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Role of plants and plant based products towards the control of insect pests and vectors: A novel review

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ABSTRACT

Insect pests bear harmful effects causing great loss to the agricultural crops, stored agricultural products and vector mosquitoes can cause diseases to human. Plants possess an array of vast repository of phytochemicals and have been used to cure many diseases and to control the infestation of insect pests from time immemorial. Plants are easily biodegradable and ecologically safe for treating on the stored or on the field crops against pests to prevent from further damage or loss of stored products or preventing human from mosquito bites, thus preventing the spreading of dreadful diseases such as chikungunya and malaria. Hence, this review can give a clear insecticidal, pesticidal and mosquitocidal property of several plants against the insect pests and vectors.

1. Introduction

Phylum Arthropoda comprises of the biggest class in the animal kingdom known as the class Insecta or otherwise known as Hexapoda. Insects belonging to the class Insecta are found everywhere in the environment and they have been always closely associated with us. They are considered as economically important to humans. Some insects are considered as beneficial and some of them are considered as serious pests to the humans as well as cultivable crops. Being an agro-based country with agriculture as a major source of work in more than 80% of population, these insect pests bring about monetary loss in the agricultural productivity both quantitatively and qualitatively and severe damage to stored agriculture products, too[1]. Therefore, the total loss throughout

the world is up to 10%–40% annually[2]. Hence, these pests are considered as a great nuisance to man and prevention of these pests has become a serious issue and thrown more light in the field of entomology.

The protection of stored products, agricultural field crops, against pests is primarily dependent on liquid, gaseous insecticides[3] and synthetic insecticides. On advent of these, chemical insecticides coming into effect result in increased risk to non-target animals, toxicity to consumers and development of genetic resistance in the pests[4]. These findings result in developing a eco-friendly plant based formulation considering human safety and environmental damage. Furthermore, plants as a rich source of bioactive phytochemicals and compounds are used as insecticides and pesticides against phytophagous insects[5]. Numerous inventions have started to develop in this regard. Also, the insecticidal constituents are present in the plant extracts and in the essential oil. So far, 2121 species of plants possessing pest management properties, 1005 plant species showing insecticidal activities, 384 plant species showing antifeedant activities, 297 plant species showing repellent properties, 27 plant species showing attractant properties and 31 plant species having growth inhibiting property have been identified[6].

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Similarly, vector mosquitoes are momentarily important in view of public health importance, since they are responsible for the spreading of several disease-causing pathogens among humans and then causing dreadful diseases such as malaria, filariasis, Japanese encephalitis, dengue, chikungunya, West Nile fever, human arbo virus, etc.

The present review gives more emphasis on the utilization of plants and plant based products towards the control of agricultural and vector insect pests. This review article is prepared with more than 100 research papers to determine the bio-efficacy of the essential oil and extracts of plants to identify its property of insecticidal, pesticidal and vectoricidal activities against the stored pests, field pests and vector mosquitoes.

2. Roles of plants and plant based products towards the control of agricultural pests

Aslan *et al.*[7] reported that *Tetranychus urticae* (*T. urticae*) and *Bemisia tabaci* (*B. tabaci*) could be controlled by the essential oil vapours of *Satureja hortensis*, *Ocimum basilicum* (*O. basilicum*) and *Thymus vulgaris* (*T. vulgaris*). From their experiments, it was revealed that though essential oil of the three plants can act as a control agent against *T. urticae* and *B. tabaci*, it was found that *Satureja hortensis* was more powerful than the others two. Luo *et al.*[8] analyzed the compounds presenting in the ethanol extract of the root bark of *Tripterygium wilfordii* and also determined the insecticidal and antifeedant activities of the compounds. In their experiment, the compounds were characterized as triptolide, triptonide and eunone by bioassay-guided fractionation of the extract. Their experiment evaluated its antifeedant activity after 24 h of treatment of the pest and effective concentration and knock-down values were recorded. Moreover, this was the first report on these three compounds for its insecticidal activity.

Çalmaşur *et al.*[9] studied the essential oil vapours of *Micromeria fruticosa* and *Origanum vulgare* to determine its insecticidal and acaricidal effect on the nymphs and the adult stage of the pests, *T. urticae* and *B. tabaci*, and found that the essential oil from all the plants could be used for the management of pests *T. urticae* and *B. tabaci* in greenhouse condition. Mishra *et al.*[10] determined the solvent extracted essential oil from the seeds of *Momordica charantia*, *Momordica dioica*, *Lagenaria siseraria* and *Luffa acutangula* were tested for its insecticidal activity against *Lipaphis erysimi*. They have observed 100% mortality in all the vegetable oils at 6% concentration. Further, no infestation was found in the vegetable oil treated crop.

Oigiangbe *et al.*[11] analyzed *Alstonia boonei* (*A. boonei*) for its insecticidal activity against *Sesamia calamistis*. They observed a significant reduction in larval survival and weight due to the incorporation of the leaf and stem bark extracts of *A. boonei* in to the diet. Hence, it was concluded that the growth of *Sesamia calamistis* is inhibited by using the leaf and stem bark extracts of *A. boonei*.

Kamaraj *et al.*[12] made the study on *Citrus sinensis* (*C. sinensis*), *Ocimum canum* (*O. canum*), *Ocimum sanctum* (*O. sanctum*) and *Rhinacanthus nasutus* to test their antifeedant and larvicidal activities against the gram pod borer, cotton leaf roller and malaria vector by using the extracts of acetone, chloroform, ethyl acetate, hexane and methanol. Their results suggested that in order to control the agricultural pests and vectors, ethyl acetate extract of *O. canum*, methanol and chloroform extract of *C. sinensis* and acetone extract of *O. sanctum* will be an ideal eco-friendly method.

Ramya *et al.*[13] analyzed the leaf aqueous extract of ten selected plants against the larvae of *Helicoverpa armigera* (*H. armigera*). Their results revealed the considerable amount of mortality in the decreasing order of *Andrographis paniculata* (*A. paniculata*), *Catharanthus roseus* (*C. roseus*), *Datura metal* (*D. metal*), *Albizia amara*, *Cardiospermum halicacabum*, *Abutilon indicum*, *Cassia tora*, *Tribulus terrestris*, *Achyranthus aspera* and *Aerva lanata*. Thus, *A. paniculata*, *C. roseus* and *D. metal* can be used as the best source to control gram pod borer. Mikami and Ventura[14] investigated the potency of the oil of *Azadirachta indica* (*A. indica*) by conducting multiple and no-choice feeding preference assays. Their study clearly revealed that males were repelled and feeding deterrence was noted. Therefore, neem oil could be used in pest management.

Ramya and Jayakumararaj[15] studied the insecticidal activity of 25 medicinal plants against *H. armigera*. The larval mortality at 1000 mg/L concentration. The results showed the mortality rate in the following order: *Melia azedarach*, *A. indica*, *Solanum trilobatum*, *A. paniculata*, *Aegle marmelos* (*A. marmelos*), *Andrographis lineata*, *Solanum surattrense*, *C. roseus*, *Adhatoda zeylanica*, *Acalypha fruticosa*, *D. metal*, *Solanum nigrum*, *O. canum*, *Plectranthus coleoides*, *O. sanctum*, *Pergularia daemia*, *Albizia amara*, *Gymnema sylvestre*, *Cardiospermum halicacabum*, *Vitex negundo*, *Abutilon indicum*, *Cassia tora*, *Tribulus terrestris*, *Achyranthus aspera* and *Aerva lanata*. Gökce *et al.*[16] suggested that the toxicity and antifeedant activities of *Bifora radians*, *Arctium lappa*, *Xanthium strumarium*, *Humulus lupulus* and *Verbascum songaricum* were against *Choristoneura rosaceana*. The researchers observed that there was a decrease in the pupal weight also due to the treated diet and also showed deterred larval feeding when it was treated in the diet. Furthermore, in each of the bioassay tests with extracts of *Humulus lupulus* and *Arctium lappa* showed the deleterious effects to the larvae. In another study, *Acalypha fruticosa* showed the maximum antifeedant activity against *Plutella xylostella* (*P. xylostella*). thin layer chromatogram fraction showed 7 fractions of which fraction 7 showed the presence of terpenoids, tannins, coumarins, anthraquinones and saponins were observed in the fraction on preliminary phytochemical analysis[17]. The leaf extracts of *Phyllanthus amarus*, *Acassia albida* and *Tithonia diversifolia* were evaluated for their insecticidal activities[18].

Jeyasankar *et al.*[19] studied the seed extracts of *Solanum pseudocapsicum* to investigate on antifeedant, insecticidal and growth inhibition against *H. armigera* and *Spodoptera litura* (*S.*

litura). From their experiments, the ethyl acetate extract of *Solanum pseudocapsicum* showed deformed larvae, pupae and adults on *H. armigera* and *S. litura*. Praveena et al.[20] investigated the plants of *Clausena dentate*, *Dodonea viscosa*, *Anacardium occidentale* (*A. occidentale*) and *Nicotiana tabacum* to study its antifeedant activity against *Earias vittella*. They found that, the maximum antifeedant activity was observed in petroleum ether extracts and still greater significant antifeedant activity was observed in the seed oil of *A. occidentale*.

Krishnappa and Elumalai[21] obtained essential oil from the leaves of *Chloroxylon swietenia* and ascertained its larvicidal and ovicidal activities. The essential oil showed 100% mortality, the highest ovicidal activity in geierene, no hatchability was recorded at 200 mg/L concentration. Yang et al.[22] examined the insecticidal activity in the ethanol extract of *Cynanchi auriculati* against *Plutella xylostella* (*P. xylostella*), *Mythimna separata*, *Pieris rapae* (*P. rapae*), aphids and *Homona coffearia* (*H. coffearia*). From their experiments, results revealed that *P. xylostella*, aphids and *H. coffearia* exhibited stronger insecticidal activities in 95% of ethanol extract of *Cynanchi auriculati*. Whereas, *P. rapae* exhibited weaker insecticidal activity and no such activity was exhibited by *Mythimna separata*. From their results, the mortality of the pests were in order of aphids, *H. coffearia*, *P. xylostella*, *P. rapae*. Also, in their experiments, *P. xylostella* mortality was calculated with the five different polar extracts.

Packiam et al.[23] analyzed the different plant oil formulation against *H. armigera* and *S. litura*. From their experiment, it was concluded that the extreme ovicidal activity was exhibited by plant oil formulation 3 – PONNEEM. Furthermore, this was the first experiment on PONNEEM for its ovicidal activity against these two pests, *H. armigera* and *S. litura*. Gokulakrishnan et al.[24] studied the repellent activity in the essential oil of ten different plants against three pests *S. litura*, *H. armigera* and *Earias vitella*. From their results, it revealed that more than 50% of repellency activity was observed in lime, calamus, lemon and tagetes oil. Therefore, these essential oil and its formulation could be used for obtaining considerable remarkable repellent activities against the Lepidopteran species – *Earias vitella*, *H. armigera* and *S. litura*. Baskaran et al.[25] reported the larvicidal activity of *Acorus calamus* (*A. calamus*), *O. sanctum*, *Eucalyptus globules*, *Rosmarinus officinalis* (*R. officinalis*) and *Cymbopogon citrates* (*C. citrates*) against the fourth instar larvae of *S. litura* and their results suggest that selected essential oil have the potential to be used as an ideal eco-friendly approach for the control of important agricultural pest *S. litura*.

Gokulakrishnan et al.[26] studied 20 kinds of different plant essential oils against *S. litura*, *H. armigera* and *Achaea janata* for determining their antifeedant activities and found that remarkable activities were noted at 1000 mg/L concentration. Hence, it was concluded that the essential oils used in this experiment could be the best way to control the Lepidopteran species – *S. litura*, *H. armigera* and *Achaea janata*. Sharma et al.[27] analyzed the insecticidal activity of the

seed extract of *Spilanthes acmella* against *P. xylostella*. Their results provided a significant insecticidal activity in spilanthol and in the crude seed extract of methanol, hexane, deltamethrin for the control of *P. xylostella*.

Degri et al.[28] conducted an experiment in order to control pod-sucking bugs with aqueous leaf extract of *A. indica*, *Chromolaena odorata* (*C. odorata*) and *Ricinus communis* (*R. communis*) and one synthetic insecticide – Uppercot 500 EC. They proposed that these leaf extracts of *A. indica* and *C. odorata* can be used to control pod-sucking bugs instead of synthetic insecticide. Sougui et al.[29] investigated the fumigant activity of the essential oils from *Foeniculum vulgare* (*F. vulgare*), *Coriandrum sativum* (*C. sativum*), *Daucus carota*, *Pelargonium graveolens*, *Origanum majorana* (*O. majorana*) and *Salvia officinalis* against third instar larvae of *S. littoralis*. From their experiment it was observed that the highest mortality was seen in *Salvia officinalis*, *F. vulgare*, *C. sativum*, *O. majorana* and *Daucus carota*. Mwine et al.[30] analyzed the extracts of *Euphorbia tirucalli*, *Jatropha curcas* and *Phytolacca dodecandra* to determine its pesticidal activity against *Brevicoryne brassicae* (*B. brassicae*) and *P. xylostella*. From their results, it was confirmed that *Euphorbia tirucalli* latex could be used against *B. brassicae* and for management of *P. xylostella*.

Maheswari et al.[31] investigated the compound presenting in the *Alangium salvifolium* to determine its insecticidal activity against *M. separate*. Jeyasankar et al.[32] investigated the crude extracts, fractions and compounds A and B in the leaves of *Syzigium lineare* in which compound A showed highest oviposition deterrent and compound B showed highest ovicidal activity. Further, on spectral analysis identified the compound presenting in A as 7-hydroxyundec-1en-3-one and in B as 3-[3-hydroxy-hexyl]-tetrahydro-pyran-4-one. Arivoli and Tennyson[33] analysed the ovicidal activity in 25 plants with different extracts hexane, diethyl ether, dichloromethane and ethyl acetate against *S. litura*. From their observations, the maximum ovicidal activity was exhibited by hexane extract of *Cleistanthus collinus*, diethyl ether extract of *Murraya koenigii* and ethyl acetate extract of *A. marmelos*. Acheuk and Doumandji-Mitiche[34] analyzed the insecticidal activity of crude alkaloid extract of aerial part of *Pergularia tomentosa* against newly emerged fifth instar larvae of *Locusta migratoria*. And it was reported that *Pergularia tomentosa* is an eco-friendly approach acting as an bioinsecticides against *Locusta migratoria*.

Abbaszadeh et al.[35] studied the insecticidal and antifeedant activities of *Clerodendron infortunatum* against the *H. armigera*. Jeyasankar et al.[36] analyzed the insecticidal and antifeedant activities in six plant against the fourth instar larvae of *Henosepilachna vigintioctopunctata*. From their findings, it was noticed that the significant levels of insecticidal activity and antifeedant index were recorded in the ethyl acetate extract of *Achyranthes aspera* on the fourth instar larvae. Selvam and Ramakrishnan[37] evaluated the *Tinospora cardifolia* to determine its antifeedant and ovicidal activities against the fourth instar larvae

of *S. litura* and *H. armigera*. The maximum ovicidal activity can be reported in the methanol leaf extract of *Tinospora cardifolia* and followed by ethylacetate, dichloromethane, diethylether and hexane. Huang *et al.*[38] investigated the insecticidal activities of *Pogostemon cablin* against the two harmful insects – *S. litura* and *Spodoptera exigua*. Devi *et al.*[39] synthesized the silver nanoparticle from *Euphorbia hirta* (*E. hirta*) and analysed the larvicidal and pupicidal potential of silver nano particles against the first to fourth instar larvae and pupae of *H. armigera*. They reported that silver nanoparticle affected the gut physiology of the test insects. Lall *et al.*[40] reported that the pesticidal activity of *Argimone maxicana* and *Calotropis procera* against the fourth instar larvae of *S. litura*. The pesticidal activity of *A. paniculata*, *Anethum graveolens*, *A. Indica*, *Cassia fistula*, *Cuscuta reflexa*, *Dendrothoe falcate*, *Lantana camara*, *Melia azedarach* and *Vitex negundo* were tested on the 3rd and 6th day old larvae of *S. litura*[41].

Vattikonda *et al.*[42] studied the antifeedant activity of *Coleus forskohlii* on *Papilio demoleus*. Arumugam *et al.*[43] evaluated benzene, dichloromethane, diethylether, ethylacetate and methanol extracts of *Rivina humilis* to determine its antifeedant, oviposition deterrent, ovicidal and larvicidal activities against *S. litura*. Motazedian *et al.*[44] analyzed essential oils extracted from the leaves and stem of *Zataria multiflora* (*Z. multiflora*), *Nepeta cataria*, *Tagetes minuta*, *Artemisia sieberi* and *Trachyspermum ammi* by using gas chromatography-mass spectrometer (GC-MS). The major compounds present in all the plants were 4 α - α , 7- β , 7 α - α -nepetalactone, carvacrol γ -terpinene, limonene and artemisia ketone. The toxicity of these compounds was studied against *B. brassicae* and found significantly controlled the infestation. Santiago *et al.*[45] extracted the oils of *Chenopodium ambrosioides* and *Philodendron bipinnatifidum* and noticed that there was a decrease in feeding activity and increase in mortality of the adult *Diabrotica speciosa*. Teixeira *et al.*[46] determined the antioxidant and insecticidal activities in the essential oil of the leaves of *Lippia organoides* and *Mentha spicata* (*M. spicata*) and identified by GC-MS. The major compounds of *Lippia organoides* were carvacrol, *p*-cymene, γ -terpinene and thymol and *M. spicata* were piperitone, piperitenone and limonene. Therefore, these essential oils could be the useful agent in the integrated pest management of *Myzus persicae*.

Baskar *et al.*[47] analyzed that the larvicidal and pupicidal activities of various crude extracts, several methanolic fractions of *Couroupita guianensis* and tested it against *S. litura*. They also noticed, fraction 8 influenced the reduced protein in midgut and hemolymph. Nia *et al.*[48] analyzed the various extracts of *Artemisia herbaalba*, *Eucalyptus camaldulensi* and *R. officinalis* for their insecticidal activity against 3–4 days old *Myzus persicae*.

Muthusamy *et al.*[49] analyzed the benzene, diethylether, ethyl acetate, dichloromethane and methanol extracts of *Caesalpinia bonducella* for their antifeedant, oviposition deterrent, larvicidal and ovicidal activities against the field pest, *H. armigera*. Different extracts of *Tinospora crispa* and *Psidium guajava* were estimated

for their larvicidal, oviposition deterrent and ovicidal activities against *H. armigera* and it was reported that the methanol extracts of these plants exhibited 100% oviposition deterrence against *H. armigera*[50]. Similarly, different solvent extracts of *Balanites aegytiaca*, *Paederia foetida*, *Limonia acidissima* and *Polyanthia longifolia* were tested for their antifeedant activities against *Lipaphis erysimi* and *S. litura*. The maximum potency was noted in the chloroform and petroleum ether extracts[51].

Recently, Kuhns *et al.*[52] suggested that essential oils played a major role against *Citrus psyllid* and *Diaphorina citri* under field condition. Jiang *et al.*[53] investigated the chemical composition, repellent and insecticidal activities in *Cinnamomum camphora* (*C. camphora*) leaves, twigs and seeds. Twigs and seeds showed good record of insecticidal activity on cotton aphids *Aphis gossypii*. Pan *et al.*[54] analyzed the *Ginkgo biloba* extracts which contained ginkgo flavonoids, ginkgolide and bilobalide and tested against *Hyphantria cunea*. Among the three secondary metabolites, ginkgolide was found to exhibit the highest antifeedant activity and significant effect on the detoxifying enzymes.

Tampe *et al.*[55] extracted the essential oil by steam distillation and its components were characterized by GC-MS to evaluate the repellent effect against *Aegorhinus superciliosus* (*A. superciliosus*) by using four-arm olfactometric bioassays. From their experiment, the major compounds presenting in the essential oil of *A. superciliosus* were 2-nonanone and 2-undecanone. In their results, it was identified that both male and female *A. superciliosus* were found greatly deterred by the essential oil treatment. Therefore, the essential oil of rue could be used as a potent source for repellent against *A. superciliosus*.

3. Roles of plants and plant based products towards the control of stored product pests

El Nadi *et al.*[56] analyzed the three plant species – *Rhazya stricta*, *A. indica* and *Heliotropium bacciferum* for their insecticidal activities with the aqueous, methanolic and acetic extracts against *Trogoderma granarium* (*T. granarium*). Their results suggested that acetone extracts exhibited remarkable toxicity on *T. granarium*. Kim *et al.*[57] analyzed the insecticidal activity of methanol extracts from 30 aromatic plants and 5 essential oils against *Sitophilus oryzae* (*S. oryzae*) and *Callosobruchus chinensis* (*C. chinensis*) for their insecticidal and fumigant toxicity. Insecticidal activities of the oils used in this invention were more significant to fumigant action since the oils used were showed remarkable effectiveness in the closed container than in open container.

Sanna Passino *et al.*[58] examined the insecticidal activity of microencapsulated essential oil obtained from *R. officinalis* and *T. vulgaris* against the indian meal moth, *Plodia interpunctella* (*P. interpunctella*). It was observed that even a lower concentration brings over 50% of mortalities. Saljoqi *et al.*[59] investigated the insecticidal activity in 6 plants, *Melia azedarach*, *Myrtus communis*,

Mentha longifolia, *Pegnum harmala* and *C. citrates* against *S. oryzae*. Similarly, the methanol extracts of *Peganum harmala*, *Ajuvaiva*, *Aristolochia baetica* and *Raphanus raphanistrum* inhibited the infestation of *Tribolium castaneum* (*T. castaneum*) [60]. Moreira et al. [61] analyzed *Ocimum selloi*, *Ruta graveolens*, *Leonotis nepetifolia*, *Datura stramonium*, *Cordia verbenacea*, *Mentha piperita* (*M. piperita*), *Mormodica charantia* and *Ageratum conyzoides* for their insecticidal active compounds against the stored pest *Rhyzopertha dominica* (*R. dominica*), *Sitophilus zeamais* (*S. zeamais*) and *Oryzaephilus surinamensis* (*O. surinamensis*). Their results revealed that the highest insecticidal activity was apparent in hexane extract of *Ageratum conyzoides* and the compounds presenting in it was fractionated and identified as 5,6,7,8,3',4',5'-heptamethoxyflavone, 5,6,7,8,3'-pentamethoxy-4',5'-methylenedioxyflavone and coumarin.

Jovanović et al. [62] reported that *Acanthoscelides obtectus* was greatly controlled by methanolic extracts of *Urtica dioica*, *Taraxacum officinale*, *Achillea millefolium*, *Sambucus nigra* and *Juglans regia*. *Piper nigrum* (*P. nigrum*), *Carum carvi* and *Sesamum indicum* were analysed for their insecticidal activities with different doses of plant extracts against *S. oryzae* by Bodroža-Solarov et al. [63]. In 2009, Pugazhvendan et al. [64] reported about the insecticidal activities of *Argemone mexicana*, *Prosopis juliflora* and *Tephrosia purpurea* (*T. purpurea*) on *T. castaneum*. Moharrampour et al. [65] evaluated the essential oil of *Prangos acaulis* for its repellency and insecticidal activity against *T. castaneum*, *S. oryzae* and *Callosobruchus maculatus* (*C. maculatus*).

Ayvaz et al. [66] reported the insecticidal activities of three essential oils, *Origanum onites*, *Satureja thymbra* and *Myrtus communis* against the adult stages of stored pests, *Ephestia kuehniella* (*E. kuehniella*), *P. interpunctella* and *Acanthoscelides obtectus*. Ashouri and Shayesteh [67] made an experiment on *P. nigrum* and *Capsicum annum* for their insecticidal activities against stored pests, *R. dominica* and *Sitophilus granarius*. Ebadollahi et al. [68] reported phytochemical components presenting in the *Agastache foeniculum* showed increase mortality rate with the period of time exposure and with the increased doses. Therefore, the detrimental effects of *E. kuehniella* and *P. interpunctella* can be decreased by using the essential oil of *Agastache foeniculum* as a fumigant.

Yankanchi and Gadache [69] investigated the insecticidal activity of *Clerodendrum inerme*, *Withania somnifera*, *Gliricidia sepia*, *Cassia tora* and *Eupatorium odoratum* on *S. oryzae*. The mortality activity was recorded in a dose-dependent manner and there was a drastic suppression in F1 progeny. Ebadollahi and Mahboubi [70] studied the insecticidal activity of *Azilia eryngioides* essential oil against *S. granaries* and *T. castaneum*. The major constituent of oil presenting in the plant were α -pinene and bornyl acetate which was identified by GC-MS. Jemâa et al. [71] analyzed that the essential oils of *Laurus nobilis* collected from Tunisia, Algeria and Morocco were tested against *R. dominica* and *T. castaneum*. Remarkable repellent activity and toxicity were observed in the filter paper test against the two major stored pests when they were treated with the essential oils

of *Laurus nobilis* from Morocco as compared to those from Tunisia and Algeria.

Chaubey [72] reported that the essential oil extracted from *Cuminum cyminum* and *P. nigrum* showed repellent activities, fumigant toxicity and effect of acetylcholinesterase enzyme on rice weevil. Mahmoudvand et al. [73] investigated the essential oils of *R. officinalis*, *Mentha pulegium*, *Z. multiflora* and *C. sinensis* for the fumigant toxicity on *T. castaneum*, *Sitophilus granarius*, *C. maculatus*, and *P. interpunctella*. Younes et al. [74] evaluated the essential oil of 7 plants against the 4th instar larvae of *T. granarium*. On their evaluation, they observed that the inhibition of adult fecundity was seen between 0.025 and 1.000 mL per 10 gm of wheat. Their results also revealed that in the treated larvae glucose, lipid content and alkaline phosphatase were less and cholinesterase and protein content were higher. These biochemical studies proposed the best way to control *T. granarium*. Lü et al. [75] investigated the essential oil of *Artemisia argyi* to identify the repellent, fumigant effect and contact toxicity against *O. surinamensis*. Khani and Rahdari [76] analyzed the compounds presenting in the essential oil of *C. sativum* seed as a source of insecticidal activity against *Tribolium confusum* (*T. confusum*) and *C. maculatus*. The predominant compounds in *C. sativum* were linalool and geranyl acetate which was identified by GC-MS. The insecticidal activity increases with concentrations and the *C. maculatus* was more influenced than *T. confusum*. *Euphorbia prostrata* silver nanoparticles were synthesized to determine the pesticidal activity on *S. oryzae*. In their study, spectral analysis was used to study the silver nanoparticles. Then, with different concentrations, pesticidal bioassay tests were performed and the results suggested that the silver nanoparticles synthesized from the aqueous leaves extract of *Euphorbia prostrata* can be used as a control agent against *S. oryzae* [77].

The insecticidal activities of these plants, *Zingiber officinale* (*Z. officinale*), *Elettaria cardamomum* and *F. vulgare*, were analyzed against *O. surinamensis*. The experimental results revealed that *Z. officinale* followed by *Elettaria cardamomum* and *F. vulgare* showed considerable insecticidal activities. Further, under polyacrylamide gel electrophoresis technique for protein analysis of *O. surinamensis*, there observed a significant alteration in the protein configuration [78]. Essential oils of *Pinus longifolia*, *Eucalyptus oblique* and *C. sativum* were tested for their fumigant toxicity against *S. oryzae*, *C. chinensis* and *Corcyra cephalonica* [79]. They found that the exposure of the pest with pine oil for 72 h exhibited 90% mortality. Pugazhvendan et al. [80] investigated the insecticidal activities of different solvent extracts of *Artemisia vulgaris*, *Sphaeranthus indicus* (*S. indicus*), *T. purpurea* and *Prosopis juliflora* against *T. castaneum*. From their results, chloroform extract of *S. indicus*, hexane extract of *Artemisia vulgaris* and ethyl acetate extract of *T. purpurea* exhibited the highest mortality activity. Therefore, these extracts could be used as an insecticidal agent against *T. castaneum*. Satti and Elamin [81] analyzed *Khaya senegalensis* and *A. indica* for their insecticidal activities against *T. granarium*.

Padin *et al.*[82] studied 9 medicinal plants for their insecticidal and repellent activities against *T. castaneum*. The significant mortality of *T. castaneum* was noticed by the researchers in *Viola arvensis* on grain, followed by *Matricaria chamomilla*, *Brassica campestris* and *Jacaranda mimosifolia*. Similarly, the significant repellent activity was detected in the *Jacaranda mimosifolia*, *Matricaria chamomilla* and *Tagetes minuta*. Extracts of *Capsicum frutescens*, *Cymbopogon citratus*, *Moringa oleifera* and *A. occidentale* showed significant insecticidal activities against *Sitotroga cerealella* (*S. cerealella*). Consequently, when the moths from egg to adult were exposed to the plant powders, the highest mortality rate showed. These extracts also prevented the hatchings of the egg of Angoumois grain moths[83].

Sümer Ercan *et al.*[84] studied the insecticidal activity against different stages of *E. kuehniella* and egg parasitoid of *Trichogramma embryophagum* by extracting the essential oil from *Prangos ferulacea* and identified the major compound as 2,3,6-trimethyl benzaldehyde, minor compound as heneicosane through GC-MS. The essential oil was lethal showing 100% mortality to both the pests. Therefore, the results suggested that the essential oil can be used as a control agent. Obembe and Kayode *et al.*[85] reported that *Crotaria retusa*, *Hyptis suaveolens*, *R. communis* and *Tithonia diversifolia* showed strong insecticidal, ovipositional deterrence and suppressed infestation rate of *C. maculatus*. Zandi-Sohani *et al.*[86] extracted the essential oil of leaves of *Callistemon citrinus* and reported that the plant essential oil has strong insecticidal activity against *C. maculatus*. Also, its repellent activity was observed in the filter paper arena test. Ali and Mohammed[87] studied the toxicity effect of the methanol extracts of *Anethum graveolens*, *Eucalyptus glauca*, *Apium graveolens*, *Malva parviflora*, *Z. officinale* and *Mentha longifolia* against *T. confusum*.

Utono *et al.*[88] evaluated the powdered dried leaves of *O. basilicum* and *Cymbopogon nardus* (*C. nardus*) for their repellent activities against *T. castaneum* and *R. dominica*. Jaya *et al.*[89] reported that *T. castaneum* showed 100% mortality with essential oils of *Hyptis suaveolens* at 250 mg/L concentration while *Coleus aromaticus* was effective at 350 mg/L concentration. Further, no adverse result on seed germination as well as non-phytotoxic nature of the oils were observed on the seedling growth of the seeds treated with the essential oils. Adjalian *et al.*[90] showed that the essential oils of *Dennettia tripetala* and *Uvariadendron angustifolium* showed insecticidal activities. In their study, the essential oils isolated from these plants were analyzed under GC-MS to determine the major components presenting in it. Then, by the fumigation method the level of toxicity of the essential oils was observed by the researcher in a closed glass jar by setting up a suitable temperature and relative humidity.

Pandey *et al.*[91] investigated the study of the essential oils of 35 plants to determine its repellent activity against *C. chinensis* and *C. maculatus*. *In vivo* evaluation showed reduced seed damage, increased feeding deterrence, weight loss of fumigated seeds and up to 6 months of storage. Sani[92] investigated the ethanol

and petroleum extracts of seeds of *Parkia biglobosa* to show its antifeedant activity on *C. maculatus*. They concluded that the secondary metabolites of *Parkia biglobosa* seed extracts may be associated with antifeedant property to protect the cowpea bean against *C. maculatus*. Khan *et al.*[93] reported that the pest *T. castaneum* showed significant mortality when they were exposed to a triterpenoid compound, 2 α ,3 β ,21 β ,23,28-pentahydroxyl 12-oleanene which was isolated from the roots of *Laportea crenulata*. It was observed that significant mortality of about 80% and 86% was recorded for 24 h. Hence, researchers concluded that this compound triterpenoid 2 α ,3 β ,21 β ,23,28-pentahydroxyl 12-oleanene exhibits pesticidal and pest repellency property so it could be used in controlling the pest of grain-based product.

Benzi *et al.*[94] evaluated the essential oils of two plants, *Aloysia polystachya* and *Aloysia citriodora*, to study its bioactivity on *T. castaneum* and *T. confusum*. The results from their experiments revealed that the highest repellent activity in both beetles. Abd El-Razik and Zayed[95] evaluated the toxicity of essential oil of *Helianthus annuus* and *Sesamum indicum* at different mixing ratios of it with pyridalyl, abamectin, spinosad and malathion against *Callosobruchus maculatus* through residual film bioassay. Their results revealed that the synergistic effect on combination of the plant essential oils with pyridalyl and abamectin where evoked antagonistic effect. Fumigation and contact toxicity effects of methanol extract of leaves of *Lantana camara* against *S. oryzae*, *C. chinensis* and molecules presenting in the extract were identified by GC-MS[96].

Wang *et al.*[97] analyzed the essential oils in the leaves of *Citrus limonum* (*C. limonum*), *Litsea cubeba*, *Cinnamomum cassia* and *Allium sativum* (*A. sativum*) for fumigant, contact, and repellent activities against 6th instars and adults of *Alphitobius diaperinus*. The strongest acetyl choline esterase activity was exhibited by *A. sativum* against the 6th instars of *Alphitobius diaperinus* followed by *C. limonum*, *Litsea cubeba*, *Cinnamomum cassia*. Emamjomeh *et al.*[98] obtained the essential oil and evaluated for its toxicity against the adults and larvae of *E. kuehniella* by fumigation method under dark condition. Their results suggested that *Z. multiflora* has a potential to use in integrated pest management of *E. kuehniella*. Najafabadi *et al.*[99] analyzed the ethanolic extract leaves of *A. indica*, *Mentha longifolia* and *Datura stramonium* for their insecticidal activities against *O. surinamensis* and *T. castaneum*. From their results revealed that the highest mortality rate was seen in the mint extract against *O. surinamensis* followed by *Datura* and neem extracts. However, neem, mint and *Datura* exhibited the effective mortality activity against *T. castaneum*. Whereas the repellency activity was maximum in *Datura* against *O. surinamensis* and maximum in mint against *T. castaneum*.

Adjalian *et al.*[100] assessed the insecticidal and repellent activity of *Premna angolensis* (*P. angolensis*) and *Premna quadrifolia* (*P. quadrifolia*) against *S. cerealella*. In their findings, essential oil of *P. angolensis* and *P. quadrifolia* displayed 29 compounds which

corresponded to 96.1% of the essential oil of *P. angolensis* and 42 compounds which corresponded to 91% of the essential oil of *P. quadrifolia*. Results of their findings suggested that these two plants have insecticidal and repellent effects on the targeted pest. Oil extracted from *Dendranthema indicum* was identified by GC-MS and 31 components corresponded to 92.44% of the oil. Out of it, the major components are chamazulene, β -caryophyllene, germacrene D, and b-cis-farnesene[101]. Furthermore, the insecticidal and repellent activities were shown by the essential oil and chamazulene on targeted pests, *T. castaneum* and *Stegobium paniceu*.

Adebisi[102] investigated the insecticidal activity of the essential oil of *Citrus aurantifolia* against *C. maculatus*. They have also identified 37 components and the major components of terpenoids were limonene, β -myrcene, cymene, and thymol. Nattudurai et al.[103] reported that the fumigant and repellent activities of *Toddalia asiatica* were studied on *C. maculatus*, *S. oryzae* and *T. castaneum*. From their findings, it was clearly revealed that *Toddalia asiatica* showed 100% repellency against *C. maculatus*, *S. oryzae* and 92% repellency against *T. castaneum*.

Wu et al.[104] characterized the essential oil of the rhizome of *Alpinia kwangsiensis* by GC-MS and reported that 92.45% of the oil were identified and 31 components were present in it. Among the 31 compounds, the four major compounds camphor, eucalyptol, β -pinene, and α -pinene exhibited contact and fumigant activity against *Lasioderma serricorne*. Wang et al.[105] studied *Zingiber purpureum* against two stored pests *T. castaneum* and *Lasioderma serricorne*. In their study, essential oil of the rhizome of *Zingiber purpureum* showed contact and fumigant toxicity against the grain storage pest. Also, major compounds sabinene, terpinen-4-ol, γ -terpinene, α -terpinene, β -thujene and α -phellandrene presenting in the essential oil were characterized by GC-MS. Eliopoulos et al.[106] analyzed the essential oil of *O. basilicum* and *M. spicata* against *E. kuehniella* and *P. interpunctella*.

Cansian et al.[107] analyzed the essential oil of *Cinnamomum camphora* var. *linaloolifera* and *Cinnamomum camphora* var. *hosyo* for their insecticidal and repellent activities against *S. zeamais*. Shahab-Ghayoor and Saeidi[108] analyzed the essential oil of *Sature jahortensis* and *Fumaria parviflora* for its antifeedant activity against *P. interpunctella*.

Recently, Jeyasankar et al.[109] evaluated the larvicidal and repellent activity in 5 essential oils against *T. castaneum*. The 5 essential oils used in the study were *Corymbia citriodora*, *C. nardus*, *Syzygium aromaticum*, *Gaultheria* oil and *C. citrates*. Their study suggested that *Corymbia citriodora* oil showed high larval mortality and high repellent activity against *T. castaneum*. Pinto et al.[110] analyzed that the powder and essential oil extracted from *Cryptocarya alba* showed the insecticidal properties against *S. zeamais* which showed 80% of mortality and 100% of reduction in the emergence of *S. zeamais*. Onaolapo Akinneye and Oyenyi[111] studied the insecticidal activity of stem and bark of *Cleistoholis patens* against *S. cerealella*. Their experiment showed a significant reduce in the

adult emergence of *S. cerealella*.

Guo et al.[112] reported that the contact and repellent activities of the essential oil distilled from the leaves of *Juniperus formosana*. From their results, among the main compounds, the compound 4-terpineol showed the strongest contact activity. Also, *T. castaneum* showed strong repellency when treated with the essential oil and the three isolated compounds. The essential oil of *Ajania fruticulosa* was assessed for its insecticidal activity against *T. castaneum* and *Liposcelis bostrychophila*[113]. Pandir and Bař[114] extracted the essential oil of *O. basilicum*, *Capsicum annum*, *M. piperita* and *R. officinalis* and identified the major components linalool, capsaicin, menthol and cineole by GC-MS. One hundred percent of toxicity was exhibited by all the essential oil to the adult stages of *E. kuehniella*.

4. Roles of plants and plant based products towards the control of vector mosquitoes

Choi et al.[115] evaluated the repellent activities in the essential oil of *Eucalyptus globulus*, *Lovender officinalis*, *R. officinalis* and *T. vulgaris* on *Culex pipiens pallens*. Mello et al.[116] analyzed the essential oil extracted from *Pilocarpus spicatus* against the fifth instar nymphae of *Rhodnius prolixus*. From their findings, it was revealed that discrete moulting inhibition by topical application, partial phagoinhibition, prolonged intermoulting period, high number of paralyzed insects were observed after oral treatment. Bagavan et al.[117] reported that the vectors and cotton pests can be controlled by using the following extracts such as *C. sinensis*, *O. canum*, *O. sanctum* and *Rhinacanthus nasutus* as they have larvicidal and nymphicidal activities against the vectors and cotton pests. *Anopheles subpictus*, *Culex tritaeniorhynchus* and *Aphis gossypii*. *Anisomeles malabarica*, *E. hirta*, *O. basilicum*, *R. communis*, *Solanum trilobatum*, *Tridax procumbens* and seeds of *Gloriosa superba* extracts were determined for their adulticidal activities against *Anopheles stephensi* (*A. stephensi*) by Zahir et al.[118].

Elango et al.[119] studied the hexane and chloroform extracts of *A. marmelos*, *Andrographis lineata*, *A. paniculata*, *Cocculus hirsutus*, *Eclipta prostrata* and *Tagetes erecta* against the important vector mosquitoes. Kumar et al.[120] investigated the study on the larvicidal and repellent activity in *M. piperita* against the fourth instar larvae and adults of *Aedes aegypti* (*A. aegypti*). Consequently, this experiment showed an extraordinary larvicidal and repellent activity against the vector, *A. aegypti*. Further, it also suggested that 100% of protection was seen till 150 min and of late, only 1–2 bites were noticed as compared to the control. Govindarajan et al.[121] reported that the crude extracts of *Ervatamia coronaria* and *Caesalpinia pulcherrima* could be used to control vectors, *Culex quinquefasciatus* (*C. quinquefasciatus*), *A. aegypti* and *A. stephensi*. From their results, the 100% egg mortality was recorded from the crude extracts of *E. coronaria* and *C. pulcherrima*, whereas the significant repellent activity was seen more in *E. coronaria* than *C. pulcherrima*.

Govindarajan and Sivakumar[122] analyzed the different solvent

extracts (benzene, hexane, ethyl acetate, methanol and chloroform) of *Eclipta alba* and *A. paniculata* against 5–6 days old adult female mosquito *A. stephensi*. From their study, the results revealed that the highest significant repellent activity was exhibited by the methanol extract of *Eclipta alba* and *A. paniculata* against *A. stephensi*. Tedeschi et al.[123] determined the insecticidal activities of *Armoracia rusticana* and *A. sativum* against *Aedes albopictus*. Similarly, Tennyson et al.[124] analyzed the ovicidal activity in the solvent crude extract of 25 plants against *C. quinquefasciatus*.

Manimaran et al.[125] studied the larvicidal activity and knockdown effects of 25 essential oils against *C. quinquefasciatus*, *A. aegypti* and *A. stephensi*. *Calamus* oil showed its promising larvicidal activity against *C. quinquefasciatus*. A significant knockdown effect was observed in the orange oil against the three vectors. Adebajo et al.[126] studied the larvicidal activity of the methanol extract of *Euphorbia macrophylla* and stem barks of *Markhamia tomentosa* and *Newboldia laevi*. They have noticed that the extracts of *Blighia sapida* stem and bark, root of *Costus speciosus* and seed of *Xylopia aethiopica* showed the significant larvicidal activities to control dengue and yellow fever and vectors. The repellent activity of *C. sinensis*, *C. limonum*, *Citrus aurantifolia*, *Citrus reticulata* and *Citrus vitis* were tested against the important human vector mosquitoes by Effiom et al.[127].

Elumalai et al.[128] evaluated the larvicidal, ovicidal and pupicidal activities of the extract from *Eranthemum roseum* against *A. stephensi*. From their studies, it was revealed that methanol extracts of *Eranthemum roseum* had more toxicity for these larvicidal, ovicidal and pupicidal activities than acetone extracts. Kovendan et al.[129] studied the different extracts of *Morinda citrifolia* for its larvicidal and pupicidal activity against three vectors, *A. stephensi*, *A. aegypti* and *C. quinquefasciatus*.

Kovendan et al.[130] studied that *Plasmodium falciparum* can be controlled by the ethanolic leaf extracts of *Carica papaya* tested against larvae and pupae. Krishnappa et al.[131] studied the larvicidal, ovicidal and pupicidal activities in *Gliricidia sepium* against third instar larvae of *A. stephensi*. Their results revealed that the ethanolic extracts showed considerable mosquitocidal activity against *A. stephensi*. Therefore, it is concluded that the vector, *A. stephensi*, could be controlled by using the crude extract of *Gliricidia sepium*. Sarah et al.[132] synthesized the silver nanoparticles from the aqueous leaf extract of *Hibiscus rosasinensis* on the larvae of mosquito *Aedes albopictus*. In their experiment, the mortality activity was recorded for different concentrations and the significant larvicidal activity was seen in the synthesized nanoparticles.

Krishnappa et al.[133] investigated *Adansonia digitata* for its larvicidal and repellent activities by using the different solvent extracts against *A. stephensi*. Further, they have also analyzed the presence of phytochemicals, triterpenoids and saponins. Hence, from their results, methanol extract exhibited the highest repellent activity and the same 100% protection was also seen in the other extracts at higher concentration. Krishnappa and Elumalai[134] ascertained

the methanol extract of *Aristolochia bracteata* for its larvicidal, ovicidal and repellent activities against three vector mosquitoes, *A. stephensi*, *A. aegypti* and *C. quinquefasciatus*. Samidurai[135] analyzed *Pemphis acidula* for its larvicidal and ovicidal potential by using the crude methanol, acetone and benzene extracts against the third instar of *Culex tritaeniorhynchus* and *A. subpictus*. Trindade et al.[136] evaluated *Piper alatabaccum* and *Piper tuberculatum* for their insecticidal activities against *Anopheles darlingi*. Their experiment clearly exhibited the larvicidal activity with the compounds 3,4,5-trimethoxy-dihydrocinamic acid, dihydropiartine, piplartine, piplartine-dihydropiartine and 5,5',7-trimethoxy and 3',4'-metilenodioxiflavone with *Piper alatabaccum* and *Piper tuberculatum*.

Murugan et al.[137] analyzed the larvicidal and pupicidal properties of the leaf extract of *Acalypha alnifolia* against *A. stephensi*. From their experiment, they have observed that the highest larvicidal and pupicidal mortality was exhibited in the leaf extract of ethanol against the larvae and pupae of *A. stephensi*. Therefore, this leaf extract exhibited a good larvicidal and pupicidal activity to control the vector. Further, this was the first report on the leaves extract and fungal pathogen to control the vector. Allison et al.[138] investigated the phytochemical composition and larvicidal activity of the plant extracts of *A. indica*, *C. sinensis*, *C. citrates* and *Annona squamosa* on *Anopheles gambiense* and *C. quinquefasciatus*. Further, it was also observed by the researchers that *C. sinensis* and *C. citrates* showed the highest mortality potential on *Anopheles gambiense* at 20 mg/mL after 72 h. Similarly, *C. sinensis* showed its larvicidal potential against *C. quinquefasciatus*. Veerakumar et al.[139] reported that the silver nanoparticle synthesized from the *Sida acuta* leaf extract as larvicidal activity against the third instar larvae of *A. aegypti*, *A. stephensi* and *C. quinquefasciatus*. In their experiments, synthesized silver nanoparticles and aqueous leaf extracts were tested against the vector with different concentrations and the results were identified. Hence, from the results, it was concluded by the researchers that the synthesized silver nanoparticle of *Sida acuta* can be used as an effective agent to control the vector mosquitoes. Moreover, this was the foremost report in the larvicidal activity of the synthesized silver nanoparticle and plant aqueous extract on mosquitoes.

Panneerselvam et al.[140] evaluated *E. hirta* for its larvicidal and pupicidal activities against the malarial vector *A. stephensi*. In their experiments, the bioactivity of larvicidal and pupicidal were determined with different concentrations ranging from 75–375 mg/L by probit analysis. The LC₅₀ and LC₉₀ values were calculated in the leaf extract of *E. hirta*. de Lima et al.[141] evaluated the essential oil of *Lippia sidoides* and *Croton* species for its insecticidal activity against *A. aegypti* mosquito. The oviposition of female gravid mosquitoes was inhibited by *Lippia sidoides*, *Croton zehntneri* and *Croton argyrophyllode* and oviposition deterrent values were calculated by them. El-Akhal et al.[142] reported that the essential oil from *O. majorana* in Morocco showed significant larvicidal activity

and also studied the chemical composition presenting in it. In their experiments, the essential oil was analyzed by GC-MS and the major compounds presenting in it was identified for the study of larvicidal activity. Bakhshi *et al.*[143] carried out the study to establish the larvicidal activity of *Lawsonia inermis* on *A. stephensi* on the early larval and late larval stages.

Suganya *et al.*[144] compared the larvicidal activity of *Leucas aspera* (*L. aspera*) with the solvent leaf extracts and with the synthesized silver nanoparticles against fourth instar larvae of *A. aegypti*. Therefore, with these results, it was revealed that synthesized nanoparticles showed the most significant larvicidal activity when compared to crude extracts and hence *A. aegypti* can be controlled effectively by this way. Naik *et al.*[145] investigated synthesized silver nanoparticles from the leaf extracts of *Pongamia pinnata* and studied its larvicidal activity and they analysed and identified two phytochemical compounds, 9-octadecenoic acid and *n*-hexadecanoic acid. Ramesh *et al.*[146] studied the insecticidal activity in leaves extract and silver nanoparticles synthesized from *Morinda tinctoria* against the third instar larvae of *A. aegypti*. The silver nanoparticles were characterized with fourier transform infrared radiation spectroscopy, UV-Vis spectroscopy and atomic force microscopy. LC₅₀ value was noticed in both the leaf extract and synthesized nanoparticles on the *A. aegypti*. Mavundza *et al.*[147] determined the adulticidal activity in the dichloromethane extract and ethanol extract of 10 different plants which were traditionally used as mosquito repellents in South Africa. It was observed by the researchers that the dichloromethane extract and ethanol extract of leaves of *Aloe ferox* leaves showed the highest mosquito mortality.

Aruna *et al.*[148] investigated *Gaultheria* oil to determine its larvicidal, pupicidal and repellent activities against the first to fourth instar larvae and pupae of *C. quinquefasciatus*. The major component present in *Gaultheria* is methyl salicylate which showed 100% repellency. Therefore, this result revealed that *Gaultheria* oil can be used to control *C. quinquefasciatus*. Thangarasu *et al.*[149] evaluated *Clausena excavata* for its larvicidal and ovicidal activities against *S. litura*, *A. aegypti*, *A. stephensi* and *C. quinquefasciatus* at different concentrations. From their experiment, they suggested that *Clausena excavata* can be used as a potent source for controlling the ovicidal activities against *S. litura*, *A. aegypti*, *A. stephensi* and *C. quinquefasciatus*.

Reegan *et al.*[150] analyzed the hexane extract of *Limonia acidissima* (*L. acidissima*) leaves on the fractions and compounds of it to determine its mosquitocidal activity against eggs, larvae and pupae of *A. aegypti*. In their experiment, eggs, larvae and pupae of *A. aegypti* were exposed to different concentrations and the active phytochemical compound niloticin was identified and exhibited good ovicidal, larvicidal and pupicidal activities. Priya *et al.*[151] synthesized silver nanoparticles from the aqueous extract of *Calotropis gigantean* to determine its mosquitocidal activity against *A. aegypti* and *A. stephensi*. Their results revealed that the plant mediated silver nanoparticles played a key role to control *A. aegypti*

and *A. stephensi*.

Ramar *et al.*[152] tested the ovicidal and oviposition response in the essential oil of *Pimpinella anisum*, *A. calamus*, *Cinnamomum verum*, *C. nardus*, *Myrtus caryophyllus*, *Citrus limon*, *C. sinensis*, *T. vulgaris*, *O. sanctum* and *Vetiveria zizanioides* against *C. quinquefasciatus*. Their experiment was carried out against the vectors with different concentrations and they noted that the highest ovicidal activity was exhibited by the essential oils of clove, aniseed and cinnamom. Followed by these essential oils, the highest ovicidal activity was also exhibited by lemon and tulsi. Whereas, clove oil showed the maximum oviposition response activity. Therefore, these essential oils are the best source for controlling the vectors. Sivapriyajothi *et al.*[153] synthesized the silver nanoparticles from the leaf extract of *L. aspera* to estimate its lethal concentration against first to fourth instar larvae and pupae of *A. aegypti* and *A. stephensi*. The synthesized silver nanoparticles were characterized by various spectral analyses.

Alayo *et al.*[154] examined the larvicidal activity of the petroleum spirit, ethanol, water and dichloromethane extracts of leaves and pods of *Cassia mimosoides* (*C. mimosoides*) against *Anopheles gambiae*. In their studies, phytochemical examination showed the presence of saponins, anthraquinones, flavonoids steroids and tannins and absence of alkaloids and cardiac glycosides in a powdered *C. mimosoides*. One hundred percent of larvicidal efficiency was observed in the petroleum ether and dichloromethane extracts at 2 mg/mL. Furthermore, their research revealed that the petroleum ether were prepared in the aqueous cream based form. It was observed in their studies that 100% repellency was viewed against the vector. Hence, it was confirmed by them that the larvicidal and repellent activity against the vector can be achieved by using the crude extracts of *C. mimosoides*. Reegan *et al.*[155] investigated hexane, ethyl acetate and methanol leaves extract of *A. marmelos*, *L. acidissima*, *S. indicus*, *Sphaeranthus amaranthoides* and *C. odorata* for its ovicidal and oviposition deterrent activities against *C. quinquefasciatus* and *A. aegypti* mosquitoes. In their experiment, among the five different plant extracts screened, significantly highest ovicidal activity and 100% oviposition deterrent were noted in the hexane extract of *L. acidissima* against the vectors. Hence, hexane extract of *L. acidissima* could be used for controlling these vectors.

Kamakshi *et al.*[156] reported that *A. aegypti* could be controlled by using the cladodes extract of *Cereus hildmannianus*. Bhuvaneshwari *et al.*[157] studied the larvicidal property of the silver nanoparticles synthesized from the leaf extract of *Belosynapsis kewensis* against *A. stephensi* and *A. aegypti*. Shanthosh *et al.*[158] evaluated the *Annona muricata* aqueous crude extract and silver nanoparticles synthesized from the leaves to study its larvicidal activities against fourth instar larvae of three important mosquitoes under different concentrations. Silver nanoparticles synthesized from the plant were characterized by spectral analysis for confirmation.

Poopathi *et al.*[159] assessed the larvicidal activity of the silver nanoparticles synthesized from the aqueous leaf extract of *A. indica*

against *A. aegypti* and *C. quinquefasciatus*. Furthermore, their results revealed that the mosquito can be controlled by the biosynthesis of silver nanoparticles from neem. Araujo *et al.*[160] evaluated the essential oil of *S. aromaticum* and *C. sinensis* alone or with combination of temephos for determining the larvicidal activity against *A. aegypti*. Further, the number of eggs decreased in the vector which were exposed to oil with that compared to tap water. Anuradha *et al.*[161] studied the repellent and adulticidal activities in the ethanol extract of *H. ovalis* on female adults of *C. quinquefasciatus*. Further, they have observed the highest adulticidal and repellent activities against *C. quinquefasciatus*.

Carvalho Kda *et al.*[162] investigated the insecticidal activity and chemical composition from the essential oil of *Croton tetradenius* against the larvae and adults of *A. aegypti* and *Mus musculus*. In their study, the significant component presenting in the essential oil was analyzed by GC-MS and flame ionization detection and it was declared as camphor. From the experiments, the toxicity level was recorded on larvae and adults of the vector. Ajaegbu *et al.*[163] investigated the bioactive compounds, leaf methanol extract and fractions of *n*-hexane, dichloromethane and ethyl acetate of *Spondias mombin* to determine its adulticidal activities against *A. aegypti*. Elumalai *et al.*[164] studied the larvicidal activity of fractions and compounds in the methanolic extracts of *L. aspera* against the fourth instar larvae of *A. aegypti*, *A. stephensi* and *C. quinquefasciatus*. They have isolated a phytochemical compound, catechin, which showed significant larvicidal activity even at a very low concentration.

Ramkumar *et al.*[165] analyzed the mosquitocidal and larvicidal activities in the leaf extract by using different solvents acetone, methanol, chloroform and ethyl acetate on three mosquito vectors. In their study, chemical compositions presenting in the leaf extract was recognized by GC-MS. From their findings, it was proposed that the acetone extracts showed significant larvicidal and adulticidal activities in the *Glycosmis pentaphylla* leaf extracts. Silapanuntakul *et al.*[166] studied the larvicidal activity of neem tree in Thailand. In their study, by using a dipping, test comparisons were made between Thai neem oil formulation and alginate bead formulation against the fourth stage of *A. aegypti* larvae. From their experiments, it was concluded that the Thai neem oil shows significantly greater larvicidal activity than alginate bead formulation. Mohankumar *et al.*[167] examined nine plant species in order to find a suitable insecticidal activity against the fourth instar larvae of *A. aegypti* and *A. stephensi*. *Annona reticulata* showed more significant results and *Cosmos bipinnatus* showed the least effect.

5. Conclusion

In agriculture and public health hygiene, insect pests are considered as a very important factor of loss crops, grains and health. As an average, they account for 20%–30% loss of production in the field, but in some cases they cause a total loss. In addition, more

than 550 species of insect pests have developed resistance against most current insecticide groups. So many scientists in industry and academia are currently trying to obtain useful compounds from plants as natural insecticides. Plant based products have been used from time immemorial in traditional insect control practice as a personal protection measure against host-seeking insects. Knowledge on traditional plants obtained through ethnobotanical studies is a valuable resource for the development of new natural products. Recently, several commercial products containing plant-based ingredients have gained increasing popularity among consumers, as these are commonly perceived as “safe” in comparison to long-established synthetic insecticides in general and pesticides in particular. This paper presents a summary of recent information on testing, efficacy and safety of plant-based repellents as well as promising new developments in the field.

Most plants contain compounds that they use in preventing attack from phytophagous (plant-eating) insects. These chemicals fall into several categories, including repellents, feeding deterrents, toxins, and growth regulators. Most can be grouped into five major chemical categories: nitrogen compounds (primarily alkaloids), terpenoids, phenolics, proteinase inhibitors and insect growth regulators. Although the primary functions of these compounds are defence against phytophagous insects, many are also effective against mosquitoes and other biting Diptera, especially those volatile components released as a consequence of herbivory. From the above review, it has been inferred that the plant kingdom consists of vast resources of phytochemical compounds and they can be possibly utilized in integrated pest management and intensive vector control programme in the near future.

Conflict of interest statement

We declare that we have no conflict of interest.

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