

Review Article

Use of neem (*Azadirachta indica* A. Juss) as a biopesticide in agriculture: A review

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Abstract

Neem (*Azadirachta indica* A. Juss) is a member of Meliaceae family, a fast-growing tropical evergreen plant whose products were found effective against economically important insect pests and diseases. All parts of this plant particularly leaf, bark, and root extracts have the biopesticidal activities. Azadirachtin, a biopesticide obtained from neem extract, can be used for controlling various insect pests in agriculture. It acts on insects by repelling them, by inhibiting feeding, and by disrupting their growth, and reproduction. Neem-based formulations do not usually kill insects directly, but they can alter their behavior in significant ways to reduce pest damage to crops and reduce their reproductive potential. The neem is considered as an easily accessible, eco-friendly, biodegradable, cheap, and non-toxic biopesticide which control the target pests. Thus, this review highlighted the extract, byproducts and roles of neem that can be used as potential biopesticide in agriculture.

Introduction

Pesticides are the chemical substances that are used to decimate, repulse, prevent, and control the pests creating nuisances and help to increase the yield in agricultural sector (Kumar et al., 2012). The increasing population has exaggerated the use of synthetic pesticides to fulfill their demand for food which have been proven hazardous to biotic and abiotic factors (Macintosh, 2017). The report presented by World Health Organization (WHO) and United Nation Environment Programme UNEP clarifies that pesticides are responsible for poisoning

around three million people and causing around 200,000 deaths each year, worldwide, more cases (95%) being reported in developing countries (World Health Organization, 1990; Yadav et al., 2015). The attractive veggies in the markets are grown with the heavy use of chemical pesticides. The risk associated with excessive usage of chemical pesticide had caused unpredicted environmental issues, insecticide resistance, pest resurgence, and health hazards on the plant and soil that are recognized as an ecologically unacceptable activity (Damalas & Eleftherohorinos, 2011).

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These days all the concern has been provided towards the organic, safe, and non-toxic pesticides that could replace the synthetic ones (Acharya et al., 2017). Biopesticides are the alternative way to the synthetic pesticides and naturally derived preparations or formulations that control pests by non-toxic mechanisms in an eco-friendly manner (Gupta & Dikshit, 2010). They are deduced from plants, animals, microbes, safe, and safe to the environment (Mazidet et al., 2011). Biopesticide circumscribes multiple pest control strategies, plant-derived pesticides (botanicals), microbial (viral, bacterial or fungal), entomophagous nematodes, secondary metabolites from microbes (antibiotics), insect pheromones used for mating disruption and genetical modification to express resistances to various pest attacks (Copping & Menn, 2000). Among various biopesticides, neem (*Azadirachta indica*) has emerged as a highly reliable source of biopesticides (Razizada et al., 2001). It is on the top list among 2400 botanicals used as biopesticide worldwide.

Neem (*Azadirachta indica*) is highly exploited recognized as “Life giving tree”, “Village pharmacy”, “Divine tree”, “sacred offering of nature” with having several valuable properties (Hossain & Nagooru, 2011; Kumar & Navartnam, 2013). It is such an amazing plant which has been declared the “Tree of the 21st century” by the United Nations (UNEP, 2012). The Neem or Margosa tree may attain a height of 30 m and have a girth of 2.5 m (Rangiah & Gowda, 2019). Neem can tolerate intense drought, poor soil, and even shallow soils because of its deep root system and can thrive in a sub-humid to sub-arid climate with an annual rainfall of 400–800 mm (Schmutterer, 1990). Each part of the neem plant like seeds, leaves, roots, barks, and flower are known to have fungicidal, insecticidal, and nematicidal properties (Bajwa & Ahmad, 2012). Among all, leaves and seed extract of neem have been most widely used because of their deleterious effects on insect pests (Nathan et al., 2008). The leaves of *A. indica* contains carbohydrates (48-58%), protein (14-18%), crude fibre (11-24%), ash (7.7-8.5%), crude fat (2.3-6.9%), calcium (0.8-2.4%) and phosphorus (0.13-0.24%), numerous of amino acids, as well as carotenoids and other

constituents (Debashri & Tamal, 2012). Neem oil cake contains high amount of Sulphur and neem oil is rich in fatty acid (Schmuttere, 2002). Sugars and polysaccharides have also been identified and isolated from the gum and bark of *A. indica* (Fulekar, 2005). The biologically active compounds present on Neem are over and above 100 compounds (Benelli et al., 2015) to the total of 300 compounds found till now (Gosse et al., 2005). In an experiment conducted by Tripathi et al. (2020), Neem was used as botanical pesticide in controlling insect pest of cucurbits in Lamjung district of Nepal.

Various biochemical products like Nimbolide, Margolone, Mahoodin, Margolonone, etc. More than of exceeding 60 biochemical products been purified from neem (Krishnaiah et al., 2007; Olabinri et al., 2013). There are about more than 540 species of major pests which are considered vulnerable to the agricultural crops belonging to the different orders of insects. These orders include: Diptera, Hymenoptera, Coleoptera, Lepidoptera, Orthoptera, and Hemiptera (Schmuttere et al., 2002; Khan et al., 2015).

The benefits of neem stated by Salako (2002) such as: i) It is readily available and is relatively cheap; ii) The active compounds of neem have brought a remarkable change in the different stages of insect’s life cycle and physiology making harder for pests to survive and resist; iii) The action of neem is systemic due to which plant protection is the foremost role played by it and has been protecting rice, maize, wheat, barley, sugarcane, tomatoes, cotton, brinjal and other various crops, and vegetables for up to 10 weeks against the harmful pests; iv) The large spectrum of insects are being controlled by Neem which includes even a lice in human to armyworms, *Locusta migratoria*, pathogens like *Meloidogyne* root-knot nematode, *rhizoctonia* root-rot fungus, and Rice stunt virus in the fields (Anjorin et al., 2004); v) It has no harmful effects to those organisms which seem to be beneficial in the field. eg: earthworm.

This review paper outlined the current state of knowledge on the potential uses of neem as a biopesticide in control of insect pests in agriculture.

Major neem products

The major neem extract such as neem oil, leaf extracts, bark extracts, and root extracts as well as the by-product of neem i.e., neem cake contain pesticidal properties and are used as bio-pesticide, fungicide and organic manure (Acharya et al., 2017). These extracts and by-products can be used singly or can be mixed with the other compounds to produce the final products (Sara et al., 2004). These products have the properties of antifungal, antibacterial, antiviral, antidiabetic, anthelmintic, anti-carcinogenic, antiinflammatory, used as contraceptive and sedative (Acharya et al., 2017)

Neem oil

Neem oil, the most important extract of neem tree, is widely used worldwide for pest control activities (Benelli & Pavela, 2018). Neem oil is a better pesticide due to its repellent, insecticidal, nematocidal, bactericidal, and fungicidal activities (Pascoli et al., 2019). The oil contains around 300 biologically active compounds, most notably azadirachtin - a triterpene (Chandramohan et al., 2016; Gupta et al., 2017). The existence of terpenoid, limonoids, and volatile sulphur containing compounds makes Azadirachtin oil as a complex oil (Ricci et al., 2009). The oil obtained from the seed contains volatile oil and fatty acids in abundant amount (Djenontin et al., 2012) whereas the oil obtained from flower and leaves have lesser number of volatile oils (0.08%), and these consists of about 85% of caryophyllene. The oil obtained from seed has been reported to have larvicidal activity on mosquitoes (Dua et al., 2009). It has been proved that the Neem oil as an effective insecticide against various pests like *Scirpophaga incertulas* (Madhu et al., 2020), *Nilaparvata lugens* (Senthil-Nathan et al., 2009), *Cnaphalocrocis medinalis* (Nathan et al., 2006), *Spodoptera frugiperda* (Tavares et al., 2010), *Helicoverpa armigera* (Ahmad et al., 2015), *Idioscopus clypealis* (Adnan et al., 2014), *Diaphorina citri* (Weathersbee & McKenzie, 2005). Similarly, the spray of two neem formulations neem seed oil, and azadirachtin were effective in causing the nymphal mortality of *Aphis glycines* (80% by azadirachtin and 77% by neem oil) (Kraiss & Cullen, 2008). Use of

neem oil causes lethal toxicity to the pupal stage of insects which leads to several morphological deformations such as malformed adults, partial ecdysis, and molt blocking, that defers and inhibits adult formation (Boulahbel et al., 2015).

Neem seed cake

Neem seed cake is the residue obtained after extracting the oil from seed kernels and can be used as biopesticide as well as biofertilizer (Chaudhary et al., 2017). It acts as a soil enricher, provides nutrients necessary for all plant growth, deters on activity of soil pest and bacteria and helps to increase the yield of plants (Roshan & Verma, 2015). Neem cake not only provides organic amendment to the soil but also reduces the loss of nitrogen in the field providing the essential nutrient and acts as a biofertilizer for effective growth and development of the plant (Ramachandran et al., 2007; Lokanadhan et al., 2012). The chemical composition of cake include Azadirachtin, Nitrogen (3.56%), phosphorous (0.83%), potassium (1.67%), calcium (0.99%), and magnesium (0.75%) (Rangiah & Godwa, 2019). Several 50 kg ripe fruits of neem having 30 kg of seeds kernels provide 24 kg of seed cake. The use of neem cake @ 200 g m⁻² with arbuscular mychorrhiza fungus was effective on increasing the plant height in okra, increased the phosphorous content in the field and was effective in controlling the root knot nematode in okra (Mohapatra et al., 2020). Similarly, Neem cake @ 1 kg per vine is reported to be efficient against nematode of black pepper (Sathyan et al., 2020). However, it is recommended to use neem cake @ 3 t ha⁻¹ along with the use of FYM in the field of spice crops like turmeric, ginger, and large cardamom for increasing productivity (Das et al., 2018). The application of neem cake @ 150 kg ha⁻¹ is effective for the management of soil borne pests in the staple crops like rice and maize. Neem cake when applied to the field is regarded as the best nutrient management option in the crops like rice, maize, buckwheat, mustard, rapeseed, soybean, ginger, and turmeric (Das et al., 2020). Neem cake was found to be more effective than the leaf extracts

in case of deterring fall army worm (*Spodoptera frugiperda*) (Silva et al., 2015).

Neem leaves

The biologically active compound present on the neem leaves are alkaloids, glycosides, tannins, flavinoids, reducing sugars, carbohydrates, and steroids (Manikandan et al., 2008). Neem leaves extract are the excellent source for the preparation of vermi-compost which increase soil fertility and also have pesticidal properties (Chaudhary et al., 2017). Neem leaves accelerates the growth and reproduction in earthworm when added while vermicomposting (Gajalakshmi & Abbasi, 2004). Use of neem leaves protects stored grain by repelling the stored grain pests and increasing the post-harvest life (Ahmad et al., 2015). Neem leaf powder @ 10 g concentration was found to be effective on the stored rice weevil (Jahan et al., 2019).

Crude water extracts of green neem leaves @ 200 g of leaves per liter of water can be effective for controlling cabbage butterfly, soybean hairy caterpillar and tobacco caterpillar (Parajuli et al., 2020). Bhatta et al. (2019) conducted an experiment in Lamjung, Nepal and found that the plant aqueous extracts of Neem (*Azadirachta indica*) reduced the aphid population in Tori. Neem leaves are used in different forms either grinded and made into powdered form or with aqueous, methanolic or ethanolic extracts (Kumar et al., 2019). In recent study, the ethanolic extracts of neem leaves-based seaweed films enhanced the anti-microbial activity which made a sustainable packaging material (Kumar et al., 2019). Similarly, the effect of neem leaves extracts showed the inhibition of biofilm of *Pseudomonas aeruginosa* (Kaverimaniyan et al., 2020). Leaf extracts are found to be effective on bean aphid (Bahar et al., 2007) and it also reduced population of whitefly and aphid on cabbage (Basedow et al., 2002; Zaki, 2008). The leaf extracts when mixed with the

garlic bulb were efficient to reduce aphids, whiteflies destructing several crops (Pareet, 2006).

Neem bark

The use of neem barks extracts as biopesticide are not as popular as the seeds and leaves, that have been used in an extensive way (Sirohi & Tandon, 2014). It is found that the bark extracts when applied to the field acts as phytotoxic materials and showed germination and growth inhibitor on rice, radish, carrot, sesame, and bean demonstrating allelopathic properties (Xuan et al., 2004). Neem bark extract dyed fabric was more significant than the leaf extracts due to the presence of higher azadirachtin, cyanogenic glucosides, and nimbin content and exhibited anti-lepidopteran efficacy (Ahmad et al., 2015). A nano formulation made to the concentration of 100 ppm from the crude neem gum, collected from the neem bark, showed 100% mortality against the larva, pupa of *Helicoverpa armigera* and *Spodoptera litura* in the field and reported the antifeedant activities on them (Kamaraj et al., 2017).

Neem roots

Neem root extracts can be used either as raw or in the powdered form or by extracting it soil. The roots of neem tree have anti-bacterial, anti-fungal, anti-septic properties (Lokanadhan et al., 2012). Endophytic fungal flora can also be isolated from the roots of the neem tree (Verma et al., 2011). Nowadays, 361 fungi and 80 bacterial endophytes have been isolated from different parts including root and these endophytes reduced the environmental microorganisms (Rangiah & Gowda, 2019). Extracts of root are used against the sucking insects and fleas (Lokanadhan et al., 2012).

The effectiveness of various neem pesticides on reducing the damage of various insect pests in major cereal crops is given in Table 1.

Table 1. The effectiveness of neem pesticides against various food crops pests

SN.	Crops	Products used	Pests	References
1.	Rice	Handi Ausadha pot mixture (5:l fermeted cow urine+ 1 kg fresh cow dung+ 1 kg karanj leaves+ 1 kg neem leaves+ 1 kg calotropis leaves and 50g Gaur @ 20mL L ⁻¹)	Reduce the incidence of pest by yellow stem borer (73.13%), Green leaf hopper (75.12%), Gall midge (69.93%), Dead heart and white ear head (69.26%), thrips (79.73%), and leaf folder (85.57%).	(Mohapatra, 2018)
		Multineem 300ppm @ 2.5 L ha ⁻¹	Brown plant hopper, Yellow Stem borer (<i>Scirpophaga incertulas</i>)	(Dash et al., 2019)
		Nimbecidine @ 5 mL L ⁻¹ W, 5mL L ⁻¹ of Neem oil	Brown plant hopper (<i>Nilaparvata lugens</i>)	(Choudhary et al., 2017)
2.	Maize	Local Neem	<i>Sitophilus zeamais</i> ,	(Khanal et al., 2019)
		Aqueous Neem extract @300 L ha ⁻¹	Corn ear worm (<i>Heliothis armigera</i>)	(Udo & Ibanga, 2019)
		Neem leaf extract @ 2 mL L ⁻¹	Maize aphid (<i>Rhopalosiphum maidis</i>)	(Alam et al., 2019)
		Neem oil and seed cake	Fallarmyworm (<i>Spodoptera furgiperda</i>)	(Shaiba et al., 2019)
3.	Wheat	Neem Seed Kernel Extract	Wheat aphid (<i>Raphalosiphum padi</i>)	(Matharu & Tanwar, 2019)
		(Indoneem) 1500ppm @ 1200 mL ha ⁻¹ 3% Neem oil and neem seed	Wheat aphid (<i>Raphalosiphum padi</i>)	(Bushra et al., 2014)

The various neem products and their targets to control insect pests in horticultural crops is given in Table 2.

Table 2. The various neem products for the control of insect pests in horticultural crops

S.N.	Crops	Products used	Pests	References
1.	Cabbage	3% concentration of Neem	<i>Plutella xylostella</i>	(Ahmad et al., 2019)
2.	Cauli-flower	Neem oil (58.26% and 57.89%), neem seed kernel extract (54.83% and 55.24%), neem leaf extract (50.70% and 51.42%)	<i>Spodoptera litura</i>	(Singh et al., 2019)
3.	Egg Plant	Neem oil	<i>Leucinodes arbonalis</i>	(Rakibuzzaman et al., 2019)
4.	Potato	Neem oil and karanja oil in ratio of 1:1, 1.4 L in 500 L water ha ⁻¹ (0.3%).	Colorado potato beetle	(Kovaříková & Pavela 2019)
		Neem oil 300ppm	Green peach aphid (<i>Myzus persicae</i>)	(El-Wahab et al., 2019)
5.	Tomato	Neem cake, leaves, and refined product "aza" 0.1% w/w	Root knot Nematode	(Javed et al., 2007)
		Nursery bed treatment 3 kg m ⁻²	Root not nematode	(Illakwahhi & Srivastava, 2019)
		Neem oil: Abamectin @ 100ppm 1:1 ratio	Tomato leaf miner (<i>Tuta absoluta</i>)	(Javed et al., 2007)
6.	Okra	2% Neem seed extract	Jassid, White fly	(Aziz & Khoso, 2019)
		Neem seed kernel extract 5%	white fly, Jassid and Fruit borer	(Ketkar, 2000)
		Soaking Okra seeds for 20-30 minutes in 5% aqueous solution of neem cake against root-knot nematode.	Root-knot nematode	(Ketkar, 2000)
7.	Pumpkin	Neem seed kernel extract 5%	Red pumpkin beetle	(Ketkar, 2000)
8.	Cucumber	Neem extract	Two spotted spider mite (<i>Tetranychus urticae</i> Koch), <i>Aphis gossypii</i> Glov.	(Saleem et al., 2019)
9.	Ginger	Neem leaf powder @ 500 g m ⁻²	Rhizome rot	(Ketkar, 2000)
10.	Coriander	Kernel (5%), neem cake (5%), neem oil (3%) and neem leaf extract (5%)	Coriander aphid (<i>Hyadaphis coriandari</i>)	(Kumari & Yadav, 2002)

The various insect pests susceptible to neem products in leguminous crops is given in Table 3.

Table 3. The various neem products for the control of insect pests in Leguminous crops

S.N.	Crops	Products used	Pests	References
1.	Chickpea	5% Neem seed kernel extract	<i>Helicoverpa armigera</i>	(Kumar et al., 2019)
2.	Greengram	Neem leaf powder	<i>Callosobruchus maculatus</i>	(Gupta et al., 2015)
3.	Cowpea	Neem seed Extract	Cow pea Bruchid	(Lale & Mustapha, 2000)
		Neem + <i>Metarhizium anisopole</i>	Cowpea thrips (<i>Megolurothipss jostedti</i>)	(Raoul et al., 2019)
4.	Pea	Neem seed kernel extract	Pea aphid	(Melesse, 2012)
5.	Sorghum	2 % Neem oil	Sorghum shoot fly (<i>Atherigona soccata</i> Rondani)	(Joshi et al., 2016)

Ingredients found in neem

A broad number of active compounds have been extracted from neem the major extracts are divided into two constituents as terpenoids, which include protolimonoids, limonoids, pentatriterpenoids and hexatriterpenoids, and non terpenoids as hydrocarbons, fatty acids, steroids, phenols, flavonoids, and other (Schmutterer, 1995).

Neem seed kernel contain significant amount of limonoids where azadirachtin ($C_{35}H_{44}O_{16}$) is the most active one and the other major limonoids are: salanin, meliantriol, and nimbin that contain insecticidal and pesticidal properties (Hashmat et al., 2012). Other bioactive compounds present in neem includes, sallanol, nimbin, nimbinin, nimbidin, nimbiol, 3-tigloylazadirachtol (azadirachtin B), and 1-tigloyl-3-acetyl-1-hydroxymeliacarpin (Azadirachtin D) (Mongkholkhajornsilp et al., 2005; Morgan, 2009; Melwita & Ju, 2010). These compounds are known to have an important role in regulating the activities of pests.

More than 200 compounds can be extracted from neem (Koul & Wahab, 2004), where azadirachtin (Az) is the most active compound of neem (Khan et al., 2015). It is the component of neem oil, leaves, flowers, and fruits with insecticidal properties (Akhtar et al., 2008). Azadirachtin is found in several forms (A to K)

(Rangiah & Gowda, 2019). It is used as anti-viral, anti-fungal, antibacterial and insecticidal residences for many years (Chopra et al., 1952). Also, it is used as anti-feedant, anti-ovipositional, anti-growth regulating, and anti-fecundity properties for insects and various other arthropods (Morgan, 2009). It consists of different isomers AZ (A, B, C, D, E, F, G, I, J, and K) where Az A is regarded as the most plentiful and bio active compounds which shows repellent, antifeedant, and insecticidal activity in opposition to a number of insect pests and hence Aza A is used for commercial insecticides (Barceloux et al., 2008).

The neem seed kernel contains an average of 2.05 – 6.10 g kg⁻¹ of azadirachtin (Zongo et al., 1993). However, azadirachtin content differs by varied factors including the extraction process, climatic condition, and genetic factors (Ismadji et al., 2012). Around 30-60 g of Azadirachtin per hectare is enough for warding off the major pests (Koul et al., 2004). The main constituent of neem seed kernels extract is the oil having insecticidal activity which contains 40% of azadirachtin i.e. the highest amount than of all the other active compound (Morgan, 2009). Azadirachtin obtained from seed is used as antifeedant, growth regulator, and as growth inhibitors of the insects (Akhtar et al., 2008). Azadirachtin have various effects on the insects and is effective for over 540 species of insects

that belongs to the order of Lepidoptera, Diptera, Coleoptera, Homoptera, and Hemiptera (Khan et al., 2015). Besides, having an insecticidal properties azadirachtin is also have the adverse effect against fungi, viruses, nematodes, and protozoans (Mordue, 2010). To a greater extent, the content of Azadirachtin can be increased by the treating it with Arbuscular mycorrhizae (Venkateswarlu et al., 2008). Azadirachtin containing tetran or triterpenoids is like insects' hormones "ecdysones" that plays an efficient role as insect growth regulator that deters the feeding habit of insects and inhibits the ability of insect to molt as it changes from

pupa to adult and eventually disrupts the overall life cycle of insects (Rangiah & Gowda et al., 2019). Azadirachtin is used as an organic biopesticide repellent against thrips, whiteflies, aphids, leaf miners, bugs, and varied number of major pests.

The active ingredient azadirachtin was isolated from the seeds of *A. indica* by David Morgan (Butterworth & Morgan, 1968) and its full structural determination was completed some 17 years later concurrently in the laboratories of Steven Ley, W Kraus and K Nakanishi (Bilton et al., 1987; Kraus et al., 1987; Turner et al., 1987).

Table 4. The effects of azadirachtin against insect pests

Effects	Target	Mode of action
Primary antifeedancy	Mouthparts and other chemoreceptors	Deterrent cell stimulation, sugar cell inhibition
Secondary antifeedancy	Guts	Peristalsis inhibited, enzyme production reduced
Insect growth regulation	cuticle	Alteration to ecdysteroid and JH titres by blockage of release of morphogenetic peptides leading to moulting defects
Sterility	Reproductive organs	Alteration to ecdysteroid and JK titres leading got reduction in number of viable eggs and live progeny
Cellular processes	Dividing cells	Blockage of cell division post metaphase in meiosis and mitosis
	Muscles	Loss of muscle tone
	Cell synthetic machinery	Blockage of digestive enzyme production in gut Inhibition of protein synthesis in various tissues

(Mordue & Nisbet, 2000)

The physiological effects of azadirachtin are more consistent than the antifeedant effects, and result from interference with growth and molting, interference with reproduction and interference with cellular processes (Table 4). In all insect species tested dose response effects be reduced growth, increased mortalities, abnormal molts, and delayed molts. These effects are related to disruption of endocrine system

controlling growth and molting. The molting effects are due to a disruption in the synthesis and release of ecdysteroids (molting hormone) and other classes of hormones and this can be demonstrated by accurately timed injections of azadirachtin into the haemolymph of 5th instar nymphs of *L. migratoria* (Mordue et al., 1986).

Table 5. The effective dose (ED50) of insects to azadirachtin

Insect orders	Effective dose (ED50) which causes 50% inhibition feeding
Lepidoptera	1-50
Coleiptera	100-500
Hemiptera	100-500
Hymenoptera	100-500

(Mordue & Nisbet, 2000)

Insects from different Orders differ markedly in their behavior responses to azadirachtin (Table 5). Lepidoptera are extremely sensitive to azadirachtin and show effective antifeedancies from <1-50 ppm, depending upon species. Coleoptera, Hemiptera, and Homoptera are less sensitive to azadirachtin behaviorally with up to 100% antifeedancy being achieved at 100-500 ppm.

Mode and Specificity of Action of Neem *Oviposition deterrents*

Neem has an ovipositional deterrent activity on many pests that may deter economic value of plants (Acharya et al., 2017). Application of neem formulations has prevented the females from depositing eggs (Roshan & Verma, 2015). Azadirachtin inhibits the oviposition of the female by disrupting the egg formation or by synthesis of the ecdysteroid (Bexolli & Shahini, 2017) where in male, it acts as a suspension for forming the meiotic process which result in sperm production (Adnan et al., 2004; Martinez & Van Emden, 2001). The oviposition deterrence activity of neem can be found against pulse beetle, *Callosobruchus chinensis* (Akter et al., 2019), cabbage moth, *Mamestra brassicae* (Jogar et al., 2009), peach fruit-fly (*B. Zonata*) (Mahmoud & Shoeib, 2008) and potato tuber moth, *Phthorimaea operculella* (El-Sinary & Rizk, 2002). The addition of neem seed extract and Neem formulations exhibit its oviposition on cauliflower (Shah et al., 2019).

Repellent

Neem oil alone or mixed with other compounds like coconut oil also exhibit repellency on mosquito (Brahmachari, 2004). Beside its mosquito repellence effect, the use of neem ei-

ther in aqueous or in formulated forms was effective on citrus leaf miner (Canarte-Bermudez et al., 2020). Similarly, the higher concentration of azatrol, triple action neem oil and pure neem oil were able to repel aphids feeding on sweet pepper plants (Shannag et al., 2014). Recently, Incense sticks of different herbal products along with neem were made and these sticks on burning were proved to be the most effective to control mosquito (Bahadur et al., 2020).

Antifeedant

The anti-feedant properties of neem have been able to degrade the numerous insects' pests and protect plants. The mode of action of anti-feedant is that when the insects starve, they try to feed on the parts of the plants treated with neem, its feeding ability starts to deter and as a result insects gets repelled away from the field (Roshan & Verma, 2015). The presence of azadirachtin, salanin and melandriol generates an antiperistaltic wave in the alimentary canal of insects and this produces something similar to vomiting sensation in the insect. Because of this sensation the insect does not feed on the neem treated surface and ability to swallow is also blocked (Vijayalakshmi et al., 1985). Antifeedant activity of neem can be observed against economically important pest *Spodoptera litura* as reported by Prianto et al. (2019). Azadirachtin, the most essential compound showing anti-feedant activities, blocks the formation of hormone "ecdysteroid" which is important for carrying out molting in insects (Bexolli & Shahini, 2017). Similarly, the presence of other compound on neem like salannin and meliantrol discourage feeding behaviour on the pests (Campos et al., 2016).

Growth regulation

Different neem extracts show decrease in fertility, growth inhibitory activity and high mortality rate on more than 400 insect species from different orders (Ragsdale et al., 2004; Liu et al., 2004). Neem oil consists of different growth regulating compounds that inhibits the enzyme ecdysone 20-monoxygenase responsible for converting ecdysone to active hormone (Morgan, 2009). The ecdysone controls the molting of different stages (Mordu, 2004). When azadirachtin enters to the body of larva, the activity of endosyne is deteriorated and hence larval moulting can't occur, thus larval mortality will occur after it has reached the pupal stage. In case of lower concentration, the adult emerging from pupae will be 100% malformed with the formation of chitin inhibited and sterile (Vijayalakshmi et al., 1985). However, the feed stuff taken by the pests determines their ability to for growth and reproduction (Chapman et al., 1998). *Azadirachta indica*

when fed to *Spodoptera frugiperda*, the weight of the pupa decreased that sooner or later hampers the growth of the insects (Roel et al., 2010). Even the fungus like *Aspergillus* was inhibited using neem oil (Rodrigues et al., 2019).

Sterility

Azadirachtin, a nonvolatile compound, when taken by the insects results into blocking the formation of ecdysteroids from the prothoracic gland and finally leads to an incomplete molting showing the sterility of the adult female (Isman, 2006). In addition, NeemAzal-T/S ® (1%) fed to the male rats which were used as an experimental study exhibit the antifertility effect because of their histopathological differences that affect the seminiferous tubules forming spermatogenesis (Morovati et al., 2009).

The commercially available neem products and their applications as agrochemicals (pesticides) and fertilizers is given in Table 6.

Table 6. The commercial product of neem

Fertilizers	Agrochemicals
Neem urea guard	Azamax
Parker neem coat	Neemix 4.5
Ozoneem coat	BioNeem
Ozoneem cake	AZA- direct
Neem cake	Neem oil
Plan "B" organics-neem cake	OzoNeem oil
Bio neem oil foliar	Neemazal technical

Future prospects of neem

Botanically derived insecticides have got more and more attention in the recent years because of the natural substances present on it and will play most important role in developing and industrialized country as well in the near future (Dimetry, 2012). Different entomopathogenic fungi in combination with neem oil tested were found to be against vegetable sucking pest (Halder et al., 2013). The use of nanoparticles of neem in combination with other botanicals like citronella were found as effective antifungal activity against phytopathogenic fungi (Ali et al., 2017). Similarly, neem acts as

an alternative, sustainable, and eco-friendly component in agriculture with the aim of decreasing the use of overall insecticide, pesticides, and fumigants (Rangiah & Gowda, 2019). Although the use of neem is safe, various limitation for the use of neem as biopesticide include photosensitivity, volatilization, short shelf life, and slow killing rate (Isman, 2006; Miresmailli & Isman, 2014). So, on decreasing the photo degradation effect on neem, enhancing its ability against pests in agriculture, use of nano technology in neem could be a promising botanical pesticide on large scale equally benefiting food and cash crops.

Conclusion

Neem based pesticides are extensively used in agriculture all over the world. It contains Azadirachtin, which is a predominant pesticidal active ingredient, having ovipositional deterrence, repellence, antifeedant, growth disruption, and sterility against great variety of insect pests. Neem provides a suitable option for developing eco-friendly and sustainable pesticides. Neem products are suitable for integrated pest management because of their non-toxicity behavior to non-target organisms, easy preparation, and compatibility with other products. So, there is need to educate everyone for judicious use of neem as biopesticide and protect their agricultural crops.

Authors Contribution

All authors contributed equally to all stages of preparation of this manuscript. Similarly, final version of manuscript was approved by all authors.

Conflict of Interest

The authors declare no conflicts of interest.

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