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A Review on Mosquitocidal Activity of the Genus *Solanum*

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Abstract: As a vector, mosquitoes are responsible for transmitting deadly diseases such as Chikungunya fever, filariasis, encephalitis, West Nile Virus infection, malaria, yellow fever, dengue fever, etc. To combat this problem, various techniques and strategies had been adopted to control the mosquito population. An alternative mosquito control strategy was available from ancient times that is the application of active toxic agents from plant extracts. This preference has several advantages over the consistent application of synthetic insecticides which cause resistance in vector species, harmful effects on environment and non-target organisms, including human health. From ancient times, plants have been used to control the vector mosquitoes, and still now, in many parts of the world, many researchers are looking for plant substances to kill the mosquitoes or cause repellency in mosquitoes. The phytochemicals that originate from the plant showed various activities such as larval mortality, disrupt insect growth, and act as a repellent and also effect as an ovipositional attractant/deterrent. Several plant species have been stated so far possessing mosquitocidal activities. The present review discussed the larvicidal activities of different solvent extracts (viz. hexane, petroleum ether, chloroform, ethyl acetate, acetone, and methanol) of thirteen species of Genus *Solanum*. Different plant parts of various species such as the leaf, berry, flower, rhizome, bulb, stem and root bark, whole plant, and essential oil demonstrated for significant larvicidal activities against different mosquito vectors viz., *Anopheles stephensi*, *Aedes* aegypti, *Culex quinquefasciatus*, *Anopheles subpictus, Anopheles culicifacies* species A, *Anopheles culicifacies* species C, *Culex vishnui* group and *Anopheles labranchiae*. This review may open the opportunity for further explorations of the efficacy of larvicidal properties of another species under Genus *Solanum* for their natural product.

Keywords: Insecticides, Plant products, Larvicide, LC_{50}, LC_{90}, Phytochemicals, Mosquitocidal

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Introduction

Mosquito is a severe threat to public health, transmitting several dangerous diseases in the tropics and subtropics (WHO, 2012). There has been a considerable increase in the insecticide resistance of these vectors, and it has become global trouble. Insecticide remains in the environment, as a result of chemical insecticide treatment, have brought the researchers' attention to the search for new safe natural products (Murty and Jamil, 1987). In the past years, the plant kingdom has been of great concern as a potential resource of insecticidal products. Many scientists reported insecticidal activities of plants belonging to different families in diverse parts of the world. This may include crude, solvent extracts of other plants, essential oils from the seed or leaves, and their chromatographic fractions. Different developmental stages of vector mosquitoes were monitored by using this bioactive compound (Mittal and Subbarao, 2003). Many species in the plant kingdom produce a variety of secondary metabolites, which play a crucial role in defense of plants and also against insects/mosquitoes. Phytochemicals obtained from plants are generally much less environmentally harmful than synthetic chemicals, and it has renewed the attention in search of these compounds, considering them as an ecologically safe substitute for synthetic insecticides (Isman, 2006). In 1944 basically, plant extracts in a crude form and synthetic chemical larvicides mainly were used as usual insecticides before the organic laboratory-synthesized insecticides became available (Rawls, 1986; Rozendaal, 1997). Since 1920s, the use of phytochemicals in mosquito control was in focus (Shahi *et al.*, 2010), but the breakthrough of artificial insecticides such as DDT in 1939 sidetracked the application of phytochemicals in the mosquito control program. The overuse of synthetic insecticides becomes an environmental issue that is responsible for pollution of the environment and it causes ill-effect on non-target organisms as well as human beings. So phytochemicals become the alternate choice because these are simply biodegradable and have no harmful effects on non-target organisms as well as these are readily available. In view of that fact, the researchers are becoming centered towards the discovery of novel active ingredients from the plant source, and an effort is made to find out its chemical nature and profitable production. Several phytochemicals such as alkaloids, steroids, terpenoids, essential oils, and phenolics from different plant parts have been reported so far to possess insecticidal activities (Shaalan *et al.*, 2005; Ghosh *et al.*, 2012). Usually, chemical insecticides are made up of a single active ingredient, but the insecticides of plant origin contain one or more bioactive compounds, which are responsible for both abnormal behavior and physiological processes. There have been some plant families reported so far for their potential of serving as novel mosquito control agents; some of them are Asteraceae, Cladophoraceae, Labiatae, Meliaceae, Oocystaceae, and Rutaceae (Gupta, 2003).

The Solanaceae, to which the genus *Solanum* L. belongs, contains around 90 genera and about 2000-3000 species. This family is commonly distributed throughout tropical and temperate regions of the world, mainly their diversity occurring in Central and South America and Australia (Edmonds, 1978; D'Arcy, 1991). *Solanum* constitutes the largest and most complex genus within this family; it contains about 1500 species, most of which are also economically crucial throughout their multi-ethnic distribution. Examples of consuming plants are the potato (*Solanum tuberosum* L.), the Aubergine or eggplant (*Solanum melongena* L.), and the lulo or naranjilla (*Solanum quitoense* Lam.); the useful plants under horticulture, include the winter cherry (*Solanum pseudocapsicum* L.) and jasmine nightshade (*S. jasminoides* Paxt.); species farming for the development of drug include bittersweet (*Solanum dulcamara* L.) and *Solanum nigrum* Dun., both are used as the basis of corticosteroids. Its family also has tobacco (*Nicotiana* sp.) - one of the most harmful yet economically essential plants in the world. Belladonna or noxious nightshade (*Atropa belladonna* L.), stramonium (*Datura stramonium* L.), and black henbane (*Hyoscyamus niger* L.) are poisonous but have medicinal value. Though the species are distributed worldwide, they occur in their utmost concentrations in tropical and warm temperate regions with diversity in the Southern Hemisphere, particularly in South America. Other centers of speciation occur within Australia and Africa, with relatively few and less varied species being found in Europe and Asia (Symon, 1981; D'Arcy, 1991). The generic name *Solanum* is generally regarded to be derived from the Latin *Solamen* and also refers to have calming or soothing effects related to many of the species.

Systematic position of the genus *Solanum* is – Kingdom- Plantae; Class- Angiosperm; Order- Solanales; Family- Solanaceae; Genus - *Solanum.*

There are altogether 13 species under this genus (Table 1), which have been reported for mosquitocidal activity. The *Solanum* species with their mosquitocidal activities are discussed below.

1. *Solanum nigrum*:

The common name of *Solanum nigrum* L. is black nightshade. The plant is an annual herb with soft and smooth stems, and its branches are small straight, and subtle. It grows diffusely up to 1 m in height with several arching branches. The plant has alternate leaves, which are egg-shaped or elliptic. Flowers are in clusters and white. Fruit is commonly called a berry, which is green in color when unripe but turns purple or black when ripe having blue or black seeds (Edmonds and Chweya, 1977). Several medicinal properties of this plant have been studied; these include cancer, chemopreventive, antitumor, anti-inflammatory, antioxidant, antinociceptive, antipyretic, antiulcerogenic, hepatoprotective, and immunomodulatory effects (Cai *et al.*, 2010; Saleem *et al.*, 2010). The plant leaves are also consumed as a vegetable. The juice of the leaves by addition with other media like coconut water, coconut milk, buttermilk, cow's milk, and fruit juice can be consumed (Edmonds and Chweya, 1977).

Singh *et al.* (2001) studied the efficacy of different concentrations of the aqueous solution of *S. nigrum* against 1st – 4th instars larvae of *Anopheles culicifacies*, *Culex quinquefasciatus,* and *Aedes aegypti*. 100% larval mortality was observed within 24 h of the study period in *An. culicifacies* species A, *Cx. quinquefasciatus* and *Ae. aegypti* at a concentration of 0.2%. The LC_{50} values for I and II instar larvae of *An. culicifacies* species A and *Cx. quinquefasciatus* were 0.0167% and 0.019%, respectively, and for III and IV instar larvae, it was 0.027% in both the species. For III and IV instar larvae of *Ae. aegypti*, it was 0.032%. The LC_{90} values for I and II instar larvae of *An. culicifacies* species A and *Cx. quinquefasciatus* were 0.169% and 0.185%, respectively. The LC_{90} values for III and IV instar larvae of the three species were 0.176%, 0.205%, and 0.212%, respectively.

Raghavendra *et al.* (2009) reported the comparative efficacy of the aqueous and hexane extracts of dried fruit of *S. nigrum* against *An. culicifacies* species A, *An. culicifacies* species C, *An. stephensi*, *Cx. quinquefasciatus* and *Ae. aegypti*. At 1000 ppm with aqueous extract and at 100 ppm with hexane extract of dried fruits, all the five species recorded 100 % mortality in larval bioassays. In bioassays with aqueous extract *An. culicifacies* species A showed the lowest LC_{50} as 208.5 ppm (range-208.5-359 ppm for different mosquito species) while with hexane extract, *An. stephensi* registered the lowest LC_{50} as 6.25 ppm (6.25-17.63 ppm for different mosquito species). The LC_{90} value was in the range of 43.38-95.28 ppm for other species in the hexane extract of dried fruit.

The crude and different solvent extracts of leaves of this plant have been tested for their mosquito larvicidal properties against *Cx. quinquefasciatus* (Rawani *et al.*, 2010). LC_{50} values of crude extracts were 0.06 %, 0.02 %, 0.05%, 0.08% against 1st-4th instar larvae, respectively after 72 h of exposure. Among the solvent extracts, mortality rate with ethyl acetate extract was significantly higher ($P<0.05$) than other extracts when 50 ppm dose was used. The ethyl acetate extract showed 100% mortality of 3rd instar larvae of *Cx. quinquefasciatus.* The corresponding LC_{50} value of acetone, absolute alcohol, petroleum ether, chloroform: methanol (1:1 v/v), benzene, and ethyl acetate extracts were 72.91 ppm, 59.81 ppm, 54.11 ppm, 32.69 ppm, 27.95 ppm, and 17.04 ppm, respectively after 24 h. Further active ingredients (a glucosinolate) from ethyl acetate extract have been evaluated by Rawani *et al.* (2014). The isolated active ingredient was also tested on 1st-4th instar of *Cx. quinquefasciatus*. The

Table 1: List of plants under Solanum genus with their mosquitocidal activities

Solanum species	Plant parts used	Effective solvent extract	Target mosquito species	Lethal concentration/ biological activity	Other effects	References
Solanum nigrum	Leaf	Aqueous	*An. culicifacies*, *Cx. quinquefasciatus* and *Ae. aegypti*	0.0167%, 0.019% and 0.027 %	--	Singh *et al.* (2001)
	Dried fruit	Hexane	*Anopheles culicifacies* species A, *An. culicifacies* species C, *An. stephensi*, *Culex quinquefasciatus*, *Aedes aegypti*	15.93 ppm, 9.04 ppm, 6.25 ppm, 12.25 ppm, 17.63 ppm, respectively	--	Raghavendra *et al.* (2009)
	Leaf	Ethyl acetate	*Culex quinquefasciatus*	17.72 ppm after 24 h, 13.87 ppm after 48 h and 20.09 ppm after 72 h	--	Rawani *et al.* (2010)
	Stem and Leaf	Ethanol and chloroform	*Culex quinquefasciatus*	Both the extract of stem cause 92.77 % and 98.77 % mortality of tested larvae at 1500 ppm; Both the extract of leaf cause 100% mortality at 1500 ppm	Antibacterial	Yoganath *et al.* (2012)
	Green Berry	chloroform: methanol (1:1, v/v)	*Culex quinquefasciatus*	77.28 ppm after 24 h, 40.91 ppm after 48 h, 23.54 ppm after 72 h	--	Rawani *et al.* (2013a)
	AgNPs from Fresh leave, dry leaves and Green Berry	Synthesized nano particles	*Culex quinquefasciatus*, *An. stephensi*	1.33, 1.59, 1.56 ppm	--	Rawani *et al.* (2013b)
	Seed	Hexane	*Anopheles stephensi, Anopheles culicifacies* species A, *Culex quinquefasciatus*, *Aedes aegypti*	100% larval mortality after 24 h in *Anopheles culicifacies* species A, *Culex quinquefasciatus* and *Aedes aegypti* at a concentration of 0.2%	Repellent & oviposition deterrent	Singh and Mittal (2013)
	Leaf	Benzene	*Culex vishnui* group	11.59 ppm at 72 h	Molluscicidal activity	Rawani *et al.* (2014)
Solanum trilobatum	Leaf	Petroleum ether	*Cx. quinquefasciatus*		inhibited adult emergence	Muthukrishnan *et al.* (1997)
	Leaf	crude	*An. stephensi*		Ovicide, oviposition deterrent, repellent	Rajkumar and Jebanesan (2005)
	Leaf				Adult emergence inhibition and adulticidal	Zahir *et al.* (2010)
	Leaf	Titanium dioxide	*An. subpictus*	28.80, 24.01,	---	Rajkumar *et al.*

		nanoparticles		and 1.94 mg/L		(2013)
	Leaf	acetone, chloroform and methanol	*Aedes aegypti*, *Culex quinquefasciatus* and *Anopheles stephensi*	100% larval mortality at 250 ppm	Pupicidal and adult emergence inhibition	Premalatha *et al.* (2013)
	Aerial part	petroleum ether, chloroform, and acetone	*Cx. quinquefasciatus*	LC_{50} values was 203.87 and 165.04 ppm after 24 h and 72 h, respectively	--	Sakthivadivel *et al.* (2014)
Solanum nigrescens	Root	aqueous	*Ae. aegypti*	91.6 and 93.3%	Seasonal variation	Reyes-villanuev *et al.* (2008)
Solanum suratense	Leaf	Ethyl acetate	*Culex quinquefasciatus*		--	Muthukrishnan *et al.* 1997
Solanum tuberosum	Pulp	Crude, Chloroform and methanol	*An. stephensi* and *Cx. quinquefasciatus*		--	Singha and Chandra (2011)
Solanum lycocarpum	Green fruit	Methanol, dichloromethane, ethyl acetate	*Cx. quinquefasciatus*	126.24, 75.13, 83.15, and 207.05 mg/L	--	Pereira *et al .* (2014)
Solanum villosum	Leaf	petroleum ether, benzene, choloform:methanol (1:1 v/v), acetone, and absolute alcohol	*Culex quinquefasciatus*	645.745 ppm, 321.890 ppm, 204.302 ppm, 107.657 ppm, and 39.192 ppm at 24 h	--	Chowdhury *et al.* (2007)
	Leaf, root, stem	crude	*Culex quinquefasciatus*		--	Chowdhury and Chandra (2007)
	Green berry	aqueous and polar/non-polar solvent	*Stegomyia aegypti*	At 50 ppm maximum mortality	--	Chowdhury *et al.* (2008a)
	Leaf	Protein fraction	*Anopheles stephensi*, *Culex quinquefasciatus* and *Stegomyia aegypti*		antimicrobial	Chowdhury *et al.* (2008b)
	Leaf	Crude and solvent	*An. subpictus*	LC_{50} values 24.20 and 33.73 ppm after 24 h	--	Chowdhury *et al.* (2009)
Solanum xanthocarpum	Leaf	Volatile oil	*Cx. quinquefasciatus*	--	Repellency	Rajkumar and Jebanasan (2005)
	Fruit and root	Volatile oil	*Cx. quinquefasciatus, An. stephensi, Ae. Aegypti*	0.112 and 0.258, 0.058 and 0.289 and 0.052 and 0.218%	Repellency	Mohan *et al.* (2005)
		Crude	*Cx. quinquefasciatus, An. stephensi, Ae. Aegypti*			Mohan *et al* (2006)
	Green and ripe fruit, leaves and root	aqueous and methanol	*Anopheles culicifacies*, *Anopheles stephensi*, *Aedes aegypti, Cx. quinquefasciatus*	green unripe and yellow ripe fruits were 112.7, 498.2 and 846.3 mg/L and 104.7, 267.7 and 832.2 mg/L	--	Bansal *et al.* (2009a)
	fruits without seeds, whole yellow ripe fruits and seeds	Methanol	*An. culicifacies*, *An. stephensi*, *Ae. aegypti* and *Cx. quinquefasciatus*	51.6 and 66.9; 52.2 and 73.7; 118.3 mg/L	--	Bansal *et al.* (2009b)
	Leaf	Ethanol	*Aedes aegypti*			Changbunjog *et al.* (2010)
	Leaf	combination activities of temephos, fenthion and petroleum ether	*Cx. quinquefasciatus*	0.0144 and 0.0056 ppm at 24 and 48 h	--	Mohan *et al.* (2010)

	Leaf	Crude	*Culex quinquefasciatus*	LC_{50} and LC_{90} value of 1st -4th instar larvae were 155.29, 198.32, 271.12, 377.44 ppm	pupicidal	Mahesh Kumar *et al.* (2012)
Solanum indicum	Shoot	Crude	*Cx. quinquefasciatus.*	100% mortality at 100 ppm	--	Nazar *et al.* (2009)
	leaf	hexane, chloroform, ethyl acetate, methanol	*An. stephensi* and *Cx. quinquefasciatus*		--	Kamaraj *et al.* (2010)
Solanum torvum	Leaf	hexane, ethyl acetate, petroleum ether, acetone and methanol	*Cx. quinquefasciatus*	LC_{50} and LC_{90} values ranges between 20 to 120 ppm	--	Rahumn *et al.* (2008)
	Leaf and seed	hexane, chloroform, ethyl acetate, methanol	*An. stephensi* and *Cx. quinquefasciatus*	LC_{50} value 29.65 and 20.56 ppm		Kamaraj *et al.* (2010)
Solanum elaeagnifolium	Leaf	Crude	*Anopheles labranchiae*	LC_{50} value at 24h ranging from 28 to 325 ppm.	--	Markouk *et al.* (2000)
Solanum sisymbriifolium	Fruit	Crude	*An. gambiae* *An. funestus*	LC_{50} value was 0.75 g/ml for both mosquito species	larvicidal	Bagalwa *et al.* (2010)
Solanum sodomaeum	Leaf	Crude	*Anopheles labranchiae*	LC_{50} value at 24 h ranging from 28 to 325 ppm	--	Markouk *et al.* (2000)

mortality rate at a concentration of 25 mg/L of the active compound was the highest ($P<0.05$) amongst all tested concentrations. The subsequent LC_{50} values of mortality of 1st to 4th instar larvae were 10.08 ppm, 12.22 ppm, 13.93 ppm and 27.77 ppm, respectively after 72 h of exposure.

Yogananth *et al.* (2012) evaluated the larvicidal activity of ethanol, hexane, and chloroform extracts of stem and leaf of *S. nigrum* at different concentrations viz., 500, 1000, and 1500 ppm against *Cx. quinquefasciatus* mosquito. The larvicidal activity of ethanol extracts of stem and leaf of *S. nigrum* showed 92% and 100% mortality using 1500 ppm concentrations, respectively, after three days. After the third day 1000 ppm concentration killed more than 90% of the larvae in both extracts. Hexane extracts of stem and leaf of *S. nigrum* caused 73% and 82% death with respect to 1500 ppm concentration of extract, respectively. The larval mortality was below 60% at 1000 and 500 ppm concentrations. Chloroform extract of stem and leaf of *S. nigrum* showed greater than 50% mortality when 500 and 1000 ppm concentrations were used. Only the highest concentration (1500 ppm) of stem and leaf extracts showed 98% and 100% mortality, respectively. Among the two extracts, the leaf extract of *S. nigrum* was found more lethal than stem extracts.

Berry of this plant had also been reported for mosquitocidal activity against *Cx. quinquefasciatus* larvae (Rawani *et al.*, 2013a). 1st – 4th instar larvae of *Cx. quinquefasciatus* were exposed to crude and chloroform: methanol (1:1, v/v) extracts of fresh, mature, green berries of *S. nigrum*. In a 72 h bioassay experiment with crude extract, the highest mortality was recorded in 3 % crude extract. In the chloroform: methanol (1:1, v/v) solvent extract, the maximum mortality was recorded at a concentration of 120 μg/ml. The corresponding LC_{50} values of mortality of 1st- 4th instar larvae were 48.41, 54.20, 23.54 and 61.15 μg/ml, respectively after 72 h of exposure.

Silver nanoparticles were also synthesized by treating $AgNO_3$ solution with aqueous extracts of fresh leaves, dry leaves, and green berries of *S. nigrum*, which showed biocontrol potentiality against the larvae of *Cx. quinquefasciatus* and *An. stephensi* mosquito (Rawani *et al.*, 2013b). The synthesized nanoparticles are characterized with the help of UV–Vis spectroscopy, X-ray diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), and Transmission Electron Microscope (TEM) analyses. The nanoparticles were found in the range of 50–100 nm in size (average size of 56.6 nm) and are spherical to polyhedral in shape. In larvicidal bioassay experimentation with synthesized AgNPs, the most significant mortality was found at 10 ppm against *An. stephensi* with LC_{50} values of 1.33, 1.59, 1.56 ppm, and LC_{90} values of 3.97, 7.31 and 4.76 ppm for dry leaves, fresh leaves, and berries, respectively.

Singh and Mittal (2013) reported the repellent and oviposition deterrent activities of *S. nigrum* against malaria vector *An. stephensi*. Hexane extract of the seeds of *S. nigrum* was tested for repellent and oviposition deterrent activity against mosquito vector *An. stephensi*. Per cent protection obtained against *An. stephensi* was 100% at 0 h and 81% after 6 h at the 10% concentration of the extract compared to 100% after 6 h at 2.5% DEET solution. The concentrations of the hexane extract of the seeds of *S. nigrum* ranging between 0.03125 % and 0.5 % showed 27 to 99.5 % oviposition deterrence in treated bowls compared to untreated control.

Benzene extract of mature leaves of this plant had a promising larvicidal effect against larvae of *Culex vishnui* group (Rawani *et al.*, 2014). In a 72 h bioassay experiment with the aqueous extract, the highest mortality was recorded in 0.5% crude extract and 150 ppm in the benzene solvent extract against larvae of *Cx. vishnui* group. The LC_{50} value was 11.59 ppm at 72 h of exposure. Qualitative phytochemical analysis of the crude extract reported the presence of some secondary metabolites, such as saponin, flavonoids, steroids, and tannin. The toxic compound was detected by IR analysis having *R*f = 0.87 (showed 76.70 % mortality of larvae of *Cx. vishnui* group). IR analysis provided preliminary information about the aliphatic amide nature of the active ingredient. Rawani *et al.* (2014) and Yoganath *et al.* (2012) also reported molluscicidal and antibacterial activities of this species.

2. *Solanum trilobatum*:

*Solanum trilobatum***,** also known as thoodhuvalai*,* is basil which is used for the treatment of the common cold, cough, and asthma (Mihira *et al.*, 2011). The leaves and whole plant is full of thorns. It is also used as a common vegetable, but before cooking, thrones should be removed as they are considered as mildly toxic. By drying the leaves under shade and making a powder, the herb can be stored for a long time. In Southern India, it is ubiquitous and one of the most important medicinal plants. Its medicinal property helps cure numerous diseases, viz., tuberculosis, respiratory problems, and bronchial asthma. *S. trilobatum* has been reported to possess hepatoprotective activity, antimicrobial activity, antioxidant activity, cytotoxic activity, hemolytic activity, protective effect, immunomodulatory activity, and anti-inflammatory properties (Sahu *et al.*, 2013). Many authors also reported the mosquitocidal activity of this plant.

Muthukrishnan *et al.* (1997) tested the petroleum ether fraction of *S. trilobatum* against the larvae of *Cx. quinquefasciatus*. These active fractions of the plant extract interrupted moulting and metamorphosis; malformation has been induced, duration of the larval period has been extended, and inhibited adult emergence. At a concentration of less than 37.64 ppm, 50% emergence of the larvae to pupae have been inhibited.

Rajkumar and Jebanesan (2005) studied the oviposition deterrent and skin repellent activities of leaf extract of *S. trilobatum* under laboratory conditions. Concentrations of 0.01, 0.025, 0.05, 0.075 and 0.1% reduced egg-laying by gravid females from 18 to 99 % compared to ethanol-treated controls. In skin repellent tests, concentrations of 0.001, 0.005, 0.01, 0.015, and

0.02% provided 70 to 120 min of protection against mosquito bites, whereas the ethanol control provided only 2.2 min of protection.

The plant was also reported for its mosquitocidal property, which includes ovicidal activity against *Cx. quinquefasciatus* and *Culex tritaeniorhynchus* (Rajkumar and Jebanasan, 2004). Zahir *et al.* (2009) evaluated the adult emergence inhibition and adulticidal activities of hexane, chloroform, ethyl acetate, and acetone extracts of leaves of *S. trilobatum* against *An. stephensi*. Rajkumar *et al.* (2013) investigated the mosquito larvicidal efficacies of synthesized titanium dioxide nanoparticles (TiO_2 NPs) by using aqueous leaf extract of *S. trilobatum* against the fourth instar larvae of the malaria vector *Anopheles subpictus* Grassi (Diptera: Culicidae). In the mosquito larvicidal activity, the average per cent mortality for synthesized TiO_2 NPs was 38, 47, 66, 79, and 100 at 1, 2, 3, 4, and 5 mg/L, respectively. The activity was observed in the aqueous leaf extract of *S. trilobatum*, $TiO(OH)_2$ solutions, and synthesized TiO_2 NPs against *An. subpictus* which showed LC_{50} values as 28.80, 24.01, and 1.94 mg/L and R^2 values as 0.965, 0.998, and 0.985, respectively.

Premalatha *et al.* (2013) reported the acetone, chloroform, and methanol leaf extracts of *S. trilobatum* for their larvicidal, pupicidal, and adult emergence inhibition properties against *Ae. aegypti*, *Cx. quinquefasciatus* and *An. stephensi*. The methanol leaf extract of *S. trilobatum* exhibited 100% larval mortality in *Cx. quinquefasciatus*, *Ae. aegypti* and *An. stephensi* at 250 ppm concentration.

Saktivedivel *et al.* (2014) reported the larvicidal activity of petroleum ether, chloroform, and acetone extracts of aerial parts of *S. trilobatum* against the filarial vector, *Cx. quinquefasciatus*. The larvicidal activity was recorded at the concentrations of 62.5, 125, 250, 500, and 1000 mg/L. Among the different solvent extracts tested, petroleum ether exhibited the highest larvicidal activity, and LC_{50} values after 24 and 48 h were 203.87 and 165.04, followed by acetone and chloroform extract, which were 295.87 and 186.38, and 535.74 and 346.08 mg/L, respectively.

3. *Solanum nigrescens*:

It is perennial or sub-shrub with a size of up to two meters high grass. There are short white hairs which covered the whole stem. The size of the leaves is up to 9 cm long with smooth or jagged edges. An umbel-shaped inflorescence is present; flowers are star-shaped with white petals of up to one centimeter wide. The base of corolla lobes has a green spot. Anthers are yellow and a few millimeters in length. The flowers bloom for much of the year. The fruit is a spherical-shaped berry that is a centimeter wide (Brako and Zarucchi, 1933). The plant is used as a folk medicine in Guatemala for the treatment of certain superficial fungal infections, particularly vaginitis (Giron *et al.*, 1988).

Reyes-Villanueva *et al.* (2008) conducted monthly bioassays with fresh field-collected *S. nigrescens* to evaluate seasonal variation in mosquito larvicidal activity with different plant parts. Mean percentage mortality of *Ae. aegypti* larvae were 46.7% and 63.4% in aqueous extracts of crushed plant and entire plant of *S. nigrescens*, respectively. Then, monthly bioassays of fresh field-collected *S. nigrescens* were also conducted to evaluate seasonal variation in larvicidal activity with different plant parts. Only extracts of crushed (range 83-100% mortality) and entire (range 88 – 98 % mortality) root were toxic to *Ae. aegypti* larvae. The monthly average mortality was 91.6% and 93.3% for aqueous extracts of the crushed and whole root of *S. nigrescens*.

4. *Solanum suratense*:

The common name of the *S. suratense* is Kanteli. It is a beneficial Ayurvedic herb, used widely to treat cough, cold, asthma, and other such respiratory tract problems (Shastry, 2005). It is one among Dashamoola that is a group of ten roots.

Muthukrishnan *et al.* (1997) reported the larvicidal activity of ethyl acetate extract of leaf of *S. suratense* against *Cx. quinquefasciatus* larvae. The active ethyl acetate extract has an LC_{50} value as 23.53 ppm after 24 h for the second instar and 46.04 ppm for the third instar larvae.

5. *Solanum tuberosum*:

Solanum tuberosum L. is a starchy, tuberous crop commonly known as potato. The plants are herbaceous perennials that grow about 60 cm (24 inches) high, depending on variety, with the culms dying back after flowering, fruiting, and tuber formation. Flowers carry yellow stamens and bear different colors such as white, pink, red, blue, or purple. In general, depending upon the color of the flower, the tubers are of different varieties. White flowers have white skins, while those with colored flowers tend to have pinkish skins (Winch, 2006). Potatoes are used to prepare alcoholic beverages such as vodka, potcheen, or aquavit. They are also serving as food for domestic animals. Potato starch is used in food manufacturing in various ways, such as thickeners and binders of soups and sauces; in the textile industry, as adhesives; and manufacturing papers and boards (Campbell *et al.*, 1997).

Singha and Chandra (2011) investigated the larvicidal activities of crude, chloroform, and methanol extracts of germinated tuber of *S. tuberosum* against *An. stephensi* and *Cx. quinquefasciatus* mosquito larvae with promising results. Larval mortality of above mosquito species was observed after 24, 48 and 72 h of exposure to five concentrations of aqueous extract (0.1%, 0.2%, 0.3%, 0.4% and 0.5%) and four concentrations (25, 50, 75, 100 ppm) of chloroform: methanol (1:1 v/v) extract. The highest mortality was observed in 0.5% crude extracts of spices and vegetable wastes, significantly higher than the mortality rates at 0.1%, 0.2%, 0.3%, and 0.4% concentrations. In chloroform: methanol (1:1 v/v) extract, 75 ppm concentration showed the highest mortality in both mosquito species. The LC_{50} and LC_{90} values of aqueous extract of tuber of *S. tuberosum* were 0.81 ppm and 3.26 ppm; and 0.62 ppm and 1.90 ppm against *An. stephensi* and *Cx. quinquefasciatus* mosquito larvae, respectively.

6. *Solanum lycocarpum*:

The plant is a shrub, and its height ranges from 1.2 to 3 m. The leaves are large, deeply lobed, and covered with soft grey-white fuzz. The flowers are star-shaped and blue or purple, bloom early or late in spring, and look like bitter nightshade flowers. The fruits are up to 13 cm in diameter, having golden yellow color and have variable red blushing when ripe. There is no proven medicine reported from the plant, but it can be used for diabetes (Oliveira-Filho and Oliveira, 1988, Lombardi and Motta, 1993). It is also believed that the plant is helpful to prevent infection from the giant kidney worm to the maned wolf, which becomes fatal for the animal.

Pereira *et al.* (2014) investigated the larvicidal activity of extracts of the green fruits of *S. lycocarpum* against larvae of *Cx. quinquefasciatus*. 3rd and 4th instar larvae of *Cx. quinquefasciatus* were exposed to different concentrations (12.5, 50, and 200 mg/L) of the methanol extract. Dichloromethane and ethyl acetate fractions showed the most significant larvicidal efficacy at 200 mg/L (83.3% and 86.7% mortality, respectively). The methanol, dichloromethane, ethyl acetate, and hydromethanolic fractions demonstrated the larvicidal effects against *Cx. quinquefasciatus*, with LC_{50} values of 126.24, 75.13, 83.15, and 207.05 mg/L, respectively.

7. *Solanum villosum*:

Solanum villosum Mill. (Solanales: Solanaceae) is commonly known as Woolly Nightshade. In India, Europe, Northern Africa, North America, it is a slumping annual weed and naturalized in Australia. The plant is up to 70 cm in height, covered with dense hairs. The leaf is 8 cm long, 3–6 cm wide, the leaf blade is ovate, it may be entire or shallowly lobed, and 4.5 cm long petiole is present. Clusters of 3–8 flowers are in the inflorescence. The corolla is white. The berries are 5–9 mm in diameter, globular in shape, and dull orange-red. The seeds are pale yellow and 1.7–2.3 mm long (Symon, 1981). *S. villosum* is an ayurvedic herb with numerous folk medicinal properties used for swelling, sore eyes, etc. This plant is widely available to the local people (Miller, 1768). Leaves of this plant are also consumed as boiled salad, and its orange berries are consumed as fruits (Olet *et al.*, 2005).

Chowdhury and Chandra (2007) performed phytochemical screening and efficacy of extracts of *S. villosum* on juveniles of *Cx. quinquefasciatus*. Extracts of green berry, stem, and root of *S. villosum* were evaluated against fourth instar larvae of *Cx. quinquefasciatus*. All extracts showed larvicidal activity. The LC_{50} values of these extracts were 0.155, 0.043 and 0.263 ml/L, respectively after 24 h. Qualitative analyses of the phytochemicals of aqueous extracts revealed the presence of carbohydrates, alkaloids, and saponins in all plant parts.

Chowdhury *et al.* (2007) extracted the dried leaves of *S. villosum* with five different solvents. Each batch of larvae (10 per batch) was treated with 30 ppm, 50 ppm, and 100 ppm of each solvent extract in 3 replicates. LC_{50} values of the leaves of different solvent extracts like petroleum ether, absolute alcohol, benzene, acetone and chloroform: methanol (1:1 v/v) were 645.745 ppm, 321.890 ppm, 204.302 ppm, 107.657 ppm, and 39.192 ppm, respectively, after 24 h of the exposure. The mortality rate with chloroform: methanol (1:1 v/v) extract was significantly higher ($P < 0.05$) in 100 ppm than the other extracts. The bioactive fraction of chloroform: methanol (1:1 v/v) was isolated by thin layer chromatography (TLC), and the LC_{50} value was determined as 3.179 mg/100 ml after 24 h of the study period.

Chowdhury *et al.* (2008a) tested the aqueous and different polar and non-polar solvent extract of fresh, mature, green berries of *S. villosum* against larvae of *Stegomyia aegypti*. In 72 h bioassay experimentation with the aqueous extract, the highest mortality was recorded in 0.5% extract. When the mortality of different solvent extracts was evaluated, the maximum ($P < 0.05$) mortality was observed at a concentration of 50 ppm of chloroform: methanol extract (1:1, v/v). The larvicidal activity was lower when compared with the chemical insecticide, Malathion ($P < 0.05$). Two toxic compounds were detected having *R*f = 0.82 (70% and 73.33% mortality at 24 and 48 h, respectively) and *R*f = 0.95 (40% and 50% mortality at 24 and 48 h, respectively). IR analysis provided prelude information about the steroidal nature of the bioactive compound.

Chowdhury *et al.* (2008b) reported mosquito larvicidal activity of protein isolated from leaves of *S. villosum*. Proteins isolated from mature leaves of *S. villosum* were found to have larvicidal properties against third instar larvae of *Cx. quinquefasciatus*, *An. stephensi* and *St. aegypti.* The observed LC_{50} and LC_{90} values were 644.745 ppm, 1882.42 ppm; 645.75 ppm, 1890.67 ppm; and 747.22 ppm, 2220.01 ppm, respectively, against *Cx. quinquefasciatus*, *An. stephensi* and *St. aegypti.* Fifteen amino acids were identified in the isolated protein, of which eight were essential amino acids. SDS-PAGE was detected with seven bands corresponding to different molecular weights in the range of 69-109 KDa.

Chowdhury *et al.* (2009) evaluated the larvicidal efficacy of *S. villosum* leaves against *An. subpictus* Grassi and showed the effect on non-target organisms, *Chironomus circumdatus.* All the concentrations (30, 50, 100 and 200 ppm) showed significant ($P < 0.05$) larval mortality. LC_{50} values for all instars were between 24.20 and 33.73 ppm after 24 h and between 23.47 and 30.63 ppm after 48 h of the exposure period. Qualitative and chromatographic analysis of the solvent extract revealed the presence of carbohydrates, saponins, terpenoids, volatile oil, steroids, phenols, and flavonoids as major bioactive phytochemicals.

8. *Solanum xanthocarpum*:

S. xanthocarpum is an annual herbaceous plant. In Hindi, it is called Kantkari. In India, it is mainly grown in Uttar Pradesh, Bihar, Uttranchal, Punjab, West Bengal, Assam, and other North-East states. It is a perennial herb, very prickly diffuse bright green somewhat woody at the base; the stem is rather zigzag, the younger branches are covered with dense stellate tomentum. There is presence of prickles more or less 1.3 cm in size, which are dense, straight, yellow, glabrous, and shining. Leaves are ovate or elliptic, sinuate or sub-pinnatifid, obtuse or subacute in shape usually 5-10 in numbers and 2.5-5.7 cm in length, having stellate hairs on both sides. The berries are green when unripe but yellow when mature. They are 1.3-2 cm in diameter, yellow or white with green veins, surrounded by the enlarged calyx (Kirtikar and Basu, 2005). The root is one of the components of Dasamulasava (Sridevi *et al.*, 2009). Seeds are used as diuretics (Ranka *et al.*, 2013). Juice of berry was reported for the treatment of sore throat. It also promotes conception in females and is used in gonorrhea. It is also reported to be helpful in cough and bronchial asthma (Gupta *et al.*, 1966; Jain, 1980; Govindan *et al.*, 1999).

Rajkumar and Jebanasan (2005) reported the repellent effects of the fruit extracts of *S. xanthocarpum* against *Cx. quinquefasciatus.* By steam distillation of the leaves of *S. xanthocarpum,* volatile oils were extracted. The volatile oil of *S. xanthocarpum* was tested in the range of 2 to 8% concentration. The 8% concentration gave more protection, about 311.4 min, whereas control provides only 4.4 min of protection against mosquito bites. The results recommend that the volatile oil of this plant was very effective as repellents and gave more than 300 min of protection against the bite of *Cx. quinquefasciatus.*

Mohan *et al.* (2005) also reported the efficacy of fruit extracts of *S. xanthocarpum* against *An. stephensi* and *Cx. quinquefasciatus* larvae. Crude, carbon tetrachloride, methanol, and petroleum ether extracts of fruit of *S. xanthocarpum* were studied. Among the tested extract, the carbon tetrachloride extract was the most effective with LC_{50} value of 5.11 ppm after 24 h and 1.27 ppm after 48 h against *An. stephensi.* In the case of *Cx. quinquefasciatus* the petroleum ether extract was most toxic with LC_{50} values of 62.62 ppm after 24 h and 59.45 ppm after 48 h.

Mohan *et al.* (2006) studied the larvicidal efficacy of different root extracts of *S. xanthocarpum* against *Cx. quinquefasciatus* and advocated its use as an eco-friendly, effective larvicide in the management of mosquito populations and in limiting the outbreak of various vector-borne epidemics. Among the different solvent extracts, petroleum ether extract showed the most significant mortality with LC_{50} as 41.28 ppm after 24 h and 38.48 ppm after 48 h post-treatment.

Bansal *et al.* (2009a) reported larvicidal activity of the aqueous and methanol extracts of green unripe and yellow ripe fruits, seeds, leaves, and roots of *S. xanthocarpum* against *An. culicifacies*, *An. stephensi*, *Ae. aegypti* and *Cx. quinquefasciatus*. Bioassay was carried out on the late 3rd or early 4th instar larvae of these species. The LC_{50} values observed for aqueous extracts for green unripe and yellow ripe fruits were 112.7, 498.2, and 846.3 mg/L and 104.7, 267.7, and 832.mg/L for *An. stephensi*, *Ae. aegypti* and *Cx. quinquefasciatus*, respectively after 24 h of post-exposure. For methanol extracts of yellow ripe fruits and seeds, the LC_{50} values were 51.6, 52.2, 118.3, and 157.1 mg/L and 66.9, 73.7, 123.8, and 154.9 mg/L after 24 h for the above said four-vector species, respectively.

Bansal *et al.* (2009b) reported the efficacy of the methanol extracts from fruits without seeds, whole yellow ripe fruits, and seeds of *S. xanthocarpum* against larvae of *An. culicifacies*, *An. stephensi*, *Ae. aegypti* and *Cx. quinquefasciatus*. The LC_{50} values after 24 h of exposure for fruit without seeds, whole fruits, and seeds after six months were 79.6, 91.7 and 131.7; 131.4, 186.9 and 195.6; 273.4, 290.9 and 377.6 and 384.9, 450.6 and 520.0 mg/L for *An. culicifacies*, *An. stephensi*, *Ae. aegypti* and *Cx. quinquefasciatus*, respectively. The LC_{50} values were also calculated after one year of fruit storage without seeds, whole fruits, and seeds. The values were 103.3, 120.1 and 195.7; 146.3, 224.3 and 251.2; 316.9, 336.5 and 426.2 and 393.0, 500.3 and 656.7 mg/L as compared to the 24 h LC_{50} values of 47.4, 51.6 and 66.9; 52.3, 52.2 and 73.7; 108.0, 118.3 and 123.8 and 141.1, 157.1 and 154.9 mg/L for the above four-vector species, respectively. The results showed that the efficacy of the seed was further decreased after one year of storage. HPLC and IR studies provided information about the presence of the active component in the fruits and seeds of this plant species.

Changbunjong *et al.* (2010) investigated the efficacy of ethanolic extract from *S. xanthocarpum* against the larvae of *Ae. aegypti*, vector of dengue hemorrhagic fever and *Cx. quinquefasciatus*. The LC_{50} values against the larvae of *Ae. aegypti* and *Cx. quinquefasciatus* were 788.10 and 573.20 mg/L, while the LC_{90} were 1,288.91 and 1,066.93 mg/L, respectively.

Mohan *et al.* (2010) evaluated the combined activities of temephos, fenthion, and petroleum ether extract of *S. xanthocarpum* against larvae of *Cx. quinquefasciatus*. At different ratios such as 1:1, 1:2, and 1:4, the temephos and *S. xanthocarpum* was combined and studied. Similar ratios were also combined for the fenthion and *S. xanthocarpum*. There was antagonistic activity observed in the temephos/plant extract combination. In comparison, the combination of fenthion and plant extract provided a synergistic effect against the target organisms at a ratio of 1:1. The LC_{50} values calculated were 0.0144 and 0.0056 ppm and LC_{90} as 0.0958 and 0.0209 ppm after 24 and 48 h post-exposure, respectively.

Mahesh Kumar *et al.* (2012) studied the biocontrol efficacy of *S. xanthocarpum* leaf extract and bacterial insecticide, *Bacillus thuringiensis*, against the first to fourth instar larvae and pupae of *Cx. quinquefasciatus*. The plant materials were dried in the shade and extracted with ethanol. The LC_{50} and LC_{90} of *S. xanthocarpum* against the first to fourth instar larvae and pupae were 155.29, 198.32, 271.12, 377.44 and 448.41 ppm; and 687.14, 913.10, 1,011.89, 1,058.85, and 1,141.65 ppm, respectively. On the other hand, the LC_{50} values for *B. thuringiensis* against the first to fourth instar larvae and pupae were 133.88, 157.14, 179.44, 206.80, and 240.74 ppm; the LC_{90} values were 321.04, 346.89, 388.86, 430.95, and 492.70 ppm, respectively. Nevertheless, when the extract of *S. xanthocarpum* and *B. thuringiensis* combined in the ratio of 1:2 showed the highest larvicidal and pupicidal activity with the LC_{50} values of 126.81, 137.62, 169.14, 238.27, and 316.02 ppm and the LC_{90} values of 476.36, 613.49, 705.29, 887.85, and 1,041.73 ppm against *Cx. quinquefasciatus* in all the tested concentrations than the individuals and ascertained a significant amount of synergist act. Mahesh Kumar *et al.* (2012) reported the larvicidal and pupicidal activities of fruit extract of *S. xanthocarpum* against the larval instars of *Ae. aegypti*. The lowest LC_{50} calculated was 170.91 ppm.

9. *Solanum indicum*:

Solanum indicum is one among ten roots known as Dashamoola group, having strong anti-inflammatory activity. The common name of this plant is Indian nightshade and African eggplant. It is found throughout India. Roots have several properties, such as it acts as a diaphoretic, diuretic, expectorant, and stimulant. The root is also helpful in treating bronchitis, itches, body aches, asthma, and curing wounds. Seeds are also used to treat toothache. By placing the leaves in the cradles of infants is helpful to promote sleep. It also helps in the treatment of cutaneous disorders. The juice of root has been used for the treatment of ringworm, gout, and earache. When mixed with vinegar, it is deemed suitable for gargle and mouthwash (Shastry, 2005).

Nazar *et al.* (2009) screened 19 Indian coastal plants, in which *S. indicum* was one of them. Crude extract of shoot was tested on larvae of *Cx. quinquefasciatus*. The percentage mortality of 4th instar larvae observed were 24, 40, 53, 58, 70, 81, 100% at 40, 50, 60, 70, 80, 90, 100 mg/L concentration, respectively. The LC_{50} value was 62 mg/L after 24 h of the exposure period.

Kamaraj *et al.* (2010) reported the mosquito larvicidal activity of *S. indicum.* The leaves were extracted with hexane, chloroform, ethyl acetate and methanol and tested against 4th instar larvae of *An. stephensi* and *Cx. quinquefasciatus* at 1000 ppm. Percentage mortality of 4th instar larvae of *An. stephensi* and *Cx. quinquefasciatus* after 24 h of exposure were 22, 48, 47, 65, 85% and 67, 53, 64, 75, 93% in different solvent extracts, respectively.

10. *Solanum torvum*:

Solanum torvum (Turkey Berry) is also known as Devil's Fig**,** Prickly Nightshade. It is a perennial plant that is bushy, erect, and spiny. It is more or less 2 or 3 m in height, having a 2 cm basal diameter, but the plant's growth may reach up to 5 m in height with an 8 cm basal diameter. The plants are also grafted, which are very vigorous and can tolerate diseases affecting the root system; thus, the crop continues for a second year. The stem bark has raised lenticels and is smooth and gray. The inner bark has two colors outer green layer and inner ivory color (Little *et al.*, 1974). The twigs are covered with star-shaped hairs and gray-green. The spines vary in thickness throughout the plant and are short and slightly curved. The fruits are known as berries that imitate green peas, grow in clusters, and are spherical (1 cm in diameter). When fruits are fully ripe, they become yellow. The fruit is thin-fleshed and contains numerous flat, round, brown seeds (Little *et al.*, 1974; Howard, 1989). It is used extensively worldwide in traditional medicine as poison, anti-dote, and for treating fever, wounds, tooth decay, reproductive problems, and arterial hypertension (Ndebia *et al.*, 2007). *S. torvum* is also reported to have antimicrobial (Ajaiyeoba, 1999; Chah, 2000), antiviral (Arthan, 2002), immuno-secretory (Israf, 2004), antioxidant (Sivapriya and Srinivas, 2007), analgesic and anti-inflammatory (Ndebia *et al.*, 2007) and anti-ulcerogenic properties (Nguelefack *et al.*, 2008). The plant also possesses cardiovascular (Mohan *et al.*, 2009), nephroprotective (Mohon *et al.*, 2010), antidiabetic (Gandhi *et al.*, 2011), angiotensin, and Serotonin receptor blocking activities (Jaiswal and Mohan, 2012).

Rahuman *et al.* (2008) studied the larvicidal activity of the leaf of *S. torvum* against the early fourth-instar larvae of *Cx. quinquefasciatus*. The percentage mortality obtained after 24 h exposure was 36, 52, 78, 60, and 14% in hexane, ethyl acetate, petroleum ether, acetone, and methanol extracts, respectively, at 1000 ppm concentration.

Kamaraj *et al.* (2010) also reported the larvicidal activity of *S. torvum.* The leaves and seeds were extracted with hexane, chloroform, ethyl acetate and methanol and tested against 4th instar larvae of *An. stephensi* and *Cx. quinquefasciatus* at 1000 ppm. Percentage mortality after 24 h of exposure were 72, 84, 87, 85, and 100% and 80, 78, 74, 83, and 100% for *An. stephensi* and *Cx. quinquefasciatus* in different solvent extracts of leaves, respectively. In different solvent extracts of seed, percentage mortality after 24 h of exposure were 84, 73, 82, 87, and 100 % and 78, 66, 73, 86, and 100 % for *An. stephensi* and *Cx. quinquefasciatus* respectively. Methanol extract showed the greatest mortality in both mosquito species. The LC_{50} value obtained were 29.65 ppm and 20.56 ppm (Leaf) and 31.30 ppm and 25.60 ppm (seed) against *An. stephensi* and *Cx. quinquefasciatus*, respectively.

11. *Solanum elaeagnifolium*:

Silver-leaf Nightshade**,** *Solanum elaeagnifolium*, is a widespread weed in western North America and South America. It is a perennial plant upto10 cm to 1 m in height. The stems are covered with nettle-like prickles, varying from one plant to another plant. Leaves and stems stretch out and hide the surface, giving a silvery or grayish appearance, and are covered with downy hairs, also called trichomes (Niehaus *et al.*, 1985). The leaves have shallowly waved edges and are up to 15 cm long and 0.5 to 2.5 cm wide. During winter, the plant produces glossy yellow, orange, or red berries, which may turn brown as they dry (Cronquist, 1984).

Markouk *et al.* (2000) studied the efficacy of 16 extracts of *S. elaeagnifolium* against *Anopheles labranchiae* mosquito larvae. Only nine extracts possess more significant larval mortality from the sixteen extracts, with the LC_{50} values ranging from 28 to 325 ppm after 24 h of the exposure period.

12. *Solanum sisymbriifolium*:

Solanum sisymbriifolium is commonly known as sticky nightshade and vila vila in different parts of world. The plant is generally grown as spiny, green husk. The fruits are red in color and its flavor resembles sour cherries and a little bit like the tomatoes (Tiwari and Ravikumar, 2014). It has been widely introduced as a trap crop for potato cyst nematodes. However, it is an aggressive weed that spreads by seeds and vegetatively by rhizomes (Timmermans *et al.* 2007). As the plant is covered with prickles, it can also be used as a hedge plant to keep animals away from a garden.

Bagalwa *et al.* (2010) evaluated the mosquito larvicidal activities of *S. sisymbriifolium* against *An. gambiae* and *An. funestus*. The calculated value of LC_{50} for both the mosquito species was 0.75 g/ml.

13. *Solanum sodomaeum*:

It is a shrub with hairs and spines, growing to a height of 1.5 m. Leaves are dark green, ovate with 2-3 serrate lobes. Flowers are violet in color. Fruit is almost globose shaped with many seeds, up to 3 cm in size and orange in color. The plant is indigenous to the Mediterranean and is plowed in Baguio and Manila gardens, propagated by seeds. The common name of this plant is the apple of Sodom (Siddiqi, 1978). It is used for cystitis, dermatitis, ringworm, pleurisy, sore throat, toothaches, and infertility. In the Congo, it is used for hypertension. In the Eastern Cape, South Africa**,** treatment of skin rashes is done by the poultice of fruit and leaves in oil or fat. In Paraguay, it is used for its diuretic, anticancer and antihypertensive properties (Cham and Meares, 1987).

Markouk *et al.* (2000) evaluated the efficacy of 16 extracts of *S. sodomaeum* against *Anopheles labranchiae* mosquito larvae. Nine extracts out of sixteen extracts showed the most significant mortality. The LC_{50} values of these nine extracts ranged from 28 to 325 ppm after 24 h of the exposure period.

Chemical constituents:

S. nigrum has pharmacological activities due to the presence of various compounds that are responsible for this activity. Its active components are glycoalkaloids, glycoproteins, and polysaccharides, polyphenolic compounds such as gallic acid, catechin, protocatechuic acid (PCA), caffeic acid, epicatechin, rutin, and naringenin (Ravi *et al.*, 2009). The presence of glucosinolate was reported by Rawani *et al.* (2014), the compound which showed good mosquitocidal activity. Chowdhury *et al.* (2009) reported phytosteroid from *S. villosum* having promising mosquito larvicidal activity.

S. xanthocarpum contains alkaloids, sterols, saponins, flavonoids, glycosides, amino acids, etc. (Gupta and Dutta, 1938). Besides, these fruits were reported to contain solasodine glycosides (Verbist and Monnet, 1974). Some species of *Solanum* contain secondary metabolite, which is plant-derived. These are alkanes, alkenes, alkynes, simple aromatics, lactones, essential oils, and fatty acids terpenes, alkaloids, steroids, isoflavonoids, pterocarpans, and lignans.

Mode of action of phytochemicals:

The plant produces various kinds of secondary metabolites that defense the plant. Insects that fed upon this affect their physiological activities in many different ways, such as it acted on various receptor sites, which in turn causes abnormalities in the nervous system (affect the neurotransmitter synthesis). Rattan (2010) also provided the idea about the plant derivative mode of action on insect body and predicted that several physiological processes become disrupted, such as inhibition of acetylcholinesterase by essential oils and inhibition of GABA-gated chloride channel by thymol, etc. Senthilnathan *et al.* (2008) also reported that acetylcholinerase activity is a crucial enzyme responsible for terminating the nerve impulse transmission through the synaptic pathway. This AChE has been observed to be organophosphate and carbamate resistant, and thus, it is well-known that the change in AChE is one of the main resistance mechanisms in insect pests. So, if there is any inhibition of AChE activity, it would disrupt some most important physiological activities.

Today's most crucially important issue is environmental safety. The most crucial factor of an insecticide is causing the mortality of the target organism and keeping the environment free of insecticidal pollution. A bioactive compound from the plant origin may serve as an insecticide as these are eco-friendly, cost-effective, and readily available in many parts of the world. Some plant parts are used in traditional medicines and are effective against mosquito larvae in many parts of the world. In recent years the natural products of herbal origin have been given much priority due to their evergreen nature, low cost, inherent biodegradability, and easy use (Green, 1991; Sakthivadivel and Thilagavathy, 2003). Insecticides of botanical origin have been given importance because of the expensiveness of synthetic insecticides with the increase of the resistance (VCRC, 1989), cross-resistance, and toxicity hazards associated with them. On the other hand, plants are loaded with effective phytochemicals that recommend an advantage over synthetic pesticides as there is less probability of development of resistance, and also, it is less toxic to other non-target organisms. Conventionally in many parts of the world, the botanical derivative has been used by human communities against vectors and pests (Jacobson, 1958). Botanical extracts have been effectively tested for various biocontrol programs (Markouk *et al.*, 2000; Jayabalan *et al.*, 2003; Sharma *et al.*, 2004, 2006; Choochote *et al.*, 2004). Effective larvicides from some selected botanicals have been shown toxic to the larval form and are more ecofriendly without affecting non-target organisms (Prakash and Rao, 1997; Ghosh *et al.*, 2008; Chowdhury *et al.*, 2009). Among the different plants reported for the mosquito larvicidal activities in many parts of the world, Genus *Solanum* is one of them. Out of 1500 species of *Solanum*, 13 species have been found to have mosquitocidal activity. This review has shown that the crude, petroleum ether, benzene, ethyl acetate, chloroform, methanol, chloroform: methanol (1:1 v/v), acetone and ethanol extracts of different parts of plants of this Genus, such as leaf, stem, root, green berries, dried fruits, bark, whole plant, and essential oil have remarkable larvicidal activities against different mosquito vectors viz., *An. stephensi*, *Ae.* aegypti, *Cx. quinquefasciatus*, *An. subpictus, An. culicifacies* species A, *An. culicifacies* species C, *Cx. vishnui* group and *An. labranchiae*.

This review has focused on different species of Genus *Solanum* which possess important medicinal plants and show strong larvicidal efficacy against different mosquito vectors. Besides mosquito larvicidal activity, these plant sources can also act as an adulticide, ovicide, pupicide, insect growth regulator, repellent, and ovipositional attractant/deterrent. Among 13 species of *Solanum* reported *S. trilobatum* and *S. suratense* were reported first to have mosquito larvicidal activity by Muthukrishnan *et al.* (1997). Among these, crude and different solvent extracts of mature leaf extract of *S. nigrum* and *S. villosum* showed more significant larval mortality at a low concentration. The active ingredient has also been analyzed, which showed the presence of glucosinolate and phytosteroid, respectively from these two species (Chowdhury *et al.*, 2008a, b; Rawani *et al.*, 2010, 2014). Berries of these two plants have been reported for their mosquitocidal activity. *S. trilobatum* and *S. xanthocarpum* have also been studied by many authors for their different mosquitocidal activities such as larvicidal, pupicidal, adult emergence inhibition, adulticidal, adult emergence, repellent, oviposition attractant, and deterrent, etc. Other eight species have shown higher values of LC_{50}. They have shown activity at very high concentrations. Among the different mosquito species, *An. stephensi* and *Cx. quinquefasciatus* have shown the highest mortality, which means these two species are more susceptible to these plant extracts tested. Ethyl acetate extract of leaf of *S. nigrum* showed the highest mortality of *Cx. quinquefasciatus* (Rawani *et al.*, 2010). *An. culicifacies* species C, *An. stephensi*, and *Cx. quinquefasciatus* are more susceptible to hexane extract of dried fruit of *S. nigrum*. The aqueous root extract of *S. nigrescens* has presented good mortality against *Ae. aegypti*. *An. subpictus* is more susceptible towards crude and solvent extract of leaf of *S. villosum* (Chowdhury *et al.*, 2009). *Stegomyia aegypti* has shown maximum mortality in aqueous and polar/non-polar solvent extract of the green berry of *S. villosum* (Chowdhury *et al.*, 2008a). Hexane, ethyl acetate, petroleum ether, acetone, and methanol extracts of leaf of *S. torvum* have shown the highest mortality against *Cx. quinquefasciatus* (Rahuman *et al.*, 2008). Crude extract of shoot of *S. indicum* has shown 100% mortality in *Cx. quinquefasciatus* (Nazar *et al.*, 2009). *An. labranchiae* is more susceptible to crude leaf extract of *S. elaeagnifolium* and *S. sodomaeum* (Markouk, 2000). 13 species of different plant parts of *Solanum* have been found to have mosquitocidal activities. Other species of this genus should also be examined for such efficiency.

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