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Eco-Friendly Mosquito-Control Strategies: Advantages and Disadvantages

Alshaimaa M.R. Hamed, Mona S.El-Sherbini and Magda S.A. Abdeltawab
Medical parasitology Department, Faculty of Medicine, Cairo University
E-mail : amsolaiman@kasralainy.edu.eg

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ABSTRACT

Mosquitoes can spread a variety of infections that can cause serious health problems and even death, including malaria, filariasis, yellow fever, and a variety of other diseases. Mosquito control using insecticides is presently the most extensively utilized disease control strategy. Insecticide resistance has emerged, and pesticides have detrimental consequences for the environment, non-target species, and human health. To avoid these issues, bio-control strategies for mosquito vectors have been developed. Bio-control is a pest-reduction method that is both environmentally friendly and effective. This article provides an overview of the most effective biological mosquito control methods, including predators (larvivorous fish and toxorhynchites larva), entomopathogenic fungi, bacteria, viruses, nematodes, herbal mosquito control, the Sterile Insect Technique, and genetically modified mosquitos. In this paper, we will review the existing research on biocontrol agents for mosquito vectors and emphasize the relevance of biological control. Finally, we'll go over the benefits and drawbacks of biological control measures.

INTRODUCTION

Mosquitoes transmit diseases like malaria, dengue fever, Japanese encephalitis, filaria, West Nile fever, chikungunya, and yellow fever, which are responsible for millions of fatalities each year throughout the world. However, synthetic insecticides are extensively employed to control a variety of vector-borne diseases, but they come with a number of downsides, including harmful environmental impacts, non-targeted species, and the development of resistance in vectors due to changes in the target location (Kumar *et al.*,2020).

Bio-control of mosquito vectors has been proposed to circumvent these issues. By employing natural enemies, bio-control is a safe and effective method of reducing pests and pest damage (Timmins, 1988). Natural enemies of almost all pests exist, and natural enemy management can effectively control a wide range of pests (Sarwar, 2015). Bio-control should be the foundation of an approach known as integrated pest management, which entails using many pests control approaches simultaneously. Insect vectors, such as mosquitos, have a variety of predators, parasites, and pathogens that live in nature. Fish, viruses, nematodes, fungus, and bacteria are among them. They differ in terms of infection mode, replication site, and pathogenicity mechanisms (Porter *et al.*, 1993). Bio-control methods include killing the vector, modifying vector activities to enhance self-mortality, and developing vectors that are either infertile or incapable of transmitting disease (Benelli *et al.*, 2016). Furthermore, these various bio-control methods have an impact on different stages of vector development (Benelli *et al.*, 2016). This review will focus on the role of bio-control agents against mosquito vectors using various biological techniques in the following sections.

Since immature stages are confined in their aquatic habitat and have a relatively limited mobility range, controlling them is far easier than controlling adult stages. Adult mosquitoes are naturally protected by being 'r-strategists,' or having a high reproductive rate and a short life cycle, in addition to evading their predators by flying. Inoculation or inundation are the two main methods for applying biological antagonists. Small quantities of mosquito opponents are delivered into the intended environment during the inoculation procedure, allowing them to reproduce and establish themselves, ensuring that their effectiveness is maintained across generations. Predator fish are inoculated in newly irrigated rice fields. Inundation, on the other hand, is accomplished by overburdening the mosquito habitat with a huge number of biological antagonists, resulting in a dramatic fall in the mosquito population. Bacillus thuringiensis and Bacillus sphaericus are two examples of bacteria that can be used. However, since a biological agent rarely establishes itself during the inundation process, the long-term effect is rarely attained (Becker *et al.*, 2010).

Biological Control Agents (BCAs):

Biological control approaches have been found to have an important influence on mosquito population reduction. Vector control is a technique that has recently gained popularity. The role of biological agents in the management of mosquito vectors will be discussed in this review (Fig.1).

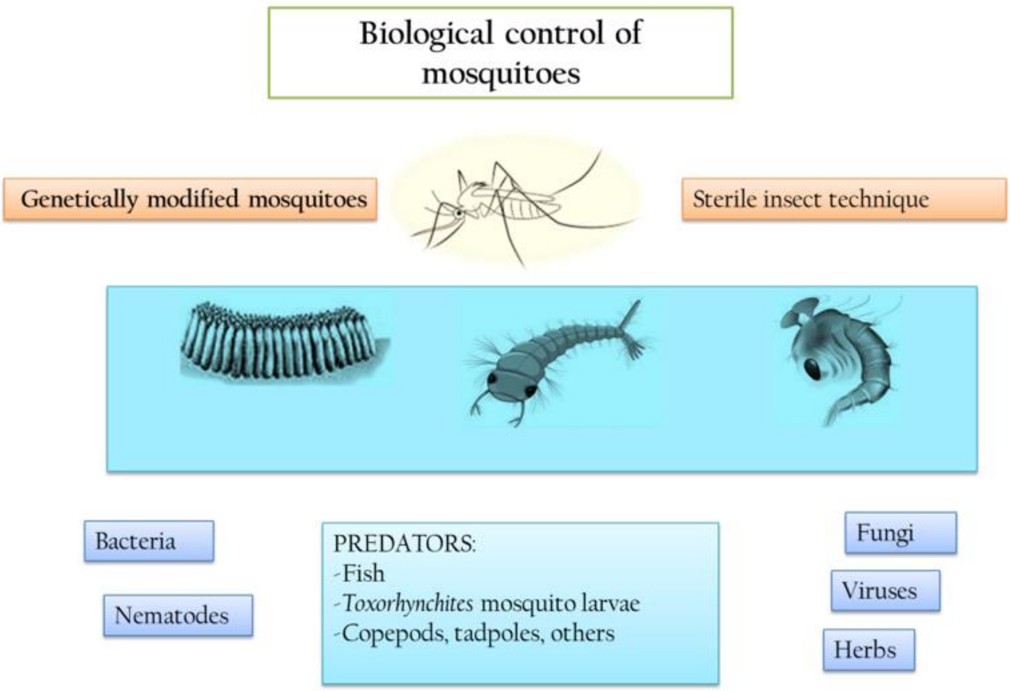

Fig.1. Diagram showing bio control techniques of mosquitoes

Predators:

1. Larvivorous Fish:

Fish have been used to reduce the larvae stage of the mosquito since about 1937. The release of native larvivorous fish into a lake or pond is one of the most cost-effective mosquito vector control strategies, resulting in a long-term reduction in mosquito vectors (Das *et al.*, 2018). This is because the introduction of an auto-reproducing predator into the environment may provide pest populations with long-term biological control. Biological control of mosquito larvae with larvivorous fish, on the other hand, is only practicable and effective when breeding places are limited or easily detected and treated (Chandra *et al.,* 2008). In addition, to achieve the optimum mosquito control aims, integrated biological control strategies should be used (Al-Akel and Suliman, 2011). Different classes of fish have been utilized, with local fish being found to be more effective in biological control (Chandra *et al.*, 2008). The mosquitofish (*Gambusia affinis*) is one of the most extensively used biological control agents (Sarwar, 2015). This fish was originally native to the southern United States and northern Mexico, and it is adapted to dwell in warm water. In an effort to eliminate mosquito larvae, it was later imported into over 60 nations, including the Pacific Islands, the Middle East, Europe, India, South Asia, and Africa (Mullen and Durden, 2009).

According to a previous study conducted in India, mosquito fish are the most effective predators of *Aedes aegypti* and *Anopheles stephensi* larvae. This predatory efficiency is mostly directed towards third instar larvae (Arijo *et al.*, 2017). A study of fish larvicidal efficacy revealed that all fish have larvicidal capability, however, their feeding efficiency varies. *Gambusia affinis* (exotic) was shown to be the most effective predator in this study, followed by *Esomus dandricus, Rasbora daniconius, Trichogaster fasciata, and Trichogaster lalia* in order of efficacy (Bano and Serajuddin, 2017). *Aphanius* is more effective than *Gambusia* at preying on mosquitoes in their third, fourth, and pupal stages, according to another study conducted in the lab. For the first two instars, however, the opposite was true (Homski *et al.,* 1994). Killifish (*Aphanius dipar*) can breed both naturally and artificially to keep a fish population healthy and protect local communities from diseases including malaria, dengue fever, and encephalitis (Al-Akel and Suliman, 2011).

The South American guppy is another popular fish (*Poecilia reticulata*). This is better suited to water bodies that are polluted by organic matter. It is also more heat resistant than *affinis* (Mullen and Durden, 2009). Carp (e.g., *Cyprinus carpio and Ctenopharyngodon idella*) and edible catfish are two more species that can be utilised to feed mosquito larvae (*Clarias fuscus*). Both can be used to control *Aedes aegypti* in water storage tanks (Mullen and Durden, 2009). Another study found that numerous additional edible fish have a lot of promise as mosquito larvivorous predators (Arijo *et al.*, 2017). Indeed, in the western Kenyan highlands, several larvivorous fishes, such as *Oreochromis niloticus* (previously *Tilapia nilotica*), are commonly farmed for food in addition to mosquito control (Howard *et al.,* 2007). Three species of larvivorous fish (*Gambusia holbrooki, Aphanius dispar, and Aphanius sp*) were recently discovered to be efficient mosquito control agents in southern Iran (Shahi *et al.*, 2020).

Fish, on the other hand, are not recommended for mosquito control in small water containers, pools, or puddles that dry out quickly. Still, some fish, such as *Nothobranchius* and *Cynolebias* species, often known as instant or annual fish, have drought-resistant eggs, which are better for introducing into small, transitory habitats that dry out frequently (Mullen and Durden, 2009).

Although utilizing larvivorous fish to eliminate mosquito larvae has been demonstrated to be more effective than using chemicals, mosquitofish may have detrimental impacts on other native fish and ruin local habitats. Such harmful fish should not be introduced into new locations, as they have harmed local species in the past (Mullen and Durden, 2009). As a result, environmentally friendly larvivorous fish that cause less harm to the environment and local fish fauna are frequently more ideal for mosquito larvae biological control.

2.The *Toxorhynchites* Mosquito Larvae:

Interestingly, the mosquito's adversary could be one of its own species. *Toxorhynchites* larvae prey on other mosquito larvae and are employed for mosquito control, according to Becker *et al.,* 2010. *Toxorhynchites* mosquito larvae prey on other mosquito species as well as aquatic organisms that live in both natural and artificial containers. *Toxorhynchites* species have been regarded as prospective biological control agents of vector species mosquitoes in a variety of scenarios since this environment is the basis of several medically significant mosquito species (Focks, 2007). (Collins and Blackwell, 2000).

They feed on the larvae stages of other mosquito species and frequently become cannibalistic. During their larval development, they can consume up to 400 larval mosquitoes, especially when introduced into small containers (Goettle and Adler, 2005).

Though there are still study gaps, the combination of carnivorous larvae and innocuous adults is highly appealing in biological control. *Toxorhynchites* species have been used successfully in biological control in Japan, Southeast Asia, the Caribbean, and the United States (Goettle and Adler, 2005).

Toxorhynchites splendens was identified as one of the most important *Toxorhynchites* species for mosquito control and has been employed as part of an integrated system in mosquito biological control. Their larvae have the potential to devour *Aedes aegypti* larvae in the amount of 20-25 larvae each day (Buxton *et al.*,2020).

The larvae of this species have been placed into the water containers or breeding sites of *Aedes aegypti*, *Aedes albopictus*, and *Culex quinquefasciatus* for mosquito control. Larvae were completely or nearly completely destroyed in such settings after 3-4 days (Pantuwatana *et al.,* 1979).

3.**Copepods** are another type of water inhabitant that can eat mosquitos like Macrocyclops albidus.

4.Tadpoles, frogs, and toads are among the other predators (Poopathi and Tyagi, 2006 and Becker *et al.,* 2010).

Bacteria:

Mosquitocidal bacteria are environmentally friendly alternatives to chemical insecticides for mosquito control, hence there have been extensive attempts around the world to find suitable mosquitocidal bacteria in the natural environment (Poopathi *et al.,* 2014). Bacillus thuringiensis (Bti) and Bacillus sphaericus (Bs) are two mosquitocidal bacteria that have been used as broad-spectrum biolarvicides under a variety of conditions with little or no ecological harm when ecological concerns such as safety for humans and other non-target organisms, pesticide residue reductions in aquatic ecology, improved activity of other natural enemies, and improved biodiversity in aquatic environments are taken into account. Both Bacillus species act as microbial insecticides rather than real biological agents that recycle and maintain themselves in the environment (Mullen and Durden, 2009).

Bacillus thuringiensis (Bt):

Bt (particularly subspecies israelensis) is a Gram-positive spore-forming bacterium that produces a diverse range of biocidal toxins. It is possible that they are delta-endotoxins (like Cry and Cyt proteins), which have a broad range of activity against insects, nematodes, and even human cancer cells. Vegetative insecticidal proteins are secreted proteins that are introduced into culture during the vegetative development phase and are hence referred to as Bt toxins (Vips). There are also Sip poisons (secreted insecticidal proteins), as well as a variety of other known and unknown harmful substances (Palma *et al.,* 2014). Bacillus sphaericus produces comparable crystalline toxins, and

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the two bacteria are frequently utilised together (Poopathi and Tyagi, 2006).

The preparation of Bacillus thuringiensis (Bti) is the most widely used microbial pesticide in the world (Ramrez-Lepe and Ramrez-Suero, 2012). It is a highly effective pathogen because it is easily mass-produced, toxicologically safe for humans and wildlife (the high-perceived safety and effectiveness of Bti were noted even at the very beginning of its use in the intervention (Ingabire *et al.,* 2017), and more or less specific in killing mosquito larvae or larvae of out-of-control species (Poopathi, 2012). After ingesting Bti, an endotoxin that causes stomach poison is released from crystal proteins in the bacterial spores, resulting in death. There have been numerous studies on the efficiency of Bti therapy in terms of mosquito abundance, but none have been conclusive.

It's usually made as a slow-release substance that floats on the water's surface and lasts up to a month. Bti can also be sprinkled on larval habitats as a powder that is mixed with water. It's worth noting that the bacteria don't not reproduce, thus spraying has to be done repeatedly in this form (as with chemical larvicides). Streptomyces avermitilis generates avermectins, which are highly effective in suppressing invertebrates from the Insecta, Arachinida, and Nematode classes (Pirali-Kheirabadi, 2012).

Bacillus sphaericus, like Bti, can be produced in the same way and kills mosquito larvae in the same way, but it differs in some circumstances because it can be regenerated in larval environments. Furthermore, when utilised in biologically polluted water, this species is more effective, and it is especially efficient against *Culex* species (Mullen and Durden, 2009).

Pseudomonas frederiksbergensis:

Pseudomonas frederiksbergensis is a Gram-negative rod-shaped bacterium that was first isolated from Frederiksberg, Denmark, and is used as a plant pest biological control agent. It has the significant benefit of being ecologically friendly. This bacterium was also isolated from Saudi soil in Riyadh, and its extract was tested against Culex pipiens third instar larvae, the most common vector of lymphatic filariasis in Saudi Arabia. It was discovered to have a powerful larvicidal effect, which was mediated via the destruction of the midgut epithelium and the integument shrinkage. It had been evaluated for biocidal efficacy against *Anopheline* and Aedine, with promising findings (Ahmed *et al.*, 2014).

Wolbachia:

Hertig and Wolbach detected Wolbachia in the ovaries of Culex pipiens for the first time in 1925. In addition to filarial nematodes, it is an alphaproteobacterium present in 66 percent of insects. It has a number of effects on insects, including parthenogenesis, male sterilisation, and male-killing. In mosquitoes, however, only cytoplasmic incompatibility has been documented. The offspring of an uninfected female and an infected male are rendered non-viable due to cytoplasmic incompatibility (De Almeida *et al.,* 2011).

Wolbachia was only used in vector control in *Culicine* because this bacterium cannot be propagated in *Anopheline*. Hughes *et al.* (2014) researched into this host selection and discovered that a mosquito-specific bacterium called Asaia infects germlines and competes with Wolbachia, preventing it from developing inside the vector. Nilsson *et al.* (2015), on the other hand, discovered some Wolbachia-infected Anopheles species in the wild. They also noticed a reduction in malaria transmission in mosquitos that had been infected experimentally. Not only does it reduce malaria transmission, but it also reduces mosquito infectivity for various arboviruses, including Dengue virus, Chikungunya, Yellow Fever, West Nile (Slatko *et al.* 2014), and Zika virus (Slatko *et al.,* 2014). (Dutra *et al.,* 2016).

Paratransgenesis

The study of the symbiotic mosquito population benefits not only from the influence of these organisms on the mosquito but also from the prospect of using these inhabitants of the vector body to produce certain effector proteins that limit disease transmission. It is termed paratransgenesis because it does not make the mosquito itself transgenic, but rather the parasite that lives inside it. *Pantoea agglomerans*, a midgut resident that has been genetically modified to produce two anti-malarial effector proteins in *Anopheles gambiae*, is one of the symbiotic bacteria employed in this procedure.

Pantoea agglomerans is an excellent option for delivering the genes encoding these effector proteins because they proliferate in enormous numbers after a blood meal and, more crucially, they share the same midgut region as the malaria parasite after the host consumes the infected meal. The expression of these anti-malarial peptides in mosquitos results in a 98 % reduction in Plasmodium development and an 84 % reduction in the number of mosquitos carrying the parasites, making *P. agglomerans* a promising vector-borne disease management strategy (Wang *et al.*, 2012).

The Gram-negative bacterium *Asaia* is another symbiont employed in paratransgenesis. It's also been used to deliver antimalarial peptides, with results showing a substantial reduction in parasite development (80%). In comparison to *P. agglomerans*, *Asaia* reproduces faster and lasts longer inside a mosquito population. It is found not only in the midgut but also in the salivary glands and reproductive organs, all of which are important in disease transmission (Bonjio and Lampe, 2015).

Viruses:

Mosquitoes are infected by a variety of viral diseases. *Baculoviruses (Baculoviridae: Nucleopolyhedrovirus), densoviruses (Parvoviridae: Brevidensovirus),* cytoplasmic polyhedrosis viruses (Reoviridae: Cyprovirus), and iridoviruses (*lridoviridae: Chloriridovirus*) are the four primary types (Huang *et al.*, 2017; Becnel and White, 2007; Federici, 1995). There are tens of thousands of entomopathogenic viruses that are active against insect pests, but only a few are commercially available.

Viruses either do not play a significant role in parasite population reduction, or our understanding of their genuine effects is too limited (PiraliKheirabadi, 2012). Occluded (*baculovirus and cyproviruses*) and non-occluded (*densovirus and iridoviruses*) viruses are the two main types of harmful viruses found in mosquitos. DNA viruses include *baculoviruses, densoviruses, and iridoviruses,* while RNA viruses include cyproviruses (Becnel, 2006). Because of the inability to transmit mosquito pathogenic viruses to their larval mosquito hosts, research on them has been limited. However, recent advances in the ability to transmit mosquito baculoviruses and cypoviruses have been significant, with the discovery that transmission is mediated by divalent cations (Becnel, 2006). The presence of magnesium ions increases baculovirus and cyprovirus oral transmissions to mosquito larvae, while calcium ions prevent them.

Nematodes:

Insect parasitic nematodes are classified as either obligatory or facultative parasitic nematodes (PiraliKheirabadi, 2012). Although the Phylum Nematoda contains five orders and 14 families of obligatory parasites, only the *Mermithidae* has been detected in wild mosquito populations (Platzer, 1981). Because of their potential as biocontrol agents, some of these nematodes are of particular interest. In addition to *Mermithidae,* eight other important nematode families are *Allantonematidae, Diplogasteridae, Neotylenchidae, Rhabditidae, Heterorhabditidae, Sphaerulariidae, Steinernematidae, Steinernematidae, and Tetradonematidae,* which attack, sterilise, and kill insects or change host growth

(Petersen, 1985). *Mermithids* are a larger and more commonly employed nematode species for controlling mosquito larvae. They are obligate parasitic arthropods, mostly insects, but also spiders, crabs, earthworms, leeches, and mollusks. They are usually restricted to a single species or one or two insect groups, and they are often lethal to their hosts.

Mermithids are particularly appealing since they pose little or no environmental risk, and because of their lifespan, they pose little threat of competitive displacement of other beneficial creatures. Several species of *mermithids* have been discovered as mosquito larvae controllers (Petersen, 1985). *Mermithid* nematodes have been found in at least 63 different mosquito species around the world, but they have gotten little attention until lately. Because they affect specific growth stages of the host, are host specific, produce high levels of parasitism, kill the hosts, are easily handled, have a high reproductive potential, are free-swimming, and can be distributed easily in the infective stage to control mosquitoes, such nematodes are major candidates as biologic control agents. However, only one *mermithid* species has been mass cultured to date (Petersen, 1973). The species infects its host through cuticle infiltration, invasion via spiracles or anus, or ingestion by the host insect (Pirali-Kheirabadi, 2012).

Entomopathogenic Fungi:

Fungal diseases that affect arthropods are common in tropical forests, and they play an important role in maintaining the natural balance of arthropod populations. To enhance infection, they can produce a variety of specialised spore forms as well as peculiar behaviours in their hosts (Evans *et al.*, 2018).

Insect fungi are numerous and widespread, and they can lead to many problems in the mosquito vectors population. Dipterans, like nearly other insect orders, are susceptible to fungal infections. *Coelomomyces, Lagenidium, and Culicinomyces* are common fungi that affect mosquito vectors and have been extensively investigated. Many other fungus species, on the other hand, infect and kill mosquitos in their larval or adult stages (Scholte *et al.*, 2004).

Several fungal diseases have been discovered attacking and manipulating *Aedes aegypti* in African woodlands, and these could be used as a long-term, cost-effective, and environmentally safe solution to the *flavivirus* pandemics in the Americas (Evans *et al.*, 2018). The feeding efficacy of the entomopathogenic fungus *Metarhizium anisopliae* against mosquito species has been proven in laboratory work. In addition, the virulence of Metarhizium anisopliae was investigated against Culex pipiens fourth instar larvae using five different fungal concentrations. The mortality of mosquito larvae treated with various fungal concentrations ranged from 4% to 96 %, according to the findings. As a result, the mortality rate of larvae increased as conidia concentration increased, according to this research. Furthermore, these studies indicate that *Metarhizium anisopliae* has the potential to be a biocontrol agent for *Culex pipiens*, making it a suitable candidate for further research and development (Benserradj and Mihoubi, 2014).

Although many isolates have not been investigated for virulence against mosquitoes, entomopathogenic fungus *(Beauveria bassiana*) may minimise disease transmission by reducing mosquito vector endurance. There were 93 isolates of entomopathogenic fungi from six species (B. *bassiana, M. anisopliae, Isaria fumosorosea, Isaria farinosa, Isaria flavovirescens, and Lecanicillium spp.*) that could be used as biological control agents for *Aedes aegypti* (Darbro *et al.,* 2011). Several entomopathogenic fungus species are found in the phylum *chytridiomycota*, but two genera (*Coelomomyces and Coelomycidium*) are known to harm the larvae of hematophagous Diptera and have been explored for biological control of mosquitoes and black flies (Tanada and Kaya, 1993). *Conidiobolus, Entomophthora, Erynia, and Neozygites* are the most investigated entomophthoraleans fungi in terms of pest control. Furthermore, the *Basidiomycota* has a limited number of entomopathogens (McCoy *et al.*, 1988).

Microsporidia are one of the biggest and most diversified genera of parasitic fungi associated with mosquito species in the natural world. Indeed, all mosquitoes are likely to be hosts for one or more *microsporidia* parasites. They are parasitic eukaryotes that have developed a unique and highly specialized mechanism for invading host cells by infectious spores (Andreadis, 2007).

Herbal Control of Mosquitoes:

Plant extracts, phytochemicals, and their nanoformulations can be used as environmentally friendly ovipositional attractants, insect growth regulators, larvicides, and repellents. These plant-derived compounds are comparably cheaper, environmentally friendlier, biodegradable, freely available, and non-toxic to non-targeted organisms, as well as having broad-spectrum resistance against numerous mosquito species. There are also various ways for the production of silver nanoparticles (AgNPs), including physical, chemical, and biological methods, as well as their mechanism of synthesis utilizing plant extract, their high larvicidal action, and the possible mechanism by which these particles kill mosquito larvae. In the long term, different research investigations can be used to produce herbal larvicidal formulations and nano insecticides against insecticide-resistant vector species (Kumar *et al.*,2020).

Currently, over 80 plant species have been used to successfully synthesise nanomosquitocides, with a focus on larvicidal applications. Studies on ovicidal and ovideterrent nanoformulations, on the other hand, are scarce (Madhiyazhagan *et al.,* 2015). Botanicals can also be used as reducing and capping agents in the quick synthesis of mosquitocidal nanoformulations (Benelli *et al.*, 2016), as well as to make low-cost repellents with low human toxicity (Semmler *et al.,* 2009).

The Sterile Insect Technique:

The Sterile Insect Technique (SIT) is a genetic suppression approach that involves growing huge numbers of target species' males and either irradiating or treating them with chemosterilizing chemicals to create chromosomal abnormalities and dominant lethal mutations in sperm. When sterilised male mosquitoes are freed, they generate no progeny when they mate with wild females. As the population declines, a sustained insect programme results in an increase in the ratio of released sterile males to wild males, eventually leading to population loss (Vreysen *et al.*, 2014). Due to the low performance of sterilized males produced by sterilization, the use of SIT for mosquitoes that transmit human disease has been restricted. (Devine *et al.,* 2009) Experiments combining SIT with other modes of delivering insect lethality (Lees *et al.*, 2014) have sparked renewed interest in SIT for the control of mosquito vectors, in addition to the *Wolbachia*-in-combination-with-female-sterility strategy.

Genetically Modified Mosquitoes:

A self-limiting gene has been introduced into mosquito populations by genetic engineering as an alternate technique to sterilize males for insect population suppression (Thomas *et al.,* 2000). The British biotech company Oxitec (www.oxitec.com) coined the term "Release of Insects a Dominant Lethal Gene" (RIDL). The lethal gene can be repressed using an antidote (tetracycline) so that mosquitoes can be reared to adulthood in rearing facilities before being released into wild populations as males, who then mate with wild females and produce offspring that die at the larval stage if tetracycline is not present.

Since the goal is to destroy the population in the release region, this technique has the advantage of being species-specific (SIT). It also has no long-term consequences on the target species. Harris *et al.* (2012) found that a self-limiting strain of *Aedes aegypti* OX513A suppressed a wild population of *Aedes aegypti* in field trials in the Cayman Islands in 2009–2010. OX513A males were found to have similar longevity and dispersal ability in Malaysia (Lacroix *et al.*, 2009), while the most recent release of OX513A males in Brazil resulted in severe suppression of the target wild population (Carvalho *et al.*, 2015).

Advantages and Disadvantages of Biocontrol (Fig.2):

Advantages:

When compared to chemical insecticides, bio-control offers a number of advantages as a pest management strategy. Bio-control is an environmentally safe strategy that does not introduce toxins into the environment, which is one of the most significant advantages (Kok and Kok, 1999). Selectivity of target species is another significant advantage, where non-target species are less likely to be harmed.

Since significant harm to non-target species might result in natural enemy population constraints, selectivity is the most critical aspect in the balance of agricultural ecosystems (Kok and Kok, 1999). Another favour of the bio-control of mosquitoes is their ability to expand in number and spread since BCAs are self-propagating and dispersing This is critical in terms of the economic sustainability of bio-control (Reichelderfer, 1981). Another benefit of biological management is that the pest is unlikely (or takes a long time) to develop resistance (Tebit, 2017). A target pest, on the other hand, is prone to developing defense systems in response to a natural enemy attack. For example, efficient pest control by a natural enemy could lead to a strong selection of the pest to evolve escape methods or tolerance to control agent attacks, causing the bio-control system to fail (Holt and Hochberg, 1997) (Fig.2).

Bio-control is also been cost-effective since self-propagation will reduce the target pest to a tolerable level for an extended length of time (Kok and Kok, 1999). Furthermore, a small number of biocontrol agents can grow to very high densities and provide continuous pest control over a vast area with a little number of bio-control agents. Bio-control is often less expensive than chemical control when considering the cost of deployment of BCAs.

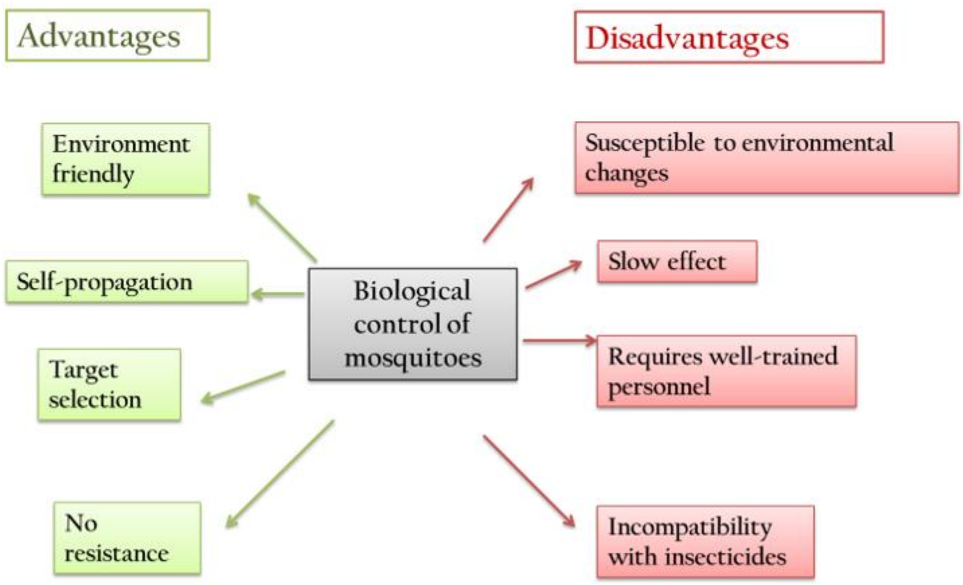

Fig.2. Diagram showing advantages and disadvantages of bio control techniques of mosquitoes.

Disadvantages:

Bio-control is harder to set up and sustain than insecticidal control. The risk of income stability is the most significant disadvantage of this strategy. BCAs are also more vulnerable to environmental factors than chemical controls. Furthermore, bio-control might be unpredictable due to the fact that natural enemies are often influenced by environmental factors (Emden, 2004).

In a study by Buxton *et al.* (2020), the effect of temperature on a predator-prey model of mosquito control was investigated. Mosquito larvae were found to have a greater thermal tolerance than their notonectid and copepod predators, suggesting and warning of a threat of predator-prey mismatch under the effects of global warming and climate change.

The incompatibility with traditional insecticides is another important issue, since the employment of insecticides in a certain environmental niche alters the biological composition of that niche, thus disturbing the fine balance between BCA and their targets (Emden, 2004).

Bio-control also takes a long time to work. It takes a few days, if not weeks, for mosquito populations to be significantly reduced (Mullen and Durden, 2009).

To achieve the desired results while deploying BCAs in a new context, a lot of research is required. Furthermore, the elimination of pests is not one of bio-control's goals. As Tebit (2017) points out, the goal is to keep the pest population below the Economic Injury Level in most cases (EIL). Selectivity, which was previously listed as a benefit, might, however, also be a disadvantage. Unaffected pests could cause damage because BCA is a specialized enemy to a single species (Reichelderfer, 1981). Furthermore, the application of bio-control necessitates highly skilled scientific personnel, which makes it difficult and sometimes expensive to develop in the field (Tebit, 2017). Variability in manufacturing batches is also a big issue. This occurs because the employment of proper rearing practises and the creation of high-quality BCAs raise the cost of natural enemy generation. As a result, many quantity companies do not use mass rearing measures, making the creation of high-quality natural enemies difficult (Lenteren, 2003) (Fig.2).

As previously stated, bio-control is an environmentally friendly strategy. Importing and releasing exotic natural enemies, on the other hand, carries some hazards. Biological treatment is best suited for exotic pests that are not closely related to native beneficial species, as Kok and Kok (1999) pointed out. Introduced predators that consume only mosquito larvae and pupae, on the other hand, are unlikely to ingest harmless or even helpful insects.

Conclusions and Recommendations:

In general, numerous approaches have been used in the control of mosquito-borne infections. These methods either prevent the parasite from developing within the mosquito body or suppress the mosquito vector itself. However, reliance on chemical vector control methods, a lack of resources and infrastructure, and poor management plans all contribute to a reduction in the effectiveness of the control of vector-botne diseases. Furthermore, chemical insecticide-based mosquito control fails due to environmental differences and variations in the behavioural characteristics of many mosquito species, such as insecticide resistance among mosquito strains and pest resurgence.

Bio-control has several advantages as a pest management method, especially when compared to conventional insecticides, despite the fact that it is more difficult to implement and maintain. It is an environmentally safe strategy that does not introduce toxins into the environment, which is one of the most significant advantages.

The use of bio-control agents that are easily adaptable, continuously reproducing and feeding continuously regardless of local environmental conditions can greatly enhance the efficacy of bio-control.

It is also of crucial importance that the professional personnel chooses and apply biological agents that have been modified to work with conventional insecticides, to avoid incompatibility and antagonism between the different methods of insect control. The benefit of bio-control can also be augmented by rearing in huge quantities and bulk-releasing effective bio-control agents. It is of utmost importance to avoid the extinction of other beneficial organisms and maintain the eco-balance in the targeted environmental niches that can be threatened by the introduction of exotic species, which can be achieved by using indigenous species as bio-control agents.

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