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Surfactant-Based Strategies for Mosquito Larvae and Pupae Management

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Review Article

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Abstract

Background: Mosquito-borne diseases remain a major global public health challenge, necessitating environmentally sustainable vector-control strategies such as biosurfactant-based disruption of mosquito larval and pupal development in aquatic habitats.
Aims: To reveal the effectivity of biosurfactant above water surface to prevent larvae and pupa of mosquito to obtain oxygen and blocking their breathing tubes, and also their effect to the environment.
Results: Surfactants, including specialized larviciding oils and Silicone-based products, kill mosquito larvae and pupae by reducing the water's surface tension, causing them to drown by blocking their breathing tubes. These films prevent larvae/pupae from breaking the surface to breathe, often providing 100% mortality within hours. Larvicide surfactants are used to control mosquito populations, but unfortunately, their environmental impact varies depending on whether they are synthetic or biological, and what is feared ranging from potential, temporary aquatic disruption to eco-friendly, biodegradable alternatives. Studies showed that biosurfactants often exhibit low toxicity to non-target organisms, such as vegetables, seeds, and microcrustaceans, making them a "green" option for mosquito larva and pupae management
Conclusion: Surfactants larvicide are widely considered non-invasive, eco-friendly, and sustainable alternatives to traditional chemical pesticides. They are Generally Recognized as Safe (GRAS), biodegradable, and low in toxicity to humans, animals, and the environment.

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Keywords: Pupa; safety; biodegradable; eco-friendly; surface tension; larvicide; biosurfactant; vector control.

1. Introduction

Mosquitoes as vector borne arthropods are always considered the world's deadliest animals (Bourne et al, 2024), causing nearly 1 million deaths annually and transmitting diseases to over 700 million people annually (Pabst et al, 2025). They act as vectors for viruses, bacteria and parasites—including malaria, dengue, Zika, and West Nile— (St. Laurent, 2025) transmitting them through saliva during bites (Alves e Silva et al, 2025, Guo et al., 2025). Insecticides reduce the spread of mosquito-borne disease (Ren et al, 2023). By reducing mosquito populations and preventing bites, they act as an important vital barrier for vulnerable host against the spread of infection.

Insecticides aimed at mosquitoes are primarily categorized into adulticides (which kill flying mosquitoes) and larvicides (which prevent them from breeding in stagnant water). The most common active chemical and biological ingredients vary depending on whether they are used by pest control professionals or consumers.

Unfortunately, as the earliest critical analysis in this review, reckless insecticide abuse drives rapid evolutionary adaptation in pest populations. By creating relentless selective pressure, misuse—such as overdosing, underdosing, or relying on a single chemical class—ensures that only genetically resistant survivors reproduce. This creates a dangerous cycle of escalating chemical use, crop failure, and public health threats.

To effectively controlling mosquitoes requires interrupting at least one out of four-stage life cycle: egg, larva, pupa, and adult (Dusfour & Chaney, 2022). Female mosquitoes lay eggs in or near stagnant water, with some species laying eggs just above the waterline in containers. After approximately 48 hours, Eggs hatch into larvae, which live in the water for approximately 4-10 days depend on the species and the milieu condition. This stage uniquely breathe air at the surface while floating to the water-air boundaries (Lee et al, 2017), even though Alvarez-Costa et al mention about their ability to breathe underwater (Alvarez-Costa et al, 2024) and feed on its surrounding organic detritus which surely affect mosquito development, size and nutritional reserves (de Souza et al, 2019). The next stage called pupae, lasts for 24-73 hours, are active in the water but do not feed (Carvajal-Lago), and quickly transforming into adults. Pupae control is basically Similar to larvae, removing water or applying reasonable control methods is essential, as this stage is very short chronologically (Dusfour & Chaney, 2022, Abd, 2020).

The first three stages which occur in water are actually reveal its vulnerability, by way of making the removal or treatment of standing water, e.g., by way of water security (Akanda et al, 2020) or water level management (Kibret et al, 2018) or disrupting its ideal equilibrium which favor mosquito life cycle, e.g., by way of surfactant (Kato-Namba et al, 2023) actually become the most effective strategy.

Insecticide use in aquatic systems presents a critical trade-off. While they are essential for vector control (preventing diseases like malaria and dengue) and agricultural protection, their presence in waterways causes severe environmental degradation and poses risks to human drinking water (Datta et al., 2025). Insecticides are inherently designed to be biologically active (Araújo et al., 2023) When they enter surface waters via runoff or direct application, they are highly toxic to non-target organisms, including beneficial insects, amphibians, and fish (de Souza et al, 2020). By decimating aquatic insect populations, insecticides deplete the primary food source for fish and birds, triggering a cascading collapse throughout the food web. Certain highly resilient chemical classes, such as organophosphates and synthetic pyrethroids, can accumulate in the fatty tissues of aquatic life (Saha & Dutta, 2024), biomagnifying as they move up the food chain.

Efforts to control mosquito populations should be comprehensive, multi-layered strategies designed to minimize the spread of diseases (Onen et al., 2023). These efforts combine public health initiatives (Obeagu & Obeagu, 2024), community action (Yulfi et al., 2025), and advanced science (Renuka 2025, Siagian, 2023) to target mosquitoes at every stage of their life cycle. This review focusing on the application of biosurfactant on the water surface to Control Mosquito’s larva and pupa Behavior under the water and its implication for the environment.

2. Surfactant and Biosurfactant

Surfactants (surface-active agents) are compounds that reduce surface tension between two liquids or a liquid and a solid (Khalfallah, 2023), with synthetic types typically derived from petroleum (Sagir et al, 2020).

Surfactants are essential chemicals and play a significant role in the upstream petroleum industry (Jia et al., 2024).

Biosurfactants are a subset produced by microorganisms such as microbes (Eras-Muñoz et al., 2022), like *Bacillus subtilis* (Cruz Mendoza et al, 2022) and *Pseudomonas* sp. (Stoica et al, 2023), fungi (da Silva et al, 2021) such as *Candida bombicola* (Pinto et al, 2022)*, Ustilago maydis* (Hewald et al., 2005), and *Aspergillus niger* (Al-Hazmi et al, 2023) and yeast (Holguín-Salas et al., 2025).

The basic difference with surfactant is that biosurfactant offering a rapid/fast process (Xu et al, 2023) and often reaching 100% biodegradability (Patel & Kharawala, 2022), lower toxicity (Fernandes et al, 2023), nontoxic (Mendes da Silva Santos et al., 2021), and longer environmental sustainability (Markam et al, 2024). While traditional surfactants are cheaper (Muthaiyan Ahalliya, 2023) and mass-produced, while on contrary, biosurfactants provide superior functional performance (Jahan et al, 2020). Biosurfactants show promise in bioremediation (Sharma et al, 2022), oil recovery (Andrade et al, 2024), and pharmaceuticals, e.g., in drug delivery (Bjerk et al, 2021).

Biosurfactants performance are also superior in following condition, namely (1) surface tension reduction (Baccile & Poirier, 2023), (2) higher tolerance to pH, temperature, and (Bello et al., 2012), and (3) multifunctional properties (Santos et al., 2016). Biosurfactants are amphiphilic microbial molecules with hydrophilic and hydrophobic moieties that partition at liquid/liquid, liquid/gas or liquid/solid interfaces (Dini et al, 2024, Santos et al., 2016). Such characteristics allow these biomolecules to play a key role in emulsification (Alara et al., 2023), foam formation (Winterburn & Martin, 2012), natural detergency (da Silva et al., 2024) and dispersal or natural dispersing agents (Bavadi et al., 2025), which are desirable qualities in different industries.

Apart from the many uses that have been mentioned, the working principle of surfactants is also effective in killing mosquito larvae and pupae underwater. These principles will be reviewed in more depth in the following section.

3. Basic Principles of Surfactant as Larvicide: from History to Application

Surfactants act as surface-active agents used in larvicide formulations to break the surface tension of water, causing mosquito larvae and pupae to sink and drown. They also act as emulsifiers that evenly disperse water-insoluble larvicidal oils (such as neem or essential oils) to maximize contact with the target pests.

The use of surfactants for mosquito control centers on "Monomolecular Films" (MMFs). Instead of chemical poisoning, these non-toxic, surface-active agents reduce the surface tension of water, preventing mosquito larvae and pupae from attaching their breathing tubes to the surface, causing them to drown. This is become the basic mechanism of physical control measures for disturbing the siphonal respiration of mosquito larvae in a way of dissolved oxygen and surface tension (Lee et al, 2018). Furthermore, Lee et al mention about the surface of the siphon was changed from hydrophobic to hydrophilic by addition of a surfactant. In addition, the surface tension and wettability have a significant influence on the opening and closing of siphon.

Table 1. Chronological advancement of the application of surfactant as mosquito's larvicide

Time	mechanism	impact
Early 1900s	before modern chemical insecticides were widely available, sanitation workers controlled malaria and yellow fever by pouring heavy petroleum-based oils onto mosquito breeding sites like swamps and drains (Gachelin et al, 2018) A thin film of oil (often kerosene or diesel) was sprayed on the surface of stagnant water. This film act as mechanical barrier which prevented mosquito larvae and pupae from attaching to the surface to breathe atmospheric oxygen, effectively drowning them. Physically, the oil also broke the water's surface tension, making it impossible for adult mosquitoes to land and lay eggs	While the oils acted as a crude surfactant to coat the water and suffocate larvae, they were highly toxic to other aquatic life, created heavy odors, and polluted the environment.

Time	**mechanism**	**impact**
1970s -1980s	the Shift to Monomolecular Films (MMF) took place, where the Methods consist of the application of non-toxic alternatives to petroleum oils. Scholar introduced specialized alcohols and synthetic surfactants that spread rapidly as a micro-thin layer (one molecule thick) over the water. mode of action against mosquito larvae and pupae is physical rather than chemical. They lower the water surface tension, preventing suspension of the larvae and pupae at the water surface, subsequently suffocating them. They also interfere with emergence of the adults. Monomolecular surface film products have been shown to be relatively safe to non-target invertebrates and vertebrates, including humans (Nayar & Ali, 2003)	These films drastically lowered the water's surface tension (from about 72 mN/m down to roughly 30 mN/m). Larvae and pupae rely on normal surface tension to anchor their respiratory siphons (breathing tubes); the lowered tension causes the larvae to sink and drown.
1990s - 2000s	Application of biodegradable and Botanical/plant-derived Innovations (Romero Vega & Gallo Stampino,2025) which considered as green (Nagtode et al., 2023) and sustainable product (Patil et al, 2025), as environmental regulations tightened and the society want a more responsible product. This allowed for larvicidal treatment in sensitive ecosystems (Harikrishnan et al, 2023), agricultural areas (Datta et al, 2024), and drinking water containers or industrial water system (Jimoh et al, 2023).	this method is entirely mechanical rather than chemical, mosquitoes are highly unlikely to develop genetic resistance to it.
Contemporary era	Silicone-Based Formulations (Tuncsoy et al, 2025) and Nano-Surfactants, e.g., Nano pesticide (Deka et al, 2021) as modern highly engineered agents. Modern surfactant-based larvicides—like the popular Aquatain (Dugassa et al, 2025)—utilize silicon-based liquids like polydimethylsiloxane (PDMS) an elastomer with excellent optical, electrical and mechanical properties, which makes it well-suited for several engineering applications (Miranda et al, 2021),	These modern MMFs are exceptionally flexible, highly spreadable, and can withstand wind better than early plant-/based oils.
Future direction	Potent surfactant combined with eco-friendly product (Hikal et al, 2023, Oprea et al 2022, Pavoni et al, 2019)	Dual Action: the combination of surfactants with natural plant-derived essential oils (e.g., orange or clove oil) to create micro emulsions and nano-larvicides, which can physically suffocate larvae while delivering natural botanical insecticidal properties.

The evolution of this method moved from the initial application of crude petroleum oils to highly advanced, biodegradable, and eco-friendly surfactant formulations. Specific aims and mechanisms of surfactants in larviciding include:

3.1 Breaking Surface Tension

Water surface tension is the dynamic, elastic-like "skin" on a liquid's surface (Hauner et al, 2017), caused by molecules pulling together. Because water molecules tightly bond with each other (cohesion), the surface layer acts as a barrier. It measures about 72.8 mN/m at 20^0C, decreasing as water heats up- When the surface temperature of a body of water (like a lake or ocean) rises, the thickness of the actively mixed top layer physically decreases. This process is known as shoaling, which traps heat at the surface, makes the upper layer warmer, and creates a stronger barrier to the colder deep water (Sallée et al, 2021). Molecules deep within the water are pulled equally in all directions (Brini et al, 2017). Surface molecules lack upward pull, causing them to cling more strongly to adjacent and downward molecules (Schiltz, 2024). This inward pull minimizes the surface area, forming spherical droplets (Mohsen et al, 2024). The surface tension of water provides a thin, elastic membrane upon which many tiny animals are adapted to live and move under water (Schwenk & Phillips, 2020). Mosquito larvae and pupae (such *as Aedes aegypti*) rely on snorkel like breathing siphons (Lee et al., 2017) that pierce (Bosak & Crans, 2002) and basically break the water's surface to get oxygen (Alvarez-Costa et al., 2024). Surfactants like monomolecular films (Nayar & Ali, 2003) dramatically reduce this surface tension (Hauner et al., 2017), causing the larvae to suffocate, sink and drown; and this has effect to mature mosquitoes, too (Kato-Namba et al., 2023, Lee et al., 2018).

3.2 Enhancing Oil Dispersion

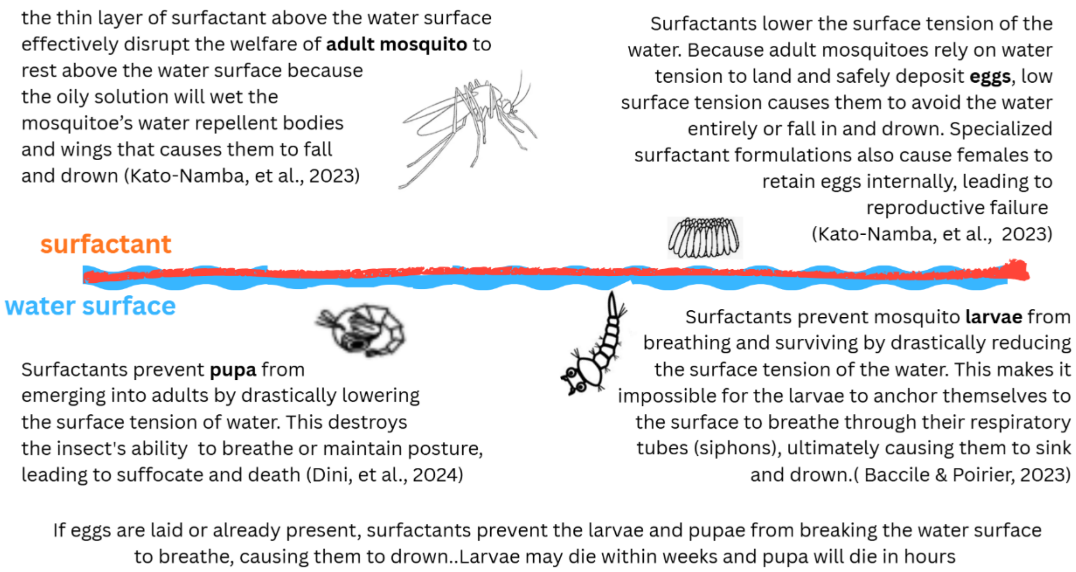
Standing or stagnant water with its cumulated dissolved organic matter/debris is the perfect breeding place for mosquito (Huzortey, et al. 2022). It may have affected by seasonal rainfall related flooding (Seltenrich, 2021). Basically, water-insoluble larvicides (both synthetic chemical and organic based) are applied to control mosquito populations in such aquatic milieu. Chemically, these substances are lipophilic or hydrophobic (water-repelling) and because they do not dissolve, they immediately sink or form a surface film. They also unspecific for larva and pupa only, but even can disrupt the behavior and survival rates of the already exist aquatic insect predators (Nelsen & Yee, 2022). To overcome these obstacles, the active ingredients rely on specific formulation technologies to work effectively (Salager et al, 2022). This insolubility, while effective against larvae, causes several negative environmental and ecological impacts (Saha & Dutta, 2024). Surfactants allow these oils to form stable emulsions or microscopic droplets in standing water, ensuring the active ingredients are evenly spread across the breeding site. Surfactants lower the interfacial tension between oil and water, allowing larvicide oils to disperse as microscopic droplets and stable emulsions in standing water. Their amphiphilic structure creates a distinct barrier film that avoids droplets from merging, ensuring even coverage and maximum effectiveness against mosquito larvae (Xie et al, 2024).

3.3. Increasing Penetration

In addition to drowning the larvae, surfactants help toxic compounds break through the protective, waxy cuticles (Ren et al, 2023) or cellular membranes of the larval midgut (Guzmán et al, 2024), allowing the active ingredients to enter their system faster. Penetration is critical for toxin substrates because the cell membrane is a highly selective barrier that prevents large or charged molecules (like proteins and enzymes) from entering (Falnes & Sandvig, 2000). The larva midgut is the primary middle section of the insect's digestive tract, responsible for digesting and absorbing the nutrients needed for growth and metamorphosis (Godoy et al, 2023). Toxins must penetrate the bilayer to deliver their active domain into the cytosol, where it can directly interfere with vital cellular machinery and cause damage Mosquito larvicides disrupt the cellular membranes of the larval midgut, leveraging its unique, highly alkaline environment (pH 10.5 - 11.5). Once ingested, the larvicides bind to or chemically degrade these membranes, destroying microvilli, causing cellular rupture, and triggering cell death, which rapidly proves fatal to the larva (Kelly et al, 2022). Histopathology analyses revealed significant changes in the midgut epithelium, characterized by a loss of cell polarity, switching from columnar to a round shape, intense vacuolization, cell disorganization, loss of cell–cell adhesion, and loss of microvilli. Damage was observed in the fat body tissue, accompanied with larval atrophy and variations in the dimensions of the treated larvae, with the integument being closer to the intestinal epithelium (da Silva et al, 2024).

3.4 Biological and Eco-Friendly Alternatives

Naturally derived biosurfactants, like surfactin produced by Bacillus strains (Théatre et al, 2021), are highly prized as eco-friendly larvicides (Salgueiro et al, 2020). Basically they have the potency to minimizing harm to non-target species, humans, and the ecosystem (Milugo et al, 2021). They disrupt larval midgut cells and provide a sustainable alternative to synthetic chemical larvicides that pollute aquatic environments. Key Pillars of Eco-Friendly Larvicide Sustainability are: (a) Highly Selectivity (no non-Target Impact) which unlike broad-spectrum chemicals (e.g., organophosphates) that can poison fish, frogs, and beneficial aquatic insects, biological larvicides specifically target mosquito larvae. For instance, *Bacillus thuringiensis israelensis* (Bti) produces crystallized toxins that only destroy the digestive tracts of specific mosquito species (Derua et al, 2018), (b) No Environmental Bioaccumulation where plant-based larvicides (such as essential oils) and bacterial agents degrade naturally in water and sunlight. While their rapid biodegradability prevents harmful accumulation (Araújo et al, 2023), it also means their active compounds break down when exposed to sunlight (photo degradation), oxygen, and heat (Soliman, 2012). This shorter residual effect often requires them to be reapplied more frequently than traditional larvicides. They do not leave toxic chemical residues that build up in the food chain or contaminate local water supplies over time, (c) Mitigating Insect Resistance (Kasman et al, 2025) where the long-term use of synthetic pesticides causes genetic mutations in mosquitoes (Meija et al, 2025), creating "superbugs" immune to standard treatments. Eco-friendly botanical formulations offer complex chemical profiles and multi target action that make it difficult for vector populations to build up resistance (Corzo-Gómez et al, 2024), ensuring long-term pest management efficacy (Lima et al, 2023), (d) Biodegradable Delivery Mechanisms (Piazzoni et al, 2022) where innovations in sustainable pest control include encapsulating natural compounds (like orange oil) inside biodegradable matrices, such as baker's yeast or chitosan (Gomes et al, 2025), which slowly release the larvicide into stagnant water (Alkenani, 2017, Mulla et al, 2004) and further reduce environmental impact.



the thin layer of surfactant above the water surface effectively disrupt the welfare of **adult mosquito** to rest above the water surface because the oily solution will wet the mosquitoe's water repellent bodies and wings that causes them to fall and drown (Kato-Namba, et al., 2023)

Surfactants lower the surface tension of the water. Because adult mosquitoes rely on water tension to land and safely deposit **eggs**, low surface tension causes them to avoid the water entirely or fall in and drown. Specialized surfactant formulations also cause females to retain eggs internally, leading to reproductive failure (Kato-Namba, et al., 2023)

Surfactants prevent **pupa** from emerging into adults by drastically lowering the surface tension of water. This destroys the insect's ability to breathe or maintain posture, leading to suffocate and death (Dini, et al., 2024)

Surfactants prevent mosquito **larvae** from breathing and surviving by drastically reducing the surface tension of the water. This makes it impossible for the larvae to anchor themselves to the surface to breathe through their respiratory tubes (siphons), ultimately causing them to sink and drown.(Baccile & Poirier, 2023)

If eggs are laid or already present, surfactants prevent the larvae and pupae from breaking the water surface to breathe, causing them to drown..Larvae may die within weeks and pupa will die in hours

Fig. 1. Principles of how surfactant blocks mosquitoe's life cycle

Microemulsion (Wahyuni et al, 2025) and nanoemulsion (Pavoni et al, 2019) technologies are emerging as cutting-edge approaches for delivering larvicides. By encapsulating active ingredients—particularly plant-based essential oils—into ultra-small, stable droplets (Yammine et al, 2024), these formulations significantly increase water solubility (Pérez-Pérez et al, 2024), improving bioavailability which delay degradation or rapid evaporation (Grgić et al, 2020), and enhance penetration through the larval cuticle, boosting overall mortality rates against disease vectors like *Aedes aegypti* (Faustino et al, 2020).

A microemulsion is a clear, thermodynamically stable, and isotropic mixture of oil, water, and surfactants (often with a co-surfactant). Unlike standard emulsions, they form spontaneously without requiring high-shear mechanical energy. Droplets are typically between 10 – 100 nm in diameter. Microemulsion formulations of combined larvicidal substances—primarily botanical essential oils and biopesticides (Wahyuni et al, 2025, Sharma et al, 2021)—are engineered to bypass the poor water solubility, rapid environmental degradation, and resistance issues of conventional chemical larvicides (Gupta et al, 2023).

Microemulsions encapsulating plant-borne essential oils (like tea tree or neem) are actually eco-sustainable larvicides (Osanloo et al, 2019). Encapsulation solves the oils' natural volatility, poor water solubility, and UV and oxidative degradation issues (Lankanayaka et al, 2025), significantly elevating their bioavailability (Gomes et al, 2025) and uniformly dispersing the active larvicidal compounds in standing water habitats. These methods bypass the poor water solubility of botanical extracts (like essential oils) (Nabi et al, 2025) and synthetic insecticides, shielding them from UV and microbial degradation (Shin et al, 2021).

There is heavy demand in the increasing market for microemulsions that encapsulate plant-borne essential oils (like tea tree or neem) (Gupta et al, 2023, Coetzee et al, 2022). Eco-friendly surfactants are required to stabilize these oils into nanomicelles, which drastically increases their bioavailability while lowering the required dosage (Gomes et al, 2025, Coetzee et al, 2022, Shin et al, 2021). Essential oils typically evaporate rapidly and insoluble, or at least form a thin surface film on water (Nabi et al, 2025). By utilizing oil-in-water (O/W) microemulsions, researchers bypass these physical and chemical limitations of natural, lipophilic larvicides (Wong et al, 2019). The breakthrough basically conducted by encapsulating hydrophobic active compounds (such as botanical essential oils) in tiny, surfactant-stabilized droplets (Lankanayaka et al, 2025), which bypass physical issues like poor aqueous dispersion, high volatility, and rapid environmental degradation.

On the other hand, a nanoemulsion is a nanoscale colloidal dispersion of two immiscible liquids (like oil and water), stabilized by surfactants, with droplet sizes typically between 20 and 200 nanometers (Preeti et al, 2023). Because of their ultra-small size, nanoemulsions are highly stable, optically transparent, and drastically improve the bioavailability due to its absorption and delivery of active ingredients. Nanoemulsions drastically improve bioavailability by increasing the surface-area-to-volume ratio of active ingredients, allowing for rapid interaction with biological membranes (Nikita & Agnihotri, 2025).

A highly effective nanoemulsion for a surfactant-based larvicide (typically targeting mosquito larvae like *Aedes aegypti*) (Duarte et al, 2024) is created using a low-energy spontaneous emulsification (Solans & Solé, 2012) or ultrasonication method (Modarres-Gheisari et al, 2019). This oil-in-water (O/W) formulation relies on plant essential oils and specific non-ionic surfactants for stability and efficacy (Lucia & Guzmán, 2021). A robust, stable formulation that drastically enhances the bioavailability and lethal action of botanical oils against larvae typically become the most ideal formulation to be engineered (Sharma et al, (2021). A common and highly effective formulation uses non-ionic surfactants, such as Tween 80 and Span 20, or Polysorbate 20, to stabilize essential oils in an aqueous medium (Raya et al, 2022). This example formulation, frequently used in vector control for species like *Aedes aegypti* and *Culex* spp., relies on a low-energy emulsification method (Mustafa & Hussein, 2020).

The future of surfactant-based larvicides lies in green and biologically derived formulations or biosurfactants (Holguín-Salas et al, 2025, Eras-Muñoz, 2022, da Silva et al, 2021). Driven by the implementation of recent eco-friendly regulations (Shang et al, 2024) and the need to halt mosquito resistance to synthetic chemicals (Hazarika et al, 2025), forcing the industry shift their focus toward renewable, biodegradable, and low-toxicity micellar systems that encapsulate natural active ingredients, such as plant-based essential oils.

Ready-to-use sustainable larvicide products are available at the market which offers several eco-conscious and botanically derived options. The market for eco-friendly larvicides—primarily driven by mosquito-borne disease control and stringent environmental regulations—is experiencing rapid growth, with the global bio-based surfactants market projected to reach up to US $27.7 billion by 2034 (Fact.MR. (2024, September). This shift balances complex supply chain constraints with surging global demand for sustainable, non-toxic vector management (Ni et al, 2025).

Nowadays limitation of its application is that surfactants based larvicide, such as monomolecular films and refined oils which rely on breaking the surface tension of the water, are highly impractical in rivers, streams, or rapidly moving water because the product is continuously washed away or heavily diluted. For moving water, vector control and public health professionals utilize completely different treatment strategies and products. The best solution is using solid or Granular LarvicidesInstead of liquids or surface films that wash away, experts drop heavy, slow-release granules, briquettes, or tablets into the water. Basically, the mechanism is as follows: the active ingredients are released slowly over several days or weeks, ensuring the larvicide remains effective despite the current. Surfactant-based insecticides enhance the efficacy of active ingredients by reducing surface tension and altering droplet dynamics. While they improve crop protection, critical analysis reveals significant trade-offs, particularly regarding non-target ecotoxicity, phytotoxicity, and altered environmental transport.

4. Conclusion

Surfactant larvicides are engneered formulations used to target and eliminate aquatic insect larvae (primarily mosquitoes) before they become mature into the stage of biting, disease-transmitting adults. They are a critical tool in preventing vector-borne diseases like malaria, dengue, and Zika. Surfactant larvicide advancements center on eco-friendly, synthetic surfactants and biosurfactants produced by microorganisms widely considered non-invasive, eco-friendly, and sustainable alternatives to traditional chemical pesticides. These breakthroughs improve target-specific mortality against disease-carrying vectors like Aedes and Culex mosquitoes, using nanoscale delivery to boost the bioavailability of natural plant oils. They are Generally Recognized as Safe (GRAS), biodegradable, and low in toxicity to humans, animals, and the environment.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Author has declared that no competing interests exist.

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