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A review on interspecific competition and population dynamics of mosquitoes

Diksha Raghav [1], Gauravi Yadav[1] , Anil Kumar[*1], Hridayesh Arya[1],

[1]Department of Zoology, N.R.E.C. College, Khurja, Bulandshahr. Affiliated to Chaudhary Charan Singh University, Meerut, Uttar Pradesh, India.

*Corresponding Author E-mail: anilkashyapnrec@gmail.com

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Abstract

As carriers of several deadly illnesses, including dengue, chikungunya, malaria, the Zika virus, and lymphatic filariasis, mosquitoes are hematophagous insects of major medical significance. They are members of the Culicidae family and have intricate life cycles and ecological relationships that affect their capacity for survival and spread. The taxonomy, disease correlations, and vectorial potential of the main mosquito genera—Aedes, Culex, and Anopheles—are examined in this paper. It also looks at population control techniques, emphasizing the drawbacks of chemical pesticides, including their damage to the environment, development of resistance, and non-target impacts, and advocating for environmentally benign substitutes including microbiological agents and herbal larvicides. A significant focus is placed on interspecific competition, particularly at the larval stage, where mosquito species compete for food, space, and oxygen. These interactions influence morphological traits such as wing length and adult body size, directly affecting survival, fecundity, and vector competence. Environmental variables, including both biotic (predators, microbial flora) and abiotic (temperature, pH, resource availability) factors, further modulate these outcomes. The review synthesizes data on how interspecific and intraspecific competition impact mosquito population dynamics, larval development, and disease ecology. Understanding these multidimensional interactions is crucial for implementing sustainable vector control strategies. By integrating ecological principles with innovative, environmentally responsible technologies, future mosquito management can be both effective and ecologically sound.

Keywords*:* Mosquito-borne diseases, Interspecific competition, Vector ecology, larval development, insecticide resistance.

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Introduction

There are more than 3,500 species of mosquitoes worldwide, particularly in tropical and subtropical areas, making them one of the most significant insect carriers. Mosquitoes are members of the class Insecta, phylum Arthropoda, kingdom Animalia, and suborder Nematocera. The main human disease vectors, Anopheles, Aedes, and Culex, are members of the subfamilies Anophelinae and Culicinae, which are subfamilies of the family Culicidae. Their importance stems from their ability to spread deadly illnesses like dengue, chikungunya, malaria, Zika virus, and lymphatic filariasis, especially in areas with little resources (WHO,2023).

Vector competence depends on species biology, environmental conditions, and human interactions (Becker *et al*., 2010). Urbanization and climate change are expanding mosquito habitats and increasing disease risk (Kraemer *et al*., 2019). Larval competition—often overlooked—is crucial in mosquito ecology. When species share breeding sites, they compete for limited resources, affecting development and vector potential. For example, Aedes albopictus often outcompetes *Aedes aegypti* in shared environments (Juliano & Lounibos, 2005).

While chemical control methods are still widely used, issues like resistance and ecological damage have led to the exploration of alternatives such as microbial agents and plant-based larvicides (Ghosh *et al*., 2012). A detailed understanding of mosquito taxonomy, ecology, and interspecific interactions is essential for designing sustainable vector control strategies.

Taxonomic Diversity

There are three subfamilies within the Culicidae family:

1) Anophelinae: This family includes the only human malaria vectors, Anopheles spp.

2)Culex, Aedes, Mansonia, and other species are members of the Culicinae family. Zika and dengue viruses are mostly spread by *Aedes aegypti* and Aedes albopictus.

3)Toxorhynchitinae: A distinct subfamily of mosquitoes with non-hematophagous members and predatory larvae that frequently feed on other mosquito larvae.

Life Cycle and Habitat:

Mosquitoes have four different life stages: egg, larva, pupa, and adult. They develop holometabolically. Every immature stage is aquatic, usually growing in bodies of water that are still or move slowly. Depending on the species, eggs might be placed single or in rafts. Often referred to as "wrigglers," mosquitoes have four unique life stages: egg, larva, pupa, and adult. They develop holometabolically. Every immature stage is aquatic, usually growing in bodies of water that are still or move slowly. They lay eggs.. Larvae commonly called wrigglers," and pupae ("tumblers") remain in water and are vulnerable to environmental changes and predators.

Even though only a small percentage of the approximately 3,500 species of mosquitoes are vectors, they are crucial in the transmission of infectious diseases, especially in tropical areas. Aedes (dengue, Zika, chikungunya, yellow fever), Culex (filariasis, West Nile virus, Japanese encephalitis), and Anopheles (malaria) are important genera. Malaria alone causes around 200 million cases annually, while dengue affects about 390 million people each year. Diseases like Zika and chikungunya are associated with neurological and joint complications, and lymphatic filariasis leads to severe disability. These mosquito-borne illnesses not only threaten public health but also place heavy economic and social burdens, necessitating comprehensive and sustained control efforts.

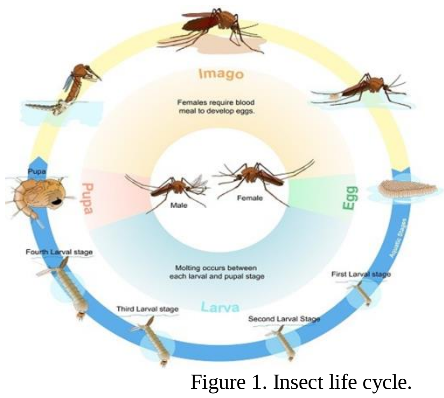

Figure 1. Insect life cycle.

(Source: https://eu.biogents.com/life-cycle-mosquitoes/)

Effect of Interspecific Competition on Population on Population Dynamics of Mosquito.

Mosquito population dynamics are significantly shaped by interspecific competition, particularly in areas where several species coexist in the same habitat. Their populations are impacted by this ecological interaction in the following ways over time:

Alters Species Abundance and Distribution: -

Each mosquito species frequently gains dominance when several species vie for the same scarce resources (such as food, habitat, and breeding grounds).For example:

•Aedes albopictus is more competitive than *Aedes aegypti* in many environments, often leading to a decline or displacement of Ae. aegypti populations (Juliano & Lounibos, 2005).

•This displacement alters species composition in urban and suburban areas, potentially changing disease transmission patterns.

Influences Reproductive Success and Growth Rates: -

Competition at the larval stage reduces access to food and space, which in turn affects:
•Larval survival
•Developmental time
•Adult size and fecundity
Smaller adult mosquitoes resulting from intense competition tend to have lower reproductive success, reducing the population's growth rate (Noden *et al*., 2016).

Drives Local Extinction or Coexistence: -

If one species consistently outcompetes another in a shared habitat, the weaker competitor may experience:
•Population decline
•Local extinction
•Or adapt by niche partitioning (using different resources or breeding at different times)
This dynamic can lead to unstable or shifting population equilibria, where dominant species vary based on environmental conditions and resource availability (Alto & Juliano, 2001).

Modifies Vectorial Capacity and Disease Risk: -

Changes in species dominance can affect which diseases are prevalent in a region. For example:
•Though often less effective than Ae. aegypti, Ae. albopictus is a capable vector for dengue and chikungunya.
•A shift in dominance from Ae. aegypti to Ae. albopictus may lead to changes in outbreak frequency or intensity (Juliano & Lounibos, 2005).

Affects Population Resilience and Recovery: -

Populations exposed to strong interspecific competition may:
•Recover more slowly after environmental disturbances (e.g., droughts, insecticide spraying)
•Become more vulnerable to additional stressors (e.g., predation or habitat loss)
This makes competitive interactions a key factor in mosquito population resilience and long-term stability.

Competition for Resources and Environmental Interactions: -

In watery environments, mosquito larvae frequently struggle for few resources like food, space, and opportunities for movement.
These interactions significantly influence their growth, development, and survival.
•Food: Mosquito larvae feed on microorganisms and detritus. In resource-limited habitats, competition intensifies, leading to slower growth and smaller adult size (Gimnig *et al*., 2002).
•**Space and Locomotion**: Dense populations reduce physical space and oxygen availability, restricting movement and access to the water surface for respiration (Juliano & Lounibos, 2005).
•**Biotic Interactions**: Presence of predators, parasites, or competing mosquito species (e.g., Ae. albopictus outcompeting Ae. aegypti) alters behavior and survival outcomes (Alto & Juliano, 2001).
•**Abiotic Factors**: Environmental variables like temperature, pH, and water quality influence larval metabolism and modify the strength of competition. For instance, high temperatures can exacerbate food scarcity by increasing metabolic demands (Tun-Lin *et al*., 2000).
These ecological pressures shape mosquito community structure, affect population dynamics, and influence disease transmission potential.

Interspecific Completion In Mosquitoes

Interspecific competition refers to the interaction between individuals of different species competing for the same limited resources, such as food, breeding sites, or habitat. In mosquitoes, this competition can significantly affect survival, development, and population dynamics, examples in mosquitoes:

Larval Stage Competition: -

Larvae of various mosquito species, including *Aedes aegypti*, Aedes albopictus, and Culex quinquefasciatus, may compete for the following in aquatic environments like ponds or containers:
•Microbial food sources
•Space
•Oxygen
For instance, it has been demonstrated that in certain container habitats, Aedes albopictus outcompetes *Aedes aegypti*, which causes the latter to be displaced in some areas (Juliano & Lounibos, 2005).

Adult Competition: -

Though less direct, adults of different species may compete for:
•Nectar or sugar sources
•Hosts for blood meals (especially in regions with limited host availability.
Ecological Impact:
•Alters species distribution in overlapping habitats
•Affects vector competence (i.e., ability to transmit disease)
•May reduce the overall population size of weaker competitors

Impact Of Interspecific Completion On Mosquito Morphology And Larval Morphology And Their Survival

Interspecific competition among mosquito larvae—particularly between species like *Aedes aegypti*, Aedes albopictus, and Culex pipiens—can significantly affect larval morphology, survival, and adult traits like :-

Impact on Mosquito Fitness

Interspecific competition among mosquito species significantly reduces larval survival, delays development, and leads to smaller adult sizes. For instance, Anopheles species showed decreased survival and delayed pupation when cohabiting with *Aedes aegypti*, consistent with previous studies on larval competition effects (Couret *et al*., 2014; Alomar *et al*., 2023; Romeo Aznar *et al*., 2018).

Developmental Delay and Resource Limitation

Extended development time under competitive conditions is often due to limited food availability and chemical cues released by larvae. Growth-inhibiting factors released by Ae. aegypti have been reported to prolong Anopheles larval development (Moore & Whitacre, 1972; Bédhomme *et al*., 2005). Additionally, increased physical contact within de nse habitats may disrupt feeding behavior (Renshaw *et al*., 1993).

Niche Partitioning through Foraging Behavior

Differences in larval positioning reduce direct competition. Ae. aegypti larvae forage near the container bottom, while Anopheles larvae feed at the surface, allowing spatial separation (Yee *et al*., 2004; Van de Wolfshaar *et al*., 2006). Such partitioning supports coexistence despite competition.

Morphological Effects of Competition

Crowding and limited resources during larval development result in smaller wing length and body size in adult mosquitoes. These morphological traits can impair flight, mating, and host-seeking efficiency, reducing vector competence (Gimnig *et al*., 2002; Takken *et al*., 1998; Suwanchaichinda & Paskewitz, 1998).

Cannibalism and Predation Dynamics

The observed disappearance of larvae suggests cannibalism or predation, particularly by Ae. aegypti, which develops faster and may prey on cohabitants. These behaviors have been reported even in the presence of adequate food, indicating facultative predation (Koenraadt & Takken, 2003; Muturi *et al*., 2010; Shoukry, 1980).

Competitive Dominance of *Aedes aegypti*)- Because of its higher foraging efficiency and quicker development, Ae. Aegypti outcompeted An. arabiensis, An. gambiae, and An. funestus. This is consistent with other research showing that Ae. aegypti outperforms other species when food is scarce (Armistead *et al*., 2008; Yee & Juliano, 2006).

Coexistence and Ecological Distribution

Despite competitive disadvantages, Anopheles species can coexist with Ae. aegypti in urban and suburban habitats due to behavioral and spatial differentiation (Lawal *et al*., 2011; Mahgoub *et al*., 2017; Mbanzulu *et al*., 2022). However, interspecific competition may still shift species dominance and affect local disease transmission patterns (Juliano *et al*., 2004; Juliano & Lounibos, 2005).

Study Limitations and Future Directions

This semi-field study lacked natural predators and used second-instar laboratory-reared larvae, possibly limiting ecological validity. Cannibalism and predation were inferred from larval disappearance without molecular confirmation (e.g., PCR or gut analysis). Future studies should examine fitness outcomes such as fecundity, vector competence, and host-seeking behavior under natural environmental conditions (Alto & Bettinardi, 2015; Romeo Aznar *et al*., 2018).

Larval Survival and Development Time: -

When different mosquito species share breeding sites, competition for food and oxygen often reduces survival and delays development. For instance, Ae. albopictus shows reduced emergence rates and longer development periods under competitive stress (Noden *et al*., 2016). Similarly, Ae. aegypti experiences extended larval duration and lower survival when reared with Anopheles stephensi (Juliano & Lounibos, 2005).

Effects on Larval and Adult Morphology: -

Reduced Body Size and Wing Length

Increased larval competition often leads to smaller adults. *Aedes aegypti* and Ae. albopictus reared under crowded conditions develop smaller wing lengths and body sizes, impairing flight, mating, and host-seeking ability (Edgerly *et al*., 1999; Noden *et al*., 2016). *Anopheles gambiae* also shows reduced adult size when larval density increases (Gimnig *et al*., 2002).

Morphological Changes in Larvae

Although less frequently documented, some studies suggest that intense larval competition can result in modified mouthparts or siphons, potentially altering feeding and breathing efficiencies (Relyea, 2002).

Carry-Over Effects on Adult Survival and Vector Competence: -

Adult Survival- Adult mosquitoes emerging from highly competitive larval environments tend to have shorter lifespans. For example, Ae. aegypti adults from dense larval groups showed reduced survival under dry condition (Alto & Bettimardi 2015)

Disease Transmission Potential

Smaller, nutritionally stressed mosquitoes may transmit disease differently. For instance, Ochlerotatus triseriatus showed altered susceptibility to arboviruses under larval stress (Grimstad & Walker, 1991). Such effects vary by vector and pathogen.

Species-Specific Competitive Interactions: -

•Aedes albopictus typically outcompetes Ae. aegypti, especially in well-resourced habitats (Juliano & Lounibos, 2005).

•Interspecific competition between Cx. pipiens and Ae. albopictus reduces adult emergence and alters morphology (Noden *et al*., 2016).

•Ae. aegypti generally survives better than An. stephensi under food-limited co-rearing conditions (Juliano & Lounibos, 2005).

Ecological and Public Health Implications; -

Interspecific competition has various ecological and public health implications, like Larval competition may restructure mosquito communities and influence vector competence. Smaller, shorter-lived mosquitoes may bite less frequently or transmit disease differently. These ecological effects must be considered when planning vector control interventions (Juliano & Lounibos, 2005).

Table 1. Generalized linear mixed model for the effects of competition, habitat, and their interactions on the developmental time for *Aedes aegypti* and *Anopheles arabiensis*, *Aedes aegypti* and *Anopheles gambiae*, and *Aedes aegypti* and *Anopheles funestus*.

Population	Species	Effects		RR (95% CI)	*p*-Value
Ae. aegypti and *An. arabiensis*	*Ae. aegypti*	Competition	Alone	1	
			Mixed	0.54 (0.25, 1.56)	0.113
		Habitat	Small	1	
			Large	1.12 (0.54, 2.30)	0.760
	An. arabiensis	Competition	Alone	1	
			Mixed	6.11 (2.59, 14.45)	<0.001
		Habitat	Small	1	
			Large	0.93 (0.44, 1.97)	0.853
Ae. aegypti and *An. gambia*	*Ae. aegypti*	Competition	Alone	1	
			Mixed	0.30 (0.12, 0.73)	0.008
		Habitat	Small	1	
			Large	1.12 (0.49, 2.57)	0.787
	An. gambiae	Competition	Alone	1	
			Mixed	1.74 (0.74, 4.09)	0.203
		Habitat	Small	1	
			Large	1.57 (0.65, 3.80)	0.319
Ae. aegypti and *An. funestus*	*Ae. aegypti*	Competition	Alone	1	
			Mixed	0.07 (0.02, 0.28)	<0.001
		Habitat	Small	1	
			Large	1.75 (0.81, 3.79)	0.156
	An. funestus	Competition	Alone	1	
			Mixed	1.40 (0.95, 2.07)	0.088
		Habitat	Small	1	
			Large	1.00 (0.50, 1.99)	0.977

RR stands for risk ratio. The interaction row was left out of the table because it didn't show any significant impacts, but it is still included in the text for clarity.

"×"

The experimental configuration of larval densities under various competitive conditions is displayed in Table 1 (Lushasi *et al*., 2025). The effects of competition, habitats, and their interactions on the survival of larvae to adulthood for *Aedes aegypti*, *Anopheles arabiensis*, *Anopheles gambiae*, and *Anopheles funestus* are examined in Table 2 using a generalized linear mixed model.

Table 2 displays the effects of habitat size, interspecific and intraspecific competition, and their interaction on larval survival to adulthood

Population	Species	Effects	RR (95% CI)	*p*-Value

Population	Species	Effects		RR (95% CI)	*p*-Value
Ae. aegypti and *An. arabiensis*	*Ae. aegypti*	Competition	Intraspecific	1	
			Interspecific	0.40 (0.30, 0.55)	<0.001
		Habitat	Small	1	
			Large	0.88 (0.66, 1.16)	0.359
	An. arabiensis	Competition	Intraspecific	1	
			Interspecific	0.23 (0.15, 0.35)	<0.001
		Habitat	Small	1	
			Large	0.84 (0.56, 1.29)	0.441
Ae. aegypti and *An. gambiae*	*Ae. aegypti*	Competition	Intraspecific	1	
			Interspecific	0.50 (0.34, 0.74)	0.001
		Habitat	Small	1	
			Large	0.89 (0.63, 1.27)	0.55
	An. gambiae	Competition	Intraspecific	1	
			Interspecific	0.43 (0.26, 0.71)	0.001
		Habitat	Small	1	
			Large	0.82 (0.52, 1.28)	0.393
Ae. aegypti and *An. funestus*	*Ae. aegypti*	Competition	Intraspecific	1	
			Interspecific	0.26 (0.17, 0.39)	<0.001
		Habitat	Small	1	
			Large	0.65 (0.45, 0.94)	0.901
	An. funestus	Competition	Intraspecific	1	
			Interspecific	0.19 (0.13, 0.28)	<0.001
		Habitat	Small	1	
			Large	1.02 (0.69, 1.52)	0.024

Note: RR stands for risk ratio. The interaction row was left out of the table because it had no discernible impacts, but it is still there in the text to give a clear explanation.

For *Aedes aegypti*, *Anopheles arabiensis*, *Anopheles gambiae*, and *Anopheles funestus*, Table 2 displays the effects of habitat size, interspecific and intraspecific competition, and their interaction on larval survival to adulthood (Lushasi *et al*., 2025).

Table 3. Generalized linear model of the effects of competition, habitat, and their interactions on the adults' wing length (mm) for *Aedes aegypti* mixed with either *Anopheles arabiensis*, *Anopheles gambiae*, or *Anopheles funestus*.

Population	Species	Effects		RR (95% CI)	*p*-Value
Ae. aegypti and *An. arabiensis*	*Ae. aegypti*	Competition	Alone	1	
			Mixed	0.76 (0.72, 0.80)	<0.001
		Habitat	Small	1	
			Large	1.16 (1.09, 1.22)	<0.001
		Competition × Habitat	Mixed × Large		
				1.21 (1.11, 1.31)	<0.001

Population	Species	Effects		RR (95% CI)	*p*-Value
	An. arabiensis	Competition	Alone	1	
			Mixed	0.47 (0.44, 0.50)	<0.001
		Habitat	Small	1	
			Large	1.13 (1.08, 1.19)	<0.001
		Competition × Habitat	Mixed × Large		
				1.61 (1.48, 1.74)	<0.001
Ae. aegypti and *An. gambiae*	*Ae. aegypti*	Competition	Alone	1	
			Mixed	0.80 (0.76, 0.84)	<0.001
		Habitat	Small	1	
			Large	0.20 (1.15, 1.26)	<0.001
		Competition × Habitat	Mixed × Large		
				1.04 (0.98, 1.12)	0.196
	An. gambiae	Competition	Alone	1	
			Mixed	0.56 (0.54, 0.58)	<0.001
		Habitat	Small	1	
			Large	1.09 (1.04, 1.14)	<0.001
		Competition × Habitat	Mixed × Large		
				0.29 (0.21, 1.37)	<0.001
Ae. aegypti and *An. funestus*	*Ae. aegypti*	Competition	Alone	1	
			Mixed	0.77 (0.73, 0.82)	<0.001
		Habitat	Small	1	
			Large	1.22 (1.17, 1.29)	<0.001
		Competition × Habitat	Mixed × Large		
				1.13 (1.05, 1.22)	0.001
	An. funestus	Competition	Alone	1	
			Mixed	0.58 (0.56, 0.60)	<0.001
		Habitat	Small	1	
			Large	1.18 (1.14, 1.22)	<0.001
		Competition × Habitat	Mixed × Large		
				0.28 (1.21, 1.35)	<0.001

Note: RR = risk ratio.

For *Aedes aegypti* co-raised with *Anopheles arabiensis*, *Anopheles gambiae*, or *Anopheles funestus*, Table 3 shows the effects of competition, habitat size, and their interaction on mature wing length (mm) (Lushasi *et al*., 2025).

Table 4: *Aedes aegypti*, *Anopheles arabiensis*, *Anopheles gambiae*, and *Anopheles funestus* cannibalistic and predacious behavior in relation to competition, food, and habitats using a generalized linear mixed model

Population	Species	Effects	RR (95% CI)	*p*-Value

Population	Species	Effects		RR (95% CI)	*p*-Value
Ae. aegypti and *An. arabiensis*	*Ae. aegypti*	Competition	Alone	1	
			Mixed	0.54 (0.38, 0.79)	0.001
		Habitat	Small	1	
			Large	1.15 (0.82, 1.62)	0.423
		Food	No	1	
			Yes	0.001 (0.0001, 0.005)	<0.001
	An. arabiensis	Competition	Alone	1	
			Mixed	8.24 (4.91, 13.83)	<0.001
		Habitat	Small	1	
			Large	1.28 (0.79, 2.06)	0.303
		Food	No	1	
			Yes	0.13 (0.07, 0.21)	<0.001
Ae. aegypti and *An. gambiae*	*Ae. aegypti*	Competition	Alone	1	
			Mixed	0.49 (0.36, 0.66)	<0.001
		Habitat	Small	1	
			Large	0.86 (0.64, 1.16)	0.326
		Food	No	1	
			Yes	0.02 (0.01, 0.03)	<0.001
	An. gambiae	Competition	Alone	1	
			Mixed	6.35 (4.34, 9.29)	<0.001
		Habitat	Small	1	
			Large	1.16 (0.83, 1.63)	0.386
		Food	No	1	
			Yes	0.16 (0.11, 0.24)	<0.001
Ae. aegypti and *An. funestus*	*Ae. aegypti*	Competition	Alone	1	
			Mixed	0.71 (0.49, 1.03)	0.07
		Habitat	Small	1	
			Large	0.98 (0.67, 1.45)	0.942
		Food	No	1	
			Yes	0.01 (0.003, 0.013)	<0.001
	An. funestus	Competition	Alone	1	
			Mixed	14.09 (8.55, 23.22)	<0.001
		Habitat	Small	1	
			Large	1.99 (1.27, 3.11)	0.002

Population	Species	Effects		RR (95% CI)	*p*-Value
		Food	No	1	
			Yes	0.26 (0.16, 0.42)	<0.001

Table 4 summarizes the percentage of missing larvae (indicative of predation or cannibalism) across treatments with and without food (Lushasi *et al*., 2025).

Conclusion

•Interspecific competition significantly affects mosquito population dynamics, influencing survival, development, reproduction, and species distribution through resource limitation and ecological overlap (Juliano & Lounibos, 2005).

•Aedes albopictus often outcompetes *Aedes aegypti* in shared habitats due to its adaptability and faster development, altering vector dominance and disease risk in various regions (Juliano *et al*., 2004).

Environmental elements that affect competition intensity include temperature, food availability, and habitat size to niche partitioning, coexistence, or local extinction (Alto & Juliano, 2001; Tun-Lin *et al*., 2000).

•Larval competition results in smaller adult mosquitoes, which affects fecundity, flight ability, host-seeking behavior, and ultimately vector competence (Noden *et al*., 2016; Gimnig *et al*., 2002).

•Cannibalism and predation are frequent under competitive stress, especially in resource-limited environments, and may further influence species survival and community structure (Muturi *et al*., 2010; Koenraadt & Takken, 2003).

•Understanding these ecological interactions is essential for vector control, as competition-driven shifts in mosquito populations can directly impact disease transmission and the effectiveness of public health interventions (Harrington *et al*., 2008; WHO, 2023).

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