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Biological control of the mosquito: An analysis of the impediments and possibilities

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Abstract

Biological control of mosquito is an eco-friendly approach for the control of some vector borne diseases. Numerous tools have been developed and applied to scale down the mosquito population, but the ultimate goal of these different strategies is only to mitigate the menace of mosquito and effectively prevent malaria like diseases. Unfortunately, most of these vectors control measurement the time limited prevention of diseases. For example, they were used as an insecticide, but insecticide resistant mosquito vectors are developed in course of time. Major efforts may be focused on generating eco-friendly alternatives. In current scenario there are many potential alternatives for eradicating and controlling the mosquito vectors biologically. Effective use of aquatic insect predators, larvivorous fishes, symbiotic bacteria, microbial agent and entopathogenic fungi for this purpose are still rather unexplored calling for further research. Biological control of mosquito vectors has been validated for several advantages over insecticides. To resolve the problem of current dependence on insecticidal-based mosquito elimination the option of biological control of this vector is ecofriendly and sustainable. The current knowledge of bio-controlling agents highlighting its significance in the field of public health with respective have been reviewed in this article along with the prospective challenges and opportunities.

Keywords: Vector borne disease, epidemic, insecticide, larvivorous, entopathogenic, biological control

Introduction

Globally most of the human population residing in climates of tropical and subtropical area is still suffering from malaria, filariasis, dengue, chikungunya, zika and many more. Now a day's vulnerability of geographically mosquito expansion is the notable point of concern. Mainly chemical and non-chemical techniques are applied to reduce the burden of the most mosquito vector borne diseases. The world health assembly granted approval to the GVCR (Global vector control response) from 2017 to 2030 in 2017. GVCR suggests a strategic direction and fundamental approach to nations and collaborators for disease prevention and outbreak management. For accomplishing of this project reshaping of vector control programme is requisite, enriched with advance technical capacity, optimize infrastructure, frequent monitoring and surveillance systems.

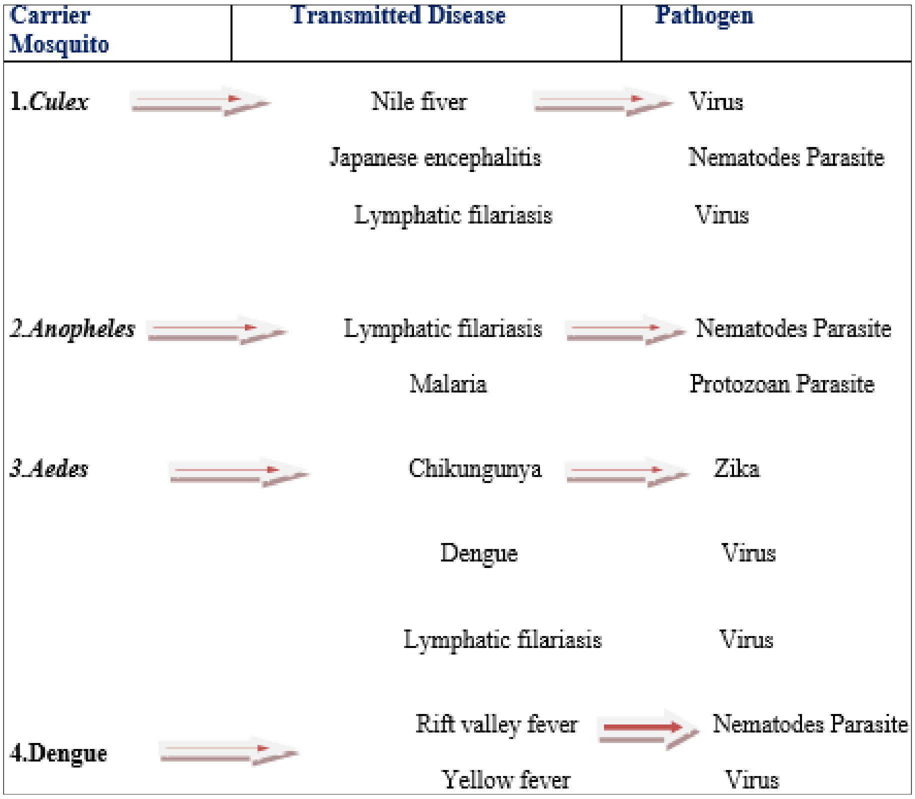
Chemical control procedures have certified hazardous to humans and ecosystems as well extremely uses of synthetic insecticides, mosquito populations have not been reduced up to the pre-planned level and still retain their potential to cause outbreak time to time [1]. In current scenario on the applications of deadly harmful insecticides as well as resistance to chemicals, biological control is an eminent preference for mosquito control. Eco-friendly methods of mosquito control are requisite to manage these disease controls as well as the threat of arboviral and malarial outbreaks [2, 3]. The only way to face disease control spread by mosquitoes is to utilize mosquito control technique properly. In the 1970s, the invasive use of chemical insecticides and their undesirable effects highlights interest in biological control employing entomophagous organisms that live in vector breeding areas [4].

Due to so many challenges like lack of expertise, insecticide resistance, climatic variations and selection of efficient natural predators against mosquito vector has become increasingly critical for biological control programmes success [5]. The basic purpose of vector control is to restrict disease transmission potential by minimizing or eliminating human contact with the vector.

The extreme uses of insecticides on mosquito vectors developed insecticide resistance in endemic areas and they become susceptible against these insecticides. Thus, there is an urgent need to use appropriate biological agents to control mosquito vector borne diseases on eco-friendly basis and also focus on their challenges and opportunities. The various bio-control strategies target different stages of the mosquito lifecycle with the aim of being safe for the environment and sustainable.

Mosquito vector borne diseases

The climatic conditions appropriateness for disease spread is directly related to rise in global mean temperature, especially in endemic areas. Unexpected spread to higher elevations and temperate zones, outbreaks may cause greater public health crisis and public health networks are unaware. In such area people are immunologically susceptible and health system are rather unequipped.



Carrier Mosquito	Transmitted Disease	Pathogen
1.*Culex*	Nile fiver	Virus
	Japanese encephalitis	Nematodes Parasite
	Lymphatic filariasis	Virus
2.*Anopheles*	Lymphatic filariasis	Nematodes Parasite
	Malaria	Protozoan Parasite
3.*Aedes*	Chikungunya	Zika
	Dengue	Virus
	Lymphatic filariasis	Virus
4.Dengue	Rift valley fever	Nematodes Parasite
	Yellow fever	Virus

Chikungunya

Alphavirus (Family-Togaviridae) is the causative agent of chikungunya and transmitted by the bite of *A. aegypti* and *A. albopictus*. This disease was firstly reported in Tanzania in 1952 and has since transmitted to other parts of Asia and Africa. Since 2004, chikungunya has rapidly spread throughout Asia, Africa, Europe, and the Americas, with over 60 nations reporting cases. Like as prior years, the area's most impacted by chikungunya were Asia and the Americas.

In 2022 and as of 31 October 2022, 108 957 cases of chikungunya virus disease, including 5320 confirmed cases and no deaths, have been reported [6].

More than 90% of the region's in Brazil reported cases, which totaled 185 000 cases all across Americas and the Caribbean. Additionally, chikungunya outbreaks have occurred in Sudan (2018), Yemen (2019), and, Cambodia (2020) [7].

Dengue

Dengue is becoming most crucial arboviral disease due to the widespread use of piped water it has markedly expanded its geographic distribution over the past 60 years and is the extremely fast viral illness carried by mosquitoes in worldwide. Dengue transmitted into various countries through peoples returning from dengue-endemic countries. Principal vector of the dengue disease is *Aedes aegypti* that is mostly found in urban areas. From the last 15 years *Aedes albopictus* (Asian tiger mosquito) has been raising the possibility of dengue transmission. The illness, which is widespread in more than 120 nations, is prioritized in terms of global health. Geographical areas of where dengue is common are Americas, South-East Asia, and Western Pacific [8].

Lymphatic filariasis

Lymphatic filariasis, is caused by microscopic thread like worm (nematode of the family Filariodidea) and recognized neglected tropical disease. This disease is transmitted by culex mosquitoes. People infected with this disease also facing challenges with lymphedema and elephantiasis and Lymphatic filariasis These individuals are not only face physical disablity, but also contended with intricate intersection of mental, social and financial losses perpetuating to stigma and poverty. Eradication of lymphatic filariasis can eliminate irrelevant suffering and and enhanced societal wellbeing (WHO, March 16, 2022).

Rift Valley fever

Rift Valley fever (RVF) majorly affects animals but in some cases humans also infected by this viral zoonosis. RVF infection range is from mild fever, weakness, back pain, and dizziness to severe symptoms, including eye disease, hemorrhage (excessive bleeding), and encephalitis (swelling of the brain). This disease also results in notable economic losses attributable to livestock fatalities and abortions from RVF infection. RVF virus is classified into taxonomic genus phlebovirus. The virus traces back in 1931 and subsequent outbreak of this virus have been documented in sub-Saharan Africa (WHO, February 19, 2018).

Yellow fever

Aedes aegypti is the causative agent of Yellow fever that is a viral haemorrhagic disease. From endemic up to the tropical areas of Africa and South America Yellow fever gives approximately 200000 instances of sickness and 30000 fatalities/year. Due to diminish population immunity (high disease susceptibility) it is more prone to infection, in last decades yellow fever cases increases (WHO, 2014).

Zika

Zika virus firstly identified in Uganda (1947) in a Rhesus macaque monkey as well as in people from African countries (1950). From the period 1960s to 1980s, infections were detected in Asia as well as Africa. 2007 outbreaks of Zika virus is well known in Africa, the Americas, Asia and the Pacific coast but somehow from 2017 onwards it was declined. In 2021 India recorded Zika virus outbreak. Global surveillance for zika virus remains limited but up to date 89 countries and territories have documented of zika infection (WHO, 2022).

Malaria

Malaria is life threatening disease transmitted by female Anopheles spp. That is infected with Plasmodium protozoan. Plasmodium falciparum and Plasmodium vivax are the most life threatening species, accounting for about 97% of all global cases (230 million). Malaria has a significant impact on 93 percent of people in Sub-Saharan Africa, and disease is closely related to unawareness, poverty, population intensity (WHO, 2019). The worldwide malaria case incidence occurs 59 cases per 1000 population in 2020 survey globally malaria cases was 59/1000 population (WHO, 2021).

Japanese encephalitis

Japanese encephalitis virus (*flavivirus*) is the causative agent of viral encephalitis in the no of Asian countries resulting in 68000 clinical cases annually. Within the WHO south East Asia and Western Pacific regions 24 countries have endemic JEV transmission. Although individual of any age can be affected but mostly children are affected. Unfortunately, there is no 100% cure but Treatment is focused on alleviating severe clinical symptoms and help the patient to recover (WHO, May 9, 2019).

Nile fever

Nile fever is spread out by West Nile Virus (WNV) that belongs to *flavivirus genus.* West Nile Virus (WNV) has the potential to induce neurological ailments and fatalities in humans. It were first reported in west Nile district of Uganda back to 1937. Its avian (crows and columbiformes) presence also known in Nile delta region in 1953. Human infections attributable to WNV have been reported in many countries in the World for over 50 years. WNV perpetuates its existence through an intricate cycle, involving transmission between avian populations and mosquitoes (WHO October 3, 2017).

Meeting challenges in the control of mosquito-borne diseases

Insecticide resistance

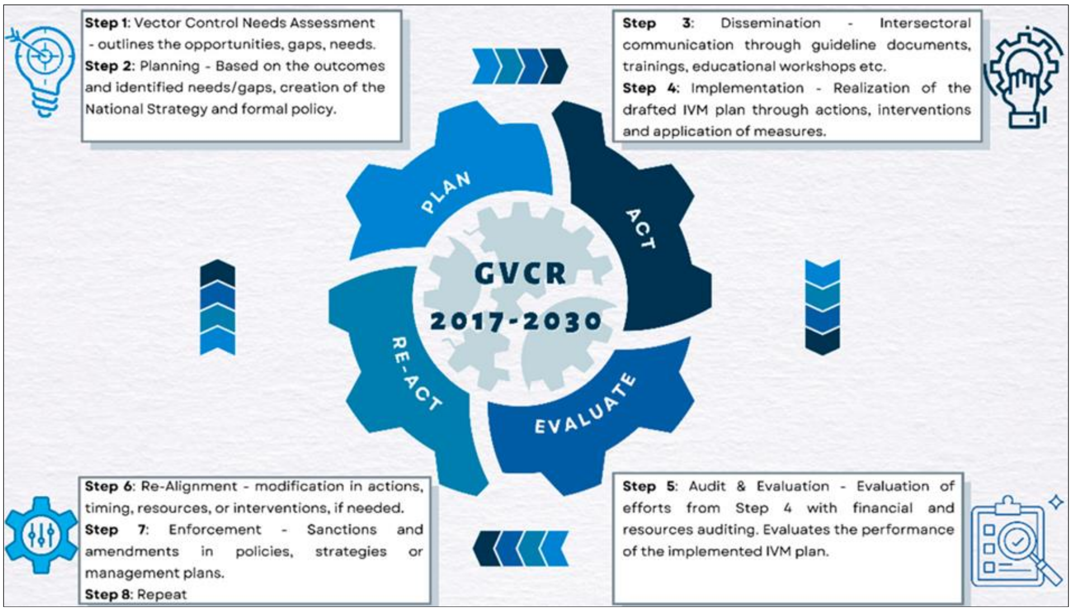
Over time, mosquito-borne epidemics removal and prevention have become increasingly challenging due to problems linked with enormously use of synthetic insecticides. Therefore, it is utmost required that considerably safer and efficient mosquito control methods should be created [9]. Resistance development is as consequences of indoor residual spraying of DDT, the emergence of resistance began in the year1957, concurrently with the commencement of the malaria eradication programme. Specific alterations to the proteins that typically bind to the insecticide can lead to insecticide resistance. For instance, mutations in acetyl cholinesterase (Ache), the direct target of organophosphates, carbamates, and sodium channels (the target of DDT and pyrethroids), have been widely reported in various insect species **[10].** Later research between 1950 and 1987 demonstrated that the increased activity of the glutathione-S-transferase (GST) enzyme was the main reason behind this resistance to DDT [11, 12]. Different classes of insecticides - organochlorines, organophosphates (OP), carbamates, pyrethroids, pyrroles, and phenyl pyrazoles are used against mosquitoes (WHO, 2013). But as a result of excessive use of chemical insecticides mosquitoes have developed resistance. Researchers found that over expression and amplification of genes, as well as alterations in protein-coding gene areas are another facts for resistance in mosquitoes. Chemicals used to control mosquitoes have adverse effect on health, increased sound pollution, and negative effects on non-targeted living beings. As a result, the greatest choice for controlling vector borne diseases; biological agents are greater option to alternatives of chemical insecticide.

Disease specific vector control program

A recent investigation further suggests that mosquito species will persist in their global expansion over the forthcoming decades, which may cause half of the world's population in jeopardy of mosquito-borne viral disease transmission by 2050 [13]. In order to combat both vector and vector-borne diseases (VBDs), the (WHO) World Health Organization has proposed a strategic plan called the Global Vector Control Response 2017–2030 (GVCR). According to this organization's estimates, nearly 80% of the world's population is encountered by contracting usually once VBD (vector borne diseases) in their lifetime, and more than 700,000 people die from VBDs every year. According to GVCR's goals, mortality from VBDs must be decreased by at least 75% by 2030 compared to 2016 (World Health Organization, 2017).

Related challenges in containing the menance of vector borne diseases (VBD)

Outlook of the consequences of current or future vector borne diseases on public health are made more difficult by the mutable and intricate character of mosquito-borne infections. The vital requirement for long lasting actions to stop and minimize pathogen transmission in order to enlighten disease burden is necessary to diminish endemic burden (World Health Organization, 2017)


Step 1: Vector Control Needs Assessment - outlines the opportunities, gaps, needs.
Step 2: Planning - Based on the outcomes and identified needs/gaps, creation of the National Strategy and formal policy.

Step 3: Dissemination - Intersectoral communication through guideline documents, trainings, educational workshops etc.
Step 4: Implementation - Realization of the drafted IVM plan through actions, interventions and application of measures.

Step 5: Audit & Evaluation - Evaluation of efforts from Step 4 with financial and resources auditing. Evaluates the performance of the implemented IVM plan.

Step 6: Re-Alignment - modification in actions, timing, resources, or interventions, if needed.
Step 7: Enforcement - Sanctions and amendments in policies, strategies or management plans.
Step 8: Repeat

Circular Policy: (2017-2030) [14].

Fig 1: Illustration of the Circular Policy method.

Variation in their Ecology, changes in the behavior and Avoidance behavior of vector

The term "behavioral resistance" refers to alteration in mosquito activity that makes it easier for them to evade or avoid being affected by insecticides. Both processes enable insects to either avoid or shorten interaction with the hazardous compound. Comparing behavioural resistance to biochemical insensitivity and resistance by changing the appropriateness accuracy of insecticides, it is more challenging to monitor field populations and use relatively simple exposure assays, which contributes to the scarcity of data on behavioural resistance [15].

Changing environment on the habitat of vectors and rapid urbanization

The effects of modifying the environment, human habitation, and/or human behaviour have been thoroughly studied and put into practice. These findings have had a significant impact on the epidemiology of diseases spread by certain vectors in general and mosquitoes in particular. However, because of either changes in the biology of the diseases' vectors over time or the inability of these treatments to keep up with current trends in Integrated Mosquito Management (IMM) procedures, mosquito-borne diseases still wreak havoc on people [16].

Ongoing issues facing humanity include biodiversity loss and climate change. Health implications of climate and biodiversity change range widely, from direct effects like warmer temperatures, floods, or heat waves to indirect effects like alterations in ecosystem services, food yield, or species relocation [17]. In other words survival rates of vectors and their disease transmission potentiality are influenced by changing climatic circumstances such as rainfall patterns, temperature, and humidity. Vector's reproductive rate, their biting behavior and survivorship all are affected by the temperature Suitable environmental conditions are the main reason for the breeding of mosquitoes.

Lack of expertise in vector

Entomologists' knowledge is crucial for vector management, but if we analyze current scenario there is a severe scarcity of entomologists around the globe. Only a few African countries have medical entomology departments, undergraduate university degree programmes and some countries just have a few experts in entomology. So it's a major challenge to control vector borne diseases without expertise knowledge.

Sanitation and access to safe drinking water

In water scarcity areas like desert areas, peoples have tendency to store the water for drinking and household activities. So that many vectors thrive because of unsanitary conditions and a lack of hygienic drinking water. Households should have piped water, according to the WHO rather than using wells, water storage tanks, rooftop catchments, and other means systems. However, it is decisive to be certain that water supplies are adequate and consistent so that people aren't forced to store water in mosquito larval spawning containers.

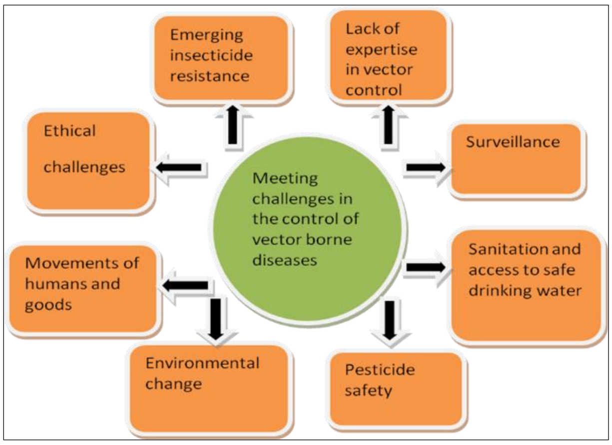


Fig 2: Meeting challenges in the control of mosquito-borne diseases

Biological controlling agents

Different species were thought to be efficient mosquito predators; here are some important organisms from microorganisms, invertebrates up to vertebrates are described as biological controlling agents.

Most common predatory insects of mosquito larvae

Coleoptera

Even several families of insects demonstrate predatory behaviour, barely the Dytiscidae and Hydrophilidae have gained researchers inspection.

Dytiscidae beetles can be found in both natural and artificial mosquito Sites where mosquitoes breed [18]. Insects falling under genera *Laccophilus, Dytiscus* and Agabus have been reported as biological control agents using a variety of means [19, 20].The other important Hydrophilidae family of predatory water beetles has also gained significance as a mosquito biological control tool. Some of the Species of watery scavenger beetles are *Tropisternus*, *Berosus*, *Enochrus*, and *Helophorus* [21, 22].

Diptera

Toxorhynchites mosquitoes are the most prevalent and eminent dipteran mosquito predators, having been reported as a biological control agent in a variety of natural environments.

Toxorhynchites (elephant mosquitoes)

After research on bioecology of Some Culicidae mosquito, it's obvious that larvae of these mosquitoes show their predacious nature on other mosquito species that are important vectors of public health. *Toxorhynchites* (T.) is a vast, worldwide mosquito genus that does not feed upon the human blood [23]**.** *Toxorhynchites* common name is "elephant mosquito" or "mosquito eater." The larvae shows cannibalism as well as other nektonic (free-swimming) creatures, instead of this the adults of this species feed upon sugar-rich diet like honeydew, fruit, and nectar.

Common habitats of this mosquito are woods; however one forest species, T. *splendens*, feeds-on larvae of mosquito in tree fissures (especially on Aedes). These findings highlight the potentiality of *Toxorhynchites* larvae as probable bio-controlling agents against mosquito vectors [24].

Dipteran insect's most likely ceratopogonid [25]**,** chaoborid [26] chironomid [27] corethrellid [28, 29], culicoid [30] dolichopodid [31], tipulid [32] and other brachyceran [33] larvae were recorded as mosquito larvae predators.

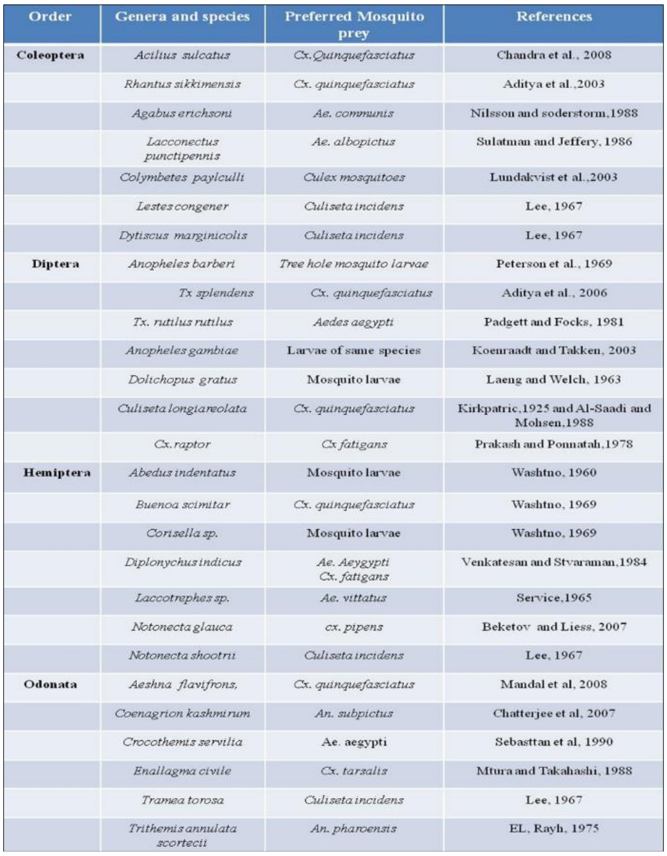
Hemiptera

The predatory tendencies of various families that live in water or near it, belonging to the Hemiptera have piqued curiosity about using them to naturally control mosquito larvae in water bodies, some are: Gelastocoridae, Naucoridae, Nepidae, Belostomatidae, and Notonectidae. Backswimmers, also known as notonectids, have been deemed the most promising [34].

Lately researchers have found that having the presence of N. hoffmani and N. kirbyi bugs in surroundings decrease the number of fully developed mosquito larvae and pipae in the area. Interestingly, when entomophagous insects are not present, the mosquito population seems to rise [35].

Predation by backswimmers has shown an indispensable role in lowering mosquito populations in the field.

From the start of the release, the predatory efficacy of backswimmer predation on Cx. *Quinquefasciatus*us larvae was obvious. Predation by first stage instar backswimmers on mosquito larvae is notable and swiftly reducing their numbers (larval densities) in the water.



Order	Genera and species	Preferred Mosquito prey	References
Coleoptera	*Acilius sulcatus*	*Cx.Quinquefasciatus*	Chandra et al., 2008
	Rhantus sikkimensis	*Cx. quinquefasciatus*	Aditya et al.,2003
	Agabus erichsoni	*Ae. communis*	Nilsson and soderstorm,1988
	Lacconectus punctipennis	*Ae. albopictus*	Sulatman and Jeffery, 1986
	Colymbetes paylculli	*Culex mosquitoes*	Lundakvist et al.,2003
	Lestes congener	*Culiseta incidens*	Lee, 1967
	Dytiscus marginicolis	*Culiseta incidens*	Lee, 1967
Diptera	*Anopheles barberi*	*Tree hole mosquito larvae*	Peterson et al., 1969
	Tx splendens	*Cx. quinquefasciatus*	Aditya et al., 2006
	Tx. rutilus rutilus	*Aedes aegypti*	Padgett and Focks, 1981
	Anopheles gambiae	Larvae of same species	Koenraadt and Takken, 2003
	Dolichopus gratus	Mosquito larvae	Laeng and Welch, 1963
	Culiseta longiareolata	*Cx. quinquefasciatus*	Kirkpatric,1925 and Al-Saadi and Mohsen,1988
	Cx.raptor	*Cx fatigans*	Prakash and Ponnatah,1978
Hemiptera	*Abedus indentatus*	Mosquito larvae	Washtno, 1960
	Buenoa scimitar	*Cx. quinquefasciatus*	Washtno, 1969
	Corisella sp.	Mosquito larvae	Washtno, 1969
	Diplonychus indicus	*Ae. Aeygypti* *Cx. fatigans*	Venkatesan and Stvaraman,1984
	Laccotrephes sp.	*Ae. vittatus*	Service,1965
	Notonecta glauca	*cx. pipens*	Beketov and Liess, 2007
	Notonecta shootrii	*Culiseta incidens*	Lee, 1967
Odonata	*Aeshna flavifrons,*	*Cx. quinquefasciatus*	Mandal et al, 2008
	Coenagrion kashmirum	*An. subpictus*	Chatterjee et al, 2007
	Crocothemis servilia	Ae. aegypti	Sebasttan et al, 1990
	Enallagma civile	*Cx. tarsalis*	Mtura and Takahashi, 1988
	Tramea torosa	*Culiseta incidens*	Lee, 1967
	Trithemis annulata scortecii	*An. pharoensis*	EL, Rayh, 1975

Aquatic insect predators and mosquito control. Tropical biomedicine, [36].

Fig 3: Digram illustrating common predatory insect of mosquito larvae

Odonata

Since the soon after of the nineteenth century, two eminent insect larvae of dragonflies and damselflies have been documented to be voracious mosquito feeders.

The Odonata are key predators of mosquito larvae in the community structure of freshwater environment [37, 38].

Enallagmacivilae, a damselfly, ingest up to 6.06 *Cx. tarsalis* larvae, with consumption increasing proportionally with prey density [38].

Dragonfly as a voracious predator of mosquito larvae

Predatory insects such as damselfly and dragonfly nymphs have received a high regard as major predators of various micro-invertebrates, including Aedes mosquito larvae, as biological control agents. Small larval forms such as Aedes larvae are favoured by dragonfly nymphs and adult dragonflies prey on adult mosquitoes [39]. Globally, considerable research efforts have been devoted to exploring the practical effectiveness of nymphal odonates as agent for mosquito control, with a significant focus regarding South Asian region. Myanmar [40] and India have effectively exploited different dragonfly's species as a possible biological resource in controlling vector and pest mosquito larvae populations.

Some predatory dragonfly species on aedes larvae are*tholymis tillarga*, *Orthetrum Sabina***,** *Gynacantha Dravida***,** *Anax indicus***,** *Pantala flavescens.*

Anax indicus, P. *flavescens*, G. *Dravida*, O. sabinasabina, and T. *tillarga* are active feeders, according to the study, and may consume *Aedes aegypti* mosquito larvae in significant numbers in laboratory circumstances [41].

Plant-based mosquito ides, Repellents, and Oviposition Deterrents

Compounds derived from plants display remarkable efficacy, capable of targeting immature larval stages of Aedes, Anopheles and culex mosquitoes at astonishingly low concentration, often just a ppm [42].

Antimalarial activity of Moringa oleifera

Across various corners of the world, ancient methods have employed for plant items to fighting against insect species and their vectors. In addition to acting as larval insecticides, IGRs, deterrents, and ovipositional attractants, phytochemicals extracted from plants also have other uses [43, 44].

In comparable to other herbal extracts, M. oleifera seed extract contain larvicidal and pupicidal properties, and research on water extracted M. oleifera seeds against Aedes mosquitoes and M. oleifera roots against Culex and *Aedes albopictus* have been documented. So conclusion made on this aspect that the principal chemical ingredient found in M. oleifera may be for the larval and pupal mortality [45].

Solanum Tribolium as oviposition deterrent

Several plant extracts and essential oils have mosquito-repelling actions against diverse mosquito species. The phenolics, terpinoids, and alkaloids found in the *solanum tribolium* plant interplay of chemical compounds and natural processes. These substances may work together or separately as deterrent and repellent effect on An. *Stephensi* [46].

Larvivorous fishes

Efforts in using vertebrates for biological mosquito control have primarily centered on the predatory function of larvivorous fish [47]. Theses fishes have ability to hunt mosquito larvae in diverse environments, spanning from artificial settings like small plastic containers to the large natural ecosystems such as coastal wetlands [48].

Since the early twentieth century, fish have been thought of as mosquito-control agents [49].

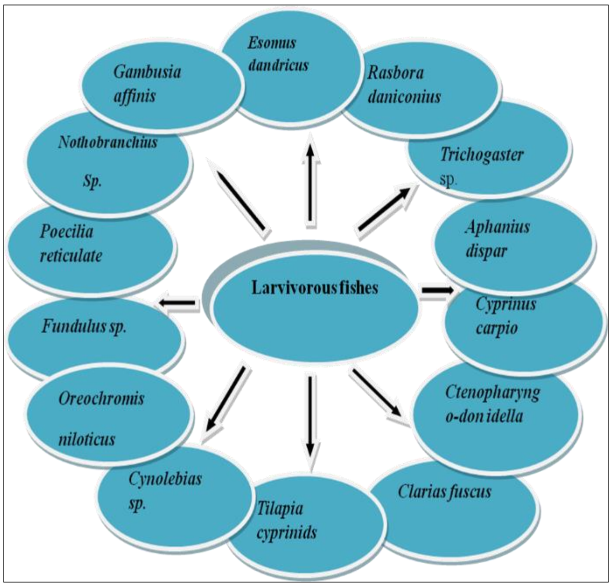


Fig 4: some common larvivorous fishes

Mosquito control by larvivorous fish. Indian Journal of Medical Research [50]

Microorganisms as biolarvicides

Bacillus thuringiensis var. israelensis (Bti)

Bti Biocontrol is also naturally occurring pathogen to mosquitoes. In Europe, Bti is well established method to use mosquito larvicide. BT is a gram-positive, spore-forming bacterium that produces insect killing toxins and virulent factors to affect insect larvae [51, 52, 53].

Bt possesses entomopathogenic attributes, and production of insecticidal proteins in the form of parasporal crystals during its sporulation phase these proteins consist of one or more proteins known as delta endotoxins.

These toxins possess a remarkable precision, targeting their chosen insect while posing no threat to vertebrates or flourishing green world and completely biodegradable [54].

The Bt species have a formidable toxicity against a variety of Aedes, Culex, and Anopheles mosquitoes. Crystalline inclusions composed of Cry4Aa, CryBa, Cry10Aa, Cry11Aa and Cry 2Ba toxins [56].

Mortality was positively proportional with *Bacillus thuringiensis* concentration and negatively with larval age. *Bacillus thuringiensis* and *Bacillus sphaericus* have more larvicidal effects on mosquitos. In mosquitoes exposed to sublethal level, these impacts can be easily detected in terms of diminished population of mosquito larvae, adult emergence, adult survival, and their fertility [57].

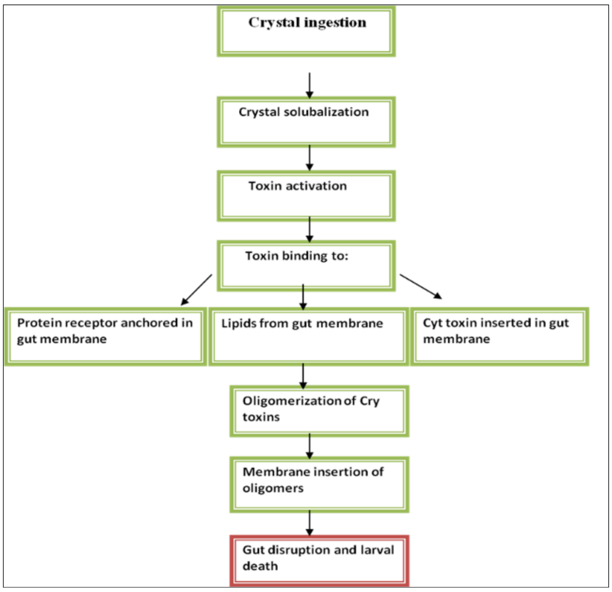


Fig 5: Action mechanism of Bti toxins in mosquito larvae [58]

Entomopathogenic Fungus

An entomopathogenic fungus is another one biological agent that can act as a killing agent on insects, killing or severely incapacitating them. In first step of infection these fungi adhere themselves to the outer exposed skin or cuticle of insects' bodies as form of conidia. These conidia sprout and develop as hyphae, and finally bore through it to enter the insect's haemocoel cavity under typically high temperature and suitable moisture conditions. The fungal cells then multiply in the host body cavity (depending on the fungus involved). Insect is normally killed after a period of time [59].

Beauveria Bassiana, a globally recognized entomopathogenic fungus, that is germinates in soils mostly. It mainly infects Arthopod species, utilizing them as hosts for its life cycle and main pathogen of White Muscardine sickness. Termites, whiteflies, aphids, and various beetles are among the pest that is used to treat as a biological insecticide [60].

Beauveria Bassiana was successfully implemented ashaving virulence against *Culex pipiens*, *Culex tarsalis*, *Culex tritaeniorhynchus*, and *Anopheles albimanus* larvae in laboratory testing, but ineffective against *Aedes aegypti, Ochlerotatus Sierrensis, and Culex quinquefasciatus* larvae [61].

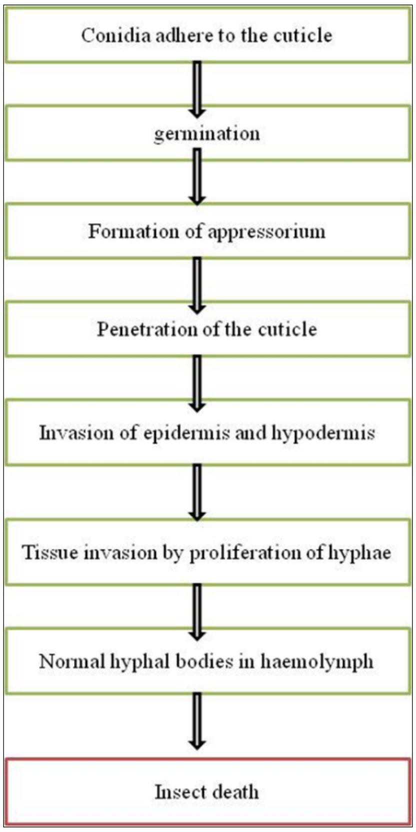


Fig 6: Different stages of life cycle of *Beauveria Bassiana* (Balsamo) in the host tissues [56]

Wolbachia Endosymbiotic Bacteria

Wolbachia endosymbiotic bacteria induce cytoplasmic incompatibility in mosquitoes causing sterility across their populations [63].

To diminish the population of *Cx. quinquefasciatus* mosquito populations from Myanmar during 1960s, this technique was used [64]. This incompatible insect method (IIT) based upon Wolbachia infected male mosquitoes competition with wild type males in order to cause infertility and reduction of mosquito quantity**.**

After eradication of Aedes polynesiensis strain with Wolbachia which exhibits bidirectional incompatibility with naturally infected wild-type mosquitoes during their papal stage, lower female fecundity as well as fertility were seen [65]. The detection of a highly potent Wolbachia strain in Drosophila melanogaster (called Mel Pop) that drastically diminished the longevity of their host [66]. Prompted towards more research to investigate if this strain may also reduce mosquito lifespan. Additional Wolbachia strains, notably the avirulent ω male strain, were later discovered to save their native hosts, (Drosophila) from deadly RNA virus infection [67].The use of Wolbachia to hinder the infections from proliferation of the mosquito is an innovative approach for mosquito vector control [68].

Conclusions and Future Perspectives

Implementation of biological agents to diminish mosquito larvae is not only an eco-friendly approach, as well as it is also a more effective and deep-rooted solution comparatively chemical insecticides use. Common and widely available predators should be seriously addressed in this bio-control context since they have the advantageous capability of acclimating themselves to adapt a variety of water bodies that are widely dispersed near vicinity and within human settlements. Once biological agents (mosquito larvae predators) established they will be able to self-reproduce and set up long-term mosquito control up to a degree that no insecticide can hope to match.

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