

The role of *Aedes* mosquito in yellow fever virus transmission and its control in Africa: A review

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Abstract

Introduction: Many nuisances and potential transmitters of human and animal infections including *Aedes* mosquitoes are distributed in different biotopes of the world. The female *Aedes* mosquitoes are commonly vectoring arboviruses by simply extracting blood from people, birds, and other animals to obtain proteins needed to develop their eggs. Yellow fever (YF), Dengue fever, Chikungunya fever, Rift Valley fever, and Zika virus disease are among the vector-borne diseases. Understanding the competent vectors and the transmission cycle of the yellow fever virus is the first step in collecting evidence since it provides a suitable contribution for control strategies in different contexts.

Objective: The main objective of this paper was to review the role of *Aedes* mosquitoes in yellow fever virus (YFV) transmission and its control in Africa.

Methods: Searches were conducted in the indexers of scientific articles from PubMed (<http://www.ncbi.nlm.nih.gov/pubmed>) and sciELO (<http://www.scielo.org>) using the combination of the terms: “*Aedes* and Yellow fever virus transmission, competent vectors of Yellow fever, Transmission of Yellow fever in *Aedes* mosquitoes population, Role of *Aedes* and its species in yellow fever transmission and Yellow fever virus control and its methods”.

Conclusion: The circulation of YFV in the tropical regions of Africa relies on distinct hosts and vectors, which can be in sylvatic, rural, or urban transmission cycles. The transmission of the virus among humans is associated with the presence of vectors and an unvaccinated population. The vectorial role can be influenced by the density, longevity, and competence of the vector and associated environmental, behavioral, cellular, and biochemical factors. *Aedes aegypti*, *Aedes africanus*, *Aedes luteocephalus*, *Aedes bromeliae*, *Aedes furcifer* and *Aedes taylori* have been shown to be the main vectors of yellow fever. The two core control strategies of yellow fever are vector control which requires a constant effort wherever the risk of vector development is high and immunization /vaccination of populations at risk. Chemical, biological and environmental sanitation are the best and most frequently used control methods in Africa. Integrated control taking into account sanitation and associated with other vector-borne diseases, is cost-effective and should be favored.

Keywords: *Aedes* mosquito; yellow fever; viral transmission; control, Africa

Introduction

Mosquitoes, many nuisances and potential disease transmitters of human and animal infections are distributing and occupying many biotopes globally (Patrick et al. 2018). Many viruses transmitted by these mosquitoes are affecting humans and animals (Leta et al. 2018). Of all mosquitoes, *Aedes* is considered one of the most relevant groups of mosquitoes in public health and got attention because of their role in the transmission of many arboviral diseases, causing large-scale outbreaks throughout the world (Mint et al. 2017). Yellow fever virus (YFV), Dengue virus (DENV), Chikungunya virus (CHIKV), Rift Valley fever virus (RVFV), and Zika virus (ZKV) are among these vector-borne diseases (Owino 2018). The viruses can be transmitted through the bite of infected mosquito vectors during a blood meal on humans and by handling the tissues and body fluids of

infected patients (Patrick et al. 2018). Members of the *Aedes* genus are known vectors for numerous viral infections. *Stegomyia* is the most important subgenus of *Aedes* under subgenera of mosquitoes from the standpoint of the transmission of pathogens (Chimaeze et al. 2018). *Aedes* mosquitoes are common vectors of arboviruses. The female *Aedes* acquires and transmits the virus by simply extracting blood from people, birds, and other animals to obtain proteins needed to develop her eggs (Morris et al. 2016). These *Aedes* activities indicate that the viruses have zoonotic importance, having major consequences for public health and economic productivity (Owino 2018). Many of them cause severe and potentially fatal illnesses in humans. The outbreaks of arboviral diseases, the rapid spread, and increasing challenges in Africa are posed by mosquito-borne viruses. This

constitutes serious health, economic and social problems (Cornel et al. 2018). The circulation of YFV currently in the tropical regions of Africa is primarily maintained through a sylvatic cycle between non-human primate hosts and sylvatic mosquito vectors. In Africa, the frequency of epidemics and the adaptation of the YFV to its hosts and vectors argue for an older presence. Based on the resemblance of their respective vector, there are five genotypes of YFV in Africa. Strains of West African genotype I, from West African genotype II from Senegal, Nigeria, and Ivory Coast (Lindern et al. 2006), east African genotype from Kenya and Uganda, east/central African genotype from Democratic Republic of Congo, Uganda, Ethiopia and the Central African Republic and Angolan genotype (Mutebi et al. 2001). YFV transmission relies on distinct hosts and vectors in the Old World (Africa) which can be sylvatic, rural, or urban, with occasional large outbreaks in urbanized regions. The sylvatic vectors of the *Aedes africanus* group and other *Aedes* species belonging to several subgenera and non-human primates (reservoir hosts) are responsible for the transmission of the YF (Klitting 2018).

High transmission of the YF virus among humans is associated with the presence of vectors and unvaccinated populations (Alhakimi et al. 2015). Sporadic YF infection occurs almost exclusively in forestry and agricultural workers because of occupational exposure (Eni et al. 2014). High densities of mosquito vectors (*Aedes* and *Haemagogus*) closer to human dwellings and reservoir hosts within unvaccinated and highly populated areas are also other factors expanding the geographical spread of this virus (WHO 2014). *Aedes* mosquito, the vector of YFV originated in Africa where numbers of primate species are infected (Clements and Harbach 2017). The capacity of disease transmission can be determined by the degree of anthropophilic (Nnanna et al. 2016). The vectorial capacity of the *Aedes* mosquito species is used to determine the ability of the mosquito to serve as a disease vector. The vectorial role can be influenced by the density, longevity, and competence of the vector (Agampodi and Wickramage 2013). In addition, associated environmental, behavioral, cellular, and biochemical factors influence the association between the virus and host (Carver et al. 2009). Competent *Aedes* mosquitoes determine the establishment of a local YF transmission cycle outside endemic areas. This is due to active *Aedes* mosquitoes all year long in tropical regions and during the warm period in temperate areas (Couto-lima et al. 2017). In genus *Aedes*, for example: in terms of transmission potential, sylvatic-cycle vectors are more efficient than those of the urban cycle (Amraoui et al. 2016).

Some species, for example, *Ae. albopictus* are anthropophilic in nature, and they are densely populated in urban areas which allows them to be a vector of YFV (Amraoui et al. 2016). During YF outbreaks, *Ae. aegypti*, *Ae. africanus*, *Ae. luteocephalus*, *Ae. bromeliae*, *Ae. furcifer* and *Ae. Taylori* is the main vector. Some other species play a secondary role, while the other species play subsidiary roles (WHO 2014). Understanding the competent vectors and the transmission cycle of YF in the occurrence of outbreaks is the first step of collecting evidence since it provides a suitable contribution for control strategies in different contexts. The two core control strategies of YF are vector control which requires a constant effort wherever the risk of vector development is high and immunization/vaccination of populations at risk based on selective strategy (Barro et al. 2011). Integrated control taking into account sanitation and associated with other vector-borne diseases, is cost-effective and should be favored (Tomor 2002).

The main objective of this paper was to review the role of *Aedes* mosquitoes in yellow fever virus transmission and its control in African regions. This review is focused on the African continent to show varying vectorial competencies of *Aedes* species for YFV transmission.

Review methods

Various ecological studies focused on YFV transmission in addition to the major responsible vectors and what control methods are being performed in African regions were systematically reviewed. The differences in transmission of the virus with different mosquito species have also been well reviewed in published documents. Combining the evidence from cross behavior/distribution and YFV transmission within the *Aedes* mosquito population, a generalization of the previous study's findings in Africa was selected and reviewed to explain the transmission of YF by this vector. Searches were conducted in the indexers of scientific articles from <http://www.ncbi.nlm.nih.gov/pubmed>, <http://www.scielo.org> using the combination of the terms: “*Aedes* and yellow fever virus transmission, competent vectors of yellow fever in African regions, Transmission of yellow fever in *Aedes* mosquitoes population, Role of *Aedes* and its species in yellow fever transmission in Africa and Yellow fever virus control and its methods.” All the studies conducted in Africa and published in high-impact journals in English were read, evaluated, and organized by mosquito species as well as the location from where the samples were collected. To avoid the inadvertent exclusion of any studies by using these pre-determined

keywords, manual searches of the articles cited in the reference lists were also conducted to include the largest possible number of publications. Subject related data that were published between 1899 and 2020 were extracted to be included for this review only from Africa. All articles were grouped according to the species of *Aedes* mosquitoes by location responsible for the transmission of yellow fever in Africa. Articles found were searched for the descriptions of the original research articles about *Aedes* mosquito's roles in YF virus transmission. Additionally, All World Health Organization reports, guidelines, and archives were considered online through a Google-based search on the subject matters.

Discussion

Yellow Fever (YF) burden in Africa: Yellow fever (YF), is a deadly viral disease caused by *Flaviviridae* (Bacha and Gustavo 2017). The disease became a major problem in the colonial settlements of the Americas and West Africa in the 1700s and was repeatedly introduced to seaports of the United States and Europe during this time (NaTHNaC 2018). The disease symptoms include jaundice, enlargement of the liver, and in several cases, hemorrhage (Bacha et al. 2017). According to viral genome sequence analysis, YFV originated in Africa about 3,000 years ago. In 1648, the earliest record of an epidemic was in the Yucatan in Mexico which then spread to other countries through the slave trade (Owino 2018) and is maintained in enzootic cycles involving monkeys and mosquitoes in 34 countries of Africa (Wilder-smith et al. 2017).

YF is known to be endemic in tropical and subtropical areas of South America and Africa. As of the annual WHO estimate, 90% of the infections occur in Africa from overall 200,000 cases of YF and 30,000 deaths (Nnanna et al. 2016). The number of YF cases has been increasing since 1980s, which can be attributed to improved surveillance systems and better access to laboratory services (Alhakimi et al. 2015). For example, between 1984 and 1990 about 22,647 cases were reported from Africa, of which 21,299 were from Nigeria (Braack et al. 2018). In the year 2013, the estimated number of YF burdens in Africa was 130,000 cases and 78,000 deaths. In the same year, 230 cases of YF (including 85 deaths) were reported to WHO from four African countries: Ethiopia, Sudan, the Democratic Republic of Congo (DRC), and Cameroon. In 2014, seven cases and two outbreaks were reported from DRC (ECDC 2016). An ongoing yellow fever epidemic has been reported in Angola since December 2015 and an outbreak was officially declared in January 2016 by WHO. In 2016, 884 cases and 373 deaths were reported. The disease spread to

Kenya and the DRC (Wilder-smith et al. 2017). In DRC 76 cases and 16 deaths were recorded in the year 2016. Seven confirmed cases from Uganda, four cases from the Republic of Congo, two cases from Sao Tome and Principe, one case from Ethiopia, four sylvatic considered cases from Ghana, and 39 confirmed cases from Guinea were reported within the same year (WHO 2016).

Role of *Aedes* Mosquito in YF Transmission in Africa: Across regions of Africa, the vectors and associated ecological patterns of YFV transmission is different (Monath and Vasconcelos 2015). Historically, dynamic interest in the mosquitoes of Africa has been derived from their ability to thrive mostly in the tropics and act as the vectors of the most debilitating human diseases caused by bio-agents (Cornel et al. 2018). The two most prominent vectors of YFV are *Ae. aegypti* and *Ae. albopictus* which also transmit Zika, Dengue fever, West Nile fever, Chikungunya, and Eastern equine encephalitis (Calderón-arguedas et al. 2016). During the 16th century, the YFV and its mosquito vector were transported on ships sailing from West Africa to the West Indies (Chippaux and Chippaux 2018). Generally, humans may become infected by exposure to vectors that have acquired infection from monkeys (Ortiz-martínez et al. 2018;).

In Africa, nearly all mosquito species implicated in YFV transmission belong to the genus *Aedes* (subgenera *Stegomyia* and *Diceromyia*) (Diallo et al. 2014). The major *Aedes* mosquito species transmitting YF include *Ae. aegypti*, *Ae. africanus*, *Ae. luteocephalus*, *Ae. simpsoni* complex, *Ae. fuscifer*, *Ae. taylori* (Chimaeze et al. 2018) and *Ae. vittatus* (belong to subgenus *Aedimorphus*) (Chimaeze et al. 2018). In parts of Africa (East Africa), during the YF epidemic, the current most important vector is *Ae. Simpsoni* sensulatu (s.l.) like *Ae. bromeliae*, which was the principal vector during the largest recorded epidemic of yellow fever in Ethiopia between 1960 and 1962 (Ellis et al. 2012). YFV is maintained in three transmission cycles (**Figure 1**). In the urban cycle, YFV is circulated between humans by domesticated *Ae. aegypti*. In the sylvatic cycle, the virus is maintained by tree hole-breeding *Ae. africanus* mosquitoes feeding on monkeys (Walter et al. 2014).

Urban transmission of YF: *Aedes aegypti* mosquito is a tropical primary vector of urban YFV that has recently established itself in many geographic locations due to globalization and a warming climate (Conway et al. 2014). In the tropics of Africa and America, *Ae. aegypti* largely feeds blood on humans and is a classical vector of urban YF (Swapnil et al. 2017). *Ae. Aegypti* is domestic and genetically distinct

with discrete geographic niches originating in Africa from its ancestral line *Ae. Aegypti formosus*, is a zoophilic tree hole mosquito (Braack et al. 2018). Due to anthropophilic, endophagic, and endophilic behavior, *Ae. aegypti* is a domestic mosquito (Dickens et al. 2018). The vectorial capacity of *Ae. aegypti* is influenced by the density, longevity, and competence of the vectors. Moreover, the association between the virus type and host is influenced by environmental, behavioral, cellular, and biochemical factors (Agampodi and Wickramage 2013). Though the population of *Ae. aegypti* occurs throughout the tropics and subtropics, the ability to transmit disease varies from place to place (Hurk et al. 2011). For instance, across sub-Saharan Africa, some *Aedes* mosquito populations are less strongly human-associated, being found in forests, ovipositing in tree holes, and feeding on other mammals (Faraji et al. 2014); whereas other populations are domestic, breeding in water in and around homes and feeding on humans (Masaninga et al. 2014). Outside Africa, *Ae. aegypti* has a strong genetic preference to feed on human blood in the houses (Kothera et al. 2017). They also can survive and oviposit in relatively clean water in manmade containers in the human environment (Agha et al. 2017). After YFV is introduced to humans, inter-human transmission can be sustained, amplified, and transmitted in dry habitats and urban areas where water is stored in containers by the domestic *Ae. aegypti* (Hanley et al. 2013). The genetic factors and inherent tolerance of the vector ensure viral transmission, infection, and replication (Agampodi and Wickramage 2013).

In the urban cycle, the deadliest form of disease spread, potentially linking thousands of human cases is transmitted from human to human as a result of *Ae. Aegypti* (Mutebi and Barrett 2002). The *Ae. Aegypti aegypti* is highly domesticated and often found in close human dwellings especially in urban settings, as opposed to the more zoophilic genetic form *Ae. Aegypti formosus* (Agha et al. 2017). In West Africa, the domestic mosquito, *Ae. Aegypti aegypti*, was found experimentally to be a relatively inefficient vector of the virus for the epidemic spread of YFV. The anthropophilic nature of this species combined with its high densities in urban areas enables it to overcome its low vectorial capacity (Hanley et al. 2013). Within the sylvatic cycle, *Ae. Aegypti formosus* is involved in the transmission of YF in non-human primates (Chippaux and Chippaux 2018). In urban cycles, larger outbreaks of YFV and further spread of YFV to dry in more populated areas are by highly anthropophilic, *Ae. aegypti* and its transovarial transmission (Klitting 2018). The virus is received from the sylvatic cycle featured by the wild mosquito. Sylvatic YFV has

emerged from the sylvatic vectors into urban transmission and cycles among humans (Bennett et al. 2015).

Sylvatic Transmission of YF: *Ae. africanus* is the dominant species that are found in forest areas and forest galleries of the savannah regions of East and Central Africa. Its distribution is more localized in West Africa (World Health Organization (WHO) 2014). *Ae. africanus* is primatophilic, very aggressive to humans, and bites preferentially in the forest canopy and ground level (Ryan et al. 2017). In the great rainforests of central Africa and extending outward along with riverine forests (Hanley et al. 2013), the main role of *Ae. africanus* mosquitoes are serving as the primary vector of sylvatic YFV transmission (Masaninga et al. 2014). *Aedes africanus* is associated with sylvan habitat throughout Africa that breeds in water-filled tree holes, stump holes, and cut bamboo in the forest and artificial containers. In some locations of Africa, for example, Nigeria, *Ae. africanus* is commonly found in villages in addition to forest habitats. This raises the possibility that some populations of *Ae. africanus* are better adapted to domestic environments (Bennett 2015). Including *Ae. africanus*, there are other species involved in YF transmission are *Ae. opok*, *Ae. metallicus*, *Ae. bromeliae*, *Ae. vittatus*, *Ae. luteocephalus*, *Ae. taylori*, *Ae. furcifer* and *Ae. simpsoni* complex (Dickson 2014). The natural breeding sites of all these species are the same rain waters with common primatophilic feeding habits and host-seeking behavior in the forest canopy (Hanley et al. 2013). In West and Central Africa, under laboratory conditions, *Ae. africanus* is an efficient YF vector and the virus has also been isolated from natural populations. *Ae. africanus* will readily bite man within the forest at ground and canopy level and near human settlements (Huang 1990). It is found to bite humans in and outside of houses and is described as anthropophilic in Africa. It is also known to feed on monkeys and is crepuscular in its biting activity through moving from ground level to the canopy (Bennett 2015).

In central Africa, *Ae. opock* could be considered a major YF vector because of its high densities, which sometimes exceed that of *Ae. africanus*. *Ae. pseudoafricanus* and *Ae. neoafricanus*. These (the later) species are involved in the wild cycle of transmission but tend to play a minor role because of their rarity (PAHO 2005). *Ae. opock* is found in the forested regions of central Africa and participate in the local spread of the virus, displaying similar transmission dynamics with limited sporadic human cases with *Ae. africanus*. As in Central and East Africa, both species remain the main sylvatic vector for YFV in West Africa (Klitting et al. 2018).

Savannah Transmission of YF: The intermediate or savannah cycle involves tree-hole breeding mosquito species (Muktar et al. 2016) such as *Ae. luteocephalus*, *Ae. furcifer*, *Ae. metallicus*, *Ae. opock*, *Ae. taylori*, *Ae. vittatus* and members of the *Ae. simpsoni* complex (Amraoui et al. 2016) spread to humans living or working in jungle border areas in Africa (Muktar et al. 2016). *Ae. luteocephalus* is another species of the subgenus *Stegomyia*, which is morphologically similar to *Ae. africanus*. It is simio-anthropophilic that has a crepuscular behavior and takes blood meals at the canopy, but occasionally bites on the ground. This species is abundant in forest habitats and may be present in very rare situations in the villages surrounding the forest. It is one of the major vectors of YF in West Africa and has been confirmed in various outbreaks (WHO 2014).

Aedes vittatus plays an important role in the maintenance and transmission of YF as an important vector in Africa (Ngoagouni et al. 2012). Because of its abundance, anthropophilic behavior, and high susceptibility and competence to transmit YFV, *Ae. vittatus* poses a major threat to public health in Africa. Throughout tropical regions of Africa, Asia, and the Mediterranean region of Europe, *Ae. vittatus* mosquito is a hungry biter of humans and predominantly a rock-hole breeder as well in diverse macro- and micro-habitats (Sudeep and Shil 2017). *Ae. vittatus* has the potential to expand its distribution and abundance due to its ability to adapt to human dwellings using available breeding habitats, such as domestic containers, in absence of its preferred breeding sites (Mulwa et al. 2018). In Africa, *Ae. vittatus* is predominantly found in the canopy (sylvatic), forest ground, or peri-domestic in rural (Diallo et al. 2012). Experimentally, it has been implicated as an important and potential vector of YFV in several African countries. In most African regions, several isolations of the virus from *Ae. vittatus* mosquitoes have been made and the high susceptibility of this mosquito to yellow fever is confirmed. The infected mosquito has been successfully capable of demonstrating the transmission of yellow fever to monkeys (Sudeep and Shil 2017). *Ae. simpsoni* consists of a complex of mosquito species responsible for YFV transmission (Mulwa et al. 2018). According to studies, there are three sibling species of the *Ae. simpsoni* group: *Ae. simpsonisensustricto*, *Ae. bromeliae* and *Ae. Lillii* (Jupp and Kemp 2002). The role of these sibling species in YF virus transmission has also been clarified. *Ae. lillii* does not play a role in the YF virus transmission to humans because of its zoophilic tendency (WHO 2014) and is found distributed from Southeast Sudan to western Ethiopia crossing from south to northern Uganda. This species is relatively

uncommon compared to *Ae. bromeliae* and has only been reported from leaf axils of *Sanseuieria spp.* in Uganda (Bennett 2015).

Aedes simpsoni.s.l. breeds in plant leaves and tree holes which are abundant in forests, and transition areas of forest and savannah with heavy rainfalls. *Ae. simpsoni* is restricted to Southern Africa is known to bite men. According to precipitin analysis, all blood meal samples from *Ae. simpsoni.s.l.* were of mammalian origin (WHO 2014). In 1941, in Uganda, *Ae. simpsoni* was responsible for the transmission of the yellow fever virus during the outbreak of YFV. The virus has also been isolated from wild-caught mosquitoes in this country. Among the three species of *Ae. simpsoni*, *Ae. bromeliae* is an important vector of yellow fever virus and potentially other arboviruses in East Africa (Bennett et al. 2015). In Central Africa, *Ae. bromeliae* is a suspected vector of the YF virus because of its close interaction with humans (Diallo et al. 2000). This mosquito is highly aggressive during the afternoon and sometimes bites at dusk and early in the morning. In West Africa, *Ae. bromeliae* is prevalently distributed with zoophilic behavior; it does not seem to play a role in YF transmission to humans (Legesse et al. 2018). The natural breeding sites of *Ae. bromeliae* are plant leaves, tree holes, fruit husks, and containers in the domestic and peri-domestic environment (Clements and Harbach 2017). *Aedes bromeliae* preferably feed on human hosts for their blood meal, maintaining the virus in the rural cycle in East Africa (Mulwa et al. 2018).

Control strategies: Strategies for the prevention of YF infections depend on either control of vectors or active immunization of the population with the vaccine (Huang et al. 2019). Both vector surveillance and control are components of the prevention and control of vector-borne diseases transmission. This is an important step in *Aedes* mosquito control operations through identifying the types and abundance of containers producing mosquitoes (CDC 2017). Using pesticides is an integral part and the most immediate method of controlling mosquitoes (PAHO 2005). The best long-term controls for the *Aedes* mosquito can be changed from chemical-based control to non-chemical approaches because of the lack of environmental safety and resistance. Pesticides should serve as a supplement to these control methods since it is the only practical technique to manage massive mosquito outbreaks or to reduce the threat of disease (Tomor 2002). Traditionally, mosquito killing using a lot of chemicals or insecticides is a major vector control (Benelli et al. 2016). Space spraying, residual spraying, barrier spraying, and using attractive toxic baits are chemical control methods used for adult mosquitoes (Muktar et al. 2016).

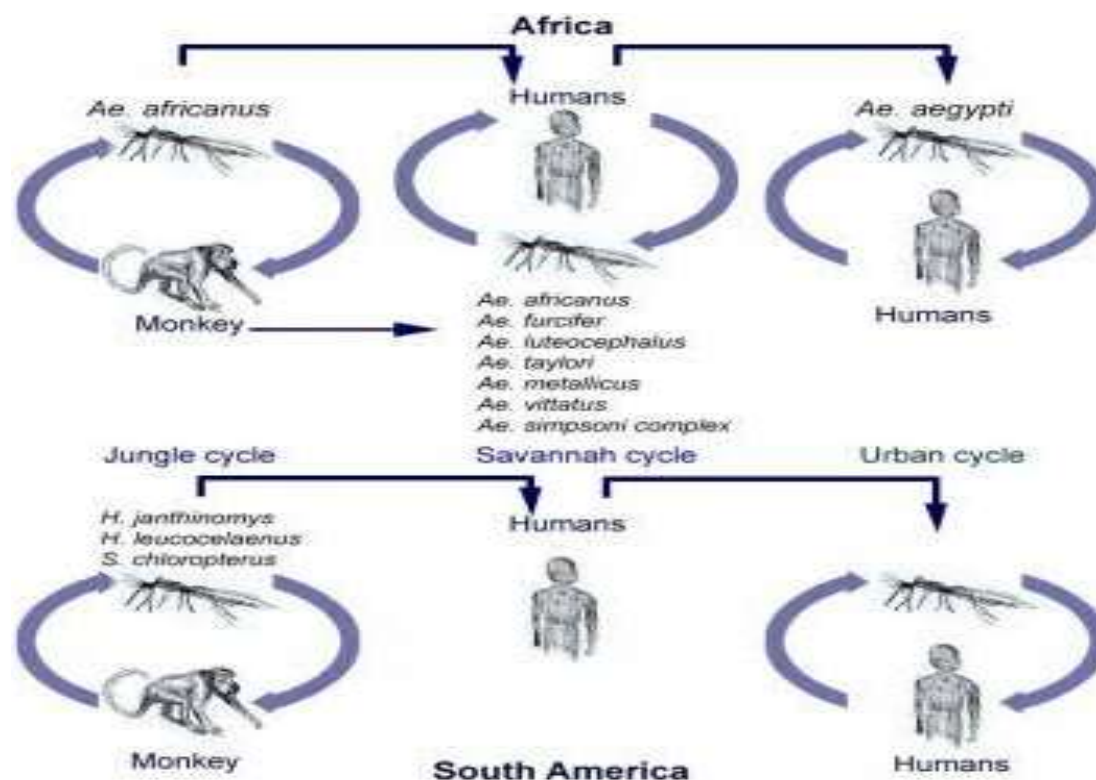


Figure 1: The Transmission cycles of yellow fever virus (YFV) and its respective responsible vectors in Africa (Huang et al. 2014)

Placing chemicals or other control agents in mosquito breeding habitats for the killing of immature (larvae) i.e. larviciding is effective and environmentally safe. Many of these products use either bacterial toxins or insect growth hormones to kill the larvae or block their development (Goddard 2016).

Environmental management as the reduction or removal of mosquito breeding sites (Sarwar 2014) has often been used together with chemical or microbiological control strategies in areas where endemic mosquito-borne diseases occur (CDC 2017). Because of the development of insecticide resistance, the damage to the environment and effects on non-target organisms are becoming a concern that limits the use of synthetic insecticides (Benelli et al. 2016). It is therefore not surprising that interest in alternative non-chemical strategies has increased over the last decades. Environmental sanitation involves the elimination of containers producing *Aedes* by various means (Muktar et al. 2016). Within the adult population, suppression of vector population is the best method that aims to reduce the number of disease-transmitting mosquitoes by substituting wild-type

mosquitoes with ones that have impaired vector competence to block pathogen transmission. For instance, *Wolbachia* (safe for human and the environment) is an extremely common bacteria that occur naturally in insect and is the best to suppress mosquitoes. Entomo-pathogenic fungi which are naturally occurring organisms that are pathogenic to mosquitoes can also be considered for biological control strategies (Muktar et al. 2016). *Bacillus thuringiensis* var. *israelensis* (Bti) is currently the most common mosquito larvicide employed in European countries and now coming to Africa (Benelli et al. 2016). Entomo-pathogenic fungi produce infective spores (conidia) that attach to and penetrate the cuticle of mosquitoes, releasing toxins that result in mosquito death. *Lagenidium*, *Coelomomyces*, and *Culicinomyces* are among the important genera of mosquito pathogenic fungi to kill both larvae and adult stages. Therefore, the evolution of fungus resistance is predicted to be much slower than the evolution of insecticide resistance (Muktar et al. 2016). Fish species are also found effective in controlling *Ae. aegypti* larvae in a variety of containers around homes.

Fish species are known to have larvivorous and herbivorous potentials in different regions of the world. The promising larvivorous fish belong to the families of *Poeciliidae*, *Cyprinidae*, and *Chichlidae* (Sarwar 2014). Integrated control seeing sanitation and mutualized with other vector-borne diseases, is cost-effective and should be favored. Integrated vector management (IVM) is a new and better approach to vector control. IVM is important in the decision-making process for optimizing resources through a careful analysis of the local ecology of vector-borne diseases (WHO 2017).

Conclusion

The circulation of YFV currently in the tropical regions of Africa is primarily maintained through a sylvatic cycle between its non-human primate hosts and sylvatic mosquito vectors. Yellow fever is known to be endemic in tropical and subtropical areas of Africa with 90% of the infection. In Africa, the major *Aedes* mosquito species transmitting YFV include *Ae. aegypti*, *Ae. africanus*, *Ae. luteocephalus*, *Ae. simpsoni* complex, *Ae. furcifer*, *Ae. taylori* and *Ae. vittatus*. In parts of Africa (East Africa), during epidemic YF, the current most important vector is *Aedes simpsoni sensulatu* (s.l.) like *Ae. bromeliae*, which was the principal vector during the largest recorded epidemic of yellow fever in Ethiopia between 1960 and 1962. YFV is maintained in three transmission cycles. Urban cycle, in which YFV is featured between humans by domesticated *Aedes aegypti*; sylvatic cycle in which the virus is maintained by tree hole-breeding *Ae. africanus* mosquitoes feeding on monkeys and savannah cycle, in which the virus is maintained by tree-hole breeding mosquito species, *Ae. luteocephalus*, *Ae. furcifer*, *Ae. metallicus*, *Ae. opock*, *Ae. taylori*, *Ae. vittatus* and members of the *simpsoni* complex spread to humans living or working in jungle border areas in Africa. The control methods of *Aedes* mosquitoes include chemical, biological and environmental sanitation. In Africa, the best and most frequented control methods are chemical and environmental sanitation. Integrated vector management (IVM) is a new and better approach to vector control. IVM has an impact on the reduction of vector breeding sites and the improvement of entomological indicators. The social outcomes of IVM are improvement of skill and competence enhancement, empowerment, and community knowledge which is a key element of sustainability, along with a framework for collaboration, institutionalization, and activity routines.

Conflict of Interest: All authors declare that they do not have any actual and potential conflicts of interest to declare.

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