Chapter

Innovative Methods of Mosquito Management

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Abstract

As the global human and animal population increases, deadly pathogens and parasites may be transmitted by arthropods. There are a number of vectors that pose a threat to human health due to their role in transmitting dangerous pathogens, including mosquitoes (Diptera: Culicidae). The most important drawback of these products is the incidence of insecticide resistance, which has increased rapidly in recent years. New approaches and vector-control tools targeting aquatic stages and adults are urgently needed. The three main mosquito genera, *Anopheles, Aedes, and Culex,* transmit the causative agents of numerous important diseases to humans as well as animals. A technique that involves the use of genetically modified (GM) mosquitoes for the purpose of vector control is another potential option. Other best ways to control the mosquito are by chemical, biological and genetic means.

Keywords: populations, pandemic, pathogens, approaches, causative

1. Introduction

There are several causes that contribute to the close relationship between fauna and flora in the globe today, including population expansion and the development of transportation networks. These variables break down biogeographic boundaries and lead to the initial occurrence of species in new environments [1]. Damage caused by these species in the Americas is estimated to be in the neighborhood of $120 billion each year [2]. Arthropods may spread deadly infections and parasites [3]. Epidemics and pandemics present a risk to the world's growing human and animal populations [4]. It is important to note that mosquitoes (Diptera: Culicidae) are considered the most harmful vector because of their involvement in the transfer of deadly infections [5]. As a result of commerce and travel, essential mosquito species are being introduced to new environments [6, 7]. Commercially accessible chemical compounds, employed for mosquito management, are often toxic to human beings imparting major skin and nervous system issues, such as rashes, swelling, or eye irritation [8]. Since pesticide resistance has been on the rise in recent years [9], treating mosquito breeding is exceedingly difficult or impossible, as these products pose a serious problem. Thus, the need for new vector control techniques and instruments that target aquatic stages and adults is critical [10]. Currently available information about mosquito-borne illnesses, as well as the most recent statistics on their reappearance, are discussed in this chapter, along with the strengths and weaknesses of the management methods currently in practice. For biological control of mosquito-borne illnesses, new inventive alternatives are recognized but seldom used, others that are not employed at all, and rest are in the test or design phase.

Mosquitoes of the three major genera *Anopheles*, *Aedes*, and *Culex* spread the pathogens that cause a wide range of serious illnesses in both people and animals [11]. There has been an increase in the number of mosquito-borne diseases that have a significant influence on human health.

As the most common parasite illness of humans, malaria, transmitted by *Anopheles* sp. is prevalent in more than 80 countries, with the majority of cases and fatalities occurring in sub-Saharan Africa, where more than 85 percent of cases and 90 percent of deaths occur, largely in children under 5 years old (**Figure 1**). There have been 228 million cases of malaria at the globe level, with 93% of them occurring in Africa alone, and recent epidemics have decimated several places [12].

Many mosquito species transmit *Wuchereria bancrofti* and *Brugia spp*., leading to lymphatic filariasis which produce diverse clinical symptoms (25 million men with hydrocele and over 15 million individuals with lymphoedema), and at least 36 million people continue to have these long-lasting illness manifestations. It is apparent, however, that eradicating lymphatic filariasis is not achievable without managing the vectors of this disease.

Likewise, *Aedes aegypti* and *Aedes albopictus* (**Figure 2**) transmit dengue, yellow fever, Chikungunya Zika, etc. in human beings. The dengue virus (DENV), containing four unique serotypes, belong to the Family Flaviviridae [13]. With 3.6 billion people living in places at risk of transmission and hundreds of millions of cases of dengue fever recorded each year [14], it is now the most common arthropod-borne viral illness affecting humans [15].

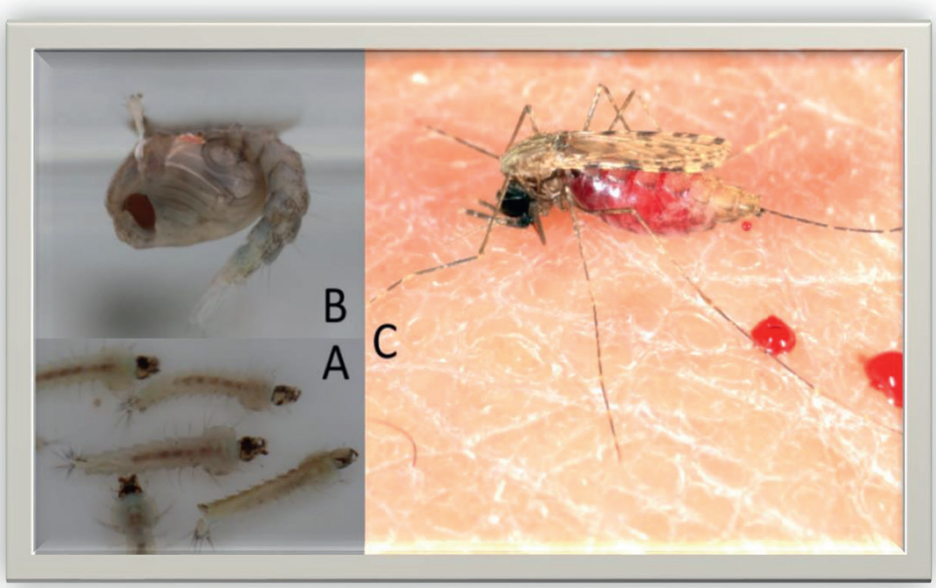

Figure 1.
Anopheles gambiae: (A) larvae, (B) pupa, and (C) adult.

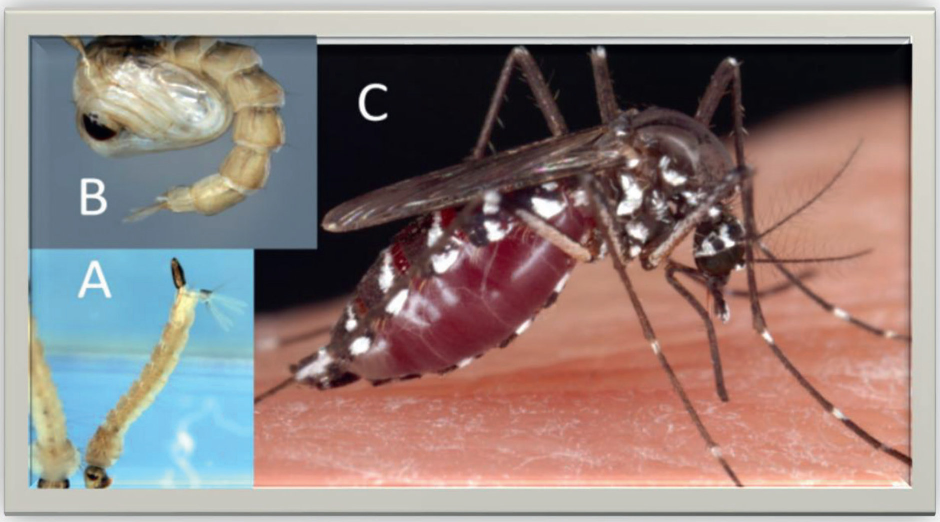

Figure 2.
Aedes albopictus: (A) larvae, (B) pupa, and (C) adult.

Zika virus (ZIKV) also belonging to Flaviviridae causes frequent disease outbreaks in numerous Latin American and Pacific nations (**Figure 3**) [16]. *A. albopictus* is the major and secondary vectors of ZIKV epidemics [17]. In addition, a number of other species are also implicated in the fast spread of this virus. It is now regarded as one of the most significant public health threats [18, 19].

Antalgic stance gait and acute articular pain are hallmarks of chikungunya fever (CHIF) caused by the Chikungunya virus (CHIKV) (**Figure 3**). The 1.4 percent to 90 percent of infected individuals often progress to the chronic stage (52 percent in the American continent). Several nations have lately had outbreaks of the disease [20].

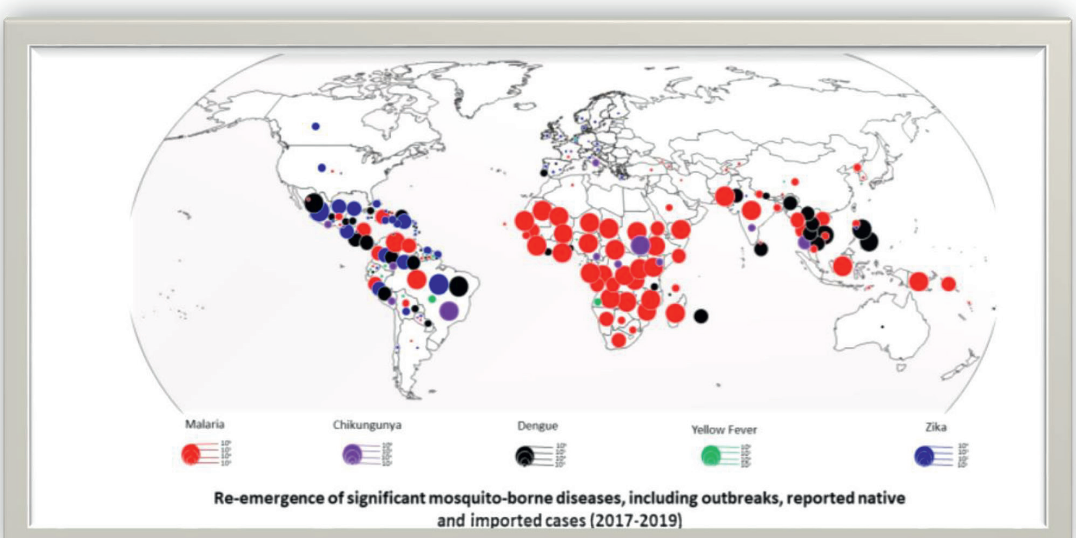

Figure 3.
Cartography of significant resurgences of mosquito-borne diseases worldwide (until September 2019). It presents outbreaks and cases of malaria, dengue fever, yellow fever, chikungunya fever, and Zika fever between 2017 and 2019. The figure clearly illustrates their resurgence in most tropical countries. There are several northern countries where the competent vector has become established, which may allow local transmission.

Apart from these diseases, the hemorrhagic and possibly deadly RNA virus, Flaviviridae [21], causes more diseases and generates more epidemics in various countries, particularly in unprotected populations [21]. A new epidemic usually appears every 7–10 years or so [22]. More than half the YFV (Yellow Fever Virus)-endemic nations in the world are located in Africa, according to the World Health Organization (WHO). Numerous outbreaks have been reported, with a death rate of up to 33.6% [23]. Roughly 70 to 90 million doses of vaccines are manufactured each year across the globe, making it the most cost-effective and safe method of preventing YF.

According to the World Health Organization, around 67,000 people per year are infected with *Culex*-borne Japanese encephalitis, 20 percent to 30 percent of whom die, and 30 to 50 percent of those who survive have major neurological consequences. As previously mentioned, new strains that are genetically similar to those implicated in prior epidemics have been discovered [24]. Louis encephalitis virus was the primary arbovirus cause of epidemic encephalitis in the United States [25]. Numerous people have been struck down by it in the last few years [26].

Similar to humans, horses are the domesticated animal most frequently infected by the West Nile virus transmitted by *Culex* (**Figure 4**). Eighty percent of cases are asymptomatic, neurological signs are the most frequently reported symptom, and 90 percent of those infected with the virus go on to develop clinical symptoms. The mortality rate for infected horses may reach 30 percent [24]. In spite of this, recent cases of human epidemics have been documented [25].

It is common to find different harmful blood-borne bacteria in mosquitoes [27]. It is not yet known whether the existence of these bacteria in mosquitoes may be attributed to their infrequent consumption of blood meals or environmental acquisition, or if they can grow and ultimately transmit during blood meals. Various pathogenic alpha-proteobacteria, such as *Anaplasma species*, *Ehrlich species*, *Candidatus neoehrlich species*, *Bartonella species*, and *Rickettsia species*, have been discovered in adult mosquitoes (xeno-monitoring studies) [28]. More intriguingly, laboratory tests have shown

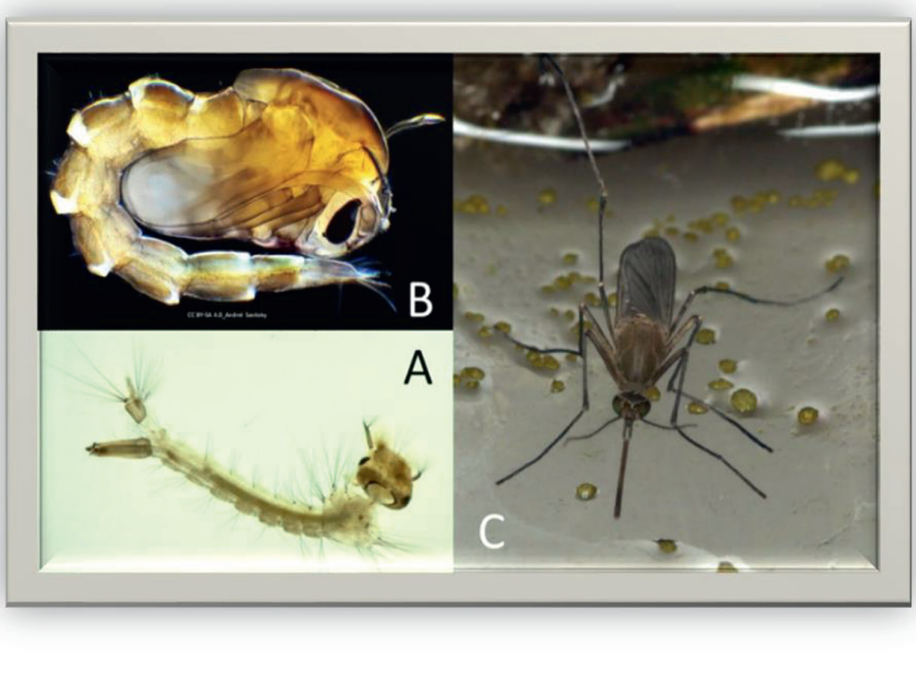

Figure 4.
Culex pipiens: (A) larvae, (B) pupa, and (C) adult.

that the agent of febrile rickettsiosis, *Rickettsia felis*, may be transmitted by *Anopheles* mosquitoes [29]. *Francisella tularensis* is the first known mosquito-borne bacteria since it is also transmitted by mosquitoes (*Aedes*), the primary vector in Sweden and Finland [30].

Inadequate vector-control efforts, limited access to quality healthcare, rapid and unplanned urbanization of tropical regions coupled with unsanitary conditions, a deterioration of public health infrastructures, and a number of complex factors, including population growth, globalisation of the economy, international travel (recreational, business, and military), may explain the spread of these diseases in the region. All of these factors are connected to climate change [31]. The misuse of insecticides and the development of resistance, however, continue to be the primary contributing causes.

2. Mosquito control

Controlling the mosquito vectors that spread the major diseases is an important part of global initiatives to get rid of and control diseases. If these initiatives are successful, they can lead to a huge drop in the number of diseases around the world. However, various problems are associated with the vector control measures, which are discussed below.

The prevalence of pesticide resistance among vectors is a major obstacle that prevents the proper implementation of vector control measures [32]. Adult vector mosquitoes may be particularly difficult to manage if insecticides are no longer effective, leading to serious implications for human health. Another issue is the wide range of mosquito susceptibilities to various pesticides [33]. Malaria has been reduced by the use of ITNs (Insecticide-treated bed nets) and IRS (Indoor Residual Sprays) but insecticide resistance and the inability to maintain these treatments might have the inverse effect. Some ITNs and IRS approaches have shown potential in malaria control, but are restricted in dengue control because of the ecology of *Anopheles* and *Aedes* mosquitoes. The enormous variety of vectors and the changing behavior of mosquitoes are a few more obstacles to overcome. In addition, rising urbanization and climate change [24] might have an unanticipated and significant effect on the distribution of vectors, creating new challenges for vector management strategies [34–36].

In addition to this, other challenges in the implementations of vector control initiatives include issues arising in prevention strategies such as a limited amount of funds or fair distribution of funds for vector control. These are just some of the challenges that are associated with the implementation of vector control programs. It is also possible for the vector control interventions to be weakened if there is a lack of effective monitoring methods relevant to pesticide resistance and the behavior of vectors. In addition, the absence of cooperation between governmental and non-governmental groups may have an impact on the vector control operations that are carried out. Migration of both people and products presents difficulties in terms of both disease emergence and vector control [37].

Although the approaches to eradicate mosquito-breeding places are very successful, they are not practicable in locations with intermittent water supply and if these methods are not applied at the grass-root level, the efficiency of these strategies is impaired [38]. For example, kerosene oil and chemical larvicides are excellent in killing larvae, but this method has a big drawback of being harmful to the environment. Similarly, application of the soil bacteria *Bacillus thuringiensis israelensis* (Bti) though effective, but works only on the larval stages and therefore using Bti is not a viable option for controlling larval populations. Further, Bti has been proven to have an influence on food chains and led to other environmental consequences in recent research [39, 40]. Likewise, the introduction of *Tilapia* and mosquito fish into the ecosystems without the use of a controlled ecosystem might potentially result in harmful environmental impacts.

The harmful effects of these chemical larvicides necessitate that the World Health Organization (WHO) understands and assesses the development of new vector control products before they are used in the field. Consequently, a variety of various vector control tactics and research are addressed below, such as the release of sterile insects by irradiation, the use of *Wolbachia* and gene-drive technologies, etc. Public acceptance and regulatory approval need a detailed risk assessment and significant stakeholder input.

While using genetically modified organisms, these kinds of hurdles are obviously far greater than they are for purely biological control methods like use of *Wolbachia*. Second, the implementation of these treatments will put enormous selection pressures, which might lead to the development of resistance in either the target pathogen (in the case of *Wolbachia* or vector competence gene drive constructs) or the vector (for population suppression genetic constructs and possibly *Wolbachia*). In addition, the long-term phenotypic stability of *Wolbachia* in *Ae. aegypti* is yet unclear at this time [41].

A technique that involves the use of genetically modified (GM) mosquitoes for the purpose of vector control is another potential option. This method has various benefits, such as the fact that it is non-toxic and prevents the use of chemical pesticides. However, the use of genetically modified mosquitoes raises a number of ethical difficulties. In addition to this, it is necessary to take into mind the possible influence that these creatures may have on the surrounding ecosystem [42]. In addition, the process of creating genetically modified mosquitoes is highly pricey and may not be feasible for economically disadvantaged endemic nations. Thus, the World Health Organization (WHO) advises and urges more field tests and risk assessments to determine how effective this method is in preventing the spread of disease [43].

Recently, the environmentally friendly production of nanoparticles has developed as an approach for vector control that is both easy and efficient in its use. The large-scale synthesis and its potential effects on the environment are, however, subject to a number of restrictions. In addition, there is a significant divide between the implications that may be theoretically drawn from this technology and those that can be drawn from its actual use. In addition, there is a very limited amount of data available about the effect that these nanoparticles have on other aquatic creatures [44]. A good number of these nanoparticles have been subjected to acute toxicity testing on non-target creatures or on other aquatic organisms that live in the same biological niche as vector mosquitoes.

The presence of high-transmission hotspots and heterogeneity both make the task of mosquito management more difficult; yet, it is possible that the task of control in low-transmission regions will be simpler than was originally anticipated based on geographically inaccurate transmission intensity forecasts [45].

Making the most of limited resources (especially in low-income regions) in order to achieve the greatest possible improvement in public health is going to be another one of the most challenging tasks. Extrapolation of clinical trial data to forecast population effect of each intervention in a wider variety of contexts and in conjunction with other control methods would require rigorous epidemiological research and mathematical modelling to ensure such optimal deployment. In addition, stringent monitoring and evaluation are necessary in order to determine whether therapies are beneficial in actual practice [36]. Meanwhile, the political commitment and implementation of collaborative vector control techniques are the keys to achieving the aim of vector control and, as a result, lowering the risk of disease transmission and making a contribution to the elimination of disease.

3. Alternative strategies for mosquito control

As many as 4 billion people are at danger of dengue virus transmission alone, despite our best attempts to manage vector-borne disease outbreaks using present intervention strategies. Because of this, new tactics for mosquito vector management must be devised in light of the current situation. With the fast rise in pesticide resistance and its harmful effects on non-target species, new methods for mosquito control are needed.

3.1 Repellents of the physical environment

To prevent interaction between people and the vector, the repellent compounds function in the vapor phase to make the area undesirable for the insect. Using this strategy, mosquitoes will be diverted to non-human hosts, reducing the damaging effects of pesticides on people and other non-target organisms, as a result. Instead of killing the insect, the repellents aim to keep it from biting humans [46]. New active chemical components can be used to change the typical behavior of the vectors and boost this method's effectiveness. Currently, there is no indication that this practice has any effect on the population. However, many hurdles must be overcome before spatial repellents may be used as a tool in vector management, as they cost too much money. Also, these repellents need the usage of power, which makes them unsuitable for places with a high transmission rate in less developed areas. If these deterrents are to be easily included into vector control programs, their cost must be comparable to that of IRS or LLINs (Long lasting insecticidal nets) [47].

Allethrin (Therma CELL) and metofluthrin (OFF! clip-ons or lamps) emanators have been tested in several early field trials for their efficiency as spatial repellents and have been found to provide more than 70% protection [48]. In push-pull systems, the application of these deterrents eventually aids in the mosquito's push towards the baited traps. Some of these trials involved the use of various repellents like as PMD, catnip oil, and delta-undecalactone.

3.2 Use of repellents derived from plants

Plant-based "natural" smelling insect repellents are now extensively used over the world since they are considered safe and effective. Many plant volatiles are effective insect deterrents and repellents due to their high vapor toxicity. Compounds present in most plants protect them from phytophagous (plant-eating) insects from being eaten. Among the compounds utilized are repellents, growth regulators, poisons, and feeding deterrents [49]. Alkaloids, terpenoids, proteinase inhibitors and phenolic compounds are among the greatest examples of secondary metabolites in plants which defend the plants. Currently, the volatile components produced by herbivory are well known for their capacity to repel mosquitoes and other biting pests. Insects detect volatile scents with the help of sensory neurons (ORNs), which are typically located on the antennae and maxillary palps of insects, and are equipped with odorant receptor (OR) proteins [50].

Many people have known for millennia that lemon eucalyptus has insect repellent properties. Essential oils containing 85 percent citronellal are far more effective than water in keeping mosquitoes away for long periods. The low vapor pressure of one of its ingredients, para-menthane-3, 8-diol, on the other hand, provides great protection against a wide range of insect vectors over an extended length of time. Eucalyptus extracts have recently been given fresh life by advances in nanotechnology [51]. As a repellent, citronella and vanillin are found in quantities of 5–10 percent in lemongrass extract and essential oil extract (5 percent). Using citronella oil in a nano-emulsion, stable droplets may be formed that help retain the oil and postpone its release. The efficacy of neem-based treatments has also been proven in various field studies in India [52].

3.3 Traps

Traps can be used to catch adult mosquitoes. The carbon dioxide that is released on conversion of propane into water can work as an attractant. Warm water vapors with carbon dioxide attract mosquitoes. As a result, mosquitoes may be lured up to 30 meters away from the trap using the pesticide octenol, or 1-octen-3-ol. This attractant mostly attracts zoophagous mosquitoes. In certain traps, a dim light is employed to attract the mosquitoes which are then into a collection chamber or bag using a fan. It is common in some mosquito traps, such as CDC light trap. This trap will catch many other flying insects, such as flies and bumblebees.

UV/visible light mosquito traps draw not only mosquitoes, but also helpful in catching pollinating insects, resulting in unintended injury. A larvicide pharmaceutical package is discharged to avoid the death of undesired insects; nevertheless, attracted insects may provide falsely optimistic image processing results. It is also possible to reduce power consumption by eliminating active traps that need actuators [42]. In order for a trap to be effective, it has to be set up, maintained, and operated correctly. Their effectiveness may be affected by the wind. An awkward location for a mosquito trap may lead to more attacks. To counter this problem, one might try setting up traps around their property [53].

3.4 Sterile insect technique (SIT)

The SIT is a pest control method that uses mass-reared sterile males to control an insect population in a certain region. When wild sterile males mate with wild females, no offspring are produced [54]. The target wild insect population is reduced over time by introducing sterile males in a systematic and repeated method. Various nations, including Brazil, Cuba, Italy, Mauritius, Mexico, and Germany, have tested the SIT on a small scale in partnership with the Food and Agriculture Organization (FAO) of the United Nations. The IAEA, TDR (Special Programme for Research and Training in Tropical Diseases), and WHO collaboration are planning larger-scale pilot releases as a part of research and technical cooperation activities, as well as test releases in connection with epidemiological investigations. There are two types of mosquitoes: those that bite and transfer diseases, and those that do not bite and do not constitute a threat to humans. Because sterile mosquitoes are unable to breed, their numbers will not rise in the wild. Normally, sterile mosquitoes are dispersed by land, but the IAEA, in partnership with the FAO and others, has achieved promising results in Brazil utilizing a drone release approach [51].

Tsetse flies, melon fruit fly, pink bollworm and the New World screwworm have all been eradicated using this method. Sterilization and genetic sexing, the development of superior strains for mass manufacturing and release, as well as the identification of molecular markers for detecting the released sterile insects in the field, can all help to increase the effectiveness of this procedure. To evaluate the SIT programme, it is critical to distinguish between sterile and wild insects that have been released [55]. A luminous transformation marker incorporated into a transgenic bug might make releasing insects easier to identify. *Anopheles gambiae* and *Aedes aegypti* mosquito species have evolved fluorescent sperm marking systems [51].

4. Management control of mosquitoes

Malaria, Mayaro fever, dengue, Chikungunya, yellow fever, filariasis, Zika, are just a few of the diseases that mosquitoes potentially spread. With the use of insecticides, larvicidal agents and bed nets, along with the use of medications as chemoprevention and treatment of the sick, these vectors can be control effectively.

Figure 5 represents the chemical, genetic and biological control techniques for mosquitoes which are discussed below.

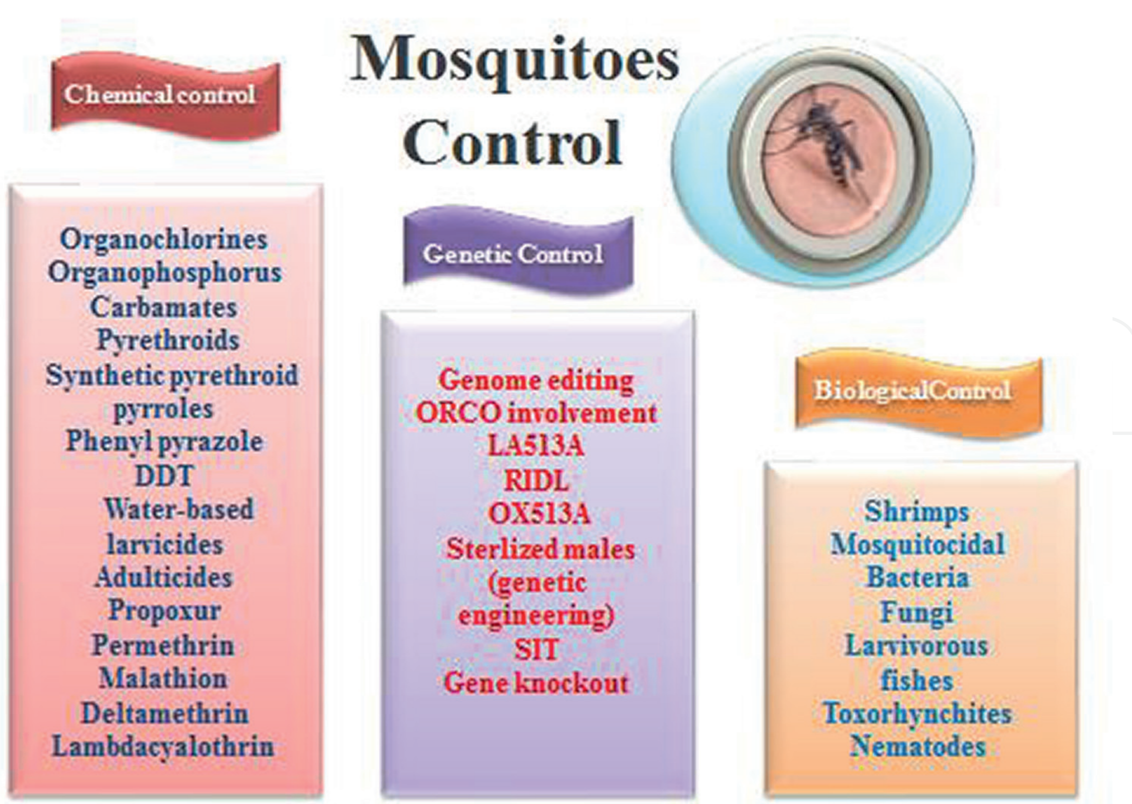

Figure 5.
Chemical, biological and genetic control of mosquitoes.

4.1 Chemical control

Mosquitoes are responsible for the death of millions of people each year from diseases transmitted by vectors. There is currently no vaccine available for viral illnesses and malaria transmitted by mosquitoes. As a result, mosquito and vector species management is critical if epidemics like malaria and dengue fever are to be kept in check.

Control strategies based on chemical, biological and physical elements have all been implemented to prevent the spread of mosquito-borne disease as the most typical and conventional method of regulating mosquito populations. Among these, chemical control is the most productive, but it damages the environment and threatens non-target individuals as well. Despite their well-known negative effects, chemical insecticides combined with personal protection techniques are currently the most frequently applied strategy for mosquito control [56].

Chemicals with mosquitocidal qualities are known as insecticides. These chemicals include organochlorines, organophosphorus, carbamates, pyrethroids, pyrroles, and phenyl pyrazole. These substances are employed in sprays for public health purposes. The application of chemical pesticides as principal agents in excessive amounts without limit, without interference, without discriminatory treatment, and on a continuous basis result in warranted toxic or lethal effects on non-target organisms, resistance in mosquitos and most importantly the potential for toxic effects on environment and adverse effects on health, posing a great threat to life and the environment [57].

Pyrethroid pesticides are neurotoxic because they interfere with voltage-gated sensitive sodium channels (VSSC). Pyrethroids have a greater effect on insect sodium channels than on vertebrate sodium channels [58]. Pyrethroids are mixed with water or oil and applied as an ultra-low volume spray to kill flying adult mosquitoes by skilled mosquito control services. Toxic effects of pyrethroids are attributed to their ability to delay the activation of the voltage-sensitive sodium channel, which leads to immobility and eventually death of the insect, an effect known as "knockdown" [59]. Pesticides incorporating pyrethroids are most often used in the various countries to suppress dengue virus vectors *Aedes albopictus* (Skuse) and *Aedes aegypti* [60].

In the programmes, actively combating malaria and reducing the lifespan of gravid female mosquitoes, DDT (dichlorodiphenyltrichloroethane) may have been the most frequently employed man-made organic pesticide during the twentieth century. Water-based larvicides are used to control the number of larvae in the environment. Adult mosquito populations can be managed with adulticides and synergists, which disguise and spray adult mosquitoes. There are numerous insect development regulators, including pyriproxyfen, diflubenzuron, and methoprene, which can be used as larvicides and adulticides, along with ovicidal attributes, in mosquito control techniques worldwide [61].

In chemical control, the most obvious issues are growing pesticide resistance, human health hazard and the pollutants that has a detrimental effect on wildlife and the environment. Propoxur, permethrin, malathion, deltamethrin and lambda-cyhalothrin have been linked to behavioral changes in *Culex quinquefasciatus* and *A. aegypti* after exposure to sub-lethal concentrations of these organic chemicals, which belong to the three primary chemical classes; pyrethroids, carbamates, and organophosphates. Females of *A. aegypti* and *C. quinquefasciatus* species avoided feeding during the WHO tunnel experiments that used treated bed nets after a single sub-lethal pesticide exposure. The ability of mosquitos to change and resist towards insecticides has been shown to have a major influence on the effectiveness of these interventions [62]. As a result, there is an urgent need for further viable supply to synthetic insecticides over the world.

4.2 Biological control

Biological control has evolved from a specialized technique to a broader one over time. As a consequence, the number and variety of biocontrol agents used to treat pests and mosquito transmission has increased tremendously in recent decades [63].

Numerous studies have shown that a number of environmentally safe natural substances have insecticidal properties, including bioactive peptides, essential oils [64], nanomaterials [65] and polyphenolic extracts. Both natural enemies of the target mosquitoes and biotoxins are used in biological control tactics. Invertebrate predators, nematodes (such as *Romanomermis culicivorax*), larvivorous fish (such as *Gambusia affinis*), some fungi (like *Lagenidium giganteum*), and protozoa are included in this regard [66].

Shrimps of the species *Macrobrachium brasiliense, Macrobrachium amazonicum, M. pantanalense*, and *Macrobrachium jelskii* can be used to suppress *A. aegypti*, *C. quinquefasciatus* and *Anopheles darlingi* larvae [67].

As a result of the management of vectors, biocontrol approaches have also already contributed in reducing the mosquito number. As a biocontrol agent, bacteria such as *Bacillus thuringiensis*, *Bacillus sphaericus* and *Streptomyces avermitilis* have been shown to be safe for the environment and a feasible approach for reducing mosquitoes. One of the insecticidal protein families found in *B. thuringiensis* subsp. *israelensis*, the Cyt (cytolysins), as well as the Cry (crystal delta)–(endotoxins), have been proven to be efficient in mosquito control [68].

In specific African regions, some fungi are capable of attacking *A. aegypti*, which can be exploited as cost effective and ecofriendly for controlling flavivirus pandemics in North as well as South America [69]. *Microsporidia coelomomyces* is virulent and is known as the most varied parasitic fungus groups against mosquitos [70].

The use of larvivorous fish as a biological and self-reproducing adversary of insects through the process of predation is not only an extremely cost-effective approach of regulating mosquito populations, but it also has a mosquito control effect that is maintained over the long term. One of the fishes that is being employed the most often as a biocontrol agent is *Gambusia* [71]. It is clear that mosquito fish biocontrol has many benefits over traditional pesticide mosquito control mechanisms. Furthermore, employing exotic mosquito fish presents a problem because they might affect native species and local ecosystems. As a result, extreme care must be exercised while using them [72].

Toxorhynchites splendens is a mosquito genus well known for its larvae's capacity to feed on mosquito species such as *C. quinquefasciatus, A. darlingi* and *A. aegypti* as well as other aquatic animals living in naturally or artificially created habitats. *Toxorhynchites* mosquito is thought to be a potential biological control tool for mosquitos residing in a variety of habitats [73].

Insects that live in water, such as the *Lethocerus americanus*, have the potential to consume mosquitoes throughout various stages of their development [74]. Frogs, tadpoles, and toads can feed on the larvae of *A. darlingi*, *C. quinquefasciatus*, and *A. aegypti*.

Rhabditidae and Heterorhabditidae worms are known to either directly or indirectly cause death in their hosts. Nematodes can infect their hosts in one of four ways:

by entering the body while the host is just being fed by a mosquito; by penetrating the cuticle; by entering through the anus or spiracle; or by entering during mosquito feeding [75].

The plant extract-based larvicidal pesticides are a promising class because of their low toxicity, low environmental impact, and lack of harm to non-targeted species [76]. Mosquitocidal activity of different plants is combined with the microbicide capabilities of silver nanoparticles (Ag–NPs), leading to an improved nanoscale (1–100 nm) effectiveness due to the increased A/v of nanoparticles. Because of these attributes, Ag–NPs are remarkably efficient against vector larvae even at extremely low concentrations [77].

4.3 Genetic control

The number of disease-carrying mosquitoes can also be controlled by genetic methods that can target both the adults and the larvae [78]. For gene functional analysis and pest control, genome editing is essential. Orco (odorant receptor co-receptor) is a critical modulator of several olfactory-driven behaviors throughout the *Anopheles sinensis* life cycle, emphasizing the role of Orco as a potential molecular target for malaria control [79].

As an alternative to sterilizing males for the purpose of insect population control, genetic engineering is often used to introduce a gene into mosquito vectors that causes them to die off on their own [80]. It was discovered that OX513A males in Malaysia had similar lifespans [81] and spreading capacities, however the most recent production of OX513A males in Brazil ended in a large drop of the target wild population.

LA513A, an *A. aegypti* strain modified to possess a non-sex specific, dominant, complicated late acting lethal genetic process that leads to death during the pupal stage rather than larval maturation, avoids density dependent effects on larval stage in natural populations. Despite the fact that without tetracycline, the vast majority (95–97 percent) of LA513A insertion carrying larvae dies during the pupal stage, they grow properly without it [82].

Release of Insects Carrying a Dominant Lethal Gene (RIDL) is a concept that was introduced by the British biotech company Oxitec. Tetracycline, an antidote, can suppress the deadly gene so that mosquitoes can be raised to adulthood in breeding locations before being released into the wild as males, where they mate with wild females and produce offspring that die at the larval stage [83].

The first successful gene knockout and transgenesis experiment was performed on mosquitoes. Instinct biological control methods based on population modification of vector mosquitoes have shown incredible potential in the struggle against mosquito-borne illnesses. These strategies include the genetics based sterile insect technique (SIT), CRISPR/Cas9 mediated gene drive, and population-replacement methodologies [84].

The development of innovative nanotechnology-based formulations for natural and synthetic repellents is a necessary aspect towards more efficient techniques with fewer adverse side effects.

5. Conclusions

In recent years, a number of new diseases that are transmitted by mosquito vectors have evolved as a consequence of climate change, dramatic population increase, degradation and increased resistance to pesticides. However, the use of pesticides can have a negative impact on other forms of life, which can then lead to an imbalance in the ecosystem. As a result, it is of the utmost importance to focus on finding novel and effective strategies that are environmentally friendly, easy to handle, safe, and inexpensive with no negative impact on populations that are not being targeted. Control strategies based on chemical, biological, and physical elements have all been implemented to prevent the spread of mosquito-borne diseases as the conventional methods of regulating mosquito populations. Due to the innovation and latest research scientist are able to explore the non-conventional methods of mosquito management based on genetic modification, nanotechnology, etc. Harmonious utilization of various control methods is the best way to manage the mosquito population.

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May Allah bless all these bright minds with long, happy and peaceful lives including me (Ameen).

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