behavior (Kahamba et al., 2022). Similarly, Indian vectors like *An. culicifacies* show variations in feeding preferences with human blood indices ranging widely across regions; reproductive traits such as proportions of gravid mosquitoes also vary geographically, affecting transmission dynamics (Rahi et al., 2022).

Secondary vectors such as *Anopheles squamosus* demonstrate behavioral plasticity that allows them to evade conventional control measures by shifting biting times or locations. Their biology remains understudied but suggests they occupy similar ecological niches as primary vectors in certain African regions, highlighting the need for further research into their life history traits to inform control strategies (Nguyen et al., 2025). Feeding behavior diversity among vector species underscores the importance of integrated approaches that consider both indoor and outdoor transmission risks.

2.3 Influence of environmental factors on vector population dynamics

Environmental factors including land cover, climate variables (temperature, precipitation), topography, and human population density significantly influence the habitat suitability and population dynamics of malaria vectors. Studies using ecological niche modeling have shown that these factors can either facilitate or restrict the occurrence of key vector species such as *An. Gambiae* s.s., *An. coluzzii*, and *An. funestus* s.s., thereby affecting malaria transmission patterns even under intervention pressure like long-lasting insecticidal nets (LLINs) (Talbot et al., 2025). Seasonal changes also impact vector densities; for instance, saltwater-tolerant species like *Anopheles merus* peak during dry seasons when freshwater mosquito populations decline (Bartilol et al., 2021).

Moreover, environmental determinants shape the bionomics of zoonotic malaria vectors in Southeast Asia by influencing abundance and survival through temperature fluctuations, humidity levels, elevation gradients, precipitation patterns, land use changes, and seasonality. These complex interactions necessitate a One Health approach integrating human health with animal reservoirs and environmental management to effectively address malaria transmission risks (Masse et al., 2025). Continuous monitoring of environmental changes is essential for adapting vector control strategies to evolving ecological contexts.

3 Mechanisms and Determinants of Malaria Transmission

3.1 Development of Plasmodium within mosquito hosts

The development of *Plasmodium parasite*s within mosquito vectors is a complex process essential for malaria transmission. After an infected female Anopheles mosquito takes a blood meal, *Plasmodium gametocytes* ingested from the human host undergo sexual reproduction in the mosquito's midgut, forming zygotes that develop into motile ookinetes. These ookinetes penetrate the midgut wall and form oocysts, where sporozoites mature over a period typically ranging from 7 to 30 days depending on the Plasmodium species and ambient temperature. *Mature sporozoites* migrate to the salivary glands, enabling the mosquito to infect new human hosts during subsequent blood meals (Rossati et al., 2016; Sato, 2021).

Temperature plays a critical role in modulating the rate of parasite development within mosquitoes, influencing transmission potential. Higher temperatures generally accelerate parasite maturation but may reduce mosquito lifespan, creating a trade-off that affects overall vectorial capacity. Different Plasmodium species exhibit variable thermal thresholds for development; for example, *P. falciparum* and *P. vivax* have distinct optimal temperature ranges that impact their geographic distribution and seasonality of transmission (Villena et al., 2022; Suh et al., 2024).

3.2 Interactions among host, vector, and pathogen

Malaria transmission depends on intricate interactions between the human host, mosquito vector, and *Plasmodium parasite*. Host factors such as immune responses and genetic traits influence gametocyte production and infectivity to mosquitoes, thereby affecting transmission efficiency. Conversely, mosquitoes possess immune mechanisms and genetic variations that determine their susceptibility to infection and ability to support parasite development. These dynamic interactions shape parasite sexual differentiation rates and vector competence, which are critical determinants of malaria epidemiology (Sollelis et al., 2024; Li et al., 2025).