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A Review on Nanoparticles in Mosquito Control - A Green Revolution in Future

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Abstract: Mosquitoes are the potential vectors of many diseases, including malaria, filariasis, dengue, brain fever, etc. There is an urgent need to check the proliferation of the population of vector mosquitoes in order to reduce vector borne diseases by appropriate control methods. Mosquito control is of serious concern in developing countries like India due to the lack of general awareness, development of resistance, and socioeconomic reasons. Nanotechnology, a promising field of research opens up in the present decade and is expected to give major impulses to technical innovations in a variety of industrial sectors in the future. Over the past few decade, nanoparticles of noble metals such as silver exhibited significantly distinct physical, chemical and biological properties from their bulk counterparts. Nano-size particles of less than 100 nm in diameter are currently attracting increasing attention for the wide range of new applications in various fields of industry. Presently, there is a need for increasing the efforts to develop newer and effective methods to control mosquito vectors. The existing chemical and biological methods are not as effective as in earlier period owing to different technical and operational reasons. In particular, this present paper focused on potential role of nanoparticles in mosquito control.
Keywords - Larvicides, Plant extracts, Fungi, Bacteria, Silver nanoparticles

I. INTRODUCTION

Vector control is an essential requirement in control of epidemic diseases such as malaria, filariasis, dengue that are transmitted by different species of mosquitoes. Emergence of insecticide resistance and their harmful effects on non-target organisms and environment has necessitated an urgent search for development of new and improved mosquito control methods that are economical and effective as well as safe for non-target organisms and the environment. Insecticides synthesized from natural products, such as silver, gold or silicon nanoparticles of herbal origin have become a priority in this search.

Nanoparticles are defined as particulate dispersions or solid particles with a size of 10-1000 nm. The word "nano" is derived from a Greek word meaning "dwarf". In technical terms, the word "nano" means 10^{-9}, or one billionth of a meter. Naturally, the word nanotechnology evolved due to use of nanometer size particles. Targeted nanoparticles exhibit many novel characteristic features, such as extra ordinary strength, more chemical reactivity, magnetic properties and or high electrical conductivity. "Nanotechnology" deals with application of such particles in biological, physical, chemical, environmental, agricultural, industrial or pharmaceutical science. Depending upon the method of preparation, nanoparticles, nanospheres or nanocapsules can be obtained. Although physical and chemical methods are more popular and widely used for synthesis of nanoparticles, the related environmental toxicity and non-biodegradable nature of the products limited their applications. So, the "green" route for synthesis of nanoparticles from herbal origin is of great interest due to eco-friendliness, economic prospects, feasibility and wide range of applications (Salam *et al.,* 2012).

II. NANOPARTICLES IN MOSQUITO CONTROL

Applications of nanotechnology have been extended in the field of mosquito control by the synthesis of silver/gold nanoparticles from environmentally acceptable plant extract. Synthesized silver or gold nanoparticles help to produce new insecticides and insect repellants. The characterization and the structure determination of these nanoparticles have become possible through the application of modern scientific instruments such as UV-VIS spectroscopy, Fourier Transform Infrared Spectroscopy, X-ray Diffraction, Scanning and Transmission Electron Microscopy (Adhikari *et al.,* 2013). The use of "green" processes for the synthesis of nanoparticles is a new and rapidly developing branch of nanotechnology. However, knowledge of the bioactivity of nanoparticles against mosquitoes is very limited. Accordingly, this review presents green synthesis of nanoparticles and their potential in

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mosquito control.

III. NANO PARTICLES OF HERBAL ORIGIN: A RECENT ECO-FRIENDLY TREND IN MOSQUITO CONTROL

The silver nanoparticles (Ag NPs) which are less likely to cause ecological damage have been identified as potential replacement of synthetic chemical insecticides. Hence the need to use green synthesized Ag NPs for the control of mosquitoes causing many diseases. The results described below were based on plant mediated Ag NPs and have been tested against the larvae of mosquito (Table 1).

Marimuthu *et al.,* (2011) synthesized Ag NPs utilizing aqueous leaf extract of *Mimosa pudica* Gaertn (Mimosaceae) and its antiparasitic activities against the larvae of malaria vector, *An. subpictus* Grassi, filariasis vector *Culex quinquefasciatus* Say (Diptera: Culicidae), and *Rhipicephalus* (Boophilus) *microplus* Canestrini (Acari: Ixodidae). Santhoshkumar *et al.,* (2011) observed the maximum efficacy in crude methanol, aqueous and synthesized Ag NPs using leaf extract of *Nelumbo nucifera* against the larvae of *An. subpictus* (LC_{50}=8.89, 11.82, and 0.69 ppm respectively) and against the larvae of *Cx. quinquefasciatus* (LC_{50}=9.51, 13.65, and 1.10 ppm respectively).

Rajakumar *et al.,* (2011) studied the larvicidal activity of synthesized Ag NPs using aqueous extract from *Eclipta prostrata* and observed the maximum efficacy in crude aqueous and synthesized Ag NPs against fourth instar larvae of *Cx. quinquefasciatus* (LC_{50}=27.49 and 4.56 mg/L; LC_{90}=70.38 and 13.14 mg/L), and against *An. subpictus* (LC_{50}=27.85 and 5.14 mg/L; LC_{90}=71.45 and 25.68 mg/L). Gnanadesigan *et al.,* (2011) synthesized Ag NPs with *Rhizophora mucronata* leaf extract to control the larvae of *Aedes aegypti* and *Cx. quinquefasciatus*. The LC_{50} and LC_{90} values of the synthesized Ag NP were identified as 0.585 mg/L and 2.615 mg/L for i and 0.891 mg/L and 6.291 mg/L for *Cx. quinquefasciatus*.

Jayaseelan *et al.,* (2011) observed the maximum larvicidal activity in the synthesized Ag NPs by leaf aqueous extract of *Tinospora cordifolia* against fourth instar larvae of *An. subpictus* and *Cx. quinquefasciatus* (LC_{50}=6.43 and 6.96 mg/ L respectively). Arjunan *et al.,* (2012) synthesized the median lethal concentration (LC_{50}) of stable Ag NPs using *A. squamosa* leaf broth that killed fourth instar larvae of *Ae. aegypti, Cx. quinquefasciatus* and *Anopheles stephensi* (LC_{50} = 0..30, 0.41, and 2.12 ppm respectively).

Priyadharshini *et al.,* (2012) synthesized Ag NPs utilizing *Euphorbia hirta* leaf extract against malarial vector *An. stephensi* and found the highest larval mortality in the first to fourth instar larvae (LC_{50} =10.14, 16.82, 21.51, and 27.89 ppm, respectively and LC_{90} =31.98, 50.38, 60.09, and 69.94 ppm, respectively). The LC_{50} and LC_{90} values of pupae were 34.52 and 79.76 ppm. Sareen *et al.,* (2012) reported that the larvicidal efficacy of Ag NPs synthesized from aqueous leaf extract of *Hibiscus rosasinensis* to control the larvae of *Aedes albopictus*. Patil *et al.,* (2012a) synthesized Ag NPs using *P. daemia* plant latex against *Ae. aegypti* and *An. stephensi*.

Table 1: Green synthesis of silver nanoparticles by using aqueous plant extracts and their potential mosquito host.

Plant Species	Common name	Vernacular name (Tamil)	Plant parts used	Test NPs	Test Mosquito Species	City / State	Source
Eclipta prostrate	False Daisy	Karisalaankani	Leaf	Ag	*An. subpictus, Cx. quinquefasciatus*	Vellore-TN	Rajakumar *et al.,* 2011
Mimosa pudica	Touch Me Not	Thotta siningi	Leaf	Ag	*An. subpictus, Cx. quinquefasciatus*	Vellore-TN	Marimuthu *et al.,* 2011
Nelumbo nucifera	Indian Lotus	Thammarai	Leaf	Ag	*An. subpictus, Cx. quinquefasciatus*	Vellore-TN	Santhoshkumar *et al.,* 2011
Rhizophora mucronata	Asiatic Mangrove	Kandal	Leaf	Ag	*Ae. aegypti, Cx. quinquefasciatus*	Madurai-TN	Gnanadesigan *et al.,* 2011
Tinospora cordifolia	Guduchi	Shindilakodi	Leaf	Ag	*An. subpictus, Cx. quinquefasciatus*	Vellore-TN	Jayaseelan *et al.,* 2011

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Annona squamosa	Custard Apple	Sitapalam	Leaf	Ag	*Ae. aegypti, An. stephensi, Cx. quinquefasciatus*	Coimbatore-TN	Arjunan *et al.*, 2012
Euphorbia hirta	Asthma Weed	Amman Pachirisi	Leaf	Ag	*An. stephensi*	Coimbatore-TN	Priyadarshini *et al.*, 2012
Hibiscus rosasinensis	China Rose	Cembaruthi	Leaf	Ag	*Ae. albopictus*	Kochi-Kerala	Sareen *et al.*, 2012
Nerium oleander	Oleander	Arali	Leaf	Ag	*An. stephensi*	Coimbatore-TN	Roni *et al.*, 2012
Pedilanthus tithymaloides	Devil's Backbone	Peru neranji	Stem	Ag	*Ae. aegypti*	Coimbatore-TN	Sundaravadivelan *et al.*, 2012
Pergularia daemia	Trellis-Vine	Veli paruthi	Plant latex	Ag	*Ae. aegypti, An. stephensi*	Jalgaon-Maharashtra	Patil *et al.*, 2012a
Plumeria rubra	Frangipani	Sampangi	Plant latex	Ag	*Ae. aegypti, An. stephensi*	Jalgaon-Maharashtra	Patil *et al.*, 2012b
Vinca rosea	Peri Wimkle	Nithya kalyani	Leaf	Ag	*An. stephensi, Cx. quinquefasciatus*	Chidambaram - TN	Subarani *et al.*, 2012
Ammannia baccifera	Blistering Ammannia	Kal-luruvi	Aerial	Ag	*An. subpictus, Cx. quinquefasciatus*	Chennai-TN	Suman *et al.*, 2013
Anthocephalus cadamba, Cymbopogan citratus	Kadam, Lemon Grass	Vellai kadambu, Karppurapul	Leaf	Au	*Cx. quinquefasciatus*	Coimbatore-TN	Arjunan *et al.*, 2013
Cadaba indica	Dabi	Manatukkurntu	Leaf	Ag	*An. stephensi, Cx. quinquefasciatus*	Coimbatore-TN	Kalimuthu *et al.*, 2013
Cocos nucifera	Coconut	Thaengaai	Mesocarp	Ag	*An. stephensi, Cx. quinquefasciatus*	Vellore-TN	Roopan *et al.*, 2013
Drypetes roxburghii	Putranjva	Irukolli	Fruit	Ag	*An. stephensi, Cx. quinquefasciatus*	Burdwan-WB	Haldar *et al.*, 2013
Jatropha gossypifolia, Euphorbia tirucalli, Pedilanthus tithymaloides, Alstonia macrophylla	Bellyache Bush, Milk Bush, Devil's Backbone, Batino	Kattamanakku, Tirucalli, Peru neranji	Leaf	Ag	*Ae. aegypti, An. stephensi*	Jalgaon-Maharashtra	Borase *et al.*, 2013
Ficus racemosa	Indian Fig	Aththi	Bark	Ag	*Cx. quinquefasciatus, Cx. Gelidus*	Vellore-TN	Velayutham *et al.*,2013
Sida acuta	Common Wireweed	Palambasi	Leaf	Ag	*Ae. aegypti, An. stephensi, Cx. quinquefasciatus*	Chidambaram - TN	Veerakumar *et al.*, 2013

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Solanum nigrum	Black Nightshade	Manathakali	Fresh leaves, dry leaves, green berries	Ag	*An. stephensi, Cx. quinquefasciatus*	Burdwan-WB	Rawani *et al.*, 2013
Delphinium denudatum	Jadwar	Nirbasi	Root	Ag	*Ae. aegypti*	Kanchipuram -TN	Suresh *et al.*, 2014
Feronia elephantum	Wood apple	Vila	Leaf	Ag	*Ae. aegypti, An. stephensi, Cx. quinquefasciatus*	Chidambaram -TN	Veerakumar *et al.*, 2014b
Heliotropium indicum	Indian Heliotrope	Thel kodukku	Leaf	Ag	*Ae. aegypti, An. stephensi, Cx. quinquefasciatus*	Chidambaram -TN	Veerakumar *et al.*, 2014a
Leucas aspera	Common Leucas	Thumbai	Leaf	Ag	*Ae. aegypti*	Salem-TN	Suganya *et al.*, 2014
Parthenium hysterophorus	Congress Grass		Root	Ag	*Cx. quinquefasciatus*	Burdwan-WB	Mondal *et al.*, 2014
Pongamia pinnata	Pongam	Pungai	Leaf	Ag	*Ae. albopictus*	Hyderabad-AP	Naik *et al.*, 2014
Sterculia foetida	Wild Indian Almond	Kutiraippitukku	Seed	Ag	*Ae. aegypti, An. stephensi, Cx. quinquefasciatus*	Hyderabad-AP	Rajasekharreddy and Rani, 2014
Calotropis gigantean	Crown Flower	Erukku	Leaf	Ag	*Ae. aegypti, An. stephensi*	Coimbatore-TN	Priya *et al.*, 2014
Cleistanthus collinus	Garari	Odaichi	Leaf	Ag	*Ae. aegypti*	Musiri-TN	Ramar *et al.*, 2014

Patil *et al.,* (2012b) synthesized Ag NPs from *Plumeria rubra* latex and observed the LC_{50} values for second and fourth larval instars after 24 hr exposure were 1.49, 1.82 ppm against *Ae. aegypti* and 1.10, 1.74 ppm against *An. stephensi*, respectively. The LC_{50} values of crude aqueous latex of *P. rubrum* were 181.67, 287.49 ppm and 143.69, 170.58 ppm against 2nd and 4th larval instars of *Ae. aegypti* and *An. stephensi*, respectively.

Roni *et al.,* (2012) determined the larvicidal activity of synthesized Ag NPs through leaf extract of *Nerium oleander* (Apocynaceae) against the first to fourth instar larvae and pupae of malarial vector, *An. stephensi* (Diptera: Culicidae). Subarani *et al.,* (2012) evaluated the larvicidal activities to determine the efficacies of synthesized Ag NPs using aqueous leaf extract of V. rosea against the larvae of malarial vector *An. stephensi* Liston and filariasis vector *Cx. quinquefasciatus* Say (Diptera: Culicidae). Sundaravadivelan *et al.,* (2012) tested the biolarvicidal effect of phyto-synthesized Ag NPs using *Pedilanthus tithymaloides* (L.) Poit stem extract against the dengue vector *Ae. aegypti*.

Suman *et al.,* (2013) synthesized Ag NP from aqueous aerial extract of *Ammannia baccifera* and found that it can effectively inhibit the activity of *An. subpictus* and *Cx. quinquefasciatus* larvae. Arjunan *et al.,* (2013) biosynthesized gold nanoparticles using *Cymbopogan citratus* and *Anthocephalus cadamba* and experimented on the larvicidal effect on the filarial vector, *Cx. quinquefasciatus* and observed that the lethal concentrations LC_{50} and LC_{90} values of 1.08 and 2.76 ppm for gold nanoparticles and 21.82 and 79.52 ppm for the third instar of *Cx. quinquefasciatus*.

Borase *et al.,* (2013) synthesized Ag NPs from aqueous leaves extracts of four plant species (*Jatropha gossypifolia, Euphorbia tirucalli, Pedilanthus tithymaloides* and *Alstonia macrophylla*) and evaluated their effects on II and IV instars larvae of *Ae. aegypti* and *An. stephensi*. Results revealed that the larvicidal activity of Ag NPs with LC_{50} values of 3.50 to 7.01 ppm against II instar and

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4.44 to 8.74 ppm against IV instar larvae of *Ae. aegypti* and 5.90 to 8.04 ppm for II instar and 4.90 to 9.55 ppm against IV instar of *An. stephensi*. Velayutham *et al.,* (2013) explored the larvicidal activity of green synthesized Ag NPs using aqueous bark extract of *F. racemosa* to control *Cx. quinquefasciatus* and *Cx. gelidus*. The maximum efficacy was observed in crude aqueous extract of *F. racemosa* (LC_{50}=67.72 and 63.70 mg/L) against the larvae of *Cx. quinquefasciatus* and *Cx. gelidus* and the synthesized Ag NPs (LC_{50}=12.00 and 11.21 mg/L).

Kalimuthu *et al.,* (2013) synthesized Ag NPs using *Cadaba indica* lam plant against *An. stephensi* and *Cx. quinquefasciatus*. Haldar *et al.,* (2013) synthesized highly stable nanoparticles of metallic silver by a simple, cost-effective, reproducible and previously unexploited biogenic source viz. dried green fruits of *Drypetes roxburghii* (Wall) and reported its mosquito larvicidal activity against *An. stephensi* and *Cx. quinquefasciatus*. Veerakumar *et al.,* (2013) synthesized Ag NPs by using Sida acuta plant leaf extract and determined their larvicidal activity against the late third instar larvae of *Cx. quinquefasciatus*, *An. stephensi*, and *Ae. aegypti*. The larvicidal activities of Ag NPs synthesized from fresh leaves, dry leaves and green berries of *S. nigrum* against larvae of *Cx. quinquefasciatus* and *An. stephensi* were tested by Rawani *et al.,* (2013). Roopan *et al.,* (2013) synthesised Ag NPs from the mesocarp layer extract of *Cocos nucifera* and assessed the anti-larvicidal agents against *An. stephensi* and Cx. quinquefasciatus.

Veerakumar *et al.,* (2014a) synthesized Ag NPs using *Helitropium indicum* plant leaves against late third instar larvae of *Ae. aegypti, An. stephensi* and *Cx. quinquefasciatus.* The LC_{50} and LC_{90} values of *H. indicum* aqueous leaf extract appeared to be effective against *An. stephensi* (LC_{50} - 68.73 µg/mL; LC_{90} - 121.07 µg/mL) followed by *Ae. aegypti* (LC_{50} -72.72 µg/mL; LC_{90} - 126.86 µg/mL) and *Cx. quinquefasciatus* (LC_{50} - 78.74 µg/mL; LC_{90} - 134.39 µg/mL). The LC_{50} and LC_{90} values of synthesized Ag NPs for *An. stephensi* were 18.40 and 32.45 µg/mL, *Ae. aegypti* were 20.10 and 35.97 µg/mL, and *Cx. quinquefasciatus* were 21.84 and 38.10 µg/mL. Veerakumar *et al.,* (2014b) prepared Ag NPs utilizing *Feronia elephantum* plant leaf extract against late third-instar larvae of *An. stephensi, Ae. aegypti*, and *Cx. quinquefasciatus*. The LC_{50} and LC_{90} values of synthesized Ag NPs were 11.56 and 20.56 µg mL−1, 13.13 and 23.12 µg mL−1 and 14.19 and 24.30 µg mL−1 for *An. stephensi, Ae. aegypti,* and *Cx. quinquefasciatus* respectively.

Naik *et al.,* (2014) tested the leaf mediated Ag NPs with *Pongamia pinnata* for mosquito control and found that plant extracts showed moderate larvicidal effects but the synthesized Ag NPs was found to be toxic to larvae at LC_{50} = 0.25 ppm and LC_{90} =1 ppm. Mondal *et al.,* (2014) investigated the bioactive components present in the root extract of *Parthenium hysterophorus* plant used for the biosynthesis of Ag NPs and analyzed the larvicidal effects of the extract as well as Ag NPs on *Cx. quinquefasciatus*. Suganya *et al.,* (2014) examined the larvicidal potential of solvent leaf extracts of *Leucas aspera* and synthesized Ag NPs using it against fourth instar larvae of *Ae. aegypti*. Rajasekharreddy and Rani (2014) synthesized silver-(protein-lipid) nanoparticles (Ag-PL NPs) (core–shell) using the seed extract from wild Indian Almond tree, *Sterculia foetida* (L.) (Sterculiaceae) and showed potential mosquito larvicidal activity against *Ae. aegypti* (L.), *An. stephensi* Liston and *Cx. quinquefasciatus* Say.

Priya *et al.,* (2014) evaluated the effect of plant synthesized Ag NPs through aqueous leaf extract of *Calotropis gigantea* to control dengue vector *Ae. aegypti* and malarial vector *An. stephensi*. Suresh *et al.,* (2014) synthesized Ag NPs using aqueous root extract of *Delphinium denudatum* (Dd) and investigated potent larvicidal activity against second instar larvae of dengue vector *Ae. aegypti* with a LC_{50} value of 9.6 ppm. Ramar *et al.,* (2014) determined the larvicidal activity of Ag NPs synthesized from aqueous leaf extract of *Cleistanthus collinus* against the larvae of *Ae. aegypti.* Acoding to Dubey *et al.,* (2010) the potential of plants as biological materials for the synthesis of nanoparticles are yet to be fully explored.

IV. FUNGUS GENERATED NOVEL NANOPARTICLES: A NEW PROSPECTIVE FOR MOSQUITO CONTROL

Currently, fungi are being utilized in nanotechnology for the production of nanoparticles; synthesis using fungi has shown that this environmentally benign and renewable source can be used as an effective reducing agent for synthesis of Ag NPs and Au NPs (Table 2). Salunkhe *et al.,* (2011) synthesized Ag NPs by filamentous fungus *Cochliobolus lunatus* and tested it against second, third, and fourth instar larvae of *Ae. aegypti* (LC_{50}=1.29, 1.48, and 1.58; LC_{90}=3.08, 3.33, and 3.41 ppm respectively) and *An. stephensi* (LC_{50}=1.17, 1.30, and 1.41; LC_{90} =2.99, 3.13, and 3.29 ppm respectively).

Soni and Prakash, (2012a) synthesized fungus mediated Ag NPs using *Chrysosporium tropicum* as a larvicide against the second instar larvae of *Ae. aegypti*. Soni and Prakash, (2012b) described the larvicidal effect of extracellularly synthesised Au NPs with

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Aspergillus niger. Soni and Prakash, (2012d) reported that the efficacy of *Chrysosporium tropicum*, a pathogenic fungus mediated Ag and Au NPs against *Cx. quinquefasciatus* and *An. stephensi*. Soni and Prakash, (2012c) tested the adulticidal efficacies of *C. keratinophilum, F. oxysporum f.sp. pisi* and *V. lecanii* against the adults of *Cx. quinquefasciatus* using the fungus mediated Ag NPs.

Table: 2 Mosquito control studies by using nanoparticles synthesized from fungus.

Fungal Species	Test NPs	Test Mosquito Species	City / State	Author / Year
Cochliobolus lunatus	Ag	*Ae. aegypti, An. stephensi*	Jalgaon-Maharashtra	Salunkhe *et al.,* 2011
Chrysosporium tropicum	Au, Ag	*Ae. aegypti*	Agra-Delhi	Soni and Prakash, 2012a
Aspergillus niger	Au	*Ae. aegypti, An. stephensi, Cx. quinquefasciatus*	Agra-Delhi	Soni and Prakash, 2012b
Chrysosporium keratinophilum, Fusarium oxysporum, Verticillium lecanii	Ag	*Cx. quinquefasciatus*	Agra-Delhi	Soni and Prakash, 2012c
Chrysosporium tropicum	Au, Ag	*Cx. quinquefasciatus, An. stephensi*	Agra-Delhi	Soni and Prakash, 2012d
Chrysosporium keratinophilum, Verticillium lecanii	Au, Ag	*Ae. aegypti, An. stephensi, Cx. quinquefasciatus*	Agra-Delhi	Soni and Prakash, 2013a
Fusarium oxysporum	Au, Ag	*Ae. aegypti, An. stephensi, Cx. quinquefasciatus*	Agra-Delhi	Soni and Prakash, 2013b
Aspergillus niger	Ag	*An. stephensi, Cx. quinquefasciatus, Ae. aegypti*	Agra-Delhi	Soni and Prakash, 2013c
Beauveria bassiana	Ag	*Ae. aegypti*	Madurai-TN	Banu and Balasubramanian, 2014
Trichoderma harzianum	Ag	*Ae. aegypti*	Coimbatore- TN	Sundaravadivelan and Padmanabhan, 2014
Penicillium verucosum	Ag	*Cx. quinquefasciatus*	Trichy-TN	Kamalakannan *et al.,* 2014

Soni and Prakash, (2013a) proposed a green process for the extracellular production of Ag and Au NPs using the soil fungi *Chrysosporium keratinophilum* and *Verticillium lecanii* and investigated the effect of synthesized Ag NPs and Au NPs against the larvae and pupae of *An. stephensi, Cx. quinquefasciatus* and *Ae. aegypti.* Soni and Prakash, (2013b) synthesized Ag and Au NPs by using the cell free extract of *Fusarium oxysporum* fungus and tested them to be larvicides and pupicides against the larvae and pupae of *Cx. quinquefasciatus, An. stephensi* and *Ae. aegypti*. Soni and Prakash, (2013c) synthesized the Ag NPs by using the soil fungus Aspergillus niger and tested against the larvae and pupae of *An. stephensi, Cx. quinquefasciatus* and *Ae. aegypti.*

Banu and Balasubramanian, (2014) synthesized silver biolarvicide with the help of entomopathogenic fungi, *Beauveria bassiana*, and assessed it against the different larval instars of dengue vector, *Ae. aegypti*. Sundaravadivelan and Padmanabhan, (2014) investigated the larvicidal and pupicidal effect of mycosynthesized Ag NPs using an entomopathogenic fungi Trichoderma *harzianum* against developmental stages of the dengue vector *Ae. aegypti*. Kamalakannan *et al.,* (2014) attempted on laboratory evaluation of mycosynthesized Ag NPs from fungus *Penicillium verrucosum* and tested against larvae of filarial vector, Cx. *quinquefasciatus*.

V. ECO-FRIENDLY BACTERIAL ROUTE TO SYNTHESIZE NPS AND ITS APPLICATION IN MOSQUITO CONTROL

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Two insecticidal bacteria have been used as larvicides to control larvae of nuisance and vector mosquitoes in many countries, *Bacillus thuringienesis ssp*. Israelensis and *Bacillus sphaericus* (Wirth *et al.,* 2010).

Marimuthu *et al.,* (2013) investigated the larvicidal activities of synthesized cobalt nanoparticles (Co NPs) using bio control agent, *Bacillus thuringiensis* against malaria vector, *An. subpictus* and dengue vector, *Ae. aegypti* (Diptera: Culicidae). Dhanasekaran and Thangaraj (2013) evaluated the larvicidal activity of biogenic nanoparticles of *Agaricus bisporus, E. coli, Pencillium sp.* and *Vibrio sp.* against filariasis causing, Culex mosquito vector.

The mortality rate of Culex larvae, using *Agaricus bisporus* biogenic nanoparticles were 100% (5 mg/L), 81% (2.5 mg/L), 62% (1.25 mg/L), 28% (0.625 mg/L) and 11% (0.312 mg/L). The results suggested that synthesized biogenic Ag NPs have the potential to be used as an ideal eco-friendly approach for controlling Culex species. Banu *et al.,* (2014) revealed that the larvicidal activity of Ag NPs synthesized using *Bacillus thuringiensis* (Bt) against *Ae. aegypti* would control many diseases of public health importance (Table 3). According to Owolade *et al.,* (2008) nanoparticles help to produce new pesticides, insecticides and insect repellants. Over the next two decades, the Green Revolution would be accelerated by means of nanotechnology.

Table: 3 Mosquito control studies by using nanoparticles synthesized from bacteria.

Bacterial Species	**Test NPs**	**Test Species**	**City / State**	**Author / Year**
Bacillus thuringiensis	Co	*An. subpictus, Ae. aegypti*	Vellore-TN	Marimuthu *et al.,* (2013)
E. coli, Pencillium sp	Ag	*Culex sp.*	Trichy-TN	Dhanasekaran and Thangaraj (2013)
Bacillus thuringiensis	Ag	*Ae. aegypti*	Madurai-TN	Banu *et al.,* (2014)

VI. TREND OF NANOPARTICLES IN MOSQUITO CONTROL

Green synthesis of nanoparticles in mosquito control using plant extracts, fungi and bacteria collected here can be sorted out as 31 on plants, 11 on fungi and 3 on bacteria in terms of subjects (Fig. 1A). Plant extracts were the prototype organisms among them. And they can be sorted as 20 on leaf, 2 on plant latex, 2 on root, 1 each on stem, fruit, seed, bark, berry, mesocarp and aerial parts respectively. Ag NPs were used in majority of the studies followed by Au NPs. In particular, *Ae. aegypti, An. stephensi* and *Cx. quinquefasciatus* were favourites for many researchers. Out of the 45 studies performed, 6 were conducted in 2011, 12 in 2012, 14 in 2013 and 13 in 2014 so far. Almost all the plant extract studies used Ag NPs, while fungal studies used both Ag and Au NPs in mosquito control. In terms of nationality, all the researches were conducted in India. About 62 % of the researches were conducted in Tamil Nadu followed by Delhi 16%, Maharashtra 9%, West Bengal 7%, Andhra Pradesh 4% and Kerala 2% (Fig. 1B). Researchers used only Ag, Au and Co NPs for mosquito control till now. Most of the fungal studies were carried out by Soni and Prakash and the studies on bacteria for NPs synthesis are very meager.

(A) **(B)**

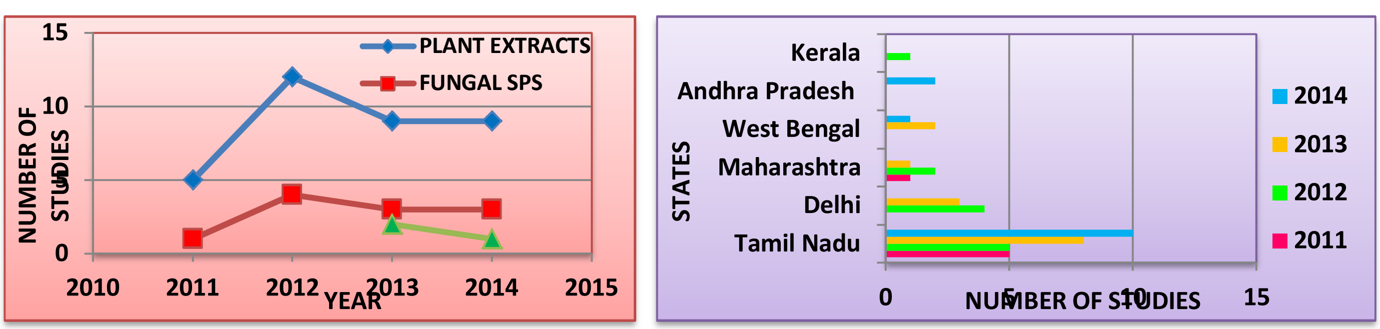

Fig. 1. Studies of nanoparticles in mosquito control as related with (A) green synthesis of nanoparticles and (B) states.

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In almost all the studies, the characterization and the structure determination of these nanoparticles were performed using the application of modern scientific instruments such as UV–VIS spectrophotometry, Transmission Electron Microscopy, High-Resolution Transmission Electron Microscopy (HR-TEM), Atomic Force Microscopy (AFM), Field Emission Scanning Electron Microscopy (FE-SEM), X-ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FT-IR) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

VII. CONCLUSION

These results revealed that the green, biological synthesis of silver/gold nano particles have the potential to be utilized as a good, rapid, eco-friendly approach for the control of mosquito population. It is totally a new pathway but, can be effectively utilized for the efficient killing of mosquitoes. Therefore, biological control can thus provide an effective and environmental friendly approach, which can be used as an alternative to minimize the mosquito population. To understand the current research trends of nanoparticles in mosquito control, research papers on NPs synthesised using biological organisms such as plant extracts, fungi and bacteria were thoroughly analyzed and discussed in terms of the type of nanoparticles, test species, exposure medium and suitable concentration. The researches demonstrated a wide range of results even when using the same nanoparticles. This was because, the particle size, surface coating, and the test medium supposedly made difference in the results. Therefore, in future, researches can be conducted by considering the above factors also.

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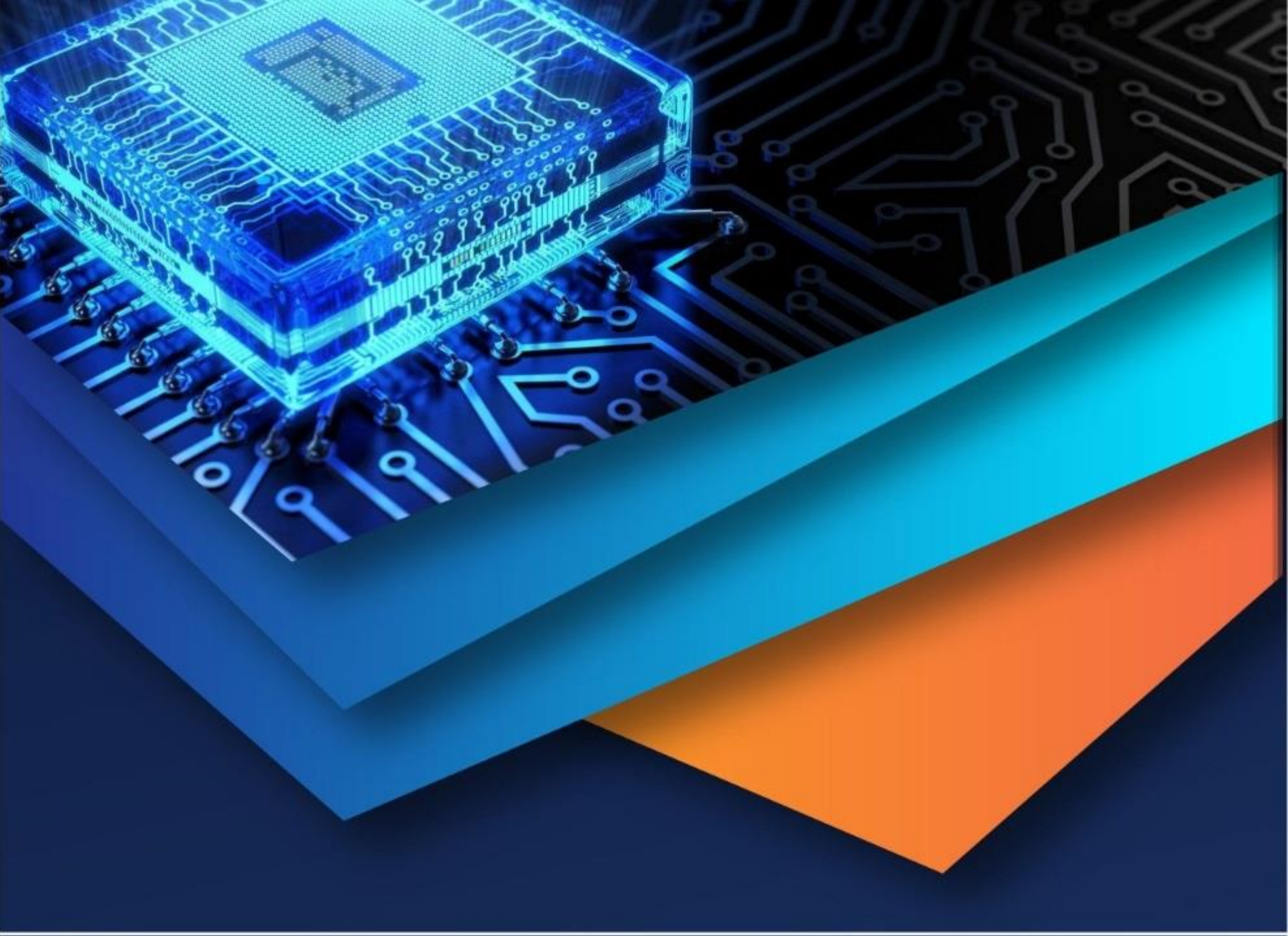

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