Chapter

Control Strategy for *Aedes aegypti* (Linnaeus, 1762) Population

Taiana Gabriela Barbosa de Souza, Eduardo José de Arruda, Raphael Antônio Borges Gomes, Alex Martins Machado and Antônio Pancrácio de Souza

Abstract

The mosquito *Aedes aegypti* (Diptera: Culicidae), is adapted to different environments, mainly urban ones. They have a high degree of vectorial competence for viral diseases, especially Dengue, the arbovirus with the highest number of cases in the world. The adaptive ability of this insect and the abundance of breeding sites have undermined attempts at population's control, resulting in a high degree of infestation in many regions of the world, resulting in a Dengue endemic. It is important to understand the different nuances of the insect in order to understand the adaptive capacity of this vector, through the knowledge of his behavior, to propose new strategies and engagement of population in proactive actions that allow the population control of this vector, especially in periods of greater proliferation. This chapter discusses population control strategies, in different scenarios and carried out by different researchers, mainly in Brazil.

Keywords: *Aedes* population control, Arbovirus, epidemiological surveillance, mosquitoes control, public health policies

1. Introduction

The *Aedes aegypti* mosquito (Linnaeus, 1762) has always accompanied human migration from his original habitat in northwest Africa, from where the Spanish and Portuguese maritime trade, through the slave trade and the transport of goods from Africa to the new world, allowed the conquest of new areas by him. The phylogenetic analyzes showed that this mosquito has a monophyletic origin from a single strain, domesticated from Africa [1, 2]. This monophyletic group presents some bioecological variations, such as size, color, host preference for blood-feeding, choice of oviposition, larval development, egg dormancy, development time and vector competence (**Figure 1**) [2].

The dissemination of this vector throughout the Brazilian territory was facilitated by the rapid displacement of the rural population to the urban environment without compatible sanitary conditions for the provision of essential services such as sewage and treated water, which contributes to the transmission of diseases, especially those of vector transmission [3–5]. In this context, *A. aegypti* is a vector of several important viral diseases, being able to transmit the Yellow Fever, Dengue, Zika, Chikungunya and Mayaro viruses. Among these arboviruses, dengue stands

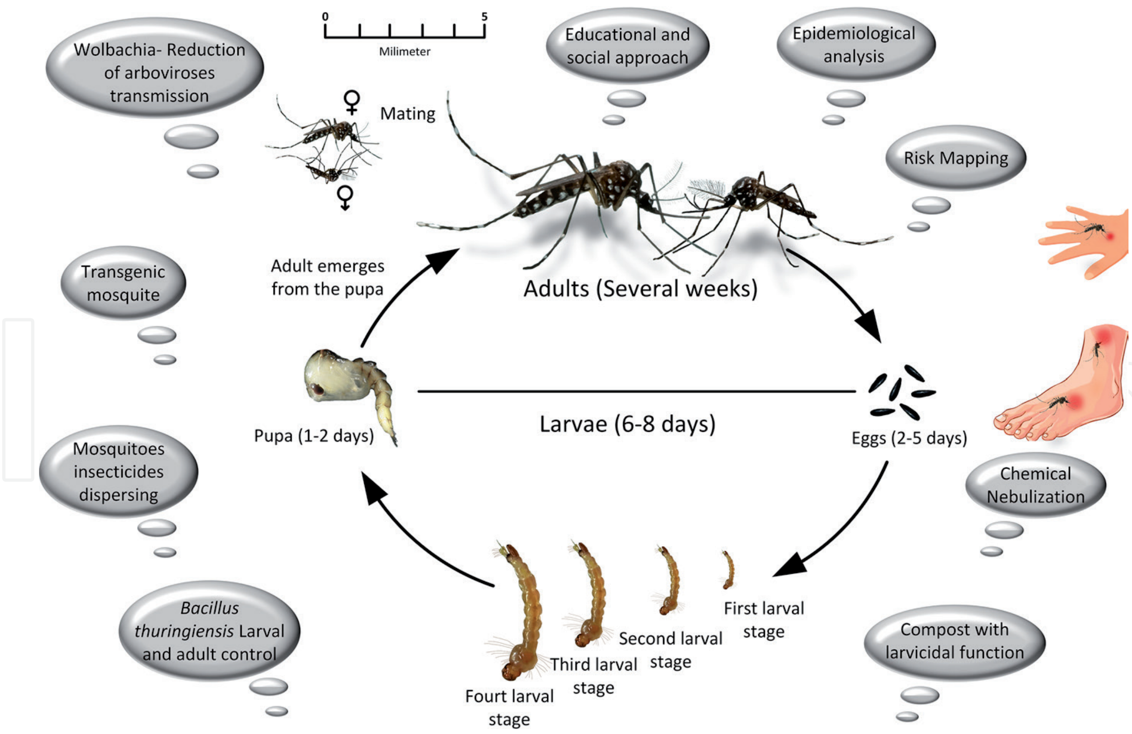

Figure 1.
Aedes aegypti: *Life cycle and control strategies.*

out for the large number of cases, which about 40% of the world population is susceptible to contracting dengue, generating about 500 million cases and 20,000 deaths per year [6].

In Brazil, the first reports of dengue occurred in the late 19th century, in São Paulo (SP), and in the early 20th century, in Niterói (RJ), without laboratory diagnosis. However, in this period, the mosquito was already a problem, but not because of dengue, due to the transmission of yellow fever - which caused numerous outbreaks with a high mortality rate. In 1955, Brazil eradicated *Aedes aegypti* as a result of measures to control yellow fever. The success in eradicating this mosquito in Brazilian territory was achieved with great effort, through awareness campaigns and control of mosquito breeding sites. In addition, the eradication of the *A. aegypti* mosquito was possible at the time because only 20% of the population lived in cities, and the products discarded by them were predominantly organic, not serving as a reservoir for the multiplication of mosquitoes [7].

At the end of the 1960s, the relaxation of the measures adopted led to the reintroduction of the vector into national territory. This period coincided with a period of intense and disorganized urbanization in several Brazilian cities. The industrialization has attracted the rural population to urban areas, leading to an exaggerated urban vegetative growth in a disorganized way and without adequate infrastructure, and many people living in conditions of poverty. The result was the resurgence of the mosquito and the occurrence of epidemic outbreaks of dengue, with the four serotypes, in addition to the proliferation of hemorrhagic dengue (the most serious manifestation of the disease) in all Brazilian states [3, 4, 7, 8].

In 1982 there was a new outbreak of Dengue in Roraima/RR, it was quickly controlled, and considered an epidemic. However, the first time that an epidemic was characterized in Brazil was in 1986–1987 from Nova Iguaçu/RJ, affecting several municipalities and with the largest number of cases in the northeast region. In 1990–1991 a second epidemic occurred, now with more than double the number of cases per 100,000 inhabitants [3, 4, 9, 10]. The Dengue virus was detected with a small outbreak of the disease in Mato Grosso do Sul during the year of 1987. Since then, the epidemics that occur in Brazil are also observed in our state, but especially in the most populous cities, where a moderate increase of cases is visible annually in the months of November and December, the first with the higher number of cases. January to July, coinciding with the increase in temperature, relative humidity and monthly precipitation [11–13].

Due to the growing number of cases, in different cities and regions of the country, the Ministry of Health started to organize itself in national actions and in 1996 launched the *Aedes aegypti* Eradication Program (AaPE). However, the results were not achieved due to the huge socio-environmental changes that Brazil experienced. It must be admitted that the AaPE was important for strengthening national actions to combat the mosquito by increasing the financial resources destined for this purpose, but without achieving a new eradication of the vector [3, 9]. It was evident due to the new outbreak that occurred in 1997–1998, when Brazil faced a new epidemic with more than 500,000 cases occurring mainly in the northeast and southeast regions, with the circulation of serotypes DEN-1 and DEN-2 [3, 4].

In 2001, it was recognized that the mosquito eradication plan was not viable and a new activity plan was launched (called the Dengue Control Action Intensification Plan - DCAIP), with priority for the municipalities that transmit Dengue the most. In order to improve the DCAIP, in 2002, the National Dengue Control Program (NDCP) was launched, with an important change focusing on community mobilization [3, 14].

The implementation of the NDCP has an additional challenge in municipalities on the international frontier due to the movement of people between countries, making it a potential for the occurrence of epidemics; in this sense, dengue is the second most expressive disease in border municipalities. For example, in the municipalities of Corumbá and Ponta Porã (border with Bolivia and Paraguay respectively), the implementation of the NDCP was evaluated and considered partial. There was a demand for improvement, with regard to the training of human resources. It was made like an answer to the inexistence or malfunction of the Municipal Committee for Mobilization, Monitoring and Evaluation of dengue control measures [15].

After a new Dengue epidemic in 2001–2002, the fight against the vector gained the participation of community health agents, who started to carry out preventive and control actions against dengue, according to the Ministry of Health Ordinance No. 44/GM. This initiative was important both for the optimization of resources and the greater involvement of the community in the fight against the mosquito [16–18].

Today, the four Dengue serotypes circulate throughout the country and it is not necessary to introduce a new serotype for new epidemics to occur, since we will always have susceptible people due to births, migration, and time interval between the occurrence of an epidemic with the same serotype [19, 20]. In addition to the number of cases that scare, the economic impact is also impressive and growing [21].

Besides that, the Dengue epidemic with thousands of cases annually across the country, in 2014 the first cases of Chikungunya in Brazil were reported and 8 months later in 2015 the first indigenous cases of Zika virus were also reported, both associated and transmitted by the vector *A. aegypti* [22]. Thus, today, we live in a scenario where there is a triple epidemic associated with this mosquito, where climatic, demographic and social changes were relevant to the current situation, in addition to the intrinsic factors of the pathogens [23].

Some characteristics of epidemics in Brazil are important to highlight, among them the greatest number of cases occur in the first semester and it is important that measures to combat breeding sites and the application of adulticides are carried out as soon as the first cases are detected and not during the period. The epidemic, as transmission between people, occurs quickly and from cases concentrated in a city the number of cases increases rapidly and spreads throughout the city and what is interesting, despite the risk of dengue infection increases with the increase in the population of the mosquito; because infected mosquitoes live less and need to live at least ten more days infected before they are able to transmit the virus [24–26], epidemics are not always related to the size of the mosquito population, but with the susceptibility of the population to the serotypes prevalent in the period [18].

In an attempt to control these important diseases, not only in Brazil but in the world, global strategies have been proposed by WHO. WHO efforts were directed at obtaining reactive responses and intense proactivity for early disease warning systems, use of preventive measures, intense entomological and epidemiological surveillance, search for vaccines and strategies/products for vector control, and reduction of morbidity and mortality. In this context, measures for the population control of the vector through the evaluation of new control agents, mapping of risk zones, storage and logistics, surveillance and early diagnosis capacity, social, educational, and environmental interventions and effective communication between the responsible sectors, can provide efficient ways to control these arboviruses [27–30]. However, despite all efforts made in the last decades, the results were not satisfactory, without being able to effectively control the mosquito population or reduce the incidence of these arboviruses.

We know that viral diseases are complex and require multifaceted responses that involve governments' integrated and global strategy to promote coordinated action between different multisectoral partners with an integrated approach to vector management, sustained control, and measures at all hierarchical levels. The guiding principle should harmonize prevention, entomological and epidemiological surveillance, and efficient case management with existing health systems. The effort must ensure that all strategies be coherent, economically sustainable, and that provide for a reduction in environmental impacts [27–30].

In Brazil, the efforts of the public authorities, especially in relation to the joint action of the federal, state and municipal powers, have been improved, in an attempt to cover all this thinking and strategy guided by WHO, as well as the training of trained human resources different areas, from the rapid diagnosis of the disease, vector control, and determination of risk areas [31]. However, it is still essential to evaluate and create more control measures applied with a robust methodology in order to point out the most efficient practices, worthy of replication and allocation of more resources, within these alternatives.

In this context, our main objective will be to present some alternatives and strategies proposed by researchers, in Brazil and worldwide, to control the vector *Aedes aegypti* and the arboviruses transmitted by it. Still, we have as specific objectives the discussion about the viability of these strategies, as well as a comparison between them, in order to understand and analyze the best methods of population control of the vector.

2. Strategies of *Aedes aegypti* control

Despite efforts to control the population of the mosquito *A. aegypti*, Brazil and other countries suffer annually with epidemics mainly of dengue, with occasional outbreaks of other arboviruses caused by the zika and chikungunya viruses. Uncontrolled urbanization, geographic expansion, vector control programs often lacking adequate resources, and use of inefficient vector control methods, combined with the insect's ability to place its eggs in containers in and around the home has made population control of the vector very difficult. In this scenario, it is necessary to evaluate the strategies adopted so far, and the insertion and evaluation of new techniques in order to identify the most efficient methods in order to allocate the available resources, privileging the most effective actions [32].

It was proposed [32] like a cyclical model of continuous improvement for vector control and, consequently, related viral diseases, with the proposal of an interactive process aiming to improve control programs through the regular and continuous evaluation of methods and techniques used and replacement by better and operationally valid alternatives. The authors propose that proactive control measures should be guided in time and space by epidemiological and entomological data. It is like if the proposed model serves as a catalyst for integrating data on mosquitoes and related arboviruses, filling a gap between control programs, the medical community, and the local government by developing a database that can also supply other activities public health and city planning.

Proactive or prophylactic population control measures for the vector *Aedes aegypti*, such as campaigns to reduce outbreaks, use of insecticide-treated material to protect homes from mosquitoes should have the following characteristics: a) potential for an application not only by control program managers but also by the population in general, b) low cost of execution, c) minimum effort for long-term maintenance. These measures have the advantage of being able to reduce the occurrences of arboviruses related to the controlled vectors [32].

Within that mode, it is very important to encourage community participation, which tends to decrease their concern with these diseases in periods of lower incidence, requiring constant campaigns since the culture and the habit of the population to discard packaging in inappropriate places, in other words, involving the society in campaigns to fight mosquitoes. Thus, the population needs to be informed about the reproductive characteristics of the vector and its biological behavior, in order for the community to be proactively involved, which is an essential condition for success in controlling the vector [32, 33].

Countless campaigns have been carried out, in the most different media to achieve the proactive participation of the population and always targeting the adult population. However, as seen in other awareness campaigns, teaching and understanding the duties of the population, when inculcated in children, has a better effect, by charging children to their parents as well as creating a population more aware of their long-term duties. In this context, it was suggested [34], through the production of informative and interactive booklets, because the education of children generates greater collective awareness in the long run.

On the other hand, there was an interesting study [35] to understand the participation of users in the coproduction of vector control of dengue in Campo Grande - MS, Brazil. It was found that users when included in the relationship with professionals, are able to produce public policy results and benefit from these results. However, the authors still consider that the actions still follow a top-down direction, in the sense that the plan arrives "ready" from the municipality's Health Secretariat, already indicating the actions to be carried out by each member (competencies of agents and actions expected by residents). The autonomy, emancipation, and involvement of managers and authors in the direction of public policy actions have not yet been sufficiently characterized, mainly due to the more effective participation of health agents and users (residents) regarding their responsibility in population control of the vector and reducing the incidence of viral diseases. In this epidemiological scenario, the importance of communication and their effective participation or role can be highlighted, in joint participation in the elaboration of the control plan and its effective application in a continuous and intensive way. In general, experiences show that *A. aegypti* control plans depend on a series of technical data and studies incorporated for decision making and discussion at all levels with ordinary citizens. It is not feasible in order to make vector control decisions.

The epidemiological surveillance system is another sector of strategic importance in the control of vectors, which houses the surveillance of cases of arboviruses (mainly Dengue) and entomological, among others. It is the responsibility of the federal, state, and municipal public authorities that should act in collaborative and synchronous ways. The focus should be on data collection, processing and analysis actions, recommendations for prevention and control measures, as well as the promotion of data collection actions; the processing of collected data; analysis and interpretation of processed data; recommendation of appropriate prevention and control measures. It can promote of the indicated prevention and control actions; evaluation of the effectiveness of the measures adopted and dissemination of relevant information [36, 37].

Incomplete data collection makes it impossible to estimate population risks and allows new epidemics to occur, in addition to reducing the effect of contingency plans and the response capacity of the government to respond satisfactorily in epidemic periods. It is important to carry out periodic assessments of the health surveillance system in general, in order to monitor it efficiently and effectively [38].

It is worth mentioning that the surveillance of cases of dengue and other arboviruses are important to monitor the number of suspected cases to know the time, magnitude and locations of the transmission cases. However, many asymptomatic cases result in silent transmission, so the extent of cases is underestimated. In addition, clinical detection is imprecise and laboratory diagnosis can be time-consuming, which compromises the effectiveness of vector control actions, therefore, interventions to interrupt transmission are impaired [39]. Although, it should be noted that investments in monitoring and case monitoring techniques, as well as the availability of rapid diagnostic tests in health centers, combined with an accurate reporting of each patient's data, can greatly assist in understanding the dynamics of the disease in a municipality, allowing decision-making and effective control methodologies aimed at that specific population.

There is a need for the continuous training of health surveillance professionals, in addition to the constant evaluation of the surveillance system, as well as the carrying out of epidemiological studies that can contribute to interventions in dengue control not only in the state of the study, but across the country [40]. One hundred and thirty-four professionals were interviewed, 70% of whom said they were unaware of the existence of a contingency plan for coping with the dengue epidemic, 59% argued that all suspected dengue cases should be confirmed in the laboratory. Still, one-third of the participants reported difficulty in closing serious cases of dengue [40]. In this context, there is a need for the continuous training of health surveillance professionals, in addition to the constant evaluation of the surveillance system, as well as the carrying out of epidemiological studies that can contribute to interventions in dengue control not only in the state of the study, but across the country.

O vector control must be carried out in response to information from epidemiological surveillance allowing to reduce the transmission force of these viruses, which contributes to better care for people who need treatment. For this, interventions need to be carried out at the beginning of the epidemic peak, at the risk of it being impossible to contain the increase in cases. These interventions require a large amount of human and material resources, intense work, and even the application of insecticides from house to house [39].

Entomological surveillance for the purpose of monitoring to detect the presence and abundance of *A. aegypti*, as well as monitoring resistance to the insecticides used has the advantages of being useful in making decisions about mosquito control interventions, are indicative of the risk of epidemics, and allow the selection of areas and/or periods most critical to the risk of epidemics, in addition to subsidizing the use of more effective insecticides. On the other hand, the disadvantages, in addition to the high cost and low prevalence in mosquitoes. The epidemiological surveillance data are poor indicators for risk of epidemics, because, in addition to the mosquito, the presence of the virus and the population vulnerable or not to the serotype are necessarily circulating, and the vector population may even be under control and still have an epidemic due to the variables related to the virus and the target population [39].

Still, vector control in response to epidemiological data has some important problems, among which we highlight 1) the silent cases that make it difficult to monitor viruses at their onset, especially with new serotypes. 2) interventions often begin with confirmation of laboratory cases, and if this confirmation takes longer, control actions are delayed to prevent an epidemic. 3) the expansion of dengue cases occurs quickly, which makes it difficult to prevent epidemics 4) people move intensely within cities, transporting viruses throughout the city in a short time, making it difficult to monitor and isolate outbreaks of the disease [39].

About the population control of vectors, the most effective methods for the control of mosquitoes that was included a variety of insecticides aimed at controlling adult or immature insects. The implementation of effective control consists of impacting the largest proportion of the vector population. It can be demonstrated that the control strategy must be effective for the high coverage of aquatic mosquito habitats and the reach of winged forms. Among these, it is possible to use methods that use adult mosquitoes to transmit insecticides and other biological products using the behavior for the transfer and dissemination of products between resting and oviposition places in a controlled way to leave residual quantities for extension of population control as a technique of control [41].

In this regard, it is important that *A. aegypti* control activities are adapted to local conditions and their availability of resources to face and control the population. Community engagement is essential, but there are areas where a social organization or local legislation makes such engagement difficult. The application of adulticides by means of adapted vehicles is considered inefficient, often used when there are no other viable alternatives [39].

An important indicator of the mosquito infestation index in a given area or region is RISAa (Rapid Index Survey of *Aedes aegypti*), which is a control method that aggregates the building, *Breteau*, and container indices used to calculate larval density, being important for making decisions about adult mosquito control. The building and *Breteau* indices are more robust than the container index and less sensitive to show sample variations for pupae and adults indices. Pupa rates per person and per household are less robust than pupae per hectare; Similar results were found with the adult mosquito indices. By this method, each city is divided into blocks and a number calculated according to the degree of the infestation, with a satisfactory one, from 1 to 3.9 alertness and above 3.9 with the risk of the epidemic [42]. The RISAa method is unreliable for some authors because even with low rates, dengue epidemics can occur [43, 44].

The traditional method of dividing the city into blocks does not allow the visualization of the city in continuity precisely by dividing the method, which obviously the mosquito is not limited to these blocks in its locomotion in the environment. Thus, methods that can evaluate the blocks in greater detail, detecting points of greater infestation that were not possible for observation by RISAa are possible by using the Gaussian Kernel method. This method, although it has a certain subjectivity which requires knowledge from the researcher, allows a quick and easy view of the risk sites without the barriers imposed by the administrative political organization [45, 46].

It was performed an excellent non-systematic literature review [47] regarding *A. aegypti* population control strategies. The control strategies considered, such as selective monitoring of infestation, social measures, dispersion of insecticides, new biological control agents, and molecular techniques. The authors considered the integrated use of different compatible and effective techniques according to the region to be possible for the possible reduction of the vector and the related arboviruses. The authors also consider that in the case of technologies in development, they still require evaluation as to their effectiveness, feasibility, and costs for their use in conjunction with other techniques already recommended by the National Program for Dengue Control (NPDC).

However, new strategies have been proposed to control the mosquito population and reduce the incidence of diseases [48]. Among these new techniques, we have the genetic modification of mosquitoes in the laboratory, which, when released to the environment, spread the modified genes to the native population, leading to a decrease in this population or its extermination.

The use of insects inoculated with *Wolbachia* could be a step forward for vector and disease control for longer periods in endemic areas around the world. Different studies have shown that the most efficient approach to control transmission can be obtained from the finding that about 60% of insect species carry *Wolbachia pipientis*, however, it is important to note that this bacterium does not naturally infect the mosquito *A. aegypti*, having to be infected in a laboratory environment, generating some production costs for these modified insects. These results show that the technique using *Wolbachia*, which has been in development since the 1990s, could be an interesting option for the reduction of mosquito-borne diseases [49, 50].

In the same vein, the use of *Bacillus thuringiensis* for the control of larvae and mosquitoes has stood out among the various strategies that make up integrated management programs, being more advantageous in relation to chemical insecticides, both in cost and in their action. The insecticidal activity is due to the toxic proteinases present in the bacteria, which when reaching the insects' intestines unfold the protoxins creating pores that interfere with the ion transport system through the tissue membrane, resulting in insect death. Efficiency studies of this methodology affirm an efficiency of more than 70% for a period of 40 days after exposure [51].

Despite the different strategies mentioned here, summarized in **Table 1** and **Figure 1**, with their potential effectiveness, it is necessary to continue the search for methodologies to control arboviruses and their vector mosquitoes, requiring the development of diversified research involving both ecological aspects, behavior, and population biology. It was a way to increase the success of the control methods used, as well as, promoting conditions for the implementation of new control tools, including knowledge, education, and cultural habits of the population.

The authors consider that partnerships between research centers (universities and institutes) and the government are important parts for the elaboration of strategies that are more appropriate to the location with resources that can be made available for the implementation of these strategies in a pilot plan like a way to evaluate the results by epidemiological and entomological criteria [39] on a continuous basis and with reassessments of the effect achieved in the programs and strategies employed. In Brazil, municipal and state committees have been organized with the presence of members from universities and research institutes, education departments, the legislature, the armed forces, as well as others leaders of organized civil society to better articulate the actions to combat this vector. These partnerships allow articulated actions in large-scale and the solution of problems related to mosquito control in a holistic way, involving different public and private sectors for intelligent decision making.

Strategies	Advantages	Disadvantages
Educational and social approach	Involvement and awareness of the population in home control of mosquito breeding sites.	It depends on the involvement of the population and the various sectors of society. Decrease in engagement during the period with the least number of cases.
Epidemiological analysis and risk mapping	It allows the precise analysis of risk regions allowing the correct targeting of resources.	Despite showing the critical regions, it is necessary to be allied with other technologies to be satisfactory.
Intra and extra-home nebulization.	It has spatial coverage and reduces disease transmission at the time of the outbreak.	Can promote selection of resistant populations insecticide; demand application agents trained; little adulticide availability.
Natural/synthetic compounds to larvicidal function	Alternative and safer products when compared to chemical insecticides. Synergistic compounds can increase the larvicidal function of natural or synthetic compounds.	Need of cost-effectiveness studies compared to chemical insecticide.
Transgenic mosquitoes	It leads to a reduction in the life span of mosquitoes; decreases infestation of mosquitoes; and dispenses with the use of radiation.	There is a need to use mosquito sexing technologies; depends on the protocol of release; requires constant production and release mosquitoes.
Wolbachia reduction of arbovirus transmission	Use of microorganism that causes a natural, self-sustaining infection, does not use insecticides and radiation.	Climatic differences, mosquito release protocols, level of urbanization and human density can limit the potential functions.
Mosquitoes insecticide dispersing	Use of larvicide already available and attested agents familiar with the type of trap used; mosquitoes take larvicides for breeding, eliminating them.	Promotes selection of resistant mosquito populations, requires insecticides with ideal concentration in small particles.

Table 1.
Summarization of new Aedes aegypti *mosquito control strategies.*

Finally, the authors conclude that the erradication of *A. aegypti* by top-down approaches how it already happened in Brazil some decades ago it is impossible today because with the rapid immigration of people from rural to urban areas without minimum sanitary infrastructure promoted outbreaks each more commun. The ocurrence of four dengue serotypes allied with constant number of susceptible people to arbovirus due to migration and births during the time interval between the occurrence of an epidemic with the same serotype are the main conditions to Brazil be a favorable local to epidemies frequently. A sustanaible control of dengue and other arboviruses relationed to *A. aegypti* must have the following steps: 1) A continuous improvement of survaillance system, 2) a good control plan linked to epidemiological survaillance, 3) a selection and continuous evaluation of control strategies to *A. aegypti* adapted to each local, 4) an excellent interaction among different social actors to define, apply, evaluated and improve better solutions to each local, 5) use of compatible control strategies among each other, and 6) effort to maintain always the engagement of local community.

3. Conclusion

The *Aedes aegypti* mosquito (Diptera: *Culicidae*) is adapted to the urban environment due to the large supply of artificial breeding sites which result in unsuccessful population control with a high degree of arbovirus spread and infestation in different regions of the world. In this scenario, the experiences over decades of population control, requires understanding about the reproductive success of the species and the adaptability of the vectors of the species *Aedes spp.* It is important to understand the nuances and details of the habitats, behaviors, habits and the ecology of the insect, and to plan the development of new products and strategies that are compatible with each other, that enhance the biological activity and scope of the control, that stimulate the population's adhesion proactive actions before insect proliferation and infestation and reduce possible environmental impacts.

Despite the proposal for different integrated population control strategies, such as breeding elimination, combined chemical control, genetic modification of mosquito populations, chemical control is still one of the most used tools for containing the insect and reducing impacts on public health. However, population control is still unsatisfactory due to the behavior, resistance to insecticides and survival strategies and adaptability, besides high fertility rate of the insect, which despite an apparent fragility, has overcome the restrictions and conditions imposed on its population control. Integrated preventive control is appropriate as long as it considers aspects of the behavior and habits of the target insect, residual and comprehensive activity, and that it can reduce the viability of breeding sites and eliminate, preferably, the egg banks present in the breeding sites. In addition, the voluntary service of the population in the control of the vector in homes and public spaces is essential, there is adequate sanitation infrastructure, health education for the community, stimulating the community's adherence to the vector's domestic control due to its anthropophilic habit. The reports show that immediate successes are not lasting and that all population control strategies, in isolation, present inefficiencies in the medium and long term or even that they present inconclusive results from the analysis of reduction of *Aedes* spp. infestation and disease incidence.

This chapter discusses new products, strategies and proposals for the population control of *Aedes* spp., considering different scenarios and using content and perceptions of experimental results made available by different researchers, mainly in Brazil. Careful analysis of the literature showed that most of the population control failures are probably due to the use of inadequate products to which there is resistance acquired by the insect and\or poorly planned strategies in population prevention or control or even inadequacy detection aspects, quantification of risk analysis that should be used in the control of vectors. The use of products, the strategies used and the application and\or environmental conditions are not periodically reviewed and compromise the effectiveness of the application of (bio) actives or insecticides that are used, in addition to the contribution of environmental and climatic factors and\or restrictions imposed or few resources made available for combat that severely affect control due to the low insecticidal activity of products and applications that are ineffective for resistant urban populations. Insecticidal or control products do not have a broad spectrum of activity or comprehensive control for the different forms of the insect, from egg to winged insect. The products do not have multifunctionality or are not yet presented in the form of intelligent controlled release of (bio) assets to obtain a more prolonged control of activity in breeding sites. Thus, all these control factors combined and\or applied in an inadequate manner and\or severely affect the effectiveness of the vector population control and allow the continuity of the reproduction and transmission of diseases by arbovirus, and, which still has a potential of growth for new diseases and the spread of other arboviruses due to the insect's competence and vector potential.

4. Future perspectives

Based on the contents, reports and data presented, it is proposed that new perspectives of population control should consider an integration between preventive and corrective forms, if necessary, based on the combination of different products and\or techniques that are compatible and synergistic in the application, due to the acquired resistance of the insect and\or the use of control strategies and\or applications of these products that are available in the regions. Still, it is important that applications of a single type of product or techniques are never carried out in isolation, which result in inefficient and non-lasting treatments, especially in conditions of high insect infestation mainly without considering environmental, climatic factors or local control peculiarities.

In this perspective, the need for a multidisciplinary approach is reinforced with the use of new technologies and products and\or combinations of different potentialized products in the form of smart devices with slow release for lasting (residual) control of the insect population, especially in breeding grounds. We can highlight as highly promising the strategies as follow: 1) an eco-bio-social approach, by focusing on social participation in insect control, in addition to compatibility with other strategies, in addition to dispensing with the use of insecticides, 2) risk mapping, by increased control accuracy, 3) *Wolbachia*, for self-sustainability and efficiency, 4) insecticide-dispersing mosquitoes, for optimization of human resources and compatibility with other strategies, in addition to combinations of techniques that can increase population control. These strategies stand out because they maintain two crucial pillars in the control of this vector: social participation and compatibility with other control strategies.

Author details

Taiana Gabriela Barbosa de Souza[1]*, Eduardo José de Arruda[2], Raphael Antônio Borges Gomes[3], Alex Martins Machado[1] and Antônio Pancrácio de Souza[4]

1 Federal University of Mato Grosso do Sul, Três Lagoas, MS, Brazil

2 Federal University of Grande Dourados, Dourados, MS, Brazil

3 Federal University of Ouro Preto, Ouro Preto, MG, Brazil

4 Federal University of Mato Grosso do Sul, Campo Grande, MS, Brazil

*Address all correspondence to: taiana.souza@ufms.br

References

[1] Brown JE, Evans B, Zheng W, Abas V, Barrera-Martinez L, Egizi A, Zhao H, Caccone A, Powell JR. Human impacts have shaped historical and recent evolution in *Aedes aegypti*, the dengue and yellow fever mosquito. Evolution. 2014:68(2):514-525. DOI: 10.1111/evo.12281.

[2] Salles TS, Sá-Guimarães TE, Alvarenga ESL, Guimarães-Ribeiro V, Meneses MDF, Castro-Salles PF, dos Santos CR, Melo ACA, Soares MR, Ferreira DF, Moreira MF. History, epidemiology and diagnostics of dengue in the American and Brazilian contexts: a review. Parasites & Vectors. 2018:11(1):264. DOI: 10.1186/s13071-018-2830-8.

[3] Terra MR, Silva RS, Pereira MGN, Lima AF. *Aedes aegypti* e as arboviroses emergentes no Brasil. Revista Uningá Review. 2017:30: 3. Available from: http://revista.uninga.br/index.php/uningareviews/article/view/2028.

[4] Lopes TRR, Silva CS, Pastor AF, Silva Junior JVJ. Dengue in Brazil in 2017: what happened? Revista Instituto Medicina Tropical de São Paulo. 2018:60. DOI: 10.1590/S1678-9946201860043.

[5] Brasil. Ministério da Saúde. Secretaria de Vigilância em Saúde. Coordenação-Geral de Desenvolvimento da Epidemiologia em Serviços. Guia de Vigilância em Saúde: volume único [recurso eletrônico]/Ministério da Saúde, Secretaria de Vigilância em Saúde, Coordenação-Geral de Desenvolvimento da Epidemiologia em Serviços. – 3ª. ed. – Brasília: Ministério da Saúde, 2019. 740 p. Available from: https://bvsms.saude.gov.br/bvs/publicacoes/guia_vigilancia_saude_3ed.pdf

[6] Pan American Health Organization/World Health Organization. Epidemiological Update: Arbovirus. Washington, D.C. PAHO/WHO. 2020. Available from: https://www.paho.org/en/documents/epidemiological-update-dengue-and-other-arboviruses-10-june-2020

[7] Mendonça FA, Souza AV, Dutra DA. Saúde pública, urbanização e dengue no Brasil. Sociedade & natureza. 2009:21(3):257-269. DOI: 10.1590/S1982-45132009000300003.

[8] Tauil PL. Aspectos críticos do controle do dengue no Brasil. Cadernos de Saúde Pública. 2002:18:3:867-871. DOI: 10.1590/S0102-311X2002000300030.

[9] Governo de Santa Catarina. Diretoria de Vigilância Epidemiológica, Vigilância e controle do *Aedes aegypti*. Orientações técnicas para pessoal de campo. Florianópolis – SC. 2019. Available from: http://www.dive.sc.gov.br/conteudos/publicacoes/Manual_completo_2019.pdf.

[10] Fares RCG, Souza KPR, Añez G, Rios M. Epidemiological scenario of Dengue in Brazil. BioMed Research International 2015(13). DOI: 10.1155/2015/321873.

[11] Quintanilha ACF. Caracterização clínica e epidemiológica de casos de dengue internados em hospital público de Campo Grande – MS. [thesis]. Federal University of Mato Grosso do Sul; 2010.

[12] Lima SFS, Moraes EC, Pereira G. Análise das relações entre as variáveis ambientais e a incidência de dengue no município de Campo Grande-MS. In: Simpósio Brasileiro De Sensoriamento Remoto – SBSR. 30 April to 5 May 2011. Curitiba: 2011. p. 28.

[13] Pacheco ICS, Carvalho AMA, Pontes ERJC, Silva, MGS. Relação entre

condições climáticas e incidência de dengue no município de Campo Grande, MS. Multitemas. 2017:22:51:235-252. DOI: 10.20435/multi.v22i51.1123

[14] Fundação Nacional de Saúde. Programa Nacional de Controle da Dengue (PNCD). Brasília: Funasa; 2002, 34p. Available from: http://bvsms.saude.gov.br/bvs/publicacoes/pncd_2002.pdf.

[15] Silva EMC, Cunha RV, Costa EA. National Dengue Control Program implementation evaluation in two border municipalities in Mato Grosso do Sul state. Epidemiologia e Serviços de Saúde. 2016:27. DOI: 10.5123/s1679-49742018000400007.

[16] Secretaria de Vigilância em Saúde. Dados e indicadores selecionados. Coordenação: Departamento de Análise de Situação de Saúde. Brasília: Ministério da Saúde; 2018.

[17] Siqueira Junior JB, Martelli CM, Coelho GM, Simplício ACR, Hatch DL. Dengue and Dengue Hemorrhagic Fever, Brazil, 1981-2002. Emerging Infectious Diseases 2005;11(1):48-53. DOI: 10.3201/eid1101.031091.

[18] Câmara FP, Theophilo RL, Santos, GT, Pereira, SRFG, Câmara DCP, Matos RRC. Estudo retrospectivo (histórico) da dengue no Brasil: características regionais e dinâmicas. Revista da Sociedade Brasileira de Medicina Tropical, 2007:40(2):192-196. DOI: 10.1590/S0037-86822007000200009.

[19] Guzmán MG, Kouri G. Dengue: an update. Lancet Infect Disease. 2002:2(1):33-42. DOI: 10.1016/s1473-3099(01)00171-2.

[20] Tsai TF, Vaughn D, Solomon T. Flaviviruses (Yellow Fever, Dengue Hemorrhagic fever, Japanese Encephalitis, St Louis Encephalitis, Tick-borne Encephalitis). In: Mandell G, Bennett J, Dolin R, eds. Principles and Practice of Infectious Diseases, 6th ed, Elsevier-Churchill-Livingstone, Philadelphia, 2005. DOI: 10.1590/S0036-46651992000200018.

[21] Machado V, Alessandra A, Negrão FJ, Júlio C, Estevan AO, Sales A, Brabes KCS. Custos diretos das hospitalizações por dengue: comparação entre o sistema de saúde público e privado em Dourados-MS. In: 49° MedTrop, 2013, Campo Grande. XLIX Congresso da Sociedade Brasileira de Medicina Tropical, 2013. p. 159.

[22] Valle D, Pimenta DN, Aguiar Z. Zika, Dengue e Chikungunya: desafios e questões. Epidemiologia Serviço de Saúde. 2016:25(2). DOI: 10.5123/S1679-49742016000200020.

[23] Neto ASL, Nascimento OJ, Sousa GS. Dengue, zika e chikungunya-desafios do controle vetorial frente à ocorrência das três arboviroses-parte I. Revista Brasileira Promoção em Saúde. 2016:29(3):305-312. DOI: 10.5020/18061230.2016.p305.

[24] Wilson ME, Chen LH. Dengue in the Americas. Dengue Bulletin. 2002:26:44-62. Available from: https://apps.who.int/iris/bitstream/handle/10665/163755/dbv26p44.pdf;sequence=1

[25] Swain S, Bhatt M, Biswal D, Pati S, Magalhães RJS. Risk factors for dengue outbreaks in Odisha, India: A case-control study. Journal of Infection and Public Health. 2020:13(4):625-631. DOI:10.1016/j.jiph.2019.08.015.

[26] Elaagip A, Alsedig K, Altahir O, Ageep T, Ahmed A, Siam HA, Samy AM, Mohamed W, Khalid F, Gumaa S, Mboera L, Sindato C, Elton L. Seroprevalence and associated risk factors of Dengue in Kassala state, eastern Sudan. Plos Neglected Tropical Disease. 2020:14(12). DOI: 10.1371/journal.pntd.0008918

[27] Ocampo CB, Mina NJ, Carabali M, Alexander N, Osorio L. Reduction in

dengue cases observed during mass control of Aedes in street catch basins in an endemic urban area in Colombia. Acta Tropica. 2014:132:15-22. DOI: 10.1016/j.actatropica.2013.12.019

[28] World Health Organization. Dengue and severe dengue [factsheet no. 117, revised January 2012]. Geneva, World Health Organization, 2012.

[29] World Health Organization. Guidelines on the quality, safety and efficacy of dengue tetravalent vaccines (live, attenuated). Geneva, World Health Organization. 2012.

[30] World Health Organization. Handbook for integrated vector management. Geneva, World Health Organization. 2012.

[31] World Health Organization. Global strategy for dengue prevention and control 2012-2020. [August 2012]. World Health Organization, 2012,

[32] Zara AL, Santos SM, Fernandes-Oliveira ES, Carvalho RG, Coelho GE. Aedes aegypti control strategies: a review. Epidemiologia e Serviços de Saúde. 2016: 25(2):391-404. DOI: 10.5123/S1679-49742016000200017.

[33] Erlanger TE, Keiser J, Utzinger J. Effect of dengue vector control interventions on entomological parameters in developing countries: a systematic review and meta-analysis. Medical and Veterinary Entomology. 2008:22:203-221. DOI: 10.1111/j.1365-2915.2008.00740.x.

[34] Souza TGB. Souza AP, Machado AM. Programa saúde na escola: Ações de combate ao mosquito *Aedes aegypti*. Editora Atena, Ponta Grossa- PR, 2019. DOI: 10.22533/at.ed.691203101.

[35] Chaebo G, Medeiros JJ. Is direct participation in co-production demogratic? Dengue vector control in Campo Grande – MS. Cadernos Gestão Publica E Cidadania, 2017:22:3-22. DOI: 10.12660/cgpc.v22n71.61067.

[36] Brasil, Ministério da Saúde. Secretaria de Vigilância em Saúde. Departamento de Vigilância Epidemiológica. Diretrizes nacionais para prevenção e controle de epidemias de dengue. Brasília: Ministério da Saúde; 2019. Available from: https://bvsms.saude.gov.br/bvs/publicacoes/diretrizes_nacionais_prevencao_controle_dengue.pdf.

[37] Brasil, Ministério da Saúde. Secretaria de Vigilância em Saúde. Departamento de Vigilância Epidemiológica. Guia de vigilância epidemiológica. 10. ed. Brasília: Ministério da Saúde; 2019.

[38] Barbosa JR, Barrado, JCS, Zara ASA, Siqueira Jr. JB. Avaliação da qualidade dos dados, valor preditivo positivo, oportunidade e representatividade do sistema de vigilância epidemiológica da dengue no Brasil, 2005 a 2009. Epidemiologia e Serviços de Saúde. 2015:24(1):49-58. DOI: 10.5123/S1679-49742015000100006.

[39] Callaway E. Mosquitoes engineered to pass down genes that would wipe out their species. Nature news 07 December 2015. DOI: 10.1038/nature.2015.18974.

[40] Santos KC, Siqueira Jr JB, Zara ALSA, Oliveira ESF. Avaliação dos atributos de aceitabilidade e estabilidade do sistema de vigilância da dengue no estado de Goiás, 2011. Epidemiologia e Serviços de Saúde. 2014: 23(2): 249-258. DOI: 10.5123/S1679-49742014000200006.

[41] Devine GJ, Perea EZ, Killeen GF, Stancil JD, Clark SJ, Morrison AC. Using adult mosquitoes to transfer insecticides to Aedes aegypti larval habitats. Proceedings of the National Academy of Sciences of the United States of

America. 2009:106(28): 11530-11534. DOI: 10.1073/pnas.0901369106.

[42] Brasil. Diagnóstico rápido nos municípios para vigilância entomológica do *Aedes aegypti* no Brasil (LIRAa): metodologia de avaliação dos índices de Breteau e predial. Brasília: Ministério da Saúde, Secretaria de Vigilância em Saúde, 2015. 60p.

[43] Sanchez L, Pelaez CO, Concepción D, Van der Stuyft P. Breteau index threshold levels indicating risk for dengue transmission in areas with low Aedes infestation. Tropical Medicine International Health. 2010:15(2):173-175. DOI: 10.1111/j.1365-3156.2009.02437.x.

[44] Shen JC, Luo L, Li L, Jing QL, Ou CQ, Yang ZC, Chen XG. The impacts of mosquito density and meterological factors on Dengue fever epidemics in Guangzhou, China, 2006-2014: a time-series analysis. Biomedical Environmental Science. 2015:28(5): 321-329.

[45] Caicedo-Torres W, Montes-Grajales D, Miranda WM, Agudelo MF. Kernal-Based machine learning models for the prediction of Dengue and Chikungunya morbidity in Colombia. Communications in Computer and Information Science. 2017:735(1). DOI: 10.1007/978-3-319-66562-7_34.

[46] Lagrotta MTF, Silva, WC, Souza-Santos R. Identification of key areas for Aedes aegypti control through geoprocessing in Nova Iguaçu, Rio de Janeiro State, Brazil. Cadernos de Saúde Pública. 2008:24(1):70-80, DOI: 10.1590/S0102-311X2008000100007.

[47] Feitosa FRS, Sobral IS, Silva MSF, Jesus EM. Estratégias de prevenção e controle da Dengue em Aracajú: Potencialidades e fragilidades. Caminhos de Geografia. 2016:17(60):149-168.

[48] Callaway E. The mosquito strategy that could eliminate dengue. Nature news 27 August 2020. DOI: 10.1038/d41586-020-02492-1.

[49] Hammond A, Galizi R, Kyrou K, Simoni A, Siniscalchi C, Katsanos D, Gribble M, Baker D, Marois E, Russell S, Burt A, Windbichler N, Crisanti A, Nolan T. A CRISPR-Cas9 gene drive system targeting female reproduction in the malaria mosquito vector Anopheles gambiae. Nature Biotechnology. 2016:34:78-83. DOI: 10.1038/nbt.3439.

[50] Gantz VM, Jasinskiene N, Tatarenkova O, Fazekas A, Macias VM, Bier E, James AA. Highly efficient Cas9-mediated gene drive for population modification of the malaria vector mosquito Anopheles stephensi. Nature Biotechnol. 2015:112(49):E6736-E6743. DOI: 10.1073/pnas.1521077112.

[51] Boyce R, Lenhart A, Kroeger A, Velayudhan R, Roberts B, Horstick O. *Bacillus thuringiensis* israelenses (Bti) for control of Dengue vectors: systematic literature review. Tropical Medicine International Health. 2013:18(5). DOI: 10.1111/tmi.12087.