So, biologically control predators should be acclimatize to the numerous water sources that are incredibly dispersed around human population. Predators can efficiently suppress the mosquito population once they are settled and auto-replicating to a level that no synthetic insecticides can do.

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