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Review Article

A Review on the Influence of Environmental Temperature in the Development, Survival, Population Dynamics and Spatial Distribution of *Aedes albopictus* (Skuse 1894) (Diptera: Culicidae) Mosquito

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A B S T R A C T

Environmental temperature is an important abiotic element that plays a significant role in various aspects of the insect life cycle. Insects have evolved different mechanisms to adjust to temperature variations in order to avoid thermal stress over evolutionary time. They have been able to invade practically every type of habitat due to these adaptations. *Aedes albopictus*, the Asian tiger mosquito, is a Southeast Asian forest-dwelling mosquito species that has spread throughout the world in the last forty years. Since it can effectively transmit a variety of viruses, *Aedes albopictus* is a significant public health issue in all areas where it has already been entrenched. The current article shows the existing understanding of the impact of environmental temperature on the dispersion and ecology of *Aedes albopictus.*

Keywords: Tiger Mosquito, Environmental Temperature, Host Seeking, Ecology, Population Dynamics, Vector Distribution, Climate Change

Introduction

The worldwide ecosystem is home to billions of insects, whose numbers and behaviours are influenced by various environmental factors. One of such most important abiotic components is environmental temperature, which has a high impact on insect physiology, behaviour, existence, and survival.[1] Due to the temporal thermal variations, insects are subject to various physiological as well as other problems regarding existence such as desiccation, changes in metabolism, and impaired motility. On the other hand, they have evolved different mechanisms to adjust to temperature variations to avoid thermal stress over evolutionary time.

They keep their cellular stability by synthesising heat shock proteins and thermoregulate or make adjustments in their various functional aspects to enhance their vigour and survival.[2-4] Insects have been able to invade practically every type of habitat due to these adaptations. These insects can spread various diseases like dengue, malaria, Zika, and chikungunya.[5] *Aedes albopictus,* the Asian tiger mosquito, is a Southeast Asian forest-dwelling mosquito species that has spread throughout the world in the last forty years. These mosquito larvae breed in temporary water sources, man-made containers, discarded tires, and tree holes. It is an ecological generalist that can live in both urban and peri-urban environments and breed in a variety of containers and receptacles in peri-domestic settings.[6]

Since it can effectively transmit a variety of viruses, *Aedes albopictus* is a significant public health issue in all areas where it has already been entrenched. It has a remarkable ability to adjust to a vast variety of environmental and climatological circumstances, as well as invasive behaviour and competitiveness with other mosquito species that share similar habitats and vector potential.[7] Environmental temperature has a significant impact on various aspects of mosquito population dynamics like survival, development, and fecundity. Under different climate change scenarios, the quantitative analysis of the relationship between different environmental temperatures and mosquito population dynamics is very critical. Several experiments and investigations have been conducted to measure the influence of various temperatures on the development, survival, and population dynamics of *Aedes albopictus.*[8-10] The current article summarises the existing understanding of the effect of environmental temperature on *Aedes albopictus* mosquitoes, with an emphasis on their ecology and dispersion.

Host-seeking and Blood-feeding

Aedes albopictus is an anthropophilic mosquito that prefers to grow in regions with plentiful human hosts.[11] It is a day-biting mosquito species with two primary activity peaks: one early in the morning and the other late in the afternoon. It is an opportunistic feeder that bites both warm-blooded and cold-blooded hosts.[12-14] It is endophilic (i.e., it seeks refuge inside buildings) and exophagic (i.e., the majority of its biting takes place outside of human habitations) in nature. According to Christopher's research, mosquitoes can bite at any temperature in their range of temperature optima where they are at the best thermal performance.[15] As with any other mosquito species*, Aedes albopictus* is also making use of different environmental stimuli like visual, chemical, and thermal in order to identify and locate their concerned hosts.[16] Apart from this, an apparent difference in the environmental temperature and the host's body temperature is very significant as it will aid the mosquito to start probing and blood feeding.[17,18] Kramer et al.[19] reported that the pre-blood meal period, which is the time gap between the mosquito emergence and first blood meal, exhibits thermal sensitivity. According to them, pre-blood meal period increases at lower temperatures. An in-depth understanding of the thermal sensitivity of feeding has important implications for disease epidemiology and control since the parasite development time and pre-blood meal period exhibit different thermal sensitivity.

In addition, Löwenberg Neto and Navarro-Silva[10] studied and compared the effects of cyclic temperatures as well as constant temperatures on *Aedes albopictus* from Registro, Brazil and Sao Paulo and proved that pre-blood mean period under 27 °C/ 20 °C was 8.0 days which was longer than in studies with constant temperatures between 24 and 29 °C. The frequency of haematophagic activity was directly affected by the rise in temperature in their investigation, which was conducted at constant temperatures of 15, 20, 25, and 30 °C. The authors also discovered that the maximum frequency of haematophagic activity occurred at temperatures below 25 °C, whereas the lowest occurred at temperatures below 15 °C. Thus their results are consistent with the inferences of Paaijmans et al. that haematophagic activity is at a higher pace during the optimal lower temperature ranges above or below which mosquitoes cease their blood-feeding activity. Regarding the blood meal for oviposition activity, some authors proved that one blood meal is sufficient for *Aedes albopictus* to lay eggs.[20-23] In addition, Delatte et al.[8] reported that at higher temperatures, *Aedes albopictus* can have the shortest but largest number of cycles.

In the study of Löwenberg Neto and Navarro-Silva, female *Aedes albopictus* mosquitoes that were grown under a 27 ^{o}C/ 20 ^{o}C thermal range completed their gonotrophic cycles in a duration of 11.2 days. The authors also found that during the first cycle, female mosquitoes deposited an average of 33.1 eggs.[10] Increased temperatures accelerated all gonotrophic cycles, according to Briegel & Timmermann.[11]

Optimum Thermal Conditions for Development and Survival

The development, as well as reproduction of mosquitoes, are affected by environmental temperature.[24] The temperature range in which *Aedes albopictus* can develop and survive varies between 10.4 ^{o}C and 29.7 ^{o}C.[8] Even though they can develop fully between 15 ^{o}C and 35 ^{o}C, they show long lifespans only at lower temperatures. However, different research works showed that based on the place of origin and the power of resistance to cold, the rate of development and duration of the life cycle of *Aedes albopictus* may change. According to Teng and Apperson,[25] the temperature threshold for larval growth in the same species was roughly 9 ^{o}C.

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Alto and Juliano[26] investigated the temperature and precipitation sensitivity in the life cycle of the caged population of *Aedes albopictus* mosquitoes and proved that higher temperature and precipitation can have a greater effect on the growth of larva as well as adult stages. Temperature and desiccation have a significant impact on eggs. The diapause phenomenon can be seen in eggs that have been exposed to lower temperatures both in the laboratory and in the wild.[27,28] According to Löwenberg Neto and Navarro-Silva, immature development differed dramatically depending on temperature regimes, with increasing temperatures having a beneficial effect on growth pace. In their research, they discovered that a combination of higher temperatures and frequent and full water changes boosted egg viability and reduced incubation time. Under constant and cyclic temperatures, the immature mean period of males is shorter than that of females.[10,17]

In *Aedes albopictus*, Ezeakacha and Yee found that changing the temperature of the larval environment affects the rivalry among intraspecific larvae, which is dependent on density. They have come across a correlation between density and temperature, such that the increased temperature and density will lead to a decreased development time and dropped adult body mass.[16]

Marini et al.[7] investigated the effects of various rearing temperatures on the rate of survival, fecundity, and time taken for the complete development of various life stages of *Aedes albopictus.* They reported that various larval stages of temperate *Aedes albopictus* show better adaptation and a high survival rate at colder temperatures. Temperate larvae were able to develop and survive even at 10 ^{0}C and at 15 ^{0}C. Their findings demonstrated the ability of *Aedes albopictus* to rapidly adapt to cooler conditions and provided new information on the species' bionomics at temperate latitudes.

Population Dynamics and Spatial Distribution

Chaves and Friberg[29] stated that diverse mosquito species' geographical and time-dependent patterns of abundance are influenced by their different responses to environmental conditions. *Aedes albopictus* can withstand very low temperatures in a diverse array of environments like temperate and tropical.[30] *Aedes albopictus* of subtropical areas can lay eggs and accomplish full development without passing through the diapause stage.[31] Works of Hawley et al.[32] and Hanson et al.[33] demonstrate the ability of *Aedes albopictus* to quickly adapt to new scenarios with varying temperatures and invade and establish in colder places.

Marini et al.[7] discovered that compared to subtropical populations, immature individuals of temperate regions have auspiciously acclimated to cooler environments after 20 years of invasion. Temperate eggs hatch quicker at 15 ^{0}C, but,10 ^{0}C is a lower existence barrier as no larval specimens mature into adults at this temperature. This is in line with prior research, which found that the temperature threshold for mature female mosquitoes to begin activity is 13 ^{0}C.[34] They discovered that at 10 ^{0}C, 38% of first-instar larvae could progress to the second larval stage whereas subtropical larvae could not reach this stage. The ability to grow in the early part of the season while temperatures are still cool could lengthen the propagation time, thereby affecting control action and surveillance plans.

Furthermore, this modification may allow *Aedes albopictus* to populate high altitudes when springtime temperatures are normally colder than in lower elevations. Low temperatures are more likely to occur during temperate springs and summers, even if only for a short while, therefore they may not be as harmful to the development. In the experiment of Tsunoda et al.,[35] they found that even the lowest water temperature (14 ^{0}C) in an artificial container that favours the successful development of *Aedes albopictus* was slightly higher than the lowest temperature boundary for the wild *Aedes albopictus* development. It indicates a higher probability of the annual occurrence of this mosquito and mosquito-borne diseases concerned. Apart from this, according to the authors, in winter, the maximum extent of distance that can be covered by *Aedes albopictus* ranges between 100-1,000 meters at an average room temperature of just below 17 ^{0}C. Since they can lay desiccation-resistant eggs, they are able to live in harsh environments and aid their capacity to propagate to new places through the export and import of objects carrying viable but dormant eggs (e.g., tires and plant pots). The growth and dispersal of this species are influenced by diurnal and seasonal temperature fluctuations. Precipitation has an effect on the number and dispersion of mosquitoes in both temperate and tropical environments.[36]

Suwonkerd et al.[37] in Japan discovered that a colder environmental temperature could explain the fall of *Aedes albopictus* during arid scenarios. In a study by Hanson et al.,[28] *Aedes albopictus* from subtropical Argentina were subjected to long-day treatment at 16 ^{0}C and they showed a higher mortality rate. This result could imply a very weaker forbearance to an abrupt temperature reduction throughout the summertime. According to Mogi,[38] warm weather is anticipated to alter overwintering techniques and vectorial capacity by altering mosquito biting activity, dispersion, and microbial growth. Since plasticity is the ability of an organism to change its phenotypic expressions according to the changing environment, ecophysiological plasticity determines a species' ability to adapt to new circumstances. Kramer et al.[19] conducted experiments with various populations of *Aedes albopictus* species from the different altitudinal gradients in South Asia in order to depict the ecophysiological plasticity regarding overwintering potential. Ecophysiological plasticity in *Aedes albopictus* overwintering capacity is high in high-altitude populations. Tsunoda et al.[39] demonstrated that overwintering is less common in temperate populations under milder (i.e., tropical) circumstances.

Vector Distribution and Climate Change

Aedes albopictus was initially found in Southeast Asia's humid tropics.[40] The mosquito's habitat expanded to other continents as globalisation accelerated.[41-43]

Aedes albopictus has geographically migrated from its natural habitats due to observed global warming in the last several decades. The mosquito population exploded in particular high-latitude temperate locations. The emergence was ascribed to increasing local temperatures, which resulted in more conducive environments and longer activity times, allowing for a higher rate of overwintering success. Furthermore, field surveys in locations with a documented dry and warm summer, such as Southern Spain and Sardinia, indicated a drop in the species' density. The drop was attributed to rising temperatures, which made previously favourable habitats unsuitable.[44-46] These disparate reactions suggested a possible regional shift as a result of changes in mosquito habitats and behaviour due to rising temperatures.

Alto and Juliano[47] looked at the effects of temperature and precipitation on *Aedes albopictus*. They showed that elevated temperatures favour faster and complete adult emergence. This study also revealed that this species can produce offspring and develop in a moderate temperature region, which aids it in the invasion and establishment in the northern parts of the United States.

Kobayashi et al.[48] analysed the dispersion pattern of *Aedes albopictus* in Japan. They predicted its future spread in both Japan and the United States using a Geographic Information System (GIS) and discovered a strong link between the yearly average temperature and the abundance of tiger mosquitoes. They pointed out that *Aedes albopictus* species is migrating North and global warming will fasten its expansion rate.

Mogi and Tuno[49] used a retrospective method to study *Aedes albopictus* in its native geographical range and discovered that a greater environmental temperature throughout the winter was one of the key factors in *Aedes albopictus's* geographical range expansion. Since the environmental temperature has a high impact on the dispersion and establishment of *Aedes albopictus* mosquito, climate change is expected to cause a larger geographical range expansion of *Aedes albopictus* with possible health consequences due to the increased pathogen transmission rates, putting another 30 million people in danger.[50]

Conclusion

Aedes albopictus continues to expand its distribution range across the world. It is most excessively found in outdoor regions of urban and suburban areas since it is greatly anthrophilic in nature. Moreover, in some areas, it is co-existing with *Aedes aegypti,* which is the primary vector of dengue fever, but the influence of temperature in the co-existence or their invasion patterns is understudied. In the era of global warming and climate change, it is critical to analyse the dispersion pattern of *Aedes albopictus* and *Aedes aegypti* along with their biology and ecology owing to the high risk associated with the coexistence of these species in dangerously modifying the epidemiology of arboviral diseases. Since the environmental temperature plays a significant role in defining the limits of the dispersion and spatial distribution of *Aedes albopictus* mosquitoes, a review of the influence of environmental temperature in the development, survival, population dynamics, and spatial distribution of the *Aedes albopictus* mosquito significantly helps to monitor its development and bionomics, which in turn enables the prediction and control of disease outbreaks.

Conflict of Interest: None

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