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A Systematic Review of Temperature-Driven Changes in Anopheles Mosquito Development and Survival and Their Implications for Malaria Control: A comprehensive Review

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Abstract:

The life-history characteristics and disease-transmission capacity of adult mosquitoes can be significantly influenced by the growing temperature during their immature stages. This review evaluated available data on how temperature affects life-history features, pesticide susceptibility, immature stages, and enzyme expression in adult Anopheles mosquitoes. The review found that compared to An. adult funestus and An. quadriannulatus, embryonic stages of An. arabiensis, however, were more resistant (in terms of their survivability) to a higher temperature. Increased temperatures led to smaller larvae and shorter hatching and pupation times. At higher temperatures than at lower ones, An. stephensi's growing rate and survival rate were considerably lower. Anopheles mosquito lifetime, body size, gonotrophic cycle duration, and fecundity all reduced with rising temperatures. Females injected with the species An. arabiensis SENN instead of DDT strain showed greater resistance to pyrethroids, while the An. arabiensis SENN variant showed increased tolerance to pyrethroids. Additionally, the level of Nitric Oxide synthesized (NOS) expression was markedly elevated and pesticide toxicity was reduced by rising temperatures. The species of mosquito generation and survival are impacted by both extremely high and low temperatures. Anopheles mosquitoes may be impacted by climate change in a number of ways. Anopeheles mosquito species vary in how sensitive they are to temperature, even within the same complex. Nevertheless, it appears that little research has been done on how temperature affects the adult life-history characteristics of Anopheles mosquitoes; further research is required to fully understand this relationship. Some of the most serious infections that affect humans are spread by mosquitoes, such as malaria, which kills between 0.6 and 1.2 million people annually, mostly children in nations with a low income. There is growing recognition that a multifaceted strategy, including vector control, is required to prevent malaria since a single measure is likely to do so. Although there are now very efficient vector control methods, the majority of which include insecticides, they is evidence of increasing issues with the emergence of resistance. Numerous innovative genetic strategies for vector control are being developed. Large investments in molecular resources, such as the availability of many full-genome sequences, have substantially aided research on mosquito targeting. I contend that in order to advance vector control—which is an application of population biology—mosquito ecology must receive the same level of attention as mosquito molecular biology.

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Introduction

Arthropods, especially mosquitoes (Culicidae), are responsible for the transmission of many of the most serious infectious diseases that affect humans. The most significant is malaria, which is spread by mosquito larvae called Anopheles It affects 200 million people annually and likely kills between 0.6 and 1.2 million primarily children in low-income nations. The yellow disease virus, which in both the 18th and 19th centuries caused catastrophic outbreaks in the Old World in Barcelona and the New World, including as far north as Washington, DC, is spread by the frequently striking black-and-white-patterned mosquitoes of the genus Aedes (D'Antonio & Spielman 2002). Dengue fever is currently the most significant illness it carries, and it is becoming a bigger issue in tropical regions and semi-tropics The parasitic organisms Wuchereria (also known as Brucia) that trigger filarial elephantiasis are spread by many mosquito taxa A group of arboviruses—arthropod-borne viruses with various evolutionary origins—that mostly survive in animal hosts and are sporadically transferred to humans but are not passed on between humans are less well understood. The West Nile virus, which is mostly a bird infection, is arguably the most well-known because of its recent entry to the nation's soil (Hayes, et al. 2005). Other viruses include the Chikungunya virus, some influenza viruses, and the pathogenic viruses that cause Ross River and Rift Valley disease (WHO 1985). Additionally, animal and wild animal diseases are spread by mosquitoes. For instance, horses in the United States suffer from various equine encephalitis viruses (Young et al. 2008). Hawaii's native bird species are declining due in large part to avian malaria and foreign mosquitoes This species of mosquitoes are poikilotherms whose life history traits are highly influenced by the surrounding temperature. The overall length of the gonotrophic phase, fertility, biting rate, resilience, and immature mosquito development are some of these traits [1]. Therefore, any element that modifies these traits may have an impact on mosquitoes' capacity to spread illness. Moisture, temperature, and rainfall are examples of climate factors that have a significant impact on the life-history characteristics of mosquitoes as well as the sporogonic growth of parasites within their bodies The mosquito's immune system is also impacted by temperature Furthermore, pesticides are typically used in the majority of interventions meant to manage Anopheles mosquito populations. These pesticides' effectiveness depends on a number of variables, including ambient temperature, in addition to the active The majority of research that has examined how temperature affects malaria development and survival has concentrated primarily on species like Culex and Aspergillus [2].For example, the authors Ezeakacha and looked at how temperature affects Aedes albopictus mosquito larval competition and carry-over effects. They discovered that temperature had an impact on both intermediate and adult mosquitoes. Both the standards of adult life and the age distribution of the population that is adult are influenced by the conditions of mosquitoes during their immature stages. Furthermore, research on Anopheles mosquitoes has examined how temperature affects certain life-history characteristics To find out how temperature affects Anopheles mosquitoes, no study has tried to compile all the research on the many types of mosquito larvae into a single study [3].We compiled and assessed the available data in this systematic review that demonstrated the connection between warmth and the immature stages, adult life-history characteristics, pesticide dependence, and enzyme levels or immunological reactions in the adult Anopheles malaria mosquito

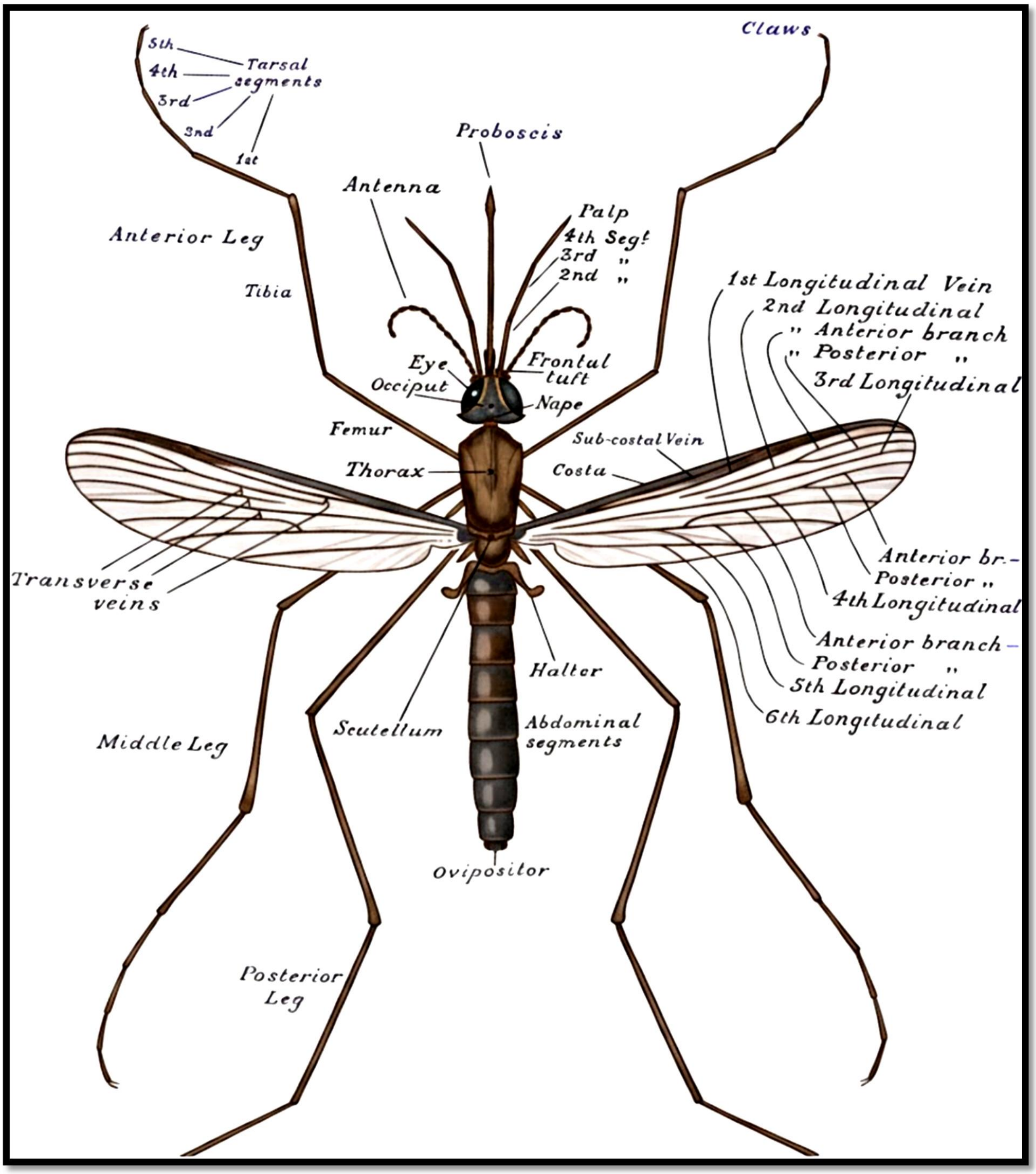

Figure 1:- Showing the morphology of female anopheles[4]

2. Man, malaria and mosquitoes

2.1 The pathogen

Most of human deaths are caused by Plasmodium falciparum, one of multiple types of parasite in the species group Plasmodium, the members of which are single-celled eukaryotes of the Apicomplexa phylum (Cavalier-Smith 1993). a second species, Plasmodium vivax, is also common, causes relapsing malaria, and is thought to be responsible for significantly fewer deaths. When people are bitten by an infectious mosquito, the malaria-causing pathogen enters the body and quickly colonizes a liver cell. Here, it replicates numerous times before rupturing the cell to produce a new version of the virus that infects red blood cells [5]. Unlike P. falciparum, Plasmodium vivax can relapse because it has a quiescent form that can linger in the liver for months or years.The

Plasmodium replicates once more within the red blood cell membrane, creating parasite forms that may spread to additional red blood cells. The Plasmodium may sustain itself in the circulatory system through cycles of infection and multiplication, which are frequently coordinated and result in fever episodes. However, certain infected cells go through a distinct developmental pathway where the Plasmodium undergoes fertilization to create male and female gametes that a feeding mosquito can consume while they are still in the red blood cells.Because the pathogen spends the majority of the time inside human cells, it is comparatively shielded from the immune system of the victim. It can be eliminated by the spleen, though, and to defend itself, it produces proteins on a cell's human wall that make red blood cell membranes stick to the edges of capillaries. Malaria-infected cells obstruct tiny capillaries, which contributes significantly to the disease's progression. Humans can develop an immunological defense against the infection despite the host cell's protection, and the majority of individuals in high-prevalence nations have some immunity. The creation of a successful malaria vaccine has thus far been hampered by the intricacy of the pathogen-immune interaction.Going back to the Falciparum life cycle, when the Anopheles mosquito consumes cells that contain both male and female gametes, the reproductive organs are released in the insect's gut and mating takes place to create a mobile zygote. After penetrating the intestinal wall, the zygote creates a cyst where the pathogen multiplies several times. The cyst releases an additional mobile form that travels to the salivary gland. This form gets introduced into the human after a blood meal and infects the liver cell.I should also mention that each type of malaria parasite has a lengthy technical designation that those of us who took traditional biology classes were required to commit to memory. Packard (2007) provides an approachable introduction to malaria biology, and Gilles, alongside Warrell & Bruce-Chwatt (1993) provides complete details[6].

2.2 The vector

Out of around forty mosquito genera, the family Anopheles is the only one that can spread malaria to humans It has been demonstrated that about 70 of the approximately 500 Anopheles species—both known and unknown—are capable of spreading the human disease. With a focus on Africa, the two primary vectors are Anopheles gambiae sensu lato, a complex of species, and Anopheles funestus, which is also likely a complex of species. The seven species that make up Anopheles gambiae sensu lato are generally genetically separated yet have similar morphologies: One.The two most significant carriers are Anopheles arabiensis and Gambiae sensu strict as , the complexity doesn't stop there. The fact that An. gambiae is composed of several chromosomal races with some restrictions to gene flow has been recognized for fifty years. Mosquito chromosomal typing takes a lot of time. Currently, two molecular marker-defined forms, "M" and "S," are regularly recorded, but they overlap with the homologous forms of the mosquito A different genetic variant has recently been discovered often in West African larval collections, although these mosquitoes don't seem to penetrate homes like typical An mosquitoes.gambiae of the ecological issues I return to below is comprehending the biology and development of variety of An. gambiae, which is undoubtedly the insects that most affects humans.The fundamental biology of the main African vectors—as well as the majority of other Anopheles—is quite similar when one looks past the intricacies of species and population organization After emerging and mating, females need one or more blood meals to develop their eggs. They might also eat nectar to get energy. The majority of different kinds of Anopheles will feed on a variety of possible host species, and as humans make up a very minor portion of their diet, many competent vectors are not much of an issue. From the perspective of the pathogen, An. gambiae (and, to a lesser extent, Anopheles funestus) are highly effective vectors because of their relative specialization on humans.In particular, Anopheles gambiae appears to have specialized to feed on people living in huts and other structures.The loaded and aerodynamically impaired insect must rest to start digestion after consuming blood, usually on the building's walls. It then flies to an oviposition site. Each type of mosquito have aquatic larvae and reproduce in various ways. An. gambiae sensu stricto, for example, usually breeds in small ephemeral wet patches like tire tracks or hoof prints, while related species breed in rice fields, slowly moving water bodies, etc. Members of the species complex that are less prevalent are specialized in salty springs or brackish water. Due to their biology, seasonal rainfall patterns have a significant impact on mosquito populations and the power of infection[7].

2.3 Control

Today, controlling the parasitic infection in humans and combating the vector are the two fundamental pillars of malaria control. Anti-malarial medications have been around since the time of herbalists, but many of them are no longer effective since the pathogen has developed immunity. Artemisinin is and its synthetic cousins and derivatives, which are found in the shrub Artemisia annua and have been used for centuries in Chinese medicine, are currently the most widely used medication It is advised by the World Health Organization as the main treatment for P. falciparum malaria, but only in conjunction with other medications (such as Artemisinen Combination Therapy, or ACT) that can eradicate low infection levels and stop resistance from spreading.There have been several reports of artemisinin resistance; if this were to become widespread, control programs would be seriously threatened because there are no significant medications that might take its place Insecticide-treated bed nets (ITNs), and indoor residual spraying, also known as IRS, are now the two main vector control methods. The majority of African Anopheles bites happen at night, so using bed nets to protect people clearly lowers the risk of illness. Bed nets sprayed with pyrethroid pesticide, which killed mosquitoes instead of deflecting them and could stay operative for six months in the field, were given by various programs starting in the 1980s. Long-lasting insecticide-treated bed nets (LLIN), which can last up to five years, have been created more recently. According to a synthesis of ITN programs, nets significantly lowered illness prevalence and death (Lengeler 2004).Economic and social scientists are actively researching the optimal ways to pass on nets, if freely or at a minimal but nonetheless substantial cost Mosquitoes are killed by indoor residual spraying (IRS), frequently while they are resting after eating [8].In contrast to ITNs, a far wider variety of pesticides can be applied, and DDT is still commonly used in many places, particularly in areas where inhabitants live in unpainted huts. It has been demonstrated that long-term IRS programs significantly reduce the prevalence of disease The spread of pesticide resistance is a significant concern for vector This is particularly problematic for bed nets because all of the insecticides employed in ITNs are pyrethroids, and resistance to one usually provides protection against the entire family Insecticides are encountered by mosquitoes as adults and larvae, sometimes as a result of intentional mosquito control programs but more frequently as a byproduct of their use in agro.Over the past ten years, governments and non-governmental organizations—such as the foundation founded by Bill and Melinda Gates and the Global Fund for the Fighting contrary to Aids Tubercular Disease and Malaria (GFTAM) and the US presidency's Malaria Initiative, which were established in 2005—have made significantly more efforts to combat malaria. Global and African malaria burdens have significantly decreased as a result of these initiatives People above the poverty mark who have access to functional health care are significantly more likely to be able to tolerate the disease, therefore many low-income countries' increased economic and governance standing will also have benefited.In addition to saving children's lives today, investments in the ACT, ITN, and IRS may someday result in the disease's elimination in our current state of evolution. However, when opposition develops, all of these instruments may become outdated, necessitating the investment in new tactics to replace them. The quest for new insects and repellents, as well as the development of new medications and potential vaccinations to target Plasmodium, are significant international research endeavors that I will not delve into further here. Before discussing what we need to know about malaria ecology to make them effective, I will instead outline some new potential techniques to target the vector [9].

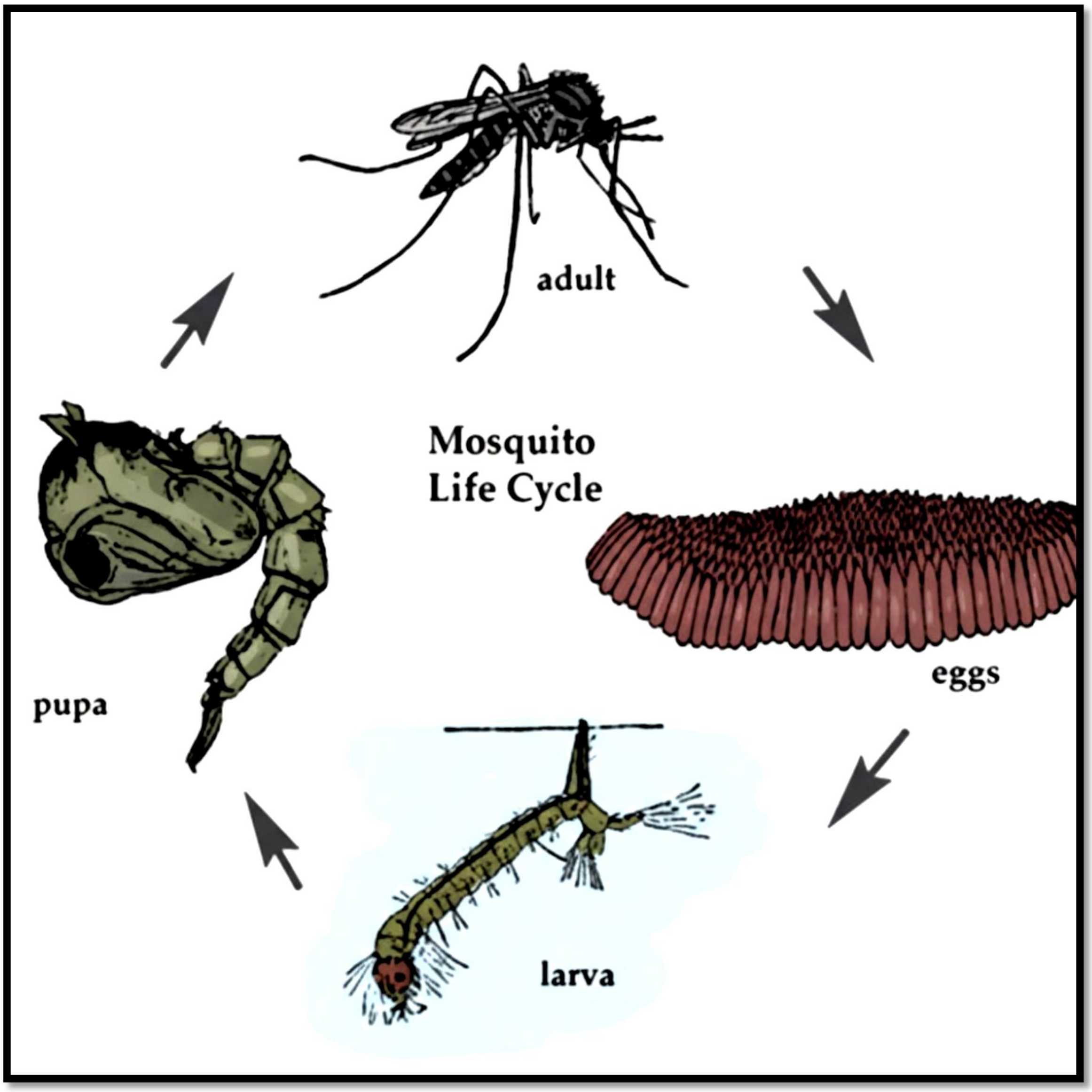

Figure 2:- Schematic diagram for life cycle of mosquito (female anopheles)[10]

3. Methods

The Preferred Reporting Materials for Systematic Studies and Meta-Analyses (PRISMA) criteria were followed when reporting the results of this systematic review [11].

3.1 Eligibility Criteria

Original research that examined either undeveloped or adult Anopheles mosquitoes, regardless of the complex, were included to evaluate the effects of ambient temperature on species of Anopheles mosquito production and survival. Additionally, studies that took into account field research, laboratory research, or both were included in this study. Included were studies that assessed development rate, longevity, fertility, length of the male reproductive cycle, biting rate, susceptibility to pesticides, and gene and enzyme expression. Nevertheless, research that did not concentrate on the Anopheles mosquito and any of the outcomes mentioned were not included. Excluded were studies that were not written in English. Review articles, novels, viewpoints, scientific studies, and duplicate entries were also disregarded [12].

3.2 Data Extraction

One reviewer pretested a data-extraction form (T.P.A.). Later, the form was updated to incorporate information on the author, study type, study site, Anopheles species taken into consideration, growing conditions, and the desired outcome. Three writers (T. P. A., I.I., and A.A.A.) autonomously extracted and reviewed data from the included papers before working together to settle disputes.

For additional information, the corresponding authors of several of the listed studies were contacted when needed [13].

3.3 Data Analysis

Based on the end result of interest, a narrative overview of all the included research was carried out, and the results were presented in tabular form for simple comprehension and interpretation. A meta-analysis was not included in this review[14]. despite the fact that all of the included papers were quantitative.

3.4Other Sources of Bias (Funding Source and Rearing of Mosquitoes)

With the exception of eight (8) trials [15-17]. that did not reveal their funding sources, the bulk of the research (20) disclosed their funding sources, and funders had no impact on the outcomes. however, had an ambiguous risk. The study did not specify or offer sufficient information to evaluate funding sources, despite indicating that financing was obtained. The majority of research evaluating the effects of temperature on Anopheles mosquitoes raised the insects in dormitories from either the egg-laying or larval stage to adulthood. It may be easier to determine how temperature affects mosquitoes if they are raised in dormitories from their egg stage or caterpillar to the adult stages. Based on mosquito rearing circumstances, nine (9) studies were very susceptible to bias The results of some of these studies may be impacted since adult mosquitoes were only exposed to the chosen temperature regimes prior to outcome evaluation[18]

4. Effects of Temperature on the Immature stages of Anopheles Mosquitoes

The impact of temperature on several Anopheles species was evaluated in sixteen (16) These investigations took into account egg hatchability as well as the growth and survival of larvae and pupae. Even within the same complex, different species exhibited different effects of temperature on the early phases of mosquitoes. Compared to An. funestus [19] and An. quadriannulatus [20], the larval stages of An. arabiensis have were more resistant (in respect to survival) to a higher temperature. Furthermore, compared to Anopheles funestus Anopheles quadriannulatus [21], Anopheles arabiensis had accelerated growth rates (in days).

These investigations yielded low and high temperatures of 10 and 40 °C, accordingly. Higher temperatures (23 to 31 °C) produced smaller larval sizes and retarded the growth from hatching to adult emergence, according to one study Nonetheless, the majority of research found that raising the temperature shortened the immature stages' growth period (in days). For example, An. dirus and An. sawadwongporni larvae raised at 30 °C showed a considerably shorter developmental time (about 7–8 days) compared to those raised at 23 °C (12–14 days) ($p < 0.05$), In two An, a higher temperature (30 and 35 °C) markedly accelerated larvae growth rates.The period from hatching to pupation of An. gambiae s.s. larvae reduced from 9.2 ± 0.05 day at 21 °C to 8.3 ± 0.04 days at 25 °C although 7.8 ± 0.05 days at 29 °C when the temperature rose, and larval mortality.27 °C, $p < 0.001$), 8 °C (from 27 °C to 35 °C, $p < 0.001$), and 12 °C (from 23 °C to 35 °C, $p < 0.001$).Raising the temperature shortened the time it took for Anopheles eggs to hatch, but it had no effect on the rate. For example, An. arabiensis eggs hatched most quickly at 27 °C and most slowly at 22 °C, but regardless of the water temperature, the majority of the embryos matured within two days [22]. The mean emergence rate of An. dirus and An. sawadwongporni eggs raised at 23 °C and 30 °C did not differ significantly ($p > 0.05$) Egg hatchability, however, may be impacted by exceptionally high temperatures. In comparison to the other temperatures, found that incubation eggs at 42 °C for a day produced an insignificant mean hatching count.

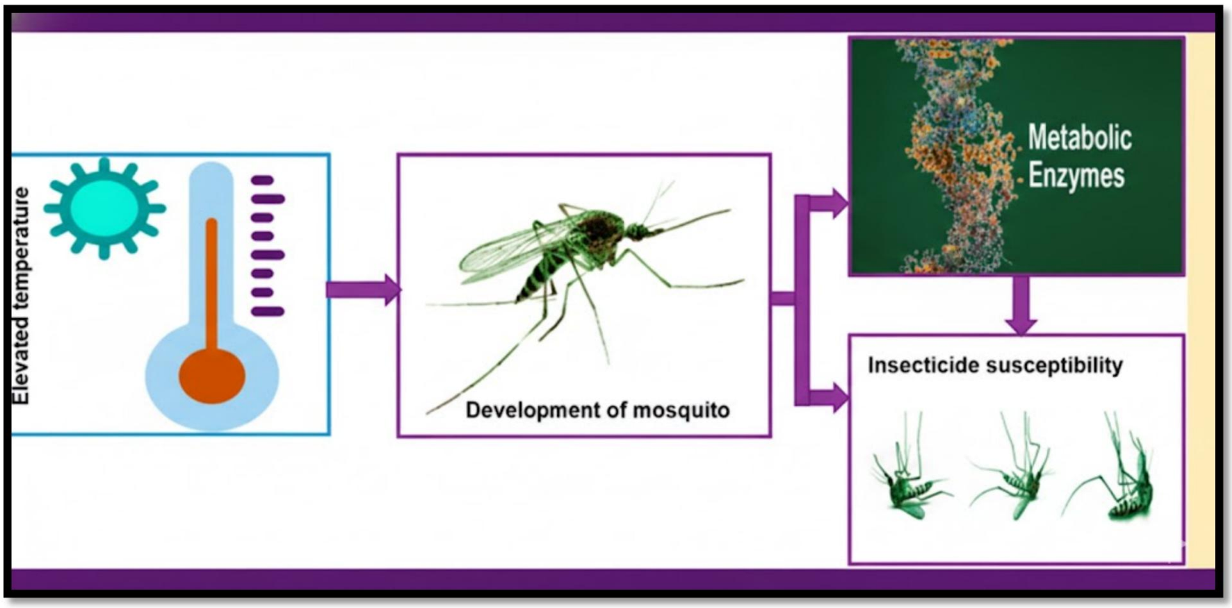

Figure 3:- showing the effect of elevated temperature[23]

5. Effects of Temperature on the Life History Traits of Adult Mosquitoes

5.1 Longevity

The lifetime of several Mosquitoes with the name Anopheles from either natural habitat or laboratory populations was evaluated in five (5) research [24] An. gambiae mosquito longevity and survival rates were higher during the rainy season (17.48 ± 2.92 days and 84.5% ± 10.46%, respectively) than during the dry season (7.29 ± 2.82 days and 57.47% ± 14.9%, respectively). Temperatures tend to be lower during the wet season and higher during the dry season. Furthermore, that An. coluzzii lived longer at lower temperatures; nevertheless, the primary effect of warmth was not of statistical importance ($p = 0.072$).They found longer lifespans at lower temperatures in all three studies and between 22 and 23.5 degrees Celsius ($p < 0.001$), but not at 27 degrees Celsius ($p = 0.072$). [25]. and that of reported similar patterns. Every time the temperature rose over the baseline (i.e., 23 °C), more adult An. gambiae s.s. perished. When comparing 27 °C to 23 °C, 31 °C to 27 °C, and 31 °C to 23 °C, all of the percentages were highly significant ($p < 0.001$) [26].

5.2Body Size

Flight length has been utilized as a stand-in for mosquito body size in the majority of mosquito research. Wing extent and body weight decreased with rising temperature in all seven (7) investigations [27, 32, 33, 34, 37, 41, 49] that evaluated on body size (Table 4). An. dirus and An. sawadwongporni mosquito raised at 23 °C, for example, were substantially longer and heavier than those raised at 30 °C ($p < 0.05$) [49]. The wing length of An. gambiae s.s. mosquitoes reduced considerably ($F(2, 181) = 35.7$, $p < 0.0001$) with rising temperature, from 3.27 mm at 21 °C to 3.23 mm at 25 °C and 3.02 mm at 29 °C, according to Barreaux et al. [34]. Anticipate Charlwood and Brag § [27],

5.3 Fecundity, Length of the Gonotrophic Cycle, and Biting Rate

The impact of humidity on fecundity was evaluated in four (4) research In a similar vein, four research evaluated how temperature affected the length of the gonotrophic cycle; only one study took biting rate into account According to three studies on fecundity [28]. fertility decreased as the temperature rose. For instance, An. dirus and An. sawadwongporni mosquitoes raised at 23 °C lay substantially more eggs on average than those raised at 30 °C ($p < 0.05$) however, found that considerably fewer Anopheles mosquitoes deposited eggs in the dry season (38.2%) compared to the rainfall period (61.8%) ($t = 8.85$, $df = 1$, $p < 0.05$). The length of the growth cycle decreased as the temperature rose, according to every study on the subject. The length of the gonotrophic cycle varied considerably between the two seasons ($X2 = 96.68$, $df = 2$, $p < 0.001$), with the first and second cycles lasting shorter in the rainy season (4.1 and

2.9 days, respectively) than during the dry season (3.0 and 2.2 days, accordingly) On the other hand, the likelihood that female An. gambiae s.s. mosquitoes would lay eggs following their first or third consumption of blood was unaffected by the weather of the adult habitat.However, an increase from 23 to 31 °C and 27 to 31 °C during the second blood meal resulted in a significantly reduced likelihood of hatching eggs (0.72 vs. 0.46, p = 0.002, and 0.65 vs. 0.46, p = 0.022, accordingly) Although there was no discernible impact of temperature on the likelihood of fertilization in either cycle, also noted that a smaller percentage of this species of mosquitoes laid eggs during the second growth cycle compared to the first.], An. stephensi bite rates rose as the temperature rose [29].

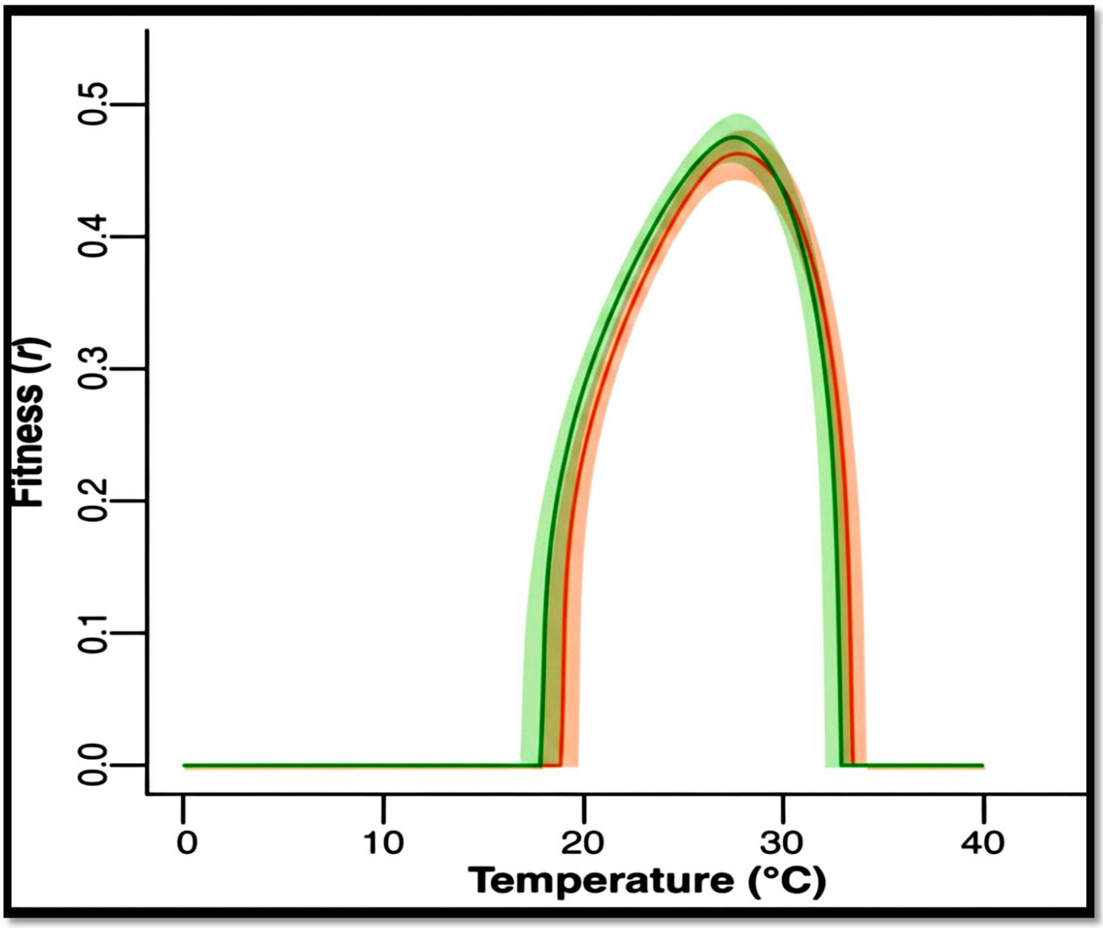

Figure 4:- Graphical Presentation of variation in temperature after bite of mosquito[30]

6. Effects of Temperature on the Expression of Enzymes and Susceptibility to Insecticides

Anopheles mosquitoes' immunological responses and enzyme expression were evaluated in four (4) investigations [31-34]An. stephensi mosquitoes, physiological darkening, defensin (DEF1), cecropin (CEC1), phagocytosis, and nitrogen dioxide synthase (NOS) were all strongly impacted by temperature. For example, mosquitoes housed at below-average temperatures (18 °C: 24 h; 22 °C: 18 h) showed higher levels of NOS expression at later sampling time points than those kept at ideal or elevated temperatures (26–34 °C: 12 h) NOS also rose significantly at higher temperatures (28 °C) as opposed to lower temperatures (20 °C vs. 28 °C, p = 0.002; 24 °C vs. 28 °C, p = 0.001).

That took pesticide susceptibility into account, rising temperatures decreased the effectiveness of insecticides Males of the An. arabiensis SENN instead of DDT strain showed greater pyrethroid resistance due to higher rearing conditions and brief exposure to 37 and 39 °C, while the An. arabiensis SENN strain showed increased pyrethroid tolerance.

As the temperature rose, the deltamethrin insecticide's toxicity decreased in the unidentified SENN strain. Similarly, the susceptible strain of An. arabiensis became more resistant to deltamethrin as temperatures rose However, one study [29] found that permethrin (two-sample t-test: p = 0.55; t = −0.63) and lambda-cyhalothrin (two-sample t-test: p = 0.64; t = 0.47) did not significantly affect mortality induced at either 37 or 39 °C [35].

7. Effects of Temperature on Susceptibility to Insecticide

The dynamics of vector-borne diseases are significantly influenced by the early developmental stages of mosquitoes. For example, changes that take place during larval growth and maturation are the main cause of fluctuations in mosquito population size, which have a direct impact on the spread of diseases carried by vectors. Furthermore, vectorial capacity features including fertility, longevity, biting action, and vector competence may be impacted by the carry-over effects of the larval stage [36].According to the review, raising the temperature considerably shortened the time it took for an An. gambiae s.s. larvae to pupate [37]. The literature currently in publication consistently shows that temperature affects how quickly mosquitoes develop into their immature stages [38]. The implications of temperature on development times, however, were largely consistent[39]. Further research is required to elucidate the disparities in the data, as it is unknown what could have caused them. High temperatures have a variety of consequences on the insect's juvenile stages and are typically linked to quicker development rates [40,41]On the other hand, exceptionally high temperatures (≥34 °C) can cause substantial mortality rates and hinder larval development No larval forms of Anopheles survived at 35 °C, according to certain research Uncertainty surrounds the physiological explanation for this, but one plausible explanation is that fourth instar larvae cannot adapt to the resulting nutrient usage, metabolism, or accumulation that is required for the complex physiological process in the transition from larvae to pupa when they grow and develop at a faster rate Furthermore, juvenile mosquito survival may be impacted by heat stress Because they often inhabit small, restricted pools and have difficulty escaping unfavorable settings, their early stages are highly dependent upon temperature Mosquitoes may need to raise their metabolic rates in order to combat the heat stress they are experiencing, which would increase their energy This could surpass the amount of oxygen provided by the surroundings, which would result in poor performance, a reduced ability to withstand heat stress and the mosquito's demise. Furthermore, our analysis revealed that larval sizes decreased at temperatures between 23 and 31 °C. This supports the outcomes of who found that Culex tarsalis had smaller bodies as the temperature rose. Many epidemiologically significant physiognomies, including longevity, digestive cycle length, biting rate, immune function, and infection severity, are influenced by the size of mosquitoes, particularly females [42]. Thus, these physiognomies have an impact on mosquito survival] and parasite development [43].This may account for the notable rise in larval mortality caused by rising temperatures.It was shown that different species, even within the same complex, had different effects of temperature on the early phases of mosquitoes. The tendency of rising temperatures with tiny larval sizes, however, remained unchanged.The implications of environmental conditions on the total quantity of adults produced were only evaluated in one study. Evaluating the population dynamics can be aided by the quantity of adults generated from the immature stages. To determine how temperature affects the total efficiency (the total amount of adults hatched) of the immature stages, more research is required. Additionally, none of the research examined how temperature affected the emerging adults' sex ratio. The quantity of male and female mosquito that emerge from their immature stages is crucial for managing mosquito populations since more males may increase the number of mosquitoes because of the higher likelihood of mating [44].

Discussion

The effects of environmental temperatures on the development of Anopheles insect intermediate stages, adult life-history features (such as reproduction rate, body size, length of the reproduction cycle, and lifespan), gene expression for enzymes and genes, and responsiveness to pesticides were all examined and evaluated in this study. To the best of our expertise, this is the first thorough study evaluating how temperature affects Anopheles mosquito development. Because of the interdependence of the mosquito's life cycle, environmental factors and personal traits in one stage have an impact on the others [45],Future generations may see long-term effects from rising temperatures [46]. Compared to juvenile stages and life history traits like development and mortality, adult mosquitoes have different sensitivity to temperature The majority of the studies that were reviewed had a low risk of reporting bias, attrition, and baseline characteristics, making them of good quality. Nevertheless, there was a significant danger of sequence creation and allocation concealment in some of the examined investigations. The results are unlikely to be affected by this. Furthermore, some of the included research raised mosquito at steady temperatures and only exposing them to various temperature regimes before evaluating the results. The outcome of interest may have been impacted since these studies may have overlooked the early effects of heat on mosquitoes. Adult life-history features and total adult fitness can be impacted by the impacts of rearing warmth on the stages of development [47-50].

Conclusions

There were certain restrictions on this review. It's possible that not all relevant studies were found using the search method. Nonetheless, we think that all significant research on the mosquito species Anopheles and temperature may have been found by researching a variety of databases and an article reference list. Additionally, we only included English-language articles, but we don't think this would have led to the exclusion of any significant papers in the field. The raising of mosquitoes is another restriction. The consequence of ambient temperature on the end result may not be adequately estimated in some of the studies cited because the adults of the mosquito have been restricted to the chosen temperature regimes before to outcome measurement. This review showed that mosquitoes that carry Anopheles are vulnerable to mean the outside temperature and temporal fluctuations, notwithstanding the restrictions mentioned. Temperature has a significant impact on a number of Anopheles mosquito life-history characteristics, including longevity, biting rate, fertility, weight, length of the reproductive cycle, adult & larval development, enzyme expression, and pesticide sensitivity. This implies that Anopheles mosquitoes may be affected in a variety of ways by the higher temperatures anticipated in a warmer climate. This could have an impact on the ecology, population dynamics, and potential for disease transmission of these mosquitoes. There was some diversity in the procedures or techniques utilised to raise the mosquitoes, even though the majority of the included research had comparable designs (laboratory- and field-based investigations). The influence of temperature on fertility, biting rate, length of the gonad cycle, and enzyme expression were not well studied. Anopheles different kinds of mosquitoes vary in their sensitivity to temperature, even within the same complex. However, research on how temperature affects Anopheles mosquito life-history characteristics appears to be scarce. and further research is required to elucidate this connection [49] A deeper comprehension of this complicated system and its processes is necessary for understanding and modelling the impact of temperatures on the young phases, life cycle traits, insecticide vulnerability, and activity of enzymes in grown-up mosquito Anopheles in order to predict the dissemination of malaria and the efficacy of prevention efforts in a future more favourable climate

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