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REVIEW **Open Access**

Lowering vector competence in insects: a review

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Abstract

Background Insects act as disease vectors, spreading disease-causing organisms between plants and animals. There have been studies devoted to determining ways to control these pests. One of the most effective ways to accomplish this is to reduce their vector competency. This review article explains how these factors can reduce vector competency.

Main body The major ways by which vector competence can be reduced were reviewed. Entomopathogens are organisms that cause disease in arthropods like insects, mites, and ticks. *Wolbachia* is a genus of intracellular bacteria that mostly infects arthropods, including a significant number of insects. It is one of the most frequent insect reproductive parasites that kill or severely disables insects. Entomopathogenic nematodes are a type of worm that attacks insects and kills them. Insect-specific viruses are a relatively new class of viruses with a variety of intriguing traits that could be used to better understand and possibly inhibit arbovirus transmission. Entomopathogenic fungi are a type of fungus that kills insects by attacking and infecting their insect hosts. Disrupting the environment and nutrition of insects could also help to reduce their ability to spread diseases to humans, animals, and plants.

Conclusions Chemical control has been one of the most widely used methods for controlling disease vectors, but there have been reports of insect resistance, environmental degradation, and a variety of other side effects. Instead of chemical control, there are a variety of techniques that can be used, including targeting insects' endosymbionts (bacteria, viruses, fungi, nematodes, and protozoa), changing insects' nutrition, manipulating their environment, and many others. This paper discussed the alternative ways to reduce vectors' competence without the use of synthetic chemical.

Keywords Vector, Competence, Endosymbionts, Environment, Insects, Nutrition

Background

Transmission efficiency (also known as vector competence), or how often a vector transmits a pathogen over time or per transmission opportunity, is the most fundamental criterion by which to describe or categorize vector transmission. After a vector first obtains a pathogen, usually by feeding, transmission efficiency can rise or decrease over time, although some pathogens are passed from a mother vector to her children via her eggs or embryos (Purcell & Almeida, 2005).

Insects are the most varied collection of living creatures on the planet. They can be found in almost any terrestrial and freshwater environment. Some have been associated with people throughout their history and have played a vital part in agriculture since its inception, as natural competitors for the food humans farm. We refer to these opponents as "pests," and we're working on a strategy to combat them (Ibarra & Rincon-Castro, 2008).

Many insects can survive in risky conditions with various microbial communities, but they are frequently exploited and killed by specialized infections. Insects and

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entomopathogenic microorganisms co-evolve and create a variety of adaptive systems that govern the long-term viability of dynamic host–parasite relationships at both the organismic and population levels (Dubovsky, 2021).

Many arthropod populations are naturally regulated by entomopathogens such as bacteria and viruses in the natural world. Entomopathogens have also been utilized as traditional biological control agents for alien insect pests, and natural pest control by entomopathogens has been improved through habitat management (Kalha et al., 2014).

A wide range of microorganisms, including viruses, bacteria, protozoa, and fungus, are currently being studied as pest control agents. The production and usage of entomopathogenic *Hyphomycetes* has received a lot of attention among fungi. There are numerous examples of this group of microorganisms effectively suppressing pest insects, demonstrating their considerable potential as biological control agents (BCAs) (Inglis et al., 2001). Every organism interacts with the ecosystem's biotic and abiotic components in order to improve its chances of survival and existence in nature. Pests and other ecosystem components, particularly humans, plants, and animals, have a variety of interactions (Arif et al., 2017). A complicated interplay between parasite and vector features, as well as how the environment influences both, determines a vector's ability to transmit an infectious disease (Burreaux et al., 2016).

Arthropod-borne viruses (arboviruses) are vertebrate-infectious viruses spread by mosquitoes, ticks, and other arthropod vectors through biological transmission (replication in the vector). They cause sporadic disease outbreaks and epidemics that affect human and animal populations around the world, posing a huge public health, social, and economic burden (Bolling et al., 2016). Insect endosymbiosis drew more attention in the 2000s, resulting in incredible findings of insect physiology, ecology, and evolution. Insect endosymbiont research, on the other hand, is limited by its intractability (Masson & Lamaitre, 2020).

The multiple problems associated with the continued use of chemical pesticides, including resistance development, insect resurgence, pesticide residue accumulation in the food chain, environmental pollution, and health risks, have led to the development of alternative pest management measures (Kidanu & Hagos, 2020). As a result, developing alternative techniques to successfully minimize pathogen transmission by insect vectors is a top concern. Abiotic and biotic variables, in addition to genetic determinants, can play a crucial role in modifying host–parasite interactions (Lazzaro & Little, 2009; Wolinska & King, 2009), according to the rapidly emerging subject of ecological immunology (Schulenburg et al., 2009). Discussing how to reduce the competence of disease vectors is the major aim of this article. Relevant studies with keywords "vector," "competence," "endosymbionts," "environment," and "insects" were reviewed.

Entomopathogenic bacteria

Endosymbiotic bacteria are thought to be present in around 50% of all insects (Buchner, 1965; Ishikawa, 2003). While many bacterial species colonize the bodies of insects, forming various levels of mutualism, only a small number of them operate as insect pathogens. Insect pathogens have developed a variety of techniques to infiltrate, overcome immune responses, infect, and kill their hosts. Biological control methods, such as bacterial entomopathogens, are generally considered to be safer than conventional chemical pesticides, and they have a number of advantages (Ruiu, 2015).

Insect bacterial endosymbionts are becoming more widely recognized as common, diverse, and important to the biology of their hosts. Heritable endosymbiotic bacteria are found in almost every insect. This means that insects without their bacteria are unable to grow and reproduce, but the symbiotic bacteria are not viable without their host (Kikuchi, 2009), implying that targeting these bacteria could prevent vectors from developing their vectorial capabilities. For example, researchers discovered that the sand fly microbiome plays a crucial role in *Leishmania* development and transmission. According to one study, eliminating the microbiota affects the intestinal environment's osmolarity, which is detrimental for the growth of *Leishmania* (Louradour et al., 2017). In addition to the local microbiota, insects carry symbiotic bacteria that live in the host's cells and tissues. These symbiotic bacteria must find tactics that allow them to tolerate the negative impacts of the host immunological defense mechanisms since they live under the pressure of an active immune system (Douglas, 2011; Gross et al., 2009; Weiss et al., 2012).

The existence of symbiotic bacteria in many insect species has been linked to increased host tolerance to diseases and parasites, according to Eleftherianos et al., (2013). The findings of this research are particularly relevant for establishing alternate ways to transgenic technologies for effective harmful insect management. *Wolbachia* and *Spiroplasma* are the most frequent facultative endosymbiotic bacteria. Insect hemolymph contains *Wolbachia* and *Spiroplasma* endosymbionts, which can interact directly with humoral immune response released molecules (Dobson et al., 1999; Haselkorn, 2010).

Wolbachia

Wolbachia, an invertebrate endosymbiont, has been utilized to restrict or modify mosquito populations as an alternate technique for arboviral control (Ferreira et al., 2020). *Wolbachia pipientis* (*Rickettsiaceae*) is a-proteobacterium endosymbiont transmitted maternally that infects at least 40% of terrestrial insect species (Zug & Hammerstein, 2012). Wolbachia was first detected in the mosquito *Culex pipiens* in 1924, causing cytoplasmic incompatibility (or CI), which causes uninfected females to become sterile when they mate with infected males (Hilgenboecker et al., 2008). This specific alteration benefits the endosymbiont, allowing *Wolbachia* to expand fast into uninfected insect populations (Hoffmann et al., 2011). The revelation that inserting specific *Wolbachia* strains into *Aedes aegypti* can increase pathogen interference was a big advance. Once the transinfection in *Ae. aegypti* is established, it is typically passed down to progeny through the mother's eggs (McMeniman et al., 2009; Xi et al., 2005). Internationally, two main *Wolbachia*-based vector control approaches have been deployed with the goal of ultimately lowering arbovirus transmission. The suppression technique, which only employs the CI mechanism, entails releasing *Wolbachia*-infected men into a population of uninfected females, resulting in sterility and mosquito population suppression. The incompatible insect technique (IIT) entails the continuous creation of millions of mosquitos as well as sex separation (male-only releases) (Ferreira et al., 2020). The second method connects the ability of particular *Wolbachia* strains to inhibit pathogens with the CI mechanism. The recent identification of a variety of symbiotic bacteria that live in the gut and/or reproductive tissues of arthropods has paved the way for novel vector-borne disease control tactics (Favia et al., 2007, 2008). Most bloodsucking insects transmit not just endosymbiotic bacteria, but also dangerous human infections such as *Rickettsia* spp., *Borrelia* spp., *Yersinia pestis*, and trypanosomes, all of which continue to have a significant impact worldwide, particularly in developing nations. Years of symbiosis and, more recently, microbiome study in insects have demonstrated that microbial symbionts can replenish restricted nutrients, aid in digestion or detoxification, and defend their hosts against antagonists, thereby increasing their ecological and evolutionary potential (Feldhaar, 2011). Over the last decade, symbiotic microbes have been the focus of research to find possible candidates for new vector control strategies.

In other insect systems, *Wolbachia*-mediated parasite interference has highlighted the intriguing idea of using them to control or limit the spread of malaria (Hadji et al., 2018). Through diverse mechanisms, *Wolbachia* has been shown to diminish the vector competence of essential arboviruses in critical mosquito species (Blagrove et al., 2012).

Insect-specific viruses (ISVs)

Viruses are known for their potential to infect and kill virtually all known living things, including people, from bacteria to plants and animals. Viruses, on the other hand, can be useful to humans in specific situations. The interaction between viruses and insects is an example of this. Insects are also attacked by a wide range of viruses, and infection can often result in the death of the infected individuals. Stollar and Thomas (1975) discovered the first insect-specific virus (ISV) nearly 40 years ago. The virus was dubbed cell fusing agent virus after it was isolated from an *Ae. aegypti* cell culture with a considerable number of syncytia. Vertical transmission, in which the virus is conveyed transovarially from infected female mosquitoes to their young, is thought to be the principal mode of ISV transmission and maintenance. Insect-specific viruses are distinguished by their inability to infect vertebrates (Ohlund et al., 2019). Insect populations are naturally regulated by several viruses, which can lead to spectacular epizootics in the field or in colonies (Myers & Cory, 2016; Szelei et al., 2011).

ISVs are thought to have the potential to be used as biocontrol agents, with effects such as superinfection exclusion, activation of the vector antiviral immune response, and transovarial transfer to maintain in nature. A new era of viral discovery has begun thanks to advances in high-throughput sequencing technology and bioinformatics tools. Arthropods are the largest animal category and have been found to be a key reservoir of many viruses, including insect-specific viruses. Mosquitoes are naturally infected with a wide range of different viruses, many of which are found within taxa occupied by arboviruses that are thought to be insect-specific (Bolling et al., 2015).

However, based on recent findings that bacterial symbionts of mosquitoes can alter the insects' vector competence for certain arboviruses (Pan et al., 2012; Ramirez et al., 2012; Zhang et al., 2013), some insect-specific viral symbionts of mosquitoes may have a similar effect, either through superinfection exclusion or alteration of the vector's immune system (O'Neal et al., 2014; Xu & Cherry, 2014). Mosquito-specific viruses could be used as biological control agents for mosquito population suppression or as innovative vaccination agents, among other things.

Viruses that naturally infect mosquitoes and reproduce in mosquito cells in vitro are referred to be "insect-specific," as they do not appear to replicate in vertebrate cells or infect humans or other mammals. Control techniques require an understanding of microbial diversity in vector mosquitoes. Insect-specific viruses have the potential to interrupt arbovirus transmission as well as serve as platforms for vaccine and diagnostic research (Bolling et al., 2015).

Entomopathogenic fungi

Entomopathogenic fungi (EPF) are myco-biocontrol agents, potentially the most flexible biological control agents with a broad host range, and an environmentally sound and effective way to reduce insect pests (Kidanu & Hagos, 2020). Fungi, unlike other possible biocontrol agents, do not require ingestion to infect their hosts; instead, they infect them directly through the cuticle (Singkaravanit et al., 2010), allowing them to be employed to control a wide range of insects, including sucking insects. Because of the prevalence of natural epizootics and the obvious symptoms associated with fungus-induced death (McCoy et al., 1988; Steinhaus, 1964), the ancient Chinese (Roberts & Humber, 1981) recognized the importance of fungi in regulating insect populations early in recorded history.

Despite having many similarities to viruses, bacteria, and other insect pathogenic microorganisms, fungal pathogens are distinct in numerous aspects (Ferron, 1978). The most major distinction is in the way they are infected. Fungi are the only major pathogens known to infect insects with sucking mouthparts in the orders *Hemiptera* and *Homoptera* (Roberts & Humber, 1981). Whereas most entomopathogens infect their hosts through the gut after consumption, fungi typically penetrate the insect cuticle.

The attachment of asexual spores to the host surface is the first step in fungal insect colonization, followed by penetration into live tissue and proliferation inside the body cavity (Vega et al., 2012). The fungus must be able to elude the animal's immune system in order to parasitize insects successfully. The fungus quickly kills the insect once it has established itself. As a result, the fungus penetrates the cuticle and enters the hemolymph of the insect, where it divides into blastospores (yeast-like asexual spores). Blastospores collect nutrients from the hemocoel and create insecticidal compounds, which cause the insect to die within days (Branine et al., 2019). Entomopathogenic fungi are important in the natural regulation of insect populations. High host specificity, low effect on non-target organisms, and easy mass manufacturing are some of the benefits of using entomopathogenic fungus in biocontainment tactics against insects and pests. *Metarhizium anisopliae* is an entomopathogenic fungus that has been shown to kill a variety of insects and pests, including termites, beetles, and locusts (Singh et al., 2017).

Entomopathogenic nematodes

Nematodes are basic roundworms with no appendages that can be free-living, predaceous, or parasitic. They are colorless, unsegmented, and lack appendages. Many parasitic organisms are responsible for serious human, plant, and animal diseases. Entomophilic nematodes refer to any association between insects and nematodes, including phoresis, parasitism, and pathogenicity. Entomogenous nematodes are parasitic worms that have either a facultative or a mandatory parasitic relationship with insects (Vashisth et al., 2013).

Entomopathogenic nematodes (EPNs) have the potential to be a non-toxic alternative to manufactured chemical pesticides, giving farmers another biological tool to use in the fight against pests while still being environmentally friendly. Above-ground insects, such as mealybugs, are likely to be relatively vulnerable to EPNs, as the latter represent a novel predator threat against which mealybugs have not evolved defenses. EPNs are often utilized in greenhouses and shade houses, where the growing conditions are generally favorable (Platt et al., 2020). Entomopathogenic nematodes of the families *Steinernematidae* and *Heterorhabditidae* are symbiotically connected with bacteria of the genera *Xenorhabdus* and *Photorhabdus*, respectively. They have a lot of potential when it comes to insect pest control. In laboratory and field tests, these nematodes can infect and kill a wide range of insect species, particularly those belonging to the Lepidoptera, Coleoptera, and Diptera orders (Laumond et al., 1979; Poinar, 1979).

EPNs have a unique set of characteristics that make them an attractive pest management option. The third-stage infective juveniles (IJs) start the parasitic cycle of worms. These non-feeding juveniles use natural body holes to find and infiltrate suitable host insects (i.e., anus, mouth, and spiracles). Entomopathogenic nematodes' symbiotic relationship with particular bacteria improves nematode reproduction (bacteria serve as food) and pathogenicity. Although axenic nematodes (nematodes without bacteria) can sometimes kill their hosts, they rarely reproduce. Furthermore, bacteria are incapable of penetrating the alimentary canal or gaining access to the hemocoel of the host on their own. As a result, nematodes serve as vectors, transporting bacteria into a host where they can multiply, and the bacteria establish the circumstances for nematode survival and reproduction within the insect carcass. The bulk of entomopathogenic nematode-based applications are for inundative biological control. They've been found to be most effective for insects in soil or cryptic environments where they're protected from quick desiccation and UV exposure (Grewal et al., 2001). EPNs are one of the most effective biocontrol agents for a variety of economically important insect pests. Operator and end-user safety, the absence of waiting periods, reducing the treated area by monitoring insect populations, minimum damage to natural enemies, and lack of environmental contamination are only a few of the advantages they have over chemical pesticides.

EPNs are soil-dwelling, fatal insect parasites that belong to the Phylum *Nematoda* and the families *Steinernematidae* and *Heterorhabditidae*, respectively, and have been shown to be the most efficient biological control agents for soil and above-ground pests (Kaya & Gaugler, 1993; Laznik et al., 2010). The choice of an EPN to manage a certain pest bug is dependent on a number of parameters, including the nematode's host range, host seeking or foraging behavior, environmental toleration, and the effects of environmental conditions on survival and efficacy.

Although most biological agents take days or weeks to kill their hosts, nematodes can frequently kill insects in 24–48 h (Gozel & Gozel, 2016). Infectious juveniles (IJs) can track down their hosts by detecting insect excretory products, carbon dioxide levels, temperature gradients, and host movement. The IJs then enter the host by natural openings such as the mouth, anus, or spiracles, while heterorhabditid IJs have a tooth that allows them to enter the host through the cuticle of certain insects. They release germs into the hemocoel, which grow and kill the host through septicemia (Georgis, 1992).

Entomopathogenic protozoa

Entomopathogenic protozoans, also known as microsporidians, are a varied collection of organisms that attack invertebrates, including insect species. Protozoa are generally host-specific and slow-acting, causing chronic infections and broad host debilitation. As inundatively applied microbial control agents, infection results in reduced eating, vigor, fertility, and longevity of the insect host (Sarwar et al., 2021).

Nutrition

The fact that "stressed" animals are more sensitive to entomopathogens than non-stressed animals is one of the most significant concepts in microbial management (Steinhaus, 1958; Vago, 1963). While many factors are thought to stress insects and predispose them to entomopathogens (e.g., crowding, nutrition, chemical stressor exposures, and environment), the physiological mechanisms of stress (i.e., a suppressed immune response) and the influence of many environmental parameters on the physiological predisposition of insects to entomopathogens are still poorly understood. Insect nutrition is a critical element in regulating insect sensitivity to entomopathogens, and it is often disregarded in disease progression. Inadequate nutrition can increase vulnerability to entomopathogens, and using resistant plant genotypes to generate nutritional stress can significantly increase entomopathogen efficacy. Insect pests' vulnerability to entomopathogenic hyphomycetes can be reduced by changing their diet (Inglis et al., 2001).

Transmission-blocking vaccines (TBVs)

Because insecticides are largely used to reduce insect vector populations, the rise of insecticide resistance as well as unexpected consequences of pesticide use offers substantial hurdles to their continued use. Transmission-blocking vaccines, which are regarded to be a viable option for reducing pathogen burden in endemic areas, have been tried as novel approaches to prevent pathogen transmission by disease vectors. TBVs work by targeting molecule(s) expressed on the surface of pathogens during their developmental phase within the insect vector or by targeting molecules expressed by the vectors to limit pathogen transmission from infected to uninfected vertebrate hosts. TBVs try to stop transmission to non-infected vertebrate hosts by interfering with and/or preventing pathogen growth within the vector (Iliano et al., 2010).

Environmental manipulation

One of the new tactics developed to combat the threat of vectors is environmental management for vector control. Abiotic factor manipulation has received widespread support as a result of laboratory and semi-field studies and findings. Planning, organizing, carrying out, and monitoring operations for the modification and/or manipulation of environmental elements or their interaction with man to avoid or minimize vector propagation and reduce man–vector–pathogen contact are all part of vector control activities (Ault, 1994; Bond et al., 2004; Randell et al., 2010).

Environmental modification entails making permanent or long-term physical changes to land, water, and vegetation with the goal of preventing, removing, or reducing vector habitats without compromising the quality of the human environment. Any planned repeated effort aiming at establishing temporary conditions adverse to vector breeding in their habitats is referred to as environmental manipulation. Water salinity adjustments, stream flushing, reservoir water level regulation, dewatering or flooding of marshes or boggy areas, vegetation removal, shade, and exposure to sunshine are among the strategies involved (Ault, 1994).

Environmental manipulation approaches, on the other hand, have not been fully exploited, particularly in terms of altering vital developmental components/factors of the vector's environment in order to reduce biological fitness. Such strategies are promising because they always target the vector's weakest link (larvae) during development. In recent years, there has been a renewed interest in environmental management strategies, fueled in part by worries about the long-term effectiveness and environmental effects of insecticide use. For example, understanding that outdoor application of insecticide often has poor penetration into the domestic resting sites of the vectors, has only transient effects, and is logistically demanding has been a major motivation for controlling dengue by removing, covering, or treating larval sites in and around houses. The success of environmental management is determined by how well the intervention is tailored to the disease's ecology (Newton & Reiter, 1992). A complicated interplay between parasite and vector features, as well as how the environment influences them, determines a vector's ability to spread an infectious disease. Rising temperature, for example, is expected to allow the parasite to develop more quickly inside the mosquito (Paaijmans et al., 2012; Lefevre et al., 2013; Thomas & Blanford, 2003), but it may also reduce the parasite's chances of surviving its developmental period (Paaijmans et al., 2012; Okech et al., 2004), and it may shorten vector longevity (Beck-Johnson et al., 2013), due to a combination of parasite survival and the proportion of survivors carrying sporozoites. Both features were impacted by the larval environment. The size of the mosquito played a role in some of these impacts. Both malnutrition and high temperatures resulted in smaller adults (as is common in invertebrates) (Horne et al., 2015).

Discussion

With over 1,200,000 species, the *Insecta* are considered the most varied animal group. Endosymbiotic partnerships can range from compulsory mutualism to facultative parasitism in the *Insecta*, which is frequently regarded as the most diversified animal group. Endosymbiosis was coined in 1953 by German entomologist Paul Buchner to describe a "well-regulated and generally undisturbed cooperative living between two differently structured partners." Buchner (1965) proposed that there are two types of endosymbionts in insects: obligatory (also known as primary endosymbionts or P-symbionts) and accessory (also known as secondary endosymbionts or S-symbionts) (currently termed facultative endosymbionts, secondary endosymbionts or S-symbionts). The primary endosymbionts are found in all specimens of a species and are always transferred transovarially (that is, maternally) from one generation to the next. Secondary endosymbionts can spread horizontally, vertically, or through the air (Eleftherianos et al., 2013). Many plants and animals have symbiotic bacteria inside their bodies, where the partners have intimate interactions. Primary symbionts live in specialized host cells called bacteriocytes, which can be arranged into more complex tissues to form a bacteriome (Baumann, 2005).

Paratransgenesis, or the creation of modified symbionts expressing antiparasite compounds, is a method of using symbiotic bacteria to control vector-borne diseases (Coutinho-Abreu et al., 2010). Durvasula et al., (1997) used a "paratransgenic strategy" to control *Trypanosoma cruzi* transmission by manipulating the genetics of the symbiotic bacterium *Rhodococcus rhodonii*. "Paratransgenesis" is a recently proposed scientific idea in which a host organism is modified physiologically, ecologically, or behaviorally by transgenesis of its symbiotic bacteria rather than genetic alteration of the organism itself (Beard et al., 2002).

Maire et al. (2020) study reveals the endosymbiont's complex journey during its host's metamorphosis through a combination of bacteriocyte-mediated translocation along the gut and active infection of epithelial stem cells by the symbiont. The presence of primary endosymbionts appears to be essential, as they are required for both host insect survival and reproduction. Secondary endosymbionts, unlike primary endosymbionts, can live not only in bacteriocytes but also in other cells (such as fat body cells) or even free in the hemolymph (Fukatsu et al., 2000; Moran & Telang, 1998; Oliver et al., 2006, 2010).

EPF that kill insects, like *Beauveria bassiana* and *M. anisopliae*, have been shown to be very good at controlling vector mosquito populations. Therefore, integrated vector management strategies have the potential to utilize them. Renuka et al., (2023) found that EPF effectively reduced the survival rate of adult mosquitoes of the *Anopheles stephensi* species.

According to El-Sadawy et al., (2020), EPNs, along with their symbiotic bacteria, are efficient biocontrol agents for managing sand fly larvae. Furthermore, Cardoso et al. (2015) documented the mortality rate of *Ae. aegypti* third and fourth stage larvae upon exposure to IJs of *Heterorhabditis indica*. Nematodes offer a number of benefits, including the fact that EPNs and their associated bacterial symbionts have been shown to be safe for warm-blooded vertebrates, including humans (Boemare et al., 1996; Poinar et al., 1982).

Several strains of the genus *Wolbachia*, a dominant endosymbiotic bacteria of various insects including significant vectors of zoonotic infections, are among the most promising choices, according to the scientific community. Indeed, *Wolbachia* is a maternally inherited pathogen that can infect mosquitos' reproductive organs in order to self-sustain in host populations, as well as somatic tissues where pathogens proliferate and compete with them. As a result, it is a fascinating biological control agent that can be utilized to halt or prevent the spread of various vertebrate infections to people and domestic animals (Shaw et al., 2016). The potential for *Wolbachia* to be used as an effective new vector control tool is significant (Ferreira et al., 2020). In order to understand the biological impacts of symbionts in host–endosymbiont interactions, one of the most important parameters to consider is their infection density (Dossi et al., 2014).

Indeed, mosquito-borne bacterial symbionts can cause disease in their hosts (Schnepf et al., 1998), interfere with reproduction (Zabalou et al., 2004; Zchori-fein et al., 2001), and diminish vector competence (Beard et al., 2001). One of the most pressing questions is whether the presence of additional viruses in the mosquito vector affects the vector's ability to transmit disease (Parry & Asgari, 2018).

The increased interest in and finding of the mosquito microbiome's diversity has provided fresh insights into the complicated nature of vector-borne illness systems. In vitro and in vivo studies of recently discovered insect-specific viruses have revealed a new class of viruses that are host-restricted to invertebrate cells, as opposed to arboviruses, which can reproduce in both vertebrate and invertebrate cells.

The goal of environmental manipulation is not to eradicate insects from the earth's surface, as is frequently advocated, but to identify the environmental factor(s)/variable(s) that contribute to their success and manipulate them to the point of producing mosquito species that are not suitable as disease vectors (Christian et al., 2021). Wilson et al., (2020) discussed various instances where environmental management was employed to regulate *Anopheles* mosquitoes, effectively curbing the transmission of malaria in both local and urban environments.

Conclusions

Disease vectors can be regulated in a variety of ways, according to this review paper. It has been demonstrated that the use of several Entomopathogens can help to control these vectors. There are, however, significant gaps in lowering vector competency that could be filled by doing several studies in this field.

Abbreviations

CI	Cytoplasmic incompatibility
IIT	Incompatible insect technique
ISVs	Insect-specific viruses
EPNs	Entomopathogenic nematodes
EPFs	Entomopathogenic fungi
UV	Ultraviolet
IJs	Infectious juveniles
TBVs	Transmission-blocking vaccines

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