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A Promising Route to Control Mosquito Larvae by Metal Nanoparticles

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ABSTRACT

The mosquitoes bear various deadly diseases, such as malaria, filariasis, dengue, Japanese encephalitis and the West Nile fever. They are responsible for millions of fatalities worldwide each year. Although synthetic insecticides are typically used to control a variety of vector-borne diseases, they have a number of disadvantages including effects on unintended species and negative impacts on the environment with the emergence of resistant vector kinds as a result of target site changes. With the least amount of environmental impact, phytochemicals, plant extracts are successful repellents, and larvicides. These plant-derived chemicals are substantially less expensive, environmentally friendlier, biodegradable, readily available, and non-toxic to untargeted organisms. They also display broad-spectrum resistance against a variety of mosquito species. Currently, plant extracts can improve their potency using green synthesized metal nano particles. This review clarifies the importance of new approaches for controlling mosquito larvae and the prospective future points to be studied.

INTRODUCTION

Arthropods are particularly deadly carriers of infections and parasites that could spread globally as epidemics or pandemics; Fig. (1) represents the life cycle of mosquito **(Mehlhorn *et al.*, 2012; Bonizzoni *et al.*, 2013; Mehlhorn, 2015; Benelli, 2016b)**. Mosquitoes (Diptera: Culicidae), which transmit serious diseases like dengue, filariasis, life cycle are presented in Figs. (2, 3), illustrating the role of mosquitoes as the vector. In addition, yellow fever, malaria, Japanese encephalitis, and the Zika virus, are among these diseases and pose a serious threat to millions of people worldwide **(Benelli & Mehlhorn, 2016; Saxena *et al.*, 2016; Jansen Van Vuren *et al.*, 2017; El-Sayed *et al.*,**

2022; Alamshany *et al.*, 2023; Mandodan *et al.*, 2023; Alkherb *et al.*, 2024). In developing nations such as Egypt, India, among others, vector control is a major issue. Various ailments, including malaria and filariasis are transmitted by mosquitoes. Hence, they are estimated as the most significant genus of insects in terms of their influence on general well-being. These illnesses claim millions of lives globally every year.

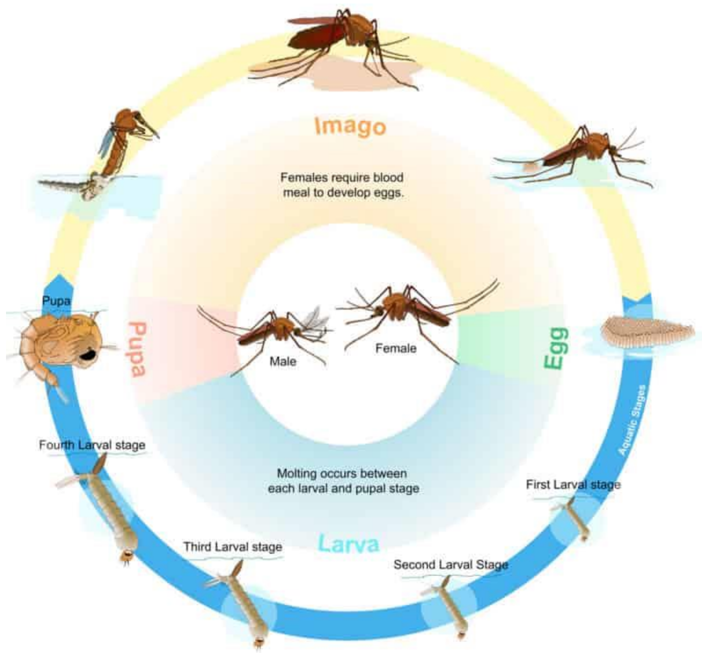


Fig. 1. Life cycle of mosquito (*Mosquito Life Cycle | Northeast Massachusetts Mosquito Control and Wetlands Management District*, n.d.)

In order to prevent vector-borne diseases by effective control measures, it is necessary to stop the reproduction of vector mosquitoes **(Kuppusamy & Murugan, 2010)**. Tropical and subtropical countries suffer from some drawbacks in economy and workers heath caused by such ailments **(Fradin & Day, 2002)**. Almost, there is no region of the world completely immunized against these infections. Mosquitos are able to resist synthetic insecticides. Thereafter, commanding these illnesses is defying **(Shelton *et al.*, 2007)**. The aquatic stage is where mosquitoes are most concentrated and immobile, making it the best stage to target for mosquito population control **(Cetin *et al.*, 2011; El Gohary *et al.*, 2021)**. Despite their effectiveness, persistent use of these controlling agents rove to many wellness disorders. *Aedes aegypti*, a day-biting mosquito, is the carrier of the virus that causes dengue fever. The only effective treatment for dengue is still mosquito control, as no medication has been shown to be a complete cure. Every year, more and more instances of dengue infection are reported globally. Thus, the urge for an effective measure remains a factor of major concern.

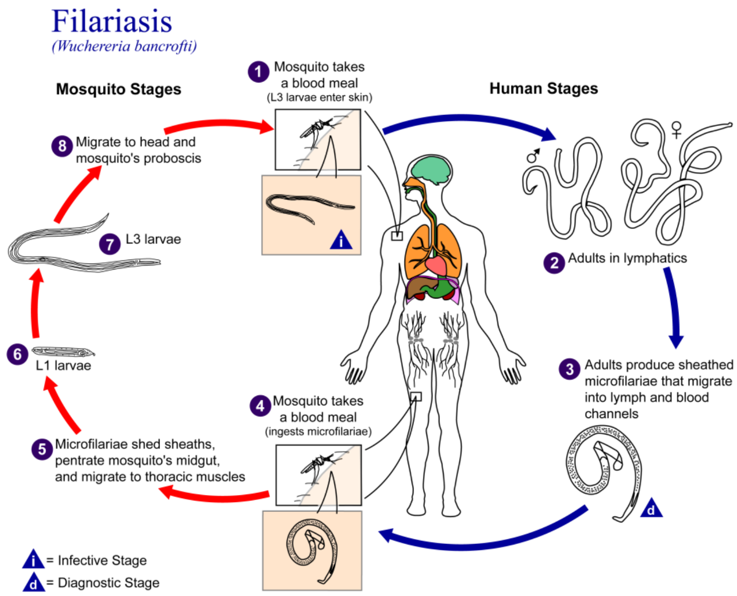


Fig. 2. Filariasis life cycle in human and mosquito **(Lourens & Ferrell, 2019)**

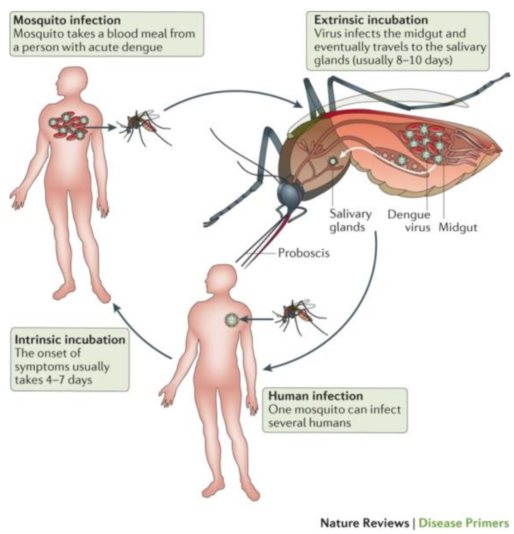


Fig. 3. The urban dengue virus cycle in humans and mosquitoes **(Guzman *et al.*, 2016)**

RESULTS

1. Current procedures for controlling mosquitoes

As mentioned in the previous section, mosquitoes are a major vector for the spread of dangerous parasites and infections that afflict a large number of people globally. The next paragraphs will list many methods used to keep mosquitoes under control.

1.1. Mosquito repellents

N,N-diethyl-metatoluamide (DEET), dimethyl phthalate (DMP), N,N-diethyl mandelic acid amide (DEM) are among the commonly employed mosquito repellents in major preventative strategies **(Mehlhorn, 2015)**. One of those strategies is putting as much of the body in light-colored clothing and using mosquito nets while sleeping **(Benelli, 2015b)**. Another strategy is implemented via reducing or eliminating Culicidae breeding sites, residents beside these ailments are endemic. Furthermore, the use of chemical or biological ovicides, larvicides, and pupicides as mosquitocidal treatments has been achieved **(Semmler *et al.*, 2009; Benelli, 2015a; Farag *et al.*, 2023)**.

1.2. Synthetic, microbial and plant-borne mosquitocides

There are various hazards that accompany utilizing pesticides. Meanwhile, these disadvantages may exceed the positive impact of using these pesticides. Some non-target species were severly affected during pesticides application. Moreover, these pesticides influence the balance of some creatures through earthbound or marine environments. It has been studied in 1995 **(Majewski & Capel, 1996)** that the majority of the used pesticides may be volatilizing for many hours after being used. Generally, this takes place upon utilizing sprayers. The evaporating pesticides spread through the atmosphere. Consequently, they may deteriorate some of the surrounding creatures. An excellent model for this situation is the damage that can affect a plant when herbicides are applied to nearby infected plants. The vapors from these herbicides which volatilize to uninfected plant causing huge damage to the latter **(Straathof, 1986)**. Unplanned use of traditional pesticides may harm various living organisms. Spraying them intimidates the life of some scarce organisms **(Helfrich *et al*., 2009)**. Moreover, chemical pesticides as a result contamination during application may form a toxic level in water, air and soil bodies **(Malone *et al*., 2004; Lefrancq *et al*., 2013; Liu *et al*., 2016)**.

Pesticides can be classified according to the targeted pest species, for example insecticides are used for insects. The others like fungicides, acaricides, molluscicides and bactericides, etc. Insecticides are the most toxic category, while fungicides are considered the second, followed by herbicides in terms of the toxicity level, as reported in pesticides categories list. Pesticides can be released to the environment through various ways according to solvability. The first one is a process known as "bio-amplification". It depends on fat-soluble pesticides. Then, the pesticides enter the bodies of animals when absorbed in the fatty tissues. For this reason, the pesticides become persistent in food chains for a long time, as shown in Fig. (4) **(Helfrich *et al*., 2009)**. On the other hand, water-soluble pesticides are released in ground water, rivers, lakes and streams resulting from the dissolved applied pesticides in water and then causing damage to non-target individuals.

Insensitive application to pesticide accompanied by shortage in safety standards leads to cases of death and illness, including tumor, reduction in fertility, and pesticide poisoning. Additionally, intensive pesticide usages and uncontrolled application methods help transfer pesticides to ecosystems around agricultural areas. Pesticide pollution is the reason of a different health effects in animal populations, viz. reproductive defects and developmental abnormalities and death. Pesticides are damaging to both land and animal populations living and eat from the areas where the pesticides are used by traces. Moreover, the resulting pollution from pesticides application introduced into an ecosystem is hardly removed. This is verified since the pesticides are directly placed on cultivated land. Pesticide compounds cannot degrade or decompose very slowly according to their chemical characteristics. As a result of exposing animals to pesticide pollution, the chemicals hazards are built-up proportionally against time inside the animal. This phenomenon is called bioaccumulation in organisms (Fig. 5) **(Malaj *et al.*, 2014; Toccalino *et al.*, 2014; Queyrel *et al.*, 2016)**. Furthermore, the excessive and repeated uses of many conventional insecticides have caused the resistant insect strains to emerge **(Mosallanejad & Smagghe, 2009)**. The distribution of pesticides uses all over the world per area is represented in Map1). Additionally, the global use of different pesticides (insecticides, herbicides, fungicides and others) are represented in Fig. (6).

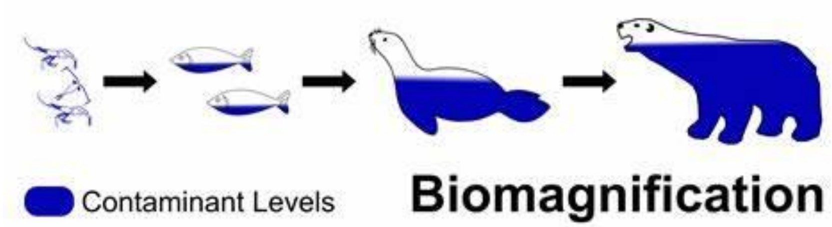


Fig. 4. Bioamplification of pesticides in organisms **(Helfrich *et al.*, 2009)**

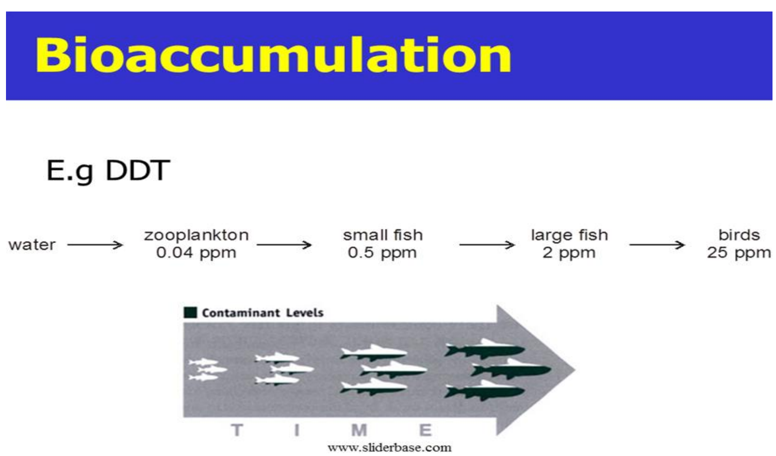
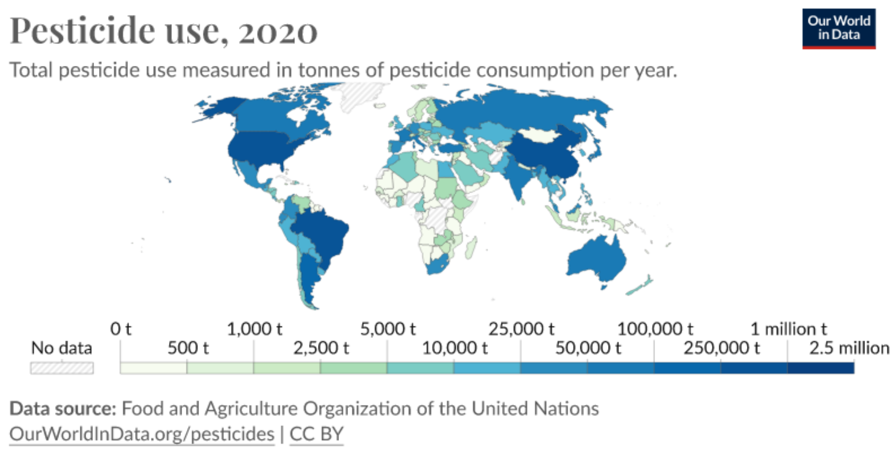


Fig. 5. Bioaccumulation of pesticides in organisms **(*Fertilizers and Pesticides - Presentation Plants, Animals, and Ecosystems*, n.d.)**



Map 1. A map exhibiting the world distribution of pesticide consumption, highlighting regions where their use is most intensive **(*Pesticide Use, 2021*, n.d.)**.

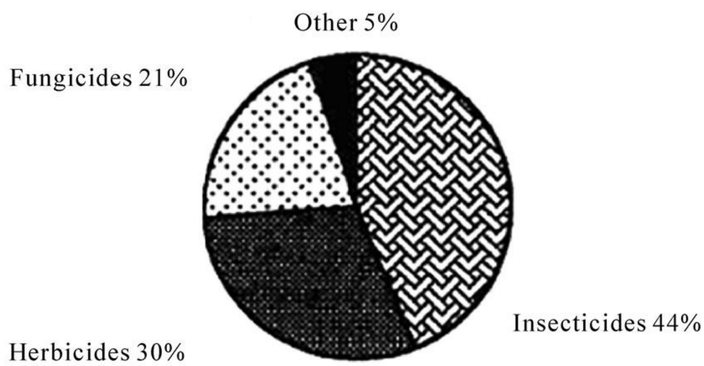


Fig. 6. An estimate representing global application of different pesticides **(Agrawal *et al*., 2010)**

Organophosphates, carbamates, and pyrethroids have historically been used in large-scale attacks against Culicidae juvenile instars (Fig. 7), with significant detrimental effects on human health and environment **(Naqqash *et al*., 2016)**. Later, insect growth regulators and microbial control agents were developed, and now, the most widely used mosquito larvalicide in the European nations is *Bacillus thuringiensis* var. *israelensis*. A parasporal crystal formed during the stationary phase of the bacterium's development cycle was the source of its insecticidal activity **(Schnepf *et al*., 1998; Lacey, 2007)**. Yet, recent research **(Tabashnik, 1994; Naqqash *et al*., 2016)** showed that a number of pests, including mosquitoes, exhibited resistance to *B. thuringiensis* var. *israelensis*. Different surveys have examined the efficiency of plant-borne products. They are countless and not limited to mosquito larvicides and adulticides **(Amer & Mehlhorn, 2006a, b, c, d; Benelli, 2015a; Pavela, 2015; Pavela & Benelli, 2016)**.

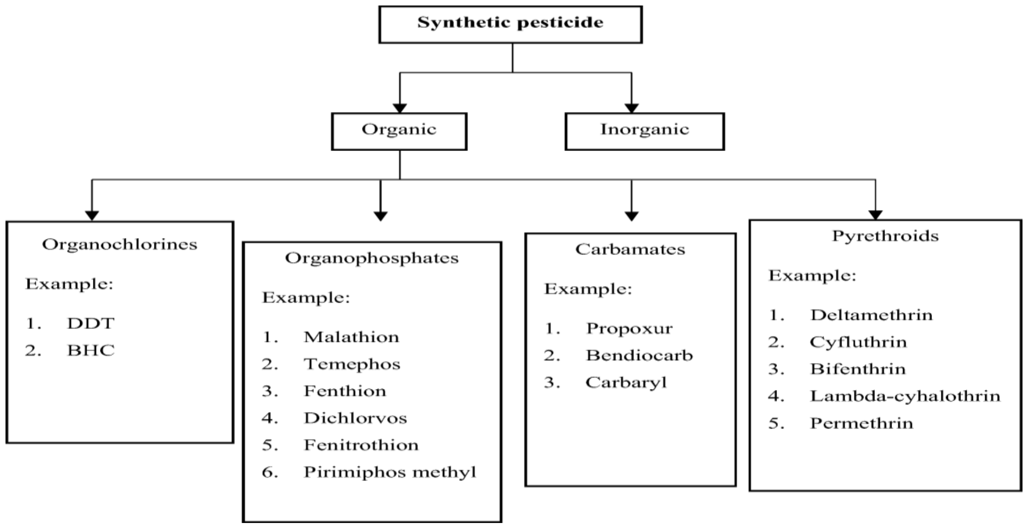


Fig. 7. A schematic diagram illustrating different types of synthetic pesticide

1.3. Biological control agents

Fishes got the most of the study interest among biocidal materials used against larvae. It's true that a variety of fish use the mosquito larvae stage as a food source. According to **Mischke *et al*. (2013)**, the mosquito fish *Gambusia* sp. are the most well-liked. The fish genus *Gambusia* sp. is one of many that feed on mosquito larvae, though **Han *et al*. (2015)** tested a variety of larval fish species, including *Poecilia reticulate*, *Tilapia mossambica*, *Sarotherodon niloticus*, and *Astyanax fasciatus*, as biological control agents against the dengue vectors *Aedes* sp. In lab settings, they were all regarded as efficient mosquito predators. Predator fishes can greatly reduce infestation of the young mosquito instars when used in conjunction with other management measures ***(*Han *et al*., 2015)**. There is currently few research examining amphibians as potential mosquito control agents **(Raghavendra *et al.*, 2008)**. Tadpoles' part in biological control, however, may be of interest. In fact, **Bowatte *et al.* (2013)** investigated five frog taxa in a lab setting as potential dengue mosquito predators.

1.4. Sterile Insect Technique

An environmentally friendly technique for controlling disease vectors is the sterile insect technique (SIT) **(Knipling, 1959)**. This method has garnered new interest in recent years **(Lees *et al.*, 2014, 2015)**. The SIT is a particular species control procedure. It involves reducing insect population of the targeted species. It employs ionizing radiation to render the males impotent. Then, they are released into the target area. Additionally, SIT has recently been paired with auto dissemination, a method that has recently shown to be particularly effective for controlling *Aedes* species but cannot be applied on a broad scale. Mature females are defiled with the dissemination hormonal stations as upbringing locations. Finally, Table (1) represents some botanical extracts and traditional insecticides which are currently used against different pests.

Table 1. Nominated botanical insecticides for pest control

SN	Plant name	Product/trade name	Group/mode of action	Targets
1	*"Lonchocarpus* spp. Derris elliptical"	"Rotenone"	"Insecticidal"	Aphids, bean leaf beetle, cucumber beetles, leafhopper, red spider mite
2	*"Chrysanthemum* cinerariaefolium"	"Pyrethrum/Pyrethrins"	"Insecticidal"	Crawling and flying insects such as cockroaches, ants, mosquitoes, termites
3	*Nicotiana* tabaccum	"Nicotine"	"Insecticidal, antifungal"	Aphids, mites, bugs, fungus, gnat, leafhoppers
4	*"Azadirachta indica"*	"Azadirachtin/neem oil, neem products, Bionimbecidine"	"Repellent, Antifeedant, Nematocide, Anti-fungal"	Nematodes, sucking and chewing insects (caterpillars, aphids mazie, weevils)
5	"Citrus tress	"d-Limonene Linalool"	"Contact poison"	Fleas, aphids, mites, paper, wasp, house cricket
6	*"Shoenocaulon officibale"*	"Sabadilla dust"	"Insecticidal"	Bugs, blister beetles flies, caterpillars, potato, leafhopper
7	*"Ryania speciosa*	"Ryania"	"Insecticidal"	Caterpillars, beetles, bugs, aphids
8	*"Adenium obesum (Heliotis sp)"*	"Chacals Baobab (Senegal)"	"Insecticidal"	Cotton pests

2. Green synthesis of metal nanoparticles

2.1. Green fabrication and characterization of different metal nanoparticles

In this paragraph, some different metal nanoparticles preparation illustrated by numerous authors clarify the fabrication that can be done by several medicinal plant extracts (aqueous extract).

2.1.1 Selenium nanoparticles

At 80 degrees Celsius, the *A. fragrantissima* extract was dissolved in ethanol and applied dropwise to 100ml of deionized water while being magnetically stirred. After dissolving 0.2 g of selenium oxides in 20ml of deionized water, the oxides were gradually added to the mixture above while gently stirring. About two hours were spent stirring and heating the solution mixture to 60°C. The solution became red in color, and some red particles participated in color change, suggesting the creation of selenium nanoparticles (SeNPs) **(Farag *et al*., 2020, 2023; Khattab *et al*., 2021; Abdelhamid *et al.*, 2022, 2023, 2024; El-Halaby *et al.*, 2024)**.

Fourier transform infrared spectroscopy, X-ray diffraction, UV-Vis spectroscopy, “X-ray diffraction” with peaks at “23.3 (100), 29.6 (101), 43.5 (012), and 50.05 (201)”, as well as “scanning electron microscopy” (oval-shaped) were used to confirm the formation of selenium nanoparticles (SeNPs) using *Dillenia indica* leaf broth, as illustrated in Fig. (8). Zeta potential (13.2 mV) and “dynamic light scattering” (Z-average value of 248.0 nm) were used to analyze the nanoparticles' stability and size **(Krishnan *et al*., 2020)**. In addition, they can be fabricated using *Cleistocalyx operculatus* (CO) leaves extract as stated by **Vu *et al*. (2022)**; their characterizations are obviously depicted in Figs. (8, 9).

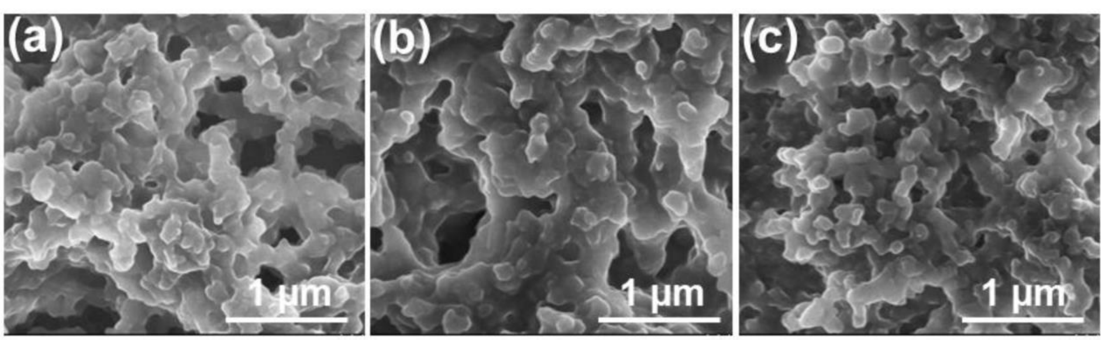


Fig. 8. SEM images of SeNPs synthesized by the CO extract with the assistance of: (a) Probe sonication; (b) Bath sonication; (c) Magnetic stirring, with Se_4^+/CO volume ratio of 1/1 **(Vu *et al.*, 2022)**

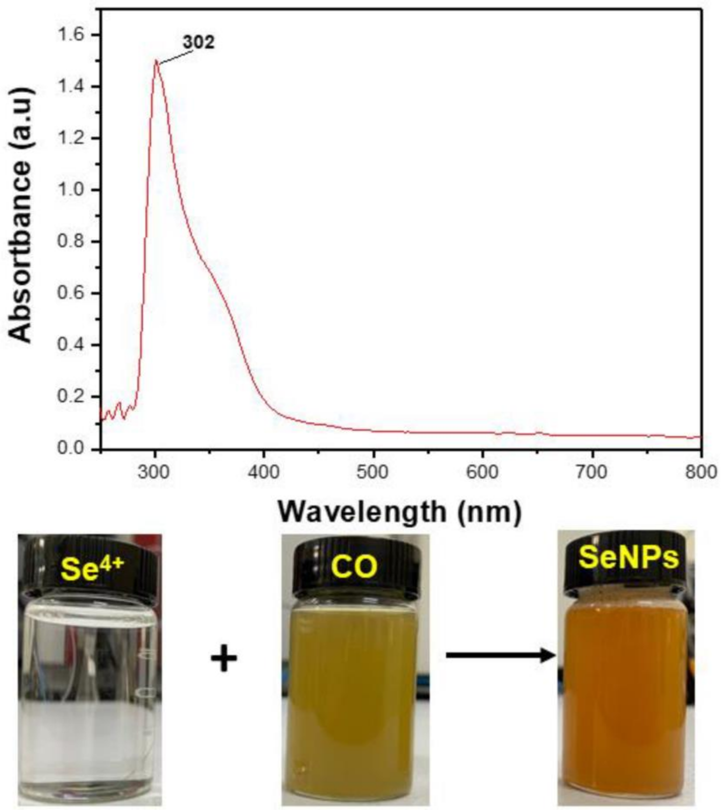


Fig. 9. Optical images of Se^{4+} precursor, the CO extract, SeNPs, and UV-spectrum of SeNPs prepared with the Se^{4+}/CO volume ratio of 1/2 **(Vu *et al.*, 2022)**

2.1.2 Zinc oxide nanoparticles (ZnO-NPs)

Zinc oxide (ZnO) nanoparticles with a spherical shape were bio-synthesized utilizing the leaf extracts of *Solanum lycopersicum* and *Indigofera tinctoria*. Different larval and pupal stages of *A. aegypti* were used as test subjects to determine the effectiveness of the greenly synthesized ZnO nanoparticles. FTIR, SEM, and XRD were used to characterize synthesized ZnO-NPs. The physicochemical parameter demonstrated the excellent purity of the synthesized nanoparticles. A prominent peak in the UV spectra was visible at 352nm. It corresponds to bandgap energy of 3.01 eV. According to the SEM, the particles had rod-like shapes. Moreover, the EDX examination largely ensures the purity of the zinc and oxygen. According to the XRD data, ZnO-NPs crystallites were 40.93nm in size **(Nityasree *et al.*, 2021)**. The fabrication of ZnO-NPs using the neem leaves aqueous extract was characterized by FTIR (Fig. 10), SEM (Fig. 11), and XRD according to the study of **Zafar and Iqbal (2024)**, as shown in Fig. (12).

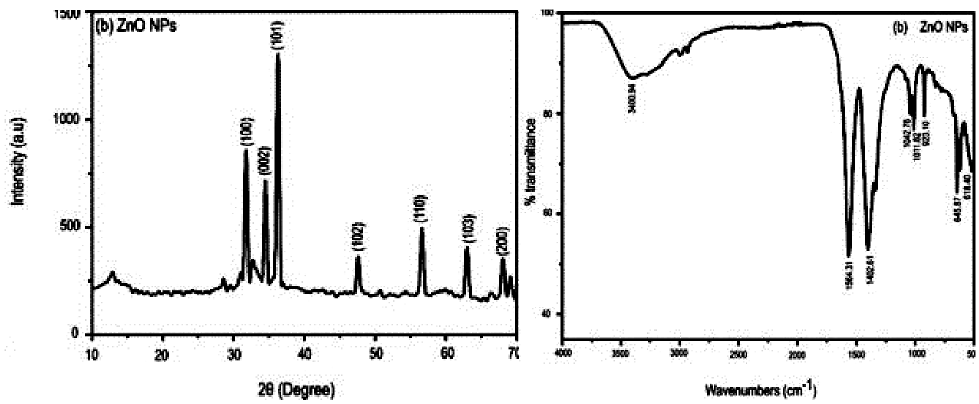


Fig. 10. The structural analysis and FTIR spectra of biosynthesized ZnO-NPs **(Zafar & Iqbal, 2024)**

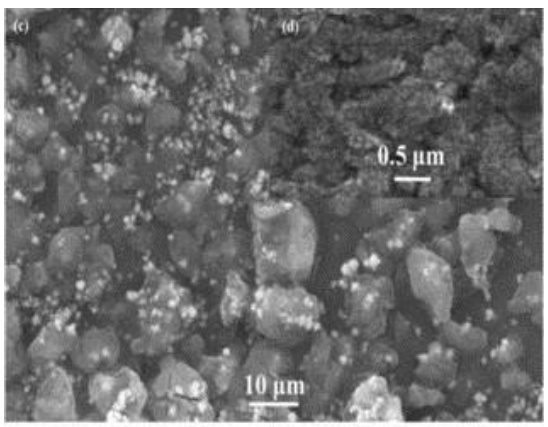


Fig. 11. Morphological evaluation of biosynthesized zinc oxide nanoparticles **(Zafar & Iqbal, 2024)**

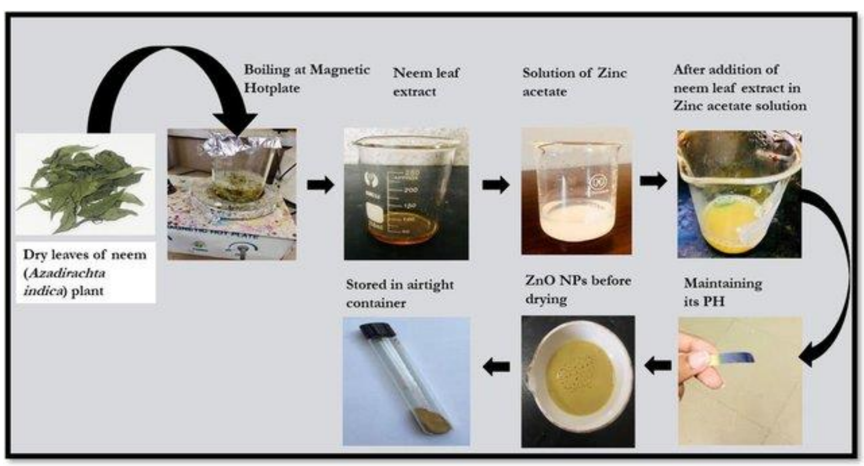


Fig. 12. Schematic of green synthesis of zinc oxide nanoparticles by using neem leaf extract **(Zafar & Iqbal, 2024)**

2.1.3 Cadmium sulphide nanoparticles (CdS-NPs)

Making nanoparticles is a cutting-edge and popular technique. This work proved the sophisticated and successful use of *Ocimum basillicum* leaves in the green manufacture of "cadmium sulphide" nanoparticles (CdS-NPs) as a defense against *Culex pipiens*. Several methods, including "UV-Vis spectrophotometry", "High Resolution Transmission Electron Microscope" (HRTEM), "Fourier transform infrared spectroscopy" (FTIR), and "X-ray diffraction" (XRD), are used to characterize CdS nanoparticles. Figs. 13, 14, 15) represent these characterizations. After 24 hours of treatment, CdS nanoparticles (CdS-NPs) were highly efficient against the larvae of "*Culex pipiens"* (3rd instar) **(Aly *et al.*, 2021)**.

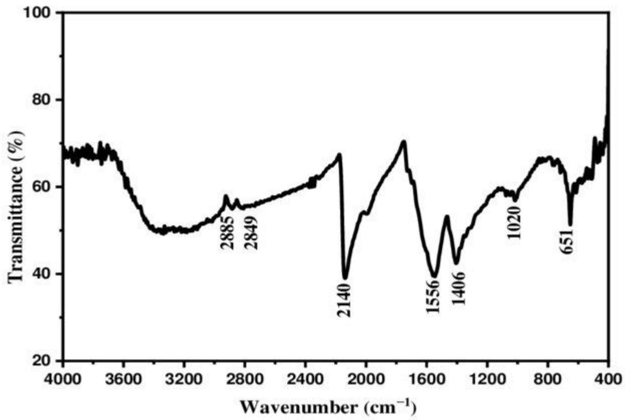


Fig. 13. "FTIR" profile of green synthesized CdS NPs **(Aly *et al.*, 2021)**

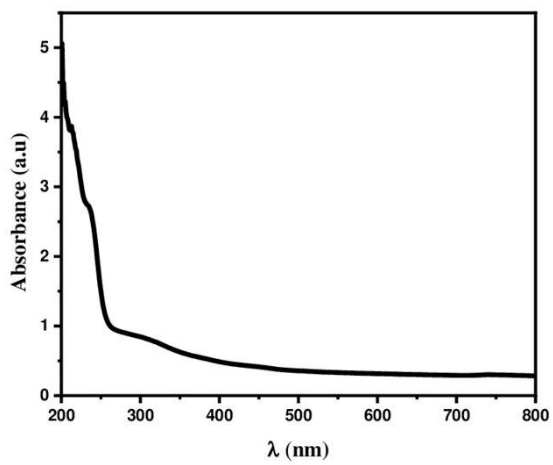


Fig. 14. The absorption coefficient vs. photon energy (hν) for synthesized CdS NPs **(Aly *et al.*, 2021)**

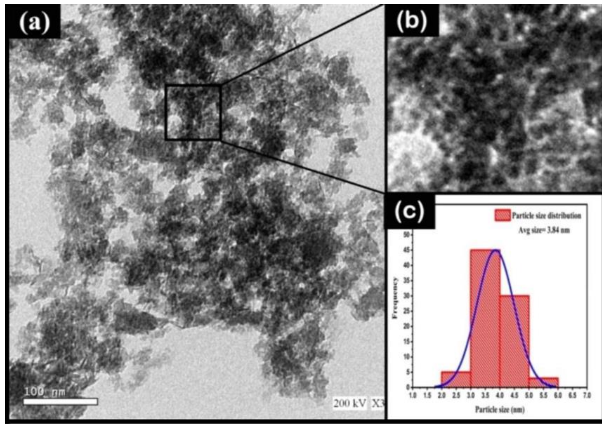


Fig. 15. (a) HR-TEM micrograph of green synthesized CdS-NPs; (b) Enlarged particle; (c) Particle size distribution **(Aly *et al.*, 2021)**

2.1.4 Titanium oxide nanoparticles (TiO_2-NPs)

Desmostachya bipinnata is used to synthesize "TiO_2-NPs". Their" larvicidal and pupicidal" effects on the target species have been investigated on "*Aedes aegypti* and *Spodoptera litura"*. Moreover, their severe lethal effect on non-target species has been studied. "*Toxorhynchites splendens"* and *Eisenia fetida*, have assessed. The biosynthesized TiO_2-NPs were characterized through "FT-IR, XRD, SEM, and EDX" analysis. It displays a broad peak in the UV-vis spectrum study. It indicates that the plant extract was successfully contributed in producing "TiO_2-NPs". The spherical, 36.4 nm-diameter synthesized TiO_2-NPs were identified via XRD analysis and SEM examination **(Shyam-Sundar *et al.*, 2023)**. In addition, Fig. (16) clarifies the preparation of "TiO_2-NPs" using *Vitex negundo* extract. It is characterized by "UV-spectrum" and represents its activity as stated by **Gandhi *et al.* (2016)**.

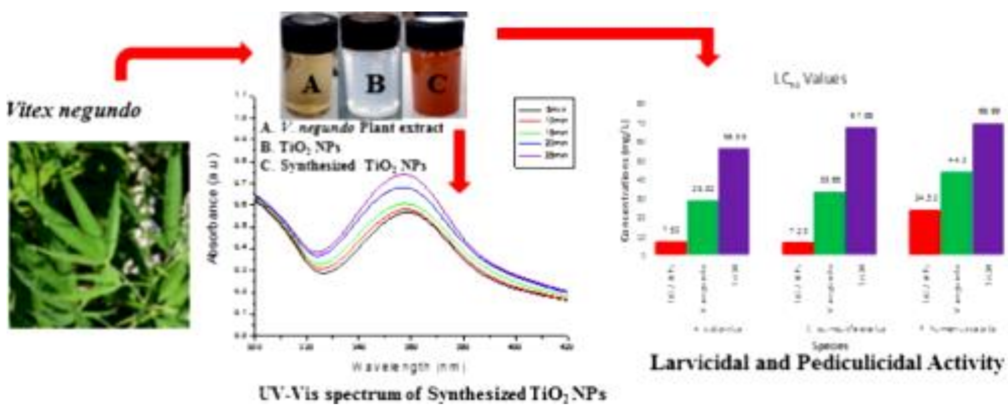


Fig. 16. Diagram representing the preparation, characterization and larvicidal activity of TiO_2NPs **(Gandhi *et al.*, 2016)**

2.1.5 Silver nanoparticles (Ag-NPs)

Anti-dengue medication is among the potential application for ecologically safe metal nanoparticles (NPs) made from plant extracts. Metal NPs can be sustainably made in a quick, inexpensive, and waste-free manner. We are reviewing the literature and mechanistic aspects of the dengue control utilizing green-synthesized NPs. It is in light of the most recent developments in multifunctional metal NPs synthesized from plants for anti-dengue application. The molecular underpinnings of viral suppression by NPs as well as risks respecting the environmental integrity have been investigated. The green production of silver and gold nanoparticles has received the majority of attention up to this point; nevertheless, other creative composite nano-materials need to be added. For assessing gained molecular concepts gained upon preparing biogenic NPs, additional in-depth mechanistic studies are needed. The harmful impacts of NPs and their extending disadvantages on the ecosystem should also be carefully evaluated **(Zohra *et al.*, 2022)**. *Aedes vittatus*, *Anopheles subpictus*, and *Culex vishnui* mosquitoes were tested against silver nanoparticles and aqueous leaf extract from *Atalantia monophylla* (Am). Additionally, the larvicidal activity of artificially created silver nanoparticles (Ag-NPs) against the fourth-instar larvae of the filariasis vector *Culex quinquefasciatus* and the malaria vector *Anopheles subpictus* Grassi (Diptera: Culicidae) was studied. The UV-vis spectrum, transmission electron microscopy (TEM), Fourier transform infrared (FTIR), and X-ray diffraction (XRD) are used to characterize the synthesized Ag-NPs. The synthesized Ag-NPs were easily identifiable in SEM studies and ranged in size from 35 to 60nm **(Rajakumar & Abdul Rahuman, 2011; Fouad *et al.*, 2021; Elumalai *et al.*, 2022)**. In addition, the scientists considered the larvicidal and pupicidal effects of myco-synthesized (Ag-NPs) against *Aedes aegypti*; the dengue vector, in its various developmental stages. Utilizing microorganisms in the production of nanosilver, particularly AgNPs, is an alluring option of green nanotechnology. The UV-visible spectrophotometer, X-ray diffraction analysis, Fourier transform infrared, and scanning electron microscopy were used to characterize the myco-synthesized Ag-NPs to determine their special properties **(Sundaravadivelan & Padmanabhan, 2014)**. The effectiveness of silver nanoparticles (Ag-NPs) made from the leaf extract of the *Euphorbia hirta* (*E. hirta*) plant against the *Anopheles stephensi* (*A. stephensi*) malaria vector has been tested **(Priyadarshini *et al.*, 2012)**. The use of an aqueous leaf filtrate from *Artemisia nilagirica* to quickly synthesize silver nanoparticles (Ag-NPs) has been validated by a UV-visible spectrophotometer. The presence of functional groups the nanoparticles has been determined by FTIR and XRD techniques, respectively. Their average particle size was nearly 6nm. A scanning electron microscopy (SEM) was used to confirm that Ag-NPs had a sphere-like shape **(Nalini *et al*., 2017)**. According to **Govindan *et al.* (2020)**, *Plumbago auriculata's* aqueous extract was used in the manufacturing silver nanoparticles (AgNPs), which were evaluated as larvicidal and antibacterial agents, as shown in Fig. (17).

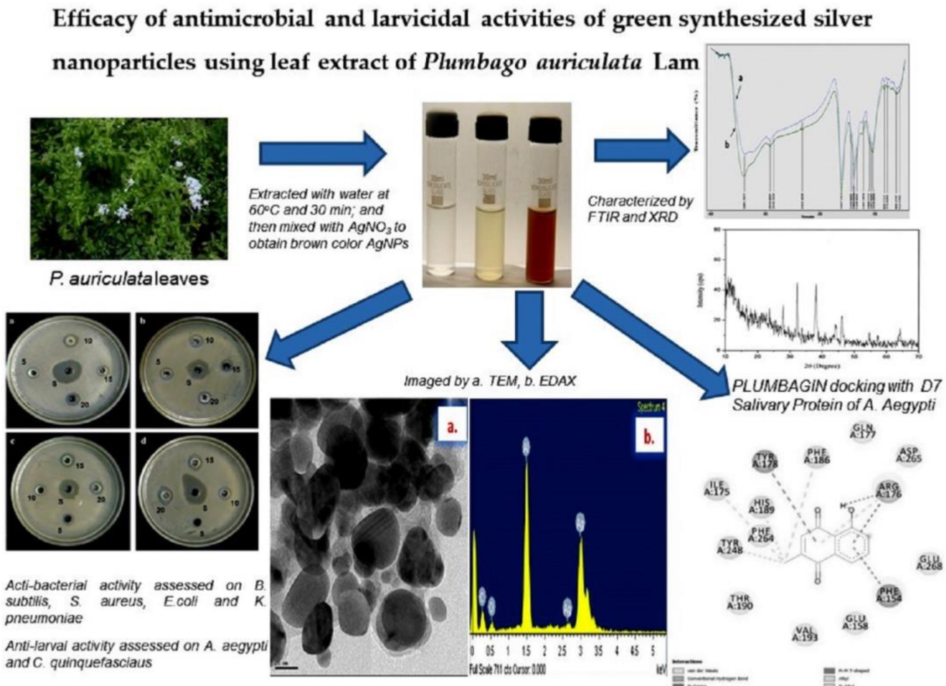


Fig. 17. Summary of synthesized silver nanoparticle using *Plumbago auriculata* Lam leaf extract, characterization, and their antimicrobial and larvicidal activities **(Govindan *et al.*, 2020)**

Ag/Ag_2O nanoparticles were bio-synthesised utilizing *Eupatorium odoratum* (EO), an aqueous leaf extract. The leaf extract's components function as stabilizers and reducers. The nanoparticles' UV-vis spectra revealed a surface plasmon resonance. Transmission electron microscopy (TEM) was used to examine the nanoparticles' size and form **(Elemike *et al.*, 2017; El-Sayed *et al.*, 2020; Fouad *et al.*, 2021; Farag *et al.*, 2023)**.

2.1.6 Cerium oxide nanoparticles (CeO_2-NPs)

The creation of cerium oxide nanoparticles (CeO_2-NPs) via an eco-friendly process is demonstrated. The aqueous extract of *Bruguiera cylindrica* leaves (BL) is used in this procedure as an oxidant and stabilizing agent. For CeO_2-NPs, UV-vis spectroscopy revealed a characteristic absorbance band with a band gap of 3.17eV at 303nm. While X-ray diffraction demonstrated the cubic fluorite orientation of CeO_2-NPs, FT-IR analysis found the functional groups from the plant extract coupled to CeO_2-NPs. The zeta potential measurements showed a surface charge of about 20.7mV. An energy dispersive spectrum analysis validated the generation of CeO_2-NPs. Meanwhile, TEM and DLS measurements showed an average diameter of 40-60nm, as shown in Fig. (18) **(Dhavan *et al.*, 2023)**.

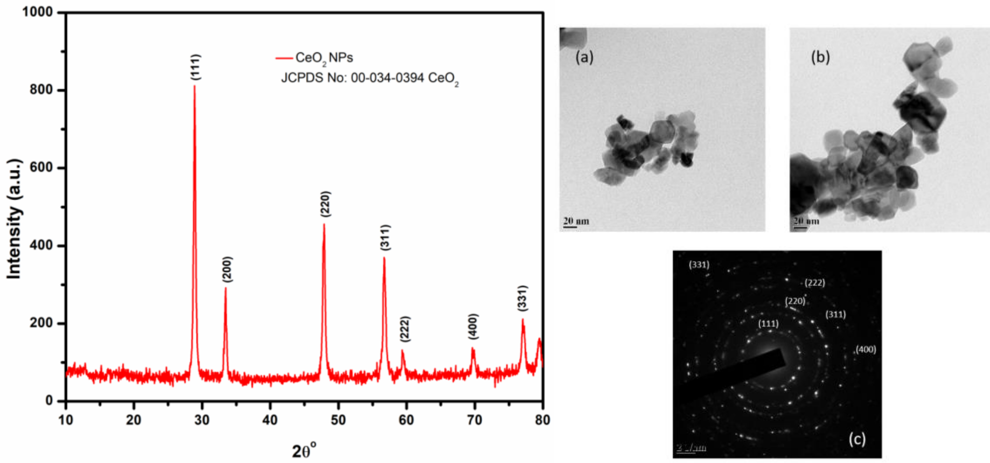


Fig. 18. Characterization of cerium oxide nano particles **(Dhavan *et al.*, 2023)**

Green herbal repellents with larvicidal action are now being produced, according to various investigations **(Madhumitha *et al*., 2012)**. Ag, Au, Pt, Cu, and Ti nanoparticles with strong antibacterial, antioxidant and anticancer activities are synthesized using these medicinal herbs **(Burlacu *et al.*, 2019; Pei *et al.*, 2019)**. Secondary metabolites which are bio-surfactant molecules exist in these curing herbs. Among these species, alkaloids, phenols and tannins are considered. For determining how well these substances may be used to create silver nanoparticles, substantial research was done. The manufacture of metal nanoparticles using ecologically friendly substances such plant extracts, bacteria, and fungi has various advantages over using harmful chemicals, including being compatible with pharmaceutical and other biomedical uses **(Amiri *et al.*, 2020; Ruddaraju *et al.*, 2020)**.

2.2. Green synthesized metal nanoparticles: Effectiveness on mosquito larvae

2.2.1 Larvicidal effect of selenium nanoparticles (Se-NPs)

Se-NPs were tested for their impact on mosquito larvae, and it appears that they have disrupted the peritrophic membrane and the epithelial layers. Histopathological changes were also seen in the midgut and *caeca of the A. aegypti* and *C. quinquefasciatus* larvae treated with SeNPs. According to **Krishnan *et al*. (2020)**, additionally active against both bacterial species, the SeNps showed sizable inhibitory zones.

2.2.2 Larvicidal effect of zinc oxide nanoparticles

In comparison with the extract alone, the aqueous leaf extract from *Solanum lycopersicum* showed a significant increase in larvicidal activity during the biogenesis of ZnO-NPs. Furthermore, histological analyses supported the existence of both beneficial and harmful alterations in the tissues of larvae, particularly in the midgut and fat cells a stated by **Nityasree, *et al*. (2021)** and **Chithiga and Manimegalai (2023)**.

2.2.3 Larvicidal effect of cadmium sulphide nanoparticles

After 24 hours of treatment, cadmium sulphide nanoparticles (CdS-NPs) were extremely efficient against the third-instar *Culex pipiens* larvae. CdS-NPs had an LC_{50} of 0.0113 g/l. LC_{50} for the leaf extract in water of "*Ocimum basillicum"* was 52.36 g/l. In the reference category, deaths didn't occur. Additionally, cadmium sulpide NPs markedly lengthened the larval early stages. Additionally, a negative effect arose on the rates of propagating their life cycles. The results through SEM showed that the thorax and head regions of the larvae had abnormalities and constrictions. The digestive tract and respiratory canal in the belly were completely distorted, but the syphon was unharmed, having conventional spiracular valves. There are slight anomalies on the outside of the tracheal trunk, as clarify in the studies of **Aly *et al*. (2021)**.

2.2.4 Larvicidal effect of titanium oxide nanoparticles

In the second instars of *A. aegypti* and *S. litura* larvae, respectively, the maximum mortality rates at 900 µg/mL for the application of biosynthesized TiO_2-NPs were 96% and 94%. Additionally, TiO_2NPs demonstrated concentration-dependent elevated pupal lethality for both *S. litura* and *A. aegypti*. Additionally, some histological changes in the midgut of *A. aegypti* and *S. litura* can noticed. They are subjected to various doses of biosynthesized TiO_2-NPs. Moreover, they have improved detoxifying enzyme activity inesterase and glutathione-S-transferase enzymes **(Shyam-Sundar *et al.*, 2023)**.

3.2.5. Larvicidal effect of silver nanoparticles

The eco-friendly synthesis approach of Ag-NPs using *Artemisia nilagircia* aqueous leaf extract appears on the of larvicidal and pupicidal potency against *Aedes aegypti* and *Anopheles stephensi* for all developmental stages of larvae and for pupal stage **(Nalini *et al.*, 2017)**. In addition, Ag-NPs fabricated by using *Atalantia monophylla* aqueous leaf extract has larvicidal activity against *Ae. vittatus*, *An. Subpictus* and *Cx. vishnui* **(Elumalai *et al.*, 2022)**. **Govindan *et al*. (2020)** stated that, the green synthesized of Ag-NPs using *Plumbago auriculata* Lam extract has potency as larvicidal against *Aedes aegypti* and *Culex quinquefasciatus* more than extract itself and affect the salivary protein which interrupt the transmission of diseases.

2.2.6 Larvicidal effect of cerium oxide nanoparticles

Both silver-doped nanoceria (AgCNPs) and cerium oxide nanoparticles (CeO_2-NPs) show larvicidal capability. The surviving larvae had changed life history features, such as lower egg hatch proportion and different sex ratios, showing that these nanoceria were involved in more than solely larvicide-related activities, as was previously indicated. The life history features of the larvae that survived were altered (e.g., lower egg hatch proportion and different sex ratios), suggesting that these nanoceria were engaged in activities other than larvicide **(Doshi *et al.*, 2020)**. There is a reduction in the permeability of the membrane, organelle and enzyme denaturation. It leads to decomposing the cell. These are the possible effects of metal-based nanoparticles binding to the sulphur and phosphorus units in proteins and nucleic acids, as demonstrated in Fig. (19). Additionally, they inhibit gonadotropin release, protein synthesis, and key insect genes, all of which affect development and reproduction **(Jincy *et al.*, 2022)**. According to the scientists' hypotheses, nanoparticles' capacity to pass through the exoskeleton may be connected to their biotoxicity toward mosquito young instars. Organelles and enzymes can quickly denature as a result of nanoparticles' intracellular binding to sulphur from proteins or to phosphorus from DNA. Destroying the cell functions occurred due diminishing the membrane permeability and disrupting the cell motility **(Subramaniam *et al.*, 2015; Benelli, 2016c, 2016a)**.

In Figure (19) and (20), CS/Ag-NPs displays a crucial effect on different species of mosquito larvae. The histological effects of the CS/Ag-NPs treated mosquito larvae, according to **Amutha** et al. **(2019)**, showed vacuolation in their adipose, epithelial, and muscle tissues. Similarly, Figure (21) presents the damage that occurred as a result of applying Neem gum, NG/ZnO-NPs and bare Zinc acetate. They release disorders in many position of treated larva, as declared by **Vijayakumar *et al*. (2021)**.

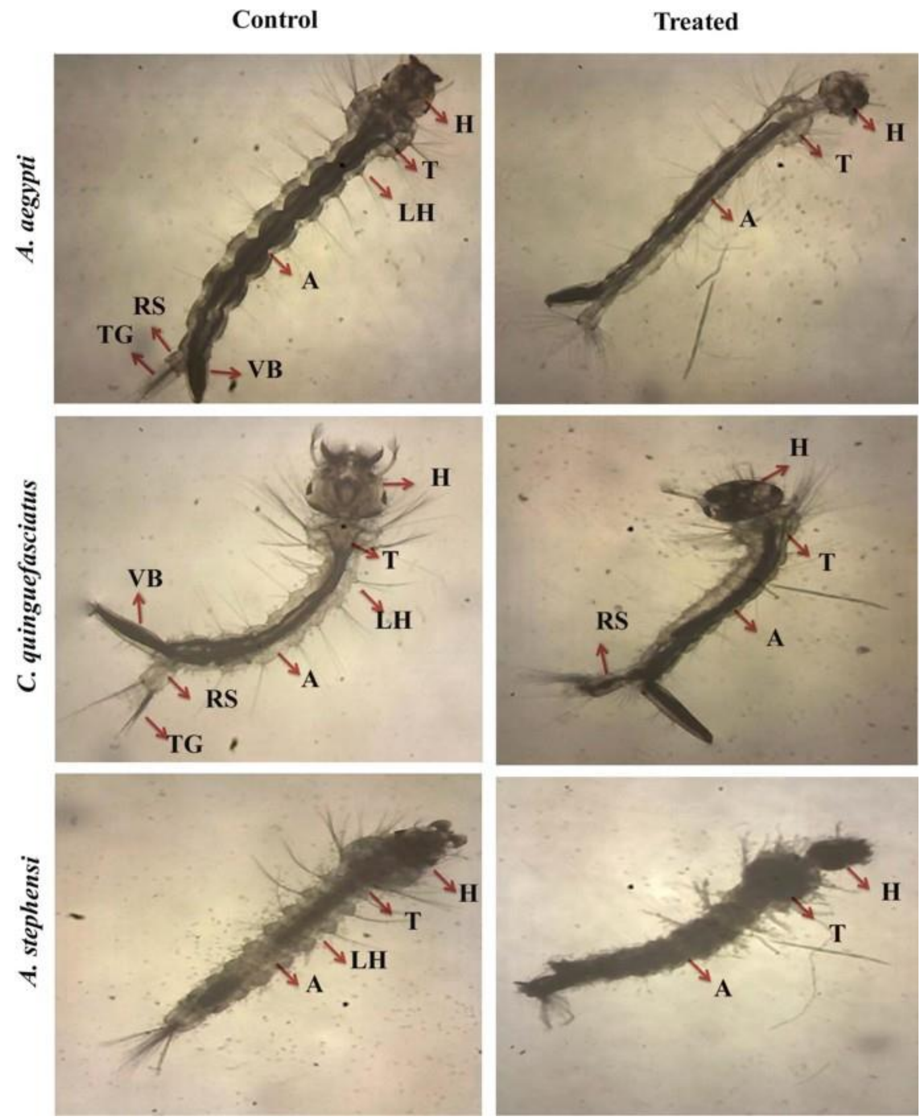


Fig. 19. Captured images by a microscope for mosquito larvae treated with various nanoparticles and a control group. Control (LH, lateral hairs; Rs, respiratory syphon; TG, tracheal gills; VB, ventral brush); H, head; T, thorax; A, abdomen. After being treated with NPs, the treated larvae show body abnormalities and shrinking of the interior cuticle **(Amutha *et al.*, 2019)**

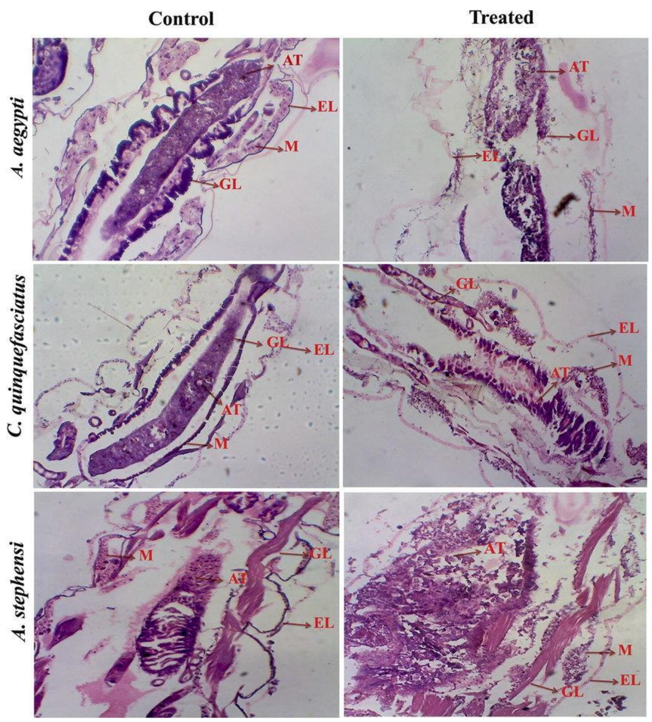


Fig. 20. The management and treatment of mosquito larvae using histology. Control (muscles; EL, epithelial layer; GL, gastrointestinal lumen; AT, adipose tissue) **(Amutha *et al*., 2019)**

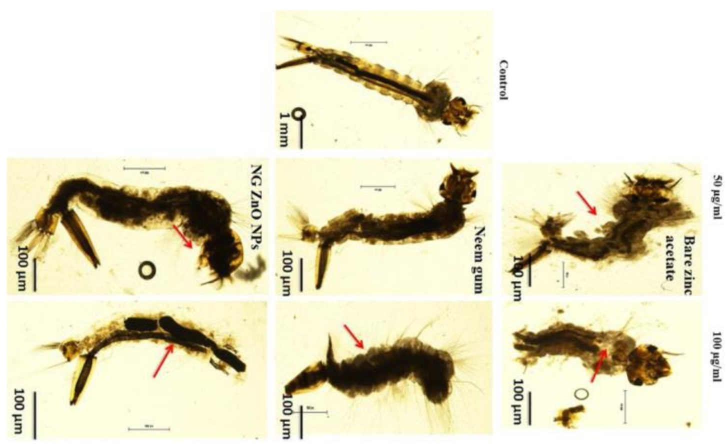


Fig. 21. Light microscopic pictures of Culex quinquefasciatus mosquito larvae in their fourth instar demonstrate the toxicity of NG-ZnONPs in contrast to neem gum and bare zinc acetate. The stomach regions, abdomen, and head of Culex quinquefasciatus treated with NG-ZnONPs at 50 and 100 µg/mL are shown by the arrow **(Vijayakumar *et al.*, 2021)**

4. Green synthesized metal nanoparticles: effectiveness on non-target organisms

There are some sporadic reports of mosquito-cidal nanoparticles' toxicity to aquatic creatures other than their intended targets have been made **(Benelli, 2016b, c; Govindarajan *et al.*, 2016; Govindarajan *et al.*, 2016)**. For the acute toxicity toward aquatic non-target species, there is fair information available. The estimated values for IV instar larvae of *A. aegypti* and *A. stephensi*, upon being treated with Ag-NPs synthesized by *Plumeria rubra* and *Pergularia daemia*, did not show any obvious toxicity effect against *P. reticulata* fishes **(Patil *et al*., 2012; Patil, *et al*., 2012)** After 48 hours of exposure to LC_{50} and LC_{90} values. A 3- day exposure to *A. stephensi* and *C. quinquefasciatus*, **Subarani, *et al*. (2013)** did not report any toxicity effects of silver nanoparticles synthesized from *Vinca rosea* against *P. reticulata*. Similarly, after 48 hours of exposure to LC_{50} levels of the fourth instar larvae of *A. stephensi* and *C. quinquefasciatus*, **Haldar *et al*. (2013)** found no evidence of toxicity for Ag-NPs made using dried green fruits of *Drypetes roxburghii* against *P. reticulata*. According to research by **Rawani *et al*. (2013)**, two mosquito predators were unaffected by mosquitocidal silver nanoparticles made with *Solanum nigrum* fruit extracts. In contrast to the extreme lethality caused by pesticides that are synthetic, "(cypermethrin and monocrotophos for *E. fetida*; and cypermethrin and temphos for *T. splendens*)", the death rate of non-target species (*T. splendens* and *E. fetida*) was decreased when exposed to "TiO_2NPs **(Shyam-Sundar *et al*., 2023)**. With LC_{50} values ranging from 2,094.5 to 10,532.8 µg•mL^{-1}, respectively, the bio-toxicity of "*Atalantia monophylla* ALE" and Am-AgNPs was examined against aquatic and terrestrial non-target species "(*Acilius sulcatus*, *Anisops bouvieri*, *Araneus mitificus*, and *Cyrtophora moluccensis*)". The selected non-target fauna hardly experienced any harmful effects from *Atalantia monophylla* ALE or Am-AgNPs **(Elumalai *et al*., 2022)**.

5. Case study

Herbal extracts have been utilized to be significant drug origins for ages **(Mansour *et al*., 2019)**. Several writers investigated the effects of moringa extract as repellant, adulticide, and larval killers on mosquitoes **(Prabhu *et al*., 2011)**. Conversely, "Nano-silver" is a highly commercialized nanomaterial with an approximate yearly use of 320 tons ***(*Pal *et al*., 2018)**. While chemical nanoparticle production is energy-intensive and environmentally hazardous, biosynthesis of silver nanoparticles can yield a cost-effective and sustainable material **(Mondal *et al*., 2014)**. Fabric, which is packed with insecticides or repellents and used in nets, curtains, military uniforms, clothing, etc., provides mosquito protection **(Medhat A. & Harry, 1981)**. Nanotechnology may be used to provide textile fabric a variety of qualities, such as resistance to water and oil, soiling, antimicrobial activity, flame retardancy, UV protection, and insect repellentness **(Ibrahim *et al*., 2020)**. The Egyptian Scientific Society of Moringa (ESSM), located at the National Research Centre in Dokki, Cairo, Egypt, provided the *Moringa oleifera* leaves. 20gm of dry moringa leaves were mashed. It was dissolved in 100ml in an aqueous medium with thermal treatment to 60^{o}C while being stirred for one hour. Then, the suspension was filtered. In a conical flask, the 10ml of filtrate (Moringa extract) was diluted with 90ml of deionized water. To create an *in-situ* suspension of silver nanoparticles, silver nitrate ($AgNO_3$, 0.17g, 0.1mmol) was added to this extract and continuously stirred for one hour at 60^{o}C. The creation of silver nanoparticles is indicated by a shift in solution color to a reddish brown color, which was further verified by a TEM and a UV spectrophotometer. The finishing bath comprising AgNPs@Moringa (50 ml), hydrolyzed GPTMS (5 ml), DMDHEU (100 g/l), magnesium chloride, and 1-Methyl imidazole (a few drops) was submerged in fabric samples (8 cm x 8 cm), cotton, CO/PET, viscose, and linen. The fabric samples have been squeezed to 100% wet pick-up, then they were dried for five min at 100ºC, and then cured for an additional 5min at 160ºC. To remove any unreacted compounds, the specimens have been carefully cleaned and left to dry overnight at room temperature. Up to six days, every treated cloth exhibited 100% repellency against Culex pipiens mosquitoes. Following a 12-day period, the percentage of repellency dropped to 50, 52, and 59% for viscose, CO/PET, and pure cotton, respectively. During the same 12-day timeframe, linen was shown to have a superior repellency level of 90%. The results of the control experiment showed that not all untreated textiles had a repelling effect. The kind of fabric, the concentration of AgNPs@Moringa composite, and the interactions between the fabric material and AgNPs@Moringa extract components were identified as the reasons for the variations in the treated textiles' efficacy. This study provides an easy-to-follow green production of silver nanoparticles utilizing water extract from Moringa oleifra. One-pot synthesis technique was used for AgNPs@Moringa extract to be applied into different textiles, including cotton, CO/PET, viscose, and linen. AgNPs@Moringa treated cloth had a good efficacy as a repellent, adulticide, and larvicidal action, suggesting potential anti-mosquito activity **(El-Sayed *et al.*, 2020)**.

CONCLUSION

Parasitology is now facing major issues, most of which are connected to the absence of efficient preventative and/or curative instruments against malaria and arboviruses, with specific reference to recent dengue, chikungunya, and Zika virus epidemics. Here, the green synthesis of nanoparticles using plants and invertebrates as reducing, stabilizing, and capping agents is preferred over chemical and physical methods due to its lower cost, one-step process, and lack of high pressure, energy, or temperature requirements, as well as its use of highly toxic chemicals. From a parasitological standpoint, green nanoparticles have actually been effectively applied to reduce the juvenile instar mosquito in the field and to cause egg mortality and oviposition deterrence. Particularly, few off-target impacts were documented and aquatic creatures have not shown acute toxicity or genotoxicity at dosages fatal to mosquito young instars.

List of abbreviation

A. or *Ae.*	*"Aedes"*
A. or *An.*	*"Anopheles"*
AgCNPs	"Silver-doped nanoceria"
AgNPs	"Silver nanoparticles"
ALE	"Aqueous Leaf Extract"
Am	*"Atalantia monophylla"*
B. thuringiensis	*"Bacillus thuringiensis"*
C. or *Cx.*	*"Culex"*
CdSNPs	"Cadmium sulphide nanoparticles"
CeO_2NPs	"Cerium oxide nanoparticles"
DEET	"N,N-diethyl-metatoluamide"
DEM	"N,N-diethyl mandelic acid amide"
DLS	"Dynamic Light Scattering"
DMP	"Dimethyl phthalate"
E. fetida	*"Eisenia fetida"*
E. hirta	*"Euphorbia hirta"*
EDX	"Electron Dispersive X-Ray"
FTIR	"Fourier Transform InfraRed spectroscopy"
HRTEM	"High Resolution Transmission Electron Microscope"
LC_{50}	"Lethal Concentration give 50% mortality in population"
LC_{90}	"Lethal Concentration give 90% mortality in population"
NG	"Neem gum"
NPs	"Nanoparticles"

P. reticulate	*"Poecillia reticulate"*
S. litura	*"Spodoptera litora"*
SEM	"Scan Electron Microscope"
SeNPs	"Selenium NanoParticles"
SIT	"Sterile Insect Technique"
Sp.	"Species"
T. splendens	*"Toxorhynchites splendens"*
TiO_2NPs	"Titanium oxide nanoparticles"
XRD	"X-Ray Diffraction"
ZnONPs	"Zinc oxide nanoparticles"

REFERENCES

Abdelhamid, A. E.; Ahmed, E. H.; Awad, H. M. and Ayoub, M. M. H. (2023). Synthesis and cytotoxic activities of selenium nanoparticles incorporated nano-chitosan. *Polymer Bulletin.*, pp.1–17. https://doi.org/10.1007/S00289-023-04768-8/FIGURES/9.

Abdelhamid, A. E.; El-Sayed, A. A.; Swelam, S. A.; Soliman, A. M. and Khalil, A. M. (2022). Encapsulation of Triazole Derivatives Conjugated with Selenium Nanoparticles onto Nano-Chitosan for Antiproliferative Activity towards Cancer Cells. *Egyptian Journal of Chemistry.*, **65**(13):1231–1239. https://doi.org/10.21608/ EJCHEM.2022.147872.6401.

Abdelhamid, A. E.; Rafea, M. A.; Zaki, M. E. A.; Kamel, O. M. H. M.; Amr, A.; El-Aassar, M. R.; Swelam, S. A. and El-Sayed, A. A. (2024). Textile Finishing Using Triazole Derivatives and Selenium Nanoparticles as an Anti-mosquito. *Fibers and Polymers.*, **25**(6): pp.2065–2079. https://doi.org/10.1007/S12221-024-00551-2/METRICS.

Agrawal, A.; Pandey, R. S.; Sharma, B.; Agrawal, A.; Pandey, R. S. and Sharma, B. (2010). Water Pollution with Special Reference to Pesticide Contamination in India. *Journal of Water Resource and Protection.*, **2**(5):432–448. https://doi.org/10. 4236/JWARP.2010.25050.

Alamshany, Z. M.; Khattab, R. R.; Hassan, N. A.; El-Sayed, A. A.; Tantawy, M. A.; Mostafa, A.; Hassan, A. A. and Eg, A. A. H. (2023). Synthesis and Molecular Docking Study of Novel Pyrimidine Derivatives against COVID-19. *Molecules.*,

28(2): pp.739. https://doi.org/10.3390/MOLECULES28020739.

Alkherb, W. A. H.; Farag, S. M.; Alotaibi, A. M.; Aloui, Z.; Alshammari, N. A. H.; El-Sayed, A. A.; Almutairi, F. M. and El-Shourbagy, N. M. (2024). Synthesis and larvicidal efficacy of pyrazolopyrimidine derivatives conjugated with selenium nanoparticles against Culex pipiens L. and Musca domestica L. larvae. *Colloids and Surfaces B: Biointerfaces.*, **241***:* pp.114040. https://doi.org/10.1016/J.COLSURFB.2024.114040.

Aly, M. Z. Y.; Osman, K. S. M.; Omar, E. M. and Mahmoud, M. A. (2021). Recent, Eco-friendly Approach for Controlling Culex pipiens (L.) using Novel Synthesized Cadmium Sulphide Nanoparticles of Ocimum basillicum Extract. *Egyptian Journal of Aquatic Biology and Fisheries.*, **25**(4): 359–377. https://doi.org/10.21608/EJABF.2021.189664.

Amer, A. and Mehlhorn, H. (2006a). Larvicidal effects of various essential oils against Aedes, Anopheles, and Culex larvae (Diptera, Culicidae). *Parasitology Research.*, **99**(4): pp.466–472. https://doi.org/10.1007/S00436-006-0182-3.

Amer, A. and Mehlhorn, H. (2006b). Persistency of larvicidal effects of plant oil extracts under different storage conditions. *Parasitology Research.,* **99**(4): 473–477. https://doi.org/10.1007/S00436-006-0183-2.

Amer, A. and Mehlhorn, H. (2006c). Repellency effect of forty-one essential oils against Aedes, Anopheles, and Culex mosquitoes. *Parasitology Research,* **99**(4): 478–490. https://doi.org/10.1007/S00436-006-0184-1.

Amer, A. and Mehlhorn, H. (2006d). The sensilla of Aedes and Anopheles mosquitoes and their importance in repellency. *Parasitology Research*, **99**(4): 491–499. https://doi.org/10.1007/S00436-006-0185-0.

Amiri, A.; Mousakhani-Ganjeh, A.; Amiri, Z.; Guo, Y. gong; Pratap Singh, A. and Esmaeilzadeh Kenari, R. (2020). Fabrication of cumin loaded-chitosan particles: Characterized by molecular, morphological, thermal, antioxidant and anticancer properties as well as its utilization in food system. *Food Chemistry.*, **310**. https://doi.org/10.1016/J.FOODCHEM.2019.125821.

Amutha, V.; Deepak, P.; Kamaraj, C.; Balasubramani, G.; Aiswarya, D.; Arul, D.; Santhanam, P.; Ballamurugan, A. M. and Perumal, P. (2019). Mosquito-Larvicidal Potential of Metal and Oxide nanoparticles Synthesized from Aqueous Extract of the Seagrass, Cymodocea serrulata. *Journal of Cluster Science.*, **30**(3): pp.797–812. https://doi.org/10.1007/S10876-019-01542-7.

Benelli, G. (2015a). Plant-borne ovicides in the fight against mosquito vectors of medical and veterinary importance: a systematic review. *Parasitology Research*, **114**(9), 3201–3212. https://doi.org/10.1007/S00436-015-4656-Z.

Benelli, G. (2015b). Research in mosquito control: current challenges for a brighter future. *Parasitology Research.*, **114**(8): 2801–2805. https://doi.org/10.1007/S00436-015-4586-9.

Benelli, G. (2016a). Green synthesized nanoparticles in the fight against mosquito-borne diseases and cancer—a brief review. *Enzyme and Microbial Technology.*, **95**: pp.58–68. https://doi.org/10.1016/J.ENZMICTEC.2016.08.022.

Benelli, G. (2016b). Plant-mediated biosynthesis of nanoparticles as an emerging tool against mosquitoes of medical and veterinary importance: a review. *Parasitology Research.*, **115**(1): pp.23–34. https://doi.org/10.1007/S00436-015-4800-9.

Benelli, G. (2016c). Plant-mediated biosynthesis of nanoparticles as an emerging tool against mosquitoes of medical and veterinary importance: a review. *Parasitology Research.*, **115**(1): pp. 23–34. https://doi.org/10.1007/s00436-015-4800-9.

Benelli, G. and Mehlhorn, H. (2016). Declining malaria, rising of dengue and Zika virus: insights for mosquito vector control. *Parasitology Research.*, **115**(5): pp.1747–1754. https://doi.org/10.1007/S00436-016-4971-Z.

Bonizzoni, M.; Gasperi, G.; Chen, X.; and James, A. A. (2013). The invasive mosquito species Aedes albopictus: current knowledge and future perspectives. *Trends in Parasitology.*, **29**(9): pp.460–468. https://doi.org/10.1016/J.PT.2013.07.003.

Bowatte, G.; Perera, P.; Senevirathne, G.; Meegaskumbura, S. and Meegaskumbura, M. (2013). Tadpoles as dengue mosquito (Aedes aegypti) egg predators. *Biological Control.*, **67**(3): pp.469–474. https://doi.org/10.1016/J.BIOCONTROL.2013.10.005.

Burlacu, E.; Tanase, C.; Coman, N. A. and Berta, L. (2019). A Review of Bark-Extract-Mediated Green Synthesis of Metallic Nanoparticles and Their Applications. *Molecules.*, **24**(23): pp.4354. https://doi.org/10.3390/MOLECULES24234354.

Cetin, H.; Yanikoglu, A. and Cilek, J. E. (2011). Larvicidal activity of selected plant hydrodistillate extracts against the house mosquito, Culex pipiens, a West Nile virus vector. *Parasitology Research.*, **108**(4): pp.943–948. https://doi.org/10.1007/S00436-010-2136-Z.

Chithiga, A. and Manimegalai, K. (2023). Biosynthesis of zinc oxide nanoparticles using Indigofera tinctoria and their efficacy against dengue vector, Aedes aegypti (Diptera: Culicidae). *Experimental Parasitology*, **249***:* pp.108513. https://doi.org/10.1016/J.EXPPARA.2023.108513.

Dhavan, P. P.; Sonawane, V. R. and Mishra, A. K. (2023). Investigating the Effectiveness of Plant-Mediated Cerium Oxide Nanoparticles as Larvicidal Agents against the Dengue Vector Aedes aegypti. *Physiologia.*, **3**(2): pp.329–346. https://doi.org/10.3390/PHYSIOLOGIA3020023.

Doshi, M.; Bosak, A.; Neal, C. J.; Isis, N.; Kumar, U.; Jeyaranjan, A.; Sakthivel, T. S.; Singh, S.; Willenberg, A.; Hines, R. B.; Seal, S. and Willenberg, B. J. (2020). Exposure to nanoceria impacts larval survival, life history traits and fecundity of Aedes aegypti. *PLoS Neglected Tropical Diseases.*, **14**(9): pp.1–29. https://doi.org/10.1371/JOURNAL.PNTD.0008654.

El Gohary, E. E. G.; Farag, M. S.; El-Sayed, A. A.; Khattab, R. R. and Mahmoud, M. D. (2021). Insecticidal Activity and Biochemical Study of the Clove Oil (Syzygium aromaticum) Nano- Formulation on Culex pipiens L. (Diptera: Culicidae). *Egyptian Journal of Aquatic Biology and Fisheries.*, **25**(1): pp.227–239. https://doi.org/10.21608/ejabf.2021.137233.

El-Halaby, L. O.; El-Magd, N. F. A.; Almehmadi, S. J.; El-Sayed, A. A.; Khattab, R. R.; El-Kalyoubi, S. and Elfeky, S. M. (2024). Synthesis, In-Vitro, In-Vivo screening, and molecular docking of disubstituted aminothiazole derivatives and their selenium nanoparticles as potential antiparkinson agents. *Journal of Molecular Structure.*, **1315**: 138951. https://doi.org/10.1016/J.MOLSTRUC.2024.138951.

El-Sayed, A. A.; Abu-Bakr, S. M.; Swelam, S. A.; Khaireldin, N. Y.; Shoueir, K. R. and Khalil, A. M. (2022). Applying nanotechnology in the synthesis of benzimidazole derivatives: A pharmacological approach. *Biointerface Research in Applied Chemistry.*, **12**(1): pp.992–1005. https://doi.org/10.33263/BRIAC121.9921005.

El-Sayed, A. A.; Amr, A.; Kamel, O. M. H. M.; El-Saidi, M. M. T. and Abdelhamid, A. E. (2020). Eco-friendly fabric modification based on AgNPs@Moringa for mosquito repellent applications. *Cellulose.*, **27**(14): pp.8429–8442. https://doi.org/10.1007/s10570-020-03355-8.

Elemike, E. E.; Onwudiwe, D. C.; Ekennia, A. C.; Sonde, C. U. and Ehiri, R. C. (2017). Green Synthesis of Ag/Ag_2O Nanoparticles Using Aqueous Leaf Extract of Eupatorium odoratum and Its Antimicrobial and Mosquito Larvicidal Activities. *Molecules.*, **22**(5): pp.674. https://doi.org/10.3390/MOLECULES22050674.

Elumalai, K.; Kavipriya, M. R.; Lakshmi Prabha, A.; Krishnappa, K.; Pandiyan, J.; Nicoletti, M.; Alharbi, N. S.; Kadaikunnan, S.; Khaled, J. M. and Govindarajan, M. (2022). Green synthesis of silver nanoparticles using Atalantia monophylla: A potential eco-friendly agent for controlling blood-sucking vectors. *Green Processing and Synthesis.*, **11**(1): pp.915–930. https://doi.org/10.1515/GPS-2022-0078/ASSET/GRAPHIC/J_GPS-2022-0078_FIG_004.JPG.

Farag, S. M.; El-Sayed, A. A. and Abdel-Haleem, D. R. (2020). Larvicidal Efficacy of Nigella Sativa Seeds Oil Culex Pipiens and Musca Domestica. *Journal of the Egyptian Society of Parasitology.*, **50**(1): pp.215-220. https://doi.org/10.12816/JESP.2020.88840.

Farag, S. M.; Kamel, O. M. H. M.; El-Sayed, A. A.; Abdelhamid, A. E. and Abdel-Haleem, D. R. (2023). Green Synthesis of ZnO and Se Nanoparticles Based on Achillea fragrantissima (Forssk.) Extract and Their Larvicidal, Biological and Ultrastructural Impacts on Culex pipiens Linnaeus. *Egyptian Journal of Aquatic Biology and Fisheries.*, **27**(2): pp.773–794. https://doi.org/10.21608/EJABF.2023.297695.

Fertilizers and Pesticides - Presentation Plants, Animals, and Ecosystems. (n.d.).

Retrieved June 7, **2024**, from https://www.sliderbase.com/spitem-897-1.html#6.

Fouad, H.; Yang, G.; El-Sayed, A. A.; Mao, G.; Khalafallah, D.; Saad, M.; Ga'al, H.; Ibrahim, E. and Mo, J. (2021). Green synthesis of AgNP–ligand complexes and their toxicological effects on Nilaparvata lugens. *Journal of Nanobiotechnology.*, **19**(1): pp.1–17. https://doi.org/10.1186/S12951-021-01068-Z/FIGURES/9.

Fradin, M. S. and Day, J. F. (2002). Comparative efficacy of insect repellents against mosquito bites. *The New England Journal of Medicine.*, **347**(1): pp.13–18. https://doi.org/10.1056/NEJMOA011699.

Gandhi, P. R.; Jayaseelan, C.; Vimalkumar, E. and Mary, R. R. (2016). Larvicidal and pediculicidal activity of synthesized TiO_2 nanoparticles using Vitex negundo leaf extract against blood feeding parasites. *Journal of Asia-Pacific Entomology.*, **19**(4): pp.1089–1094. https://doi.org/10.1016/J.ASPEN.2016.10.001.

Govindan, L.; Anbazhagan, S.; Altemimi, A. B.; Lakshminarayanan, K., Kuppan, S.; Pratap-Singh, A. and Kandasamy, M. (2020). Efficacy of Antimicrobial and Larvicidal Activities of Green Synthesized Silver Nanoparticles Using Leaf Extract of Plumbago auriculata Lam. *Plants.*, **9**(11): pp.1577. https://doi.org/10.3390/PLANTS9111577.

Govindarajan, M.; Hoti, S. L.; Rajeswary, M. and Benelli, G. (2016). One-step synthesis of polydispersed silver nanocrystals using Malva sylvestris: an eco-friendly mosquito larvicide with negligible impact on non-target aquatic organisms. *Parasitology Research.*, **115**(7): pp.2685–2695. https://doi.org/10.1007/S00436-016-5038-X.

Govindarajan, M.; Nicoletti, M. and Benelli, G. (2016). Bio-physical Characterization of Poly-dispersed Silver Nanocrystals Fabricated Using Carissa spinarum: A Potent Tool Against Mosquito Vectors. *Journal of Cluster Science.*, **27**(2): pp.745–761. https://doi.org/10.1007/S10876-016-0977-Z.

Guzman, M. G.; Gubler, D. J.; Izquierdo, A.; Martinez, E. and Halstead, S. B. (2016). Dengue infection. *Nature Reviews. Disease Primers.*, **2**: 16055 https://doi.org/10.1038/NRDP.2016.55.

Han, W. W.; Lazaro, A.; Mccall, P. J.; George, L.; Runge-Ranzinger, S.; Toledo, J.; Velayudhan, R. and Horstick, O. (2015). Efficacy and community effectiveness of larvivorous fish for dengue vector control. *Tropical Medicine & International Health.*, **20**(9): pp.1239–1256. https://doi.org/10.1111/TMI.12538.

Helfrich, L. A.; Weigmann, D. L.; Hipkins, P. A. and Stinson, E. R. (2009). *Pesticides and Aquatic Animals: A Guide to Reducing Impacts on Aquatic Systems*. https://api.semanticscholar.org/CorpusID:130287236.

I**brahim, N. A.; Amr, A. and Eid, B. M. (2020)**. Multipurpose Treatment of Cellulose-Containing Fabrics to Impart Durable Antibacterial and Repellent Properties. *Fibers and Polymers.*, **21**(3): pp.513–521. https://doi.org/10.1007/S12221-020-9221-4.

Jansen Van Vuren, P.; Wiley, M. R.; Palacios, G.; Storm, N.; Markotter, W.; Birkhead, M.; Kemp, A. and Paweska, J. T. (2017). Isolation of a novel orthobunyavirus from bat flies (Eucampsipoda africana). *Journal of General Virology.*, **98**(5): pp.935–945. https://doi.org/10.1099/JGV.0.000753/CITE/REFWORKS.

Jincy, G. A.; Sejal, D.; Saher, T.; Gopishankar, T. and Paari, K. A. (2022). Review on microbially synthesized nanoparticles: a potent biocontrol agent against Aedes species of mosquito. *Research Journal of Biotechnology.*, **17**(12): pp.171–189. https://doi.org/10.25303/1712RJBT1710189.

Khattab, R. R.; Swelam, S. A.; Khalil, A. M.; Abdelhamid, A. E.; Soliman, A. M. and El-Sayed, A. A. (2021). Novel Sono-synthesized Triazole Derivatives Conjugated with Selenium Nanoparticles for cancer treatment. *Egyptian Journal of Chemistry.*, **64**(8): pp.4675–4688. https://doi.org/10.21608/EJCHEM.2021.81154.4018.

Knipling, E. F. (1959). Sterile-Male Method of Population Control. *Science.*, **130**(3380): pp.902–904. https://doi.org/10.1126/SCIENCE.130.3380.902.

Krishnan, M.; Ranganathan, K.; Maadhu, P.; Thangavelu, P.; Kundan, S. and Arjunan, N. (2020). Leaf Extract of Dillenia indica as a Source of Selenium Nanoparticles with Larvicidal and Antimicrobial Potential toward Vector Mosquitoes and Pathogenic Microbes. *Coatings.*, **10**(7): *pp.626*. https://doi.org/10.3390/COATINGS10070626.

Kuppusamy, C. and Murugan, K. (2010). Effects of Andrographis paniculata Nees on growth, development and reproduction of malarial vector Anopheles stephensi Liston (Diptera: Culicidae). *Tropical Biomedicine.*, **27**(3): pp.509–516.

Lacey, L. A. (2007). BACILLUS THURINGIENSIS SEROVARIETY ISRAELENSIS AND BACILLUS SPHAERICUS FOR MOSQUITO CONTROL. *J Am Mosq Control Assoc.*, **23**(sp2): pp.133–163. https://doi.org/10.2987/8756-971X(2007)23.

Lees, R. S.; Gilles, J. R.; Hendrichs, J.; Vreysen, M. J. and Bourtzis, K. (2015). Back to the future: the sterile insect technique against mosquito disease vectors. *Current Opinion in Insect Science.*, **10**: pp.156–162. https://doi.org/10.1016/J.COIS.2015.05.011.

Lees, R. S.; Knols, B.; Bellini, R.; Benedict, M. Q.; Bheecarry, A.; Bossin, H. C.; Chadee, D. D.; Charlwood, J.; Dabiré, R. K.; Djogbenou, L.; Egyir-Yawson, A.; Gato, R., Gouagna, L. C.; Hassan, M. M.; Khan, S. A.; Koekemoer, L. L.; Lemperiere, G.; Manoukis, N. C.; Mozuraitis, R. and Gilles, J. R. L. (2014). Review: Improving our knowledge of male mosquito biology in relation to genetic control programmes. *Acta Tropica.*, **132**(1): pp.S2-S11 https://doi.org/10.1016/J.ACTATROPICA.2013.11.005.

Lefrancq, M.; Imfeld, G.; Payraudeau, S. and Millet, M. (2013). Kresoxim methyl deposition, drift and runoff in a vineyard catchment. *The Science of the Total*

Environment., **442**: pp.503–508. https://doi.org/10.1016/J.SCITOTENV.2012.09.082.

Liu, Y.; Li, S.; Ni, Z.; Qu, M.; Zhong, D.; Ye, C. and Tang, F. (2016). Pesticides in persimmons, jujubes and soil from China: Residue levels, risk assessment and relationship between fruits and soils. *The Science of the Total Environment.*, **542**(Pt A): pp.620–628. https://doi.org/10.1016/J.SCITOTENV.2015.10.148.

Lourens, G. B. and Ferrell, D. K. (2019). Lymphatic Filariasis. *Nursing Clinics of North America.*, **54**(2): pp.181–192. https://doi.org/10.1016/J.CNUR.2019.02.007.

Madhumitha, G.; Rajakumar, G.; Roopan, S. M.; Rahuman, A. A.; Priya, K. M.; Saral, A. M.; Khan, F. R. N.; Khanna, V. G.; Velayutham, K.; Jayaseelan, C.; Kamaraj, C. and Elango, G. (2012). Acaricidal, insecticidal, and larvicidal efficacy of fruit peel aqueous extract of Annona squamosa and its compounds against blood-feeding parasites. *Parasitology Research.*, **111**(5): pp.2189–2199. https://doi.org/10.1007/S00436-011-2671-2.

Majewski, M. S. and Capel, P. D. (1996). *Pesticides in the atmosphere: distribution, trends, and governing factors* (Vol. 1). Ann Arbor Press, Inc.; CRC Press. https://pubs.usgs.gov/publication/70038380

Malaj, E.; Von Der Ohe, P. C.; Grote, M.; Kühne, R.; Mondy, C. P.; Usseglio-Polatera, P.; Brack, W. and Schäfer, R. B. (2014). Organic chemicals jeopardize the health of freshwater ecosystems on the continental scale. *Proceedings of the National Academy of Sciences of the United States of America.*, **111**(26): pp.9549–9554. https://doi.org/10.1073/PNAS.1321082111/-/DCSUPPLEMENTAL/PNAS.1321082111.SAPP.PDF.

Malone, R. W.; Ahuja, L. R.; Ma, L.; Wauchope, R. D.; Ma, Q. and Rojas, K. W. (2004). Application of the Root Zone Water Quality Model (RZWQM) to pesticide fate and transport: an overview. *Pest Management Science.*, **60**(3): pp.205–221. https://doi.org/10.1002/PS.789.

Mandodan, S.; Kunnikuruvan, A.; Bora, B.; Padmanaban, H.; Vijayakumar, A.; Gangmei, K.; Sivaprakasam, M.; Lukose, J.; Ashokkumar, M.; Krishnamoorthy, V. and Poopathi, S. (2023). Applications of nanomaterials in mosquito vector control: A review. *Asian Pacific Journal of Tropical Medicine.*, **16**(11): pp.479–489. https://doi.org/10.4103/1995-7645.390164.

Mansour, M.; Mohamed, M. F.; Elhalwagi, A.; El-Itriby, H. A.; Shawki, H. H. and Abdelhamid, I. A. (2019). Moringa peregrina Leaves Extracts Induce Apoptosis and Cell Cycle Arrest of Hepatocellular Carcinoma. *BioMed Research International.*, **2019***:* 698570,. https://doi.org/10.1155/2019/2698570.

Medhat A., D. and Harry, H. (1981). Arboviruses infecting humans and lower animals in Egypt: a review of thirty years of research. *Journal of the Egyptian Public Health Association.*, pp.1–112.

Mehlhorn, H. (Ed.). (2015). *Encyclopedia of Parasitology* (4th ed.). Springer, New

York, p. 893.

Mehlhorn, H.; Al-Rasheid, K. A. S.; Al-Quraishy, S. and Abdel-Ghaffar, F. (2012). Research and increase of expertise in arachno-entomology are urgently needed. *Parasitology Research.*, **110**(1): pp.259–265. https://doi.org/10.1007/S00436-011-2480-7.

Mischke, C. C.; Griffin, M. J.; Greenway, T. E. and Wise, D. (2013). Effects of Mosquitofish, Gambusia affinis, on Channel Catfish, Ictalurus puncatatus, Production Ponds. *Journal of the World Aquaculture Society.*, **44**(2): pp.288–292. https://doi.org/10.1111/JWAS.12015.

Mondal, N. K.; Chowdhury, A.; Dey, U.; Mukhopadhya, P.; Chatterjee, S.; Das, K. and Datta, J. K. (2014). Green synthesis of silver nanoparticles and its application for mosquito control. *Asian Pacific Journal of Tropical Disease,* **4**(S1): pp.S204–S210. https://doi.org/10.1016/S2222-1808(14)60440-0.

Mosallanejad, H. and Smagghe, G. (2009). Biochemical mechanisms of methoxyfenozide resistance in the cotton leafworm Spodoptera littoralis. *Pest Management Science*, 65(7): pp.732–736. https://doi.org/10.1002/PS.1753.

Mosquito Life Cycle | Northeast Massachusetts Mosquito Control and Wetlands Management District. (n.d.). Retrieved June 7, **2024**, from https://www.nemassmosquito.org/mosquitos/pages/mosquito-life-cycle.

Nalini, M.; Lena, M.; Sumathi, P. and Sundaravadivelan, C. (2017). Effect of phyto-synthesized silver nanoparticles on developmental stages of malaria vector, Anopheles stephensi and dengue vector, Aedes aegypti. *Egyptian Journal of Basic and Applied Sciences.*, **4**(3): pp.212–218. https://doi.org/10.1016/J.EJBAS.2017.04.005.

Naqqash, M. N.; Gökçe, A.; Bakhsh, A. and Salim, M. (2016). Insecticide resistance and its molecular basis in urban insect pests. *Parasitology Research.*, **115**(4): pp.1363–1373. https://doi.org/10.1007/S00436-015-4898-9.

Nityasree, B. R.; Chalannavar, R. K.; Kouser, S.; Divakar, M. S.; Gani, R. S.; Sowmyashree, K. and Malabadi, R. B. (2021). Bioinspired synthesis of zinc oxide nanoparticles by using leaf extract of Solanum lycopersicum L. for larvicidal activity of Aedes aegypti L. *Advances in Natural Sciences: Nanoscience and Nanotechnology.*, **12**(1): pp.015009. https://doi.org/10.1088/2043-6262/ABEAAE.

Pal, S.; Mondal, S.; Maity, J. (2018). Green Synthesis of silver nanoparticles using Moringa Oleifera leaf extract: Investigation of Photocatalytic activity. *Journal of Nanoscience Nanoengineering and Applications.*, **8**(2): pp.60–68. https://techjournals.stmjournals.in/index.php/JoNSNEA/article/view/205.

Patil, C. D.; Borase, H. P.; Patil, S. V.; Salunkhe, R. B. and Salunke, B. K. (2012). Larvicidal activity of silver nanoparticles synthesized using Pergularia daemia plant latex against Aedes aegypti and Anopheles stephensi and nontarget fish Poecillia reticulata. *Parasitology Research.*, **111**(2): pp.555–562.

https://doi.org/10.1007/S00436-012-2867-0.

Patil, C. D.; Patil, S. V.; Borase, H. P.; Salunke, B. K. and Salunkhe, R. B. (2012). Larvicidal activity of silver nanoparticles synthesized using Plumeria rubra plant latex against Aedes aegypti and Anopheles stephensi. *Parasitology Research.*, **110**(5): pp.1815–1822. https://doi.org/10.1007/S00436-011-2704-X.

Pavela, R. (2015). Essential oils for the development of eco-friendly mosquito larvicides: A review. *Industrial Crops and Products.*, **76**: pp.174–187. https://doi.org/10.1016/J.INDCROP.2015.06.050.

Pavela, R. and Benelli, G. (2016). Ethnobotanical knowledge on botanical repellents employed in the African region against mosquito vectors - A review. *Experimental Parasitology.*, **167**: pp.103–108. https://doi.org/10.1016/J.EXPPARA.2016.05.010.

Pei, J.; Fu, B.; Jiang, L. and Sun, T. (2019). Biosynthesis, characterization, and anticancer effect of plant-mediated silver nanoparticles using Coptis chinensis. *International Journal of Nanomedicine.*, **14**: pp.1969–1978. https://doi.org/10.2147/IJN.S188235.

Pesticide use, **2021**. (n.d.). Retrieved June 7, **2024**, from https://ourworldindata.org/grapher/pesticide-use-tonnes.

Prabhu, K.; Murugan, K.; Nareshkumar, A.; Ramasubramanian, N. and Bragadeeswaran, S. (2011). Larvicidal and repellent potential of Moringa oleifera against malarial vector, Anopheles stephensi Liston (Insecta: Diptera: Culicidae). *Asian Pacific Journal of Tropical Biomedicine.*, **1**(2): pp.124–129. https://doi.org/10.1016/S2221-1691(11)60009-9.

Priyadarshini, K. A.; Murugan, K.; Panneerselvam, C.; Ponarulselvam, S.; Hwang, J. S. and Nicoletti, M. (2012). Biolarvicidal and pupicidal potential of silver nanoparticles synthesized using Euphorbia hirta against Anopheles stephensi Liston (Diptera: Culicidae). *Parasitology Research.*, **111**(3). pp.997–1006. https://doi.org/10.1007/S00436-012-2924-8.

Queyrel, W.; Habets, F., Blanchoud, H.; Ripoche, D. and Launay, M. (2016). Pesticide fate modeling in soils with the crop model STICS: Feasibility for assessment of agricultural practices. *The Science of the Total Environment*, **542**(Pt A): pp.787–802. https://doi.org/10.1016/J.SCITOTENV.2015.10.066.

Raghavendra, K.; Sharma, P. and Dash, A. P. (2008). Biological control of mosquito populations through frogs: opportunities & constrains. *The Indian Journal of Medical Research.*, **128**(1): pp.22–25.

Rajakumar, G. and Abdul Rahuman, A. (2011). Larvicidal activity of synthesized silver nanoparticles using Eclipta prostrata leaf extract against filariasis and malaria vectors. *Acta Tropica.*, **118**(3): 196–203. https://doi.org/10.1016/J.ACTATROPICA.2011.03.003.

Rawani, A.; Ghosh, A. and Chandra, G. (2013). Mosquito larvicidal and antimicrobial activity of synthesized nano-crystalline silver particles using leaves and green berry extract of Solanum nigrum L. (Solanaceae: Solanales). *Acta Tropica.*, **128**(3): pp.613–622. https://doi.org/10.1016/J.ACTATROPICA.2013.09.007.

Ruddaraju, L. K.; Pammi, S. V. N.; Guntuku, G. sankar; Padavala, V. S. and Kolapalli, V. R. M. (2020). A review on anti-bacterials to combat resistance: From ancient era of plants and metals to present and future perspectives of green nano technological combinations. *Asian Journal of Pharmaceutical Sciences.*, **15**(1): pp.42–59. https://doi.org/10.1016/J.AJPS.2019.03.002.

Saxena, S. K.; Elahi, A.; Gadugu, S. and Prasad, A. K. (2016). Zika virus outbreak: an overview of the experimental therapeutics and treatment. *Virusdisease.*, **27**(2): pp.111–115. https://doi.org/10.1007/S13337-016-0307-Y.

Schnepf, E.; Crickmore, N.; Van Rie, J.; Lereclus, D.; Baum, J.; Feitelson, J.; Zeigler, D. R. and Dean, D. H. (1998). Bacillus thuringiensis and its pesticidal crystal proteins. *Microbiology and Molecular Biology Reviews : MMBR.*, **62**(3): pp.775–806. https://doi.org/10.1128/MMBR.62.3.775-806.1998.

Semmler, M.; Abdel-Ghaffar, F.; Al-Rasheid, K. and Mehlhorn, H. (2009). Nature helps: from research to products against blood-sucking arthropods. *Parasitology Research.*, **105**(6): pp.1483–1487. https://doi.org/10.1007/S00436-009-1634-3.

Shelton, A. M.; Roush, R. T.; Wang, P. and Zhao, J.-Z. (2007). Resistance to insect pathogens and strategies to manage resistance: An update. *Field Manual of Techniques in Invertebrate Pathology.*, pp.793–811. https://doi.org/10.1007/978-1-4020-5933-9_39.

Shyam-Sundar N.; Karthi, S.; Senthil-Nathan, S.; Narayanan, K. R.; Santoshkumar, B.; Sivanesh, H.; Chanthini, K. M. P.; Stanley-Raja, V.; Ramasubramanian, R.; Abdel-Megeed, A. and Malafaia, G. (2023). Eco-friendly biosynthesis of TiO_2 nanoparticles using Desmostachya bipinnata extract: Larvicidal and pupicidal potential against Aedes aegypti and Spodoptera litura and acute toxicity in non-target organisms. *Science of The Total Environment.*, **858***:* 159512. https://doi.org/10.1016/J.SCITOTENV.2022.159512.

Straathof, H. J. M. (1986). Investigations on the phytotoxic relevance of volatization of herbicides. *Mededelingen,* **51**(2A): pp.433–438.

S**ubramaniam, J.; Murugan, K.; Panneerselvam, C.; Kovendan, K.; Madhiyazhagan, P.; Kumar, P. M.; Dinesh, D., Chandramohan, B.; Suresh, U.; Nicoletti, M.; Higuchi, A.; Hwang, J. S.; Kumar, S.; Alarfaj, A. A.; Munusamy, M. A.; Messing, R. H. and Benelli, G. (2015).** Eco-friendly control of malaria and arbovirus vectors using the mosquitofish Gambusia affinis and ultra-low dosages of Mimusops elengi-synthesized silver nanoparticles: towards an integrative approach? *Environmental Science and Pollution Research International.*, **22**(24): pp.20067–20083. https://doi.org/10.1007/S11356-015-5253-5.

Tabashnik, B. E. (1994). Evolution of resistance to Bacillus thuringiensis. *Annual Review of Entomology.*, **39**(1): pp.47–79.

https://doi.org/10.1146/ANNUREV.EN.39.010194.000403/CITE/REFWORKS.

Toccalino, P. L.; Gilliom, R. J.; Lindsey, B. D. and Rupert, M. G. (2014). Pesticides in groundwater of the United States: decadal-scale changes, 1993-2011. *Ground Water.*, **52**(1): pp.112–125. https://doi.org/10.1111/GWAT.12176.

Vijayakumar, S.; Divya, M.; Vaseeharan, B.; Ranjan, S.; Kalaiselvi, V.; Dasgupta, N.; Chen, J. and Durán-Lara, E. F. (2021). Biogenic Preparation and Characterization of ZnO Nanoparticles from Natural Polysaccharide Azadirachta indica .L. (neem gum) and its Clinical Implications. *Journal of Cluster Science.*, **32**(4): pp.983–993. https://doi.org/10.1007/S10876-020-01863-Y.

Vu, T. T.; Nguyen, P. T. M.; Pham, N. H.; Le, T. H.; Nguyen, T. H.; Do, D. T. and La, D. D. (2022). Green Synthesis of Selenium Nanoparticles Using Cleistocalyx operculatus Leaf Extract and Their Acute Oral Toxicity Study. *Journal of Composites Science.*, **6**(10): 307. https://doi.org/10.3390/JCS6100307.

Zafar, M. and Iqbal, T. (2024). Green synthesis of silver and zinc oxide nanoparticles for novel application to enhance shelf life of fruits. *Biomass Conversion and Biorefinery.*, **14**(4): pp.5611–5626. https://doi.org/10.1007/S13399-022-02730-8.

Zohra, T.; Khalil, A. T.; Saeed, F.; Latif, B.; Salman, M.; Ikram, A.; Ayaz, M. and Murthy, H. C. A. (2022). Green Nano-Biotechnology: A New Sustainable Paradigm to Control Dengue Infection. *Bioinorganic Chemistry and Applications*, **2022**: pp. 1-22. https://doi.org/10.1155/2022/3994340.