Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(3): 4176-4184
Received: 25-03-2019
Accepted: 27-04-2019

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Neem as an organic plant protectant in agriculture

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Abstract
Neem plant is considered as the most useful traditional plant in India. The various properties of different parts of neem tree are used mainly as insecticide, fertilizer, manure, soil conditioner, urea coating agent, fumigant etc. in recent era the major challenge is to increase the food production without harming the environment and can control the pest. Since, last decades pesticides have become an integral component in sustainable agriculture and the modern cultural practices like use of chemical pesticides and fertilizers are in eliminable. The natural pesticides from *Azadirachta indica* are considered as less harmful, biodegradable, least persistence, less toxic to non-target organism and also economic. Fruitful results of application of formulated neem based products in agriculture will provide a cost effective technology to the farming community.

Keywords: Neem, biofertilizers, sustainable, agriculture

1. Introduction
Neem (*Azadirachta indica*) commonly called 'Indian Lilac' and belongs to the family *Meliaceae*, subfamily *Meloideae* and tribe *Melieae*. Neem is an evergreen, tall, fast-growing tree, which a height of 25m and 2.5m in girth which has an attractive crown of deep green foliage and honey scented flowers). Neem is the most versatile, multifarious trees of tropics, with immense potential. It possesses maximum useful non-wood products (leaves, bark, flowers, fruits, seed, gum, oil and neem cake) than any other tree species. These non-wood products are known to have antiallergenic, antidermatic, antifeedent, antifungal, antiinflammatory, antipyorrhoeic, antiscabic, cardiac, diuretic, insecticidal, larvicidal, nematicidal, spermicidal and other biological activities. Because of these activities neem has found enormous applications making it a green treasure.

2. Taxonomical Classification
The neem plant is taxonomically classified as (Girish and Shankara, 2008; Anon, 2011) [28, 8]
Kingdom: Plantae
Division: Tracheophyta
Class: Magnoliopsida
Order: Sapindles
Family: Meliaceae
Subfamily: Melioideae
Tribe: Melieae
Genus: *Azadirachta*
Species: *indica*
A. indica is synonymous with *Melia azadirachta* L. and *Antelaea azadirachta* (L.) Adelb (Anon, 2011) [8].

3. Plant Description
Azadirachta indica belongs to Meliaceae, a family of dicots mostly represented by trees and shrubs. The family includes about 51 genera and 550 species, with many of them prized for their wood, edible fruits, and medicinal and ornamental qualities (Wiart, 2006) [94]. It is a small to medium-sized evergreen tree with a height of 15 m (30 m maximum), having a large rounded crown (10–20 m) with spreading branches and a branchless bole (7.5 m, diameter 90 cm). The bark of the tree is thick, fissured, dark gray to red (inside) in color, and it possesses a gummy colorless sap. The leaves are long (20–40 cm), alternate, pinnate, exstipulate, and glabrous with a light green hue. The leaves have two pairs of basal glands with a subglabrous petiole (2–7 cm) and above, channeled rachis. Each leaf comprises 8–19 serrated, proximally alternate, ovate to lanceolate leaflets. Inflorescence is axillary clustered multiflowered thyrsus

(150–250 flowers) with a length of 15–30 cm and minute caducous bracts. Flowers of the tree are small (1 cm in diameter), white or pale yellow, and sweet smelling. They are actinomorphic, pentamerous, and bisexual or unisexual male on the same plant. The calyx of the flowers is imbricate, ovate, thin, and puberulous from inside, while petals are free, spreading, imbricate, spathulate and ciliolate from inside. Fruits are single (maximum of two) and small (1–2 cm) in size. They are greenish to yellow in color and an ellipsoidal seeded drupe. The tree has a thin exocarp, pulpy mesocarp, and cartilaginous endocarp. Seeds are an unwinged, oval, or spherical structure with thin testa. The tree has a profound taproot system with widespread lateral roots. It may form suckers if roots encounter some damage (Hearne 1975; Csurhes, 2008; Hashmat *et al*., 2012) [34, 18, 33].

4. Chemistry of neem

Neem plants contain several thousands of chemical constituents. Of special interest are the terpenoids from different parts of the neem plant. Of its biological constituents the most active and well studied compound is Azadirachtin. However, in most traditional preparations of neem as pesticide or medicine a mixture of neem chemicals are present and provide the active principles. Several kinds of azadirachtins (A to K) have been isolated, the most abundant of which is Azadirachtin. The neem terpenoids are present in all parts of the plant, in the living tissues. Recently, the site of synthesis and accumulation of the neem chemicals have been identified as secretory cells. Secretory cells are the most abundant in the seed kernels. The secretory cells can be seen with iodine solution. Besides the terpenoids, neem also contains more than 20 sulphurous compounds responsible for the characteristic smell of crushed seeds and neem oil.

5. Bioactive compounds from neem to perform beneficial effect (Biswas *et al*., 2002) [12]

Neem compound	Source	Biological activity
Nimbidin	Seed oil	Anti-inflammatory, Antiarthritic, Antipyretic, Hypoglycaemic Antigastric ulcer, Spermicidal Antifungal, Antibacterial Diuretic
Nimbin	Seed oil	Spermicidal
Azadirachtin	Seed	Antimalarial
Mahmoodin	Seed oil	Antibacterial
Gallic acid, (–) epicatechin and catechin	Bark	Anti-inflammatory Immunomodulatory
Polysaccharides GIa, GIb	Bark	Antitumour
Cyclic trisulphide and cyclic tetrasulphide	Leaf	Antifungal

6. Composition of Neem Oil

Neem oil is a vegetable oil pressed from the fruits and seeds of neem (*Azadirachta indica*). An evergreen tree which is endemic to the indian subcontinent and has been introduced to many other areas in the tropics. It is the most important of commercially available products of neem for organic farming and medicines. Neem oil varies in colour, it can be golden yellow, yellowish brown, reddish brown, dark brown, greenish brown or bright red. Each part of neem tree has some medicinal properties and it is commercially exploitable. It is considered as a valuable source of unique natural products for development of medicines against various diseases.

Neem essential oil from flower and leaves is a minor source of volatile oil (0.08%), composed mainly of caryophyllene (85%) (Narsing Rao *et al*., 2014) [50]. Neem seed oil (NSO) is a main source of volatiles, being composed of essential oil and fatty acids (Djenontin *et al*., 2012) [23]. Neem seed oil is subjected to extensive phytochemical studies due to its strong biological, agricultural, and medicinal properties (Lokanadhan *et al*., 2012) [40]. The chemical composition of neem seed oil is very complex and rich in terpenoids, limonoids, and volatile sulfur compounds (Ricci *et al*., 2009) [63]. Until now, more than 300 compounds have been isolated from various parts of *A. indica* (Gosse *et al*., 2005) [29]. However, neem seed oil alone recounted more than 100 determined biologically active compounds (Benelli *et al*., 2015) [11].

Neem seed oil is a major source of fatty acid and is mainly composed of oleic acid (50%–60%), palmitic acid (13%–15%), stearic acid (14%–19%), linoleic acid (8%–16%), and arachidic acid (1%–3%). Oleic acid, linoleic acid, and α-linoleic acid are the principal ω-9, ω-6, and ω-3 fatty acids, respectively, in neem seed oil (Mongkholkhajornsilp *et al*., 2005) [44]. Besides, palmitic (31.76%), linoleic (18.57%), linolenic (12.64%), oleic (9.74%), arachidonic (7.38%), and docosatrienoic (5.7%) acids were also reported in flower oil (Narsing Rao *et al*., 2014) [50].

The important bioactive compounds of neem seed oil belong to the limonoid class of triterpenoids, such as azadirachtin (azadirachtin A), salannin, salannol, nimbin,– nimbinin, nimbidin, nimbidiol, nimolicinol, gedunin, 3-tigloylazadirachtol (azadirachtin B), epoxyazadiradione, 17β-hydroxyazadiradione, 1-tigloyl-3-acetyl-11-hydroxymeliacarpin (azadirachtin D), 1α,2α-epoxy-17β-hydroxyazadiradione, 1α,2α-epoxynimolicinol, and 7-deacetylnimolicinol (Hallur *et al*., 2002; Ismadji *et al*., 2012) [31, 36]. In 1942, Siddiqui reported bitter principles, nimbin, nimbinin, and nimbidin, where nimbidin was the major bitter principle of neem seed oil. All these plant metabolites are well known for their effective biological properties against insects and pests; among them, azadirachtins (0.3%–0.6%) are the most active component of neem essential oil (Brahmachari, 2004) [14]. The concentration of triterpenoid secondary metabolite in neem seeds is dependent on the geographical location of the plant grown (Sidhu *et al*., 2003) [76].

Azadirachtins are the most celebrated and studied active principles of neem oil due to their deterrent, antiovipositional, antifeedant, growth-disrupting, growth-regulating, fecundity, and fitness-reducing properties against insects and various kinds of arthropods (Ambrosino *et al*., 1999; Morgan, 2009) [6, 46]. They are a group of closely related isomers that belong to the steroid-like tetranortriterpenoid class, called azadirachtin A to H (Rembold *et al*., 1984, 1987) [61, 62]. Among all azadirachtins identified so far, azadirachtin A (azadirachtin) is a highly appreciated and interesting compound, as it is considered the most potent and principal agent for controlling insects (Sinha *et al*., 1999) [79]. Hence, it acts as a biomarker for standardization of neem oil and commercial insecticidal formulations (Sundaram and Curry,

1993; Sidhu *et al*., 2003) [86, 76]. The azadirachtin content in crude neem oil varies (100–4000 ppm), depending on the extraction technique, seed quality, environment, and genetic factors (Ambrosino *et al*., 1999; Ismadji *et al*., 2012) [6, 36].
The major sterols in neem seed oil reported were β-sitosterol, stigmasterol, campesterol, and fucosterol (Momchilova *et al*., 2007) [43]. The total tocopherols (298 ppm) indicate α-tocopherol and γ-tocopherol as major components (30.8% and 62.3%, respectively) (Djenontin *et al*., 2012) [23].

7. Physical and Chemical Properties of Oil

Neem oil is normally a golden-yellow, yellowish-brown, reddish-brown, dark brown, greenish-brown, or bright red liquid. It has an unpleasantly strong and offensive odor. The smell of the oil is a partial combination of peanut and garlic. The obnoxious odor of neem oil is ascribed to the presence of sulfur-containing volatile compounds (Dasa Rao and Seshadri, 1941) [19]. It has an acrid taste, which is attributed to several triterpenoids present in it. It is a nondrying oil and, due to its hydrophobic nature, needs appropriate surfactants for proper emulsification during industrial application (Mongkholkhajornsilp *et al*., 2005; Usman *et al*., 2013; Edres, 2014) [44, 90, 24]. The quality of the oil depends on its composition, which in turn affects the properties. Since neem oil mainly contains fatty acids as one of the active components, it is commonly analyzed for its quality by determining the saponification value (SV), acid value (AV), and iodine (IV) value.
Neem oil contains at least 100 biologically active compounds. Among them, the major constituents are triterpenes known as limonoids, the most important being azadirachtin (Figure 1), which appears to cause 90% of the effect on most pests. The compound has a melting point of 160ºC and molecular weight of 720 g/mol. Other components present include meliantriol, nimbin, nimbidin, nimbinin, nimbolides, fatty acids (oleic, stearic, and palmitic), and salannin. The main neem product is the oil extracted from the seeds by different techniques. The other parts of the neem tree contain less azadirachtin, but are also used for oil extraction (Nicoletti *et al*., 2012) [52]. It has been suggested that the content of azadirachtin in the seeds can be increased by artificial infection with arbuscular mycorrhiza (Venkateswarlu *et al*., 2008) [91].
Among the botanical insecticides currently marketed, neem oil is one of the least toxic to humans and shows very low toxicity to beneficial organisms, so it is, therefore, very promising for the control of many pests. Target insect species include the following: *Anopheles stephensi* (Lucantoni *et al*., 2006) [41], *A. culicifacies* (Chandramohan *et al*., 2016) [15], *Ceraeochrysa claveri* (Scudeler *et al*., 2013, 2014; Scudeler and dos Santos, 2013) [69, 70, 71], *Cnaphalocrocis medinalis* (Senthil Nathan *et al*., 2006) [73], *Diaphorina citri* (Weathersbee and McKenzie, 2005) [93], *Helicoverpa armigera* (Ahmad *et al*., 2015) [3], *Mamestra brassicae* (Seljasen and Meadow, 2006) [72], *Nilaparvata lugens Stal* (Senthil-Nathan *et al*., 2009) [74], *Pieris brassicae* (Hasan and Shafiq-Ansari, 2011) [32], and *Spodoptera frugiperda* (Tavares *et al*., 2010) [87]. Arachnid targets include *Hyalomma anatolicum excavatum* (Abdel-Shafy and Zayed, 2002) [1] and *Sarcoptes scabie* var. cuniculi larvae (Xu *et al*., 2010) [96].
The oil is considered a contact insecticide, presenting systemic and translaminar activity (Cox, 2002) [17]. It has a broad spectrum of action, inhibiting feeding, affecting hormone function in juvenile stages, reducing ecdysone, deregulating growth, altering development and reproduction, suppressing fertility, sterilizing, repelling oviposition, and disrupting molting processes (Brahmachari, 2004) [14]. Azadirachtin, salannin, and other limonoids present in neem oil inhibit ecdysone 20-monooxygenase, the enzyme responsible for catalyzing the final step in conversion of ecdysone to the active hormone, 20-hydroxyecdysone, which controls the insect metamorphosis process (Morgan, 2009) [46]. Meliantriol and salannin also act to inhibit the feeding of insects, while nimbin and nimbidin mainly present antiviral activity (Embrapa, 2008) [25]. Azadirachtin can also interfere in mitosis, in the same way as colchicine, and has direct histopathological effects on insect gut epithelial cells, muscles, and fatty tissues, resulting in restricted movement and decreased flight activity (Wilps *et al*., 1992; Mordue (Luntz) and Blackwell, 1993; Qiao *et al*., 2014) [95, 45, 55].

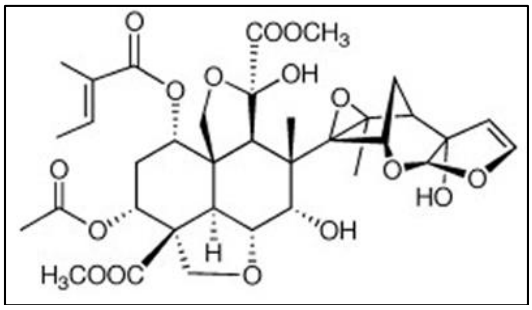

Fig 1: Chemical structure of Azadiractin

The use of neem in agriculture is not a new practice. In India, the traditional farming system employed neem extracts for pest management and to supply nutrients to plants (Mossini and Kemmelmeier, 2005; Sujarwo *et al*., 2016) [47, 85]. Scientific research has shown that neem is safe for workers, with no handling risks, and can be used throughout the entire crop production cycle (Boeke *et al*., 2004) [13].
Features of neem support its contribution to organic agricultural production systems that are more sustainable and do not generate chemical residues (plants and crops are grown without the use of any agrochemicals). This method also helps to maintain soil productivity, ensuring longer production times. Organic agriculture can be a viable alternative production method for farmers, but there are numerous challenges to be overcome. A key to success is to be open to new approaches, and in this respect neem products can effectively contribute to organic agriculture, being used as organic pesticides and as soil fertilizers.

8. Benefits of Neem

8.1. Neem as Fertilizer

Neem has proven use as a fertilizer, with the organic and inorganic compounds present in the plant material acting to improve soil quality and enhance the quality and quantity of crops. The waste remaining after extraction of the oil from neem seeds (neem seed cake) can be used as a biofertilizer, providing the macronutrients essential for plant growth (Ramachandran *et al*., 2007; Lokanadhan *et al*., 2012) [57,40].
Nitrogen is one of the main nutrients required by plants for their development, and urea is the main source of nitrogen fertilizer used worldwide to supply the nitrogen demand of crops. The control of urea hydrolysis and nitrification is one of the principal strategies employed to avoid nitrogen losses in agriculture (Ni *et al*., 2014) [51]. Neem has demonstrated activity as a nitrification inhibitor, helping to slow the bacterial activity that is responsible for denitrification, hence decreasing the loss of urea from the soil (Musalia *et al*., 2000; Mohanty *et al*., 2008) [49, 42].

Benefits
Neem seed cake performs the dual function of both fertilizer and pesticide, acts as a soil enricher, reduces the growth of soil pest and bacteria, provides macro nutrients essential for all plant growth, helps to increase the yield of plants in the long run, bio degradable and Eco friendly and excellent soil conditioner.

8.2. Neem as Manure
Manure is any animal or plant material used to fertilize land especially animal excreta for improving the soil fertility and thus promoting plant growth (Tiwari, 2002; Singh *et al*., 2006) [88, 78]. Neem manure is gaining popularity because it is environmental friendly and also the compounds found in it help to increase the nitrogen and phosphorous content in the soil. It is rich in sulphur, potassium, calcium, nitrogen, etc (Adeoye *et al*., 2008) [2]. Neem cake is used to manufacture high quality organic or natural manure, which does not have any adverse effect on plants, soil and other living organisms. It can be obtained by using high technology extraction methods like cold pressing or other solvent extraction. It can be used directly by mixing with the soil or it can be blended with urea and other organic manure like farm yard manure and sea weed for best results.

Benefits
It is bio degradable and eco-friendly, nourishes the soil and plants by providing all the macro and micro-nutrients, helps to eliminate bacteria responsible for denitrifying the soil, ideal for cash crops and food crops, increases the yield of crops, helps to reduce the usage of fertilizer, thus reducing the cost of growing plants, antifeedant properties that help to reduce the number and growth of insects and pests.

8.3. Neem as urea coating agent
Neem and its parts are being used to manufacture urea coating agent to improve and maintain the fertility of soil. Use of neem urea coating agent helps to retard the activity and growth of the bacteria responsible for denitrification (Bains *et al*., 1971) [9]. It prevents the loss of urea in the soil. It can also be used to control a large number of pests such as caterpillars, beetles, leafhoppers, borer, mites etc. Urea coating is generally available either in liquid form or powdered form. Properties of Neem Urea Coating are Anti feedant, anti fertility and pest growth regulator.

Benefits
Neem Urea Coatings are excellent soil conditioners, natural or bio pesticides, environmental friendly, non toxic, reduces urea consumption, convenient and easy to apply, high soil fertility and increases the yield of crops.

8.4. Neem as Soil Conditioner
Neem seed granules or powdered seeds are used to manufacture the soil conditioner. It can be applied during sowing of plants or can be sprinkled and raked into the soil.
The process of sprinkling should be followed by proper irrigation so that the product reaches the roots. It is a natural soil conditioner that helps improve the quality of soil, thereby enhancing the growth of plants and fruits (Smith *et al*., 2001) [80]. Organic soil conditioner is gaining popularity in agricultural industry, not only in Asian countries like India but also in western counterparts such as USA, UK and Australia.

Benefits
Neem is a natural soil conditioner that helps improve the quality of soil, thereby enhancing the growth of plants and fruits. It not only helps the plants grow, but also prevents them from being destroyed by certain pests and insects.
Organic soil conditioner is gaining popularity in agricultural industry. Because they are organic, they have no harmful effects and are cheaper than the other soil conditioners. This natural soil conditioner is also multi-functional and in the sub tropical regions. Neem soil conditioner application in plantation crops is known to be a soil enhancer that help to increase its fertility.

8.5. Neem as fumigant
Neem tree has been used against household, storage pests and crop pests. Neem pest fumigant is available in gaseous state and is used as a pesticide and disinfectant. It is being used by a large number of countries on a commercial basis by farmers and agriculturists. This 100% natural product is being exported as it is non-toxic and does not affect the environment.
It assumes more importance in developing countries where millions of deaths are reported every year due to the accidental intake of synthetic pest fumigants. This natural fumigant not only kills pests but also affects them negatively by acting as feeding and ovi position deterrence, mating disruption, inhibition of growth etc. According to studies undertaken, neem fumigant helps to protect stored rice grains from pests. One of the major benefits of this organic fumigant is that pests do not develop resistance to it (Grace, 1991) [30].
With the increasing trend of using bio fertilizers, insecticides and pesticides, neem is being increasingly cultivated and grown all over the world to get active ingredient-azadirachtin, responsible for stopping the growth cycle of insects and pests, fungi etc. Neem is also assuming a lot of importance in crop management. Considering the fact that neem is not only a cheaper, naturally occurring product and an effective method to control pests and insects, but also has no side effects on plants or other living beings, it is not a wonder that researches are being carried to try neem and its products for large scale production of natural pesticides and insecticides. This is a good opportunity for manufacturers and exporters to produce quality bio agricultural products. Neem oil and seed extracts are known to possess germicidal and anti-bacterial properties which are useful to protect the plants from different kinds of pests. This natural product does not leave any residue on plants.

Benefits
Neem fumigants are eco-friendly, do not harm other micro-organisms, are non-toxic, and do not contaminate terrestrial and aquatic environment. Pests do not develop resistance to it, there are no negative effects, relatively less expensive, pest repellent and nourish the soil and function as pest reproduction controller.

8.6. Neem as pesticide
Neem oil is recognized as a powerful biopesticide and may offer a solution to global agricultural, environmental, and public health problems. The neem seed oil allelochemicals are reported to have feeding and oviposition deterrence, repellency, growth disruption, reduced fitness, and sterility activities, and hence have been widely used in agricultural pest control (Brahmachari, 2004) [14]. In neem seed oil, high concentrations of bioinsecticide limonoids are reported,

mainly azadirachtin A, azadirachtin B, nimbin, and salannin (Stark and Walter, 1995) [84]. The most potent limonoid in neem seed oil, azadirachtin, primarily acts as an insect repellent and insect growth regulator (IGR). Its structure is similar to that of insect hormones, "ecdysones," responsible for metamorphosis in insects. It is active at minute concentrations (1–10 ppm) and responsible for hindering the action of ecdysones, thus preventing the larvae from shedding their exoskeletons. Thus, azadirachtin alters their life cycle and inhibits the development of immature insects (Lokanadhan *et al*., 2012; Radwan and El-Shiekh, 2012) [40, 56].

Neem seed oil exhibits antifeedent and oviposition deterrent activity (Benelli *et al*., 2015) [11]. Antifeedent activity, credited to azadirachtin, nimbin, salannin, epoxyazadiradione, and melandriol, causes antiperistalitic movement in the alimentary canal and initiates a vomiting sensation in the insect (Esparza-Diaz *et al*., 2011) [26]. The nauseated feeling and inability to swallow do not allow insects to feed on NSO-treated surfaces. It checks feeding in approximately 200 types of insects at concentrations of 10–100 ppm. Similarly, NSO sprayed during storage does not allow female insects to lay eggs (Lokanadhan *et al*., 2012) [40].

The broad-spectrum activity coupled with non-toxicity to mammals brands NSO as a perfect candidate for biopesticide treatment. The use of biopesticides is assumed to be a significant component of integrated pest management (IPM) for the realization of sustainable agriculture, due to their economic viability and eco-friendly nature. Recent research has been conducted to exploit neem pesticidal potential in agriculture has been described in Table 1.

Neem pesticides play a vital role in pest management and hence have been widely used in agriculture. There has been an evident shift all over the world from synthetic pesticides to non-synthetic ones. This is largely because of the wide spread awareness of the side effects of these synthetic pesticides not only on plants and soil but also on other living organisms. This is a great opportunity for neem pesticides manufacturers to cash in on the growing popularity of natural or herbal pesticides. Neem pesticides are being manufactured and exported to various countries as a lot of research has been conducted to test the safety and efficacy of neem for use as a pesticide (Anis Joseph *et al.*, 2010; Vethanayagam, and Rajendran, 2010) [7, 92]. Azadirachtin is the main ingredient used to manufacture bio pesticides. Neem oil and seed extracts are known to possess germicidal and anti-bacterial properties which are useful to protect the plants from different kinds of pests. One of the most important advantages of neem-based pesticides and neem insecticides is that they do not leave any residue on the plants.

It also helps to nourish and condition the soil, it is environmental friendly, it is non-toxic and it can be used in combination with other pesticide and oil for more effectiveness. Instead of killing the pests, it affects the life cycle of the pests. Anti-feedant properties found in neem compounds helps to protect the plants (Saxena *et al*., 1989) [66]. Pests generally do not develop a resistance to neem based pesticides. Neem pesticides are generally water soluble and help in the growth of the plants. It acts as pest repellent and pest reproduction controller. The transition from use of synthetic products to natural ones is evident in agricultural industry also. Excessive use of synthetic insecticides has resulted in a series of problems like the development of insect resistance to insecticides, harm to other natural enemies of insects, toxic effects on plants and soil etc. Neem is being used to manufacture what is known as the natural or bio insecticide, that are environmental friendly and do not have any toxic effects on plants and soil (Mukhopadhay *et al*., 1992). Neem insecticides are used to protect both food as well as cash crops like rice, pulses, cotton, oils seeds, etc. Great for use on all crops, trees, plants, flowers, fruits and vegetable round the home as well as organic and commercial growers. Active ingredient Azadirachtin, found in neem tree, acts as an insect repellent and insect feeding inhibitor, thereby protecting the plants. This ingredient belongs to an organic molecule class called tetranortriterpenoids. It is similar in structure to insect hormones called "ecdysones," which control the process of metamorphosis as the insects pass from larva to pupa to adult stage. It is interesting to note that neem doesn't kill insects, but alters their life process. The major parts/extracts of neem seed that are used for making neem insecticides. According to recent studies conducted on parts of neem, it was found that neem seed extracts contain azadirachtin, which in turn works by inhibiting the development of immature insects. Neem oil or the neem seed oil is extensively used to manufacture insecticides used for different crops. Neem oil enters the system of the pests and obstructs their proper working. Insects do not eat, mate and lay eggs resulting in the breaking of their life cycle. Another interesting function of neem oil pesticides is that they do not harm the beneficial insects. The neem oil insecticides only target the chewing and sucking insects.

Table 1: Recent research on neem essential oil for pesticidal potential in agriculture

Crop	Pathogen/Disease	Treatment	Reference
Mango	Powdery Mildew and Mango Malformation	Neem oil (1%)	Ismail, 2016 [35]
Cowpea (Brazil)	*Spodoptera eridania* (southern armyworm)	Neem oil (0.35% and 0.7%)	Rodrigues *et al*., 2015 [64]
Brinjal	Shoot and fruit borer	Neem oil	Singh and Sachan, 2015 [77]
Cowpea	*Maruka vitrata*	Multinucleopolyhedrovirus+neem oil	Sokame *et al*., 2015 [81]
Kinnow mandarin	*Penicillium digitatum* and *P. italicum*	Neem essential oil	Jhalegar *et al*., 2015 [37]
Cultivated crops	*Helicoverpa armigere*	Neem oil	Ahmad *et al*., 2015 [3]
Cotton	Cotton pest	*Beauveria bassiana* + neem oil	Togbe *et al*., 2015 [89]
Cabbage	Cabbage aphid	Neem oil (1%)	Pissinati and Ventura, 2015 [54]
Okra	Whitefly	Mineral oil+Neem oil	Sridharan *et al*., 2015 [83]
Western white pine	*Zootermopsis augusticollis* (Dampwood termite)	Neem oil	Fatima and Morrell, 2015 [27]
Cashew trees	*Toxoptera odinae*	Neem oil	Ambethgar, 2015b [5]
Stone fruit	*Monilinia fructicola*	Neem oil	Lalancette and McFarland, 2015 [39]
Watermelon	*Aphis gossypii*	Neem oil	Souza *et al*., 2015 [64]
Coconut	*Aceria guerreronis*	Neem oil (3%)	Balaji and Hariprasad, 2015 [10]

Cultivated crops	*Helicoverpa armigera*	PONNEEM (neem+pongania oil, 1:1 ratio)	Packiam *et al*., 2015 [53]
Jasminum auriculatum	Eriophid mite	Neem oil 30 ml/l	Devi *et al*., 2015 [22]
Tomato	White fly and Leaf minor	Neem oil	Chavan *et al*., 2015 [16]
Cashew	*Ferrisia virgata*	Neem oil	Ambethgar, 2015a [4]
Okra	*Bemisia tabaci*	Neem oil	Kumar *et al*., 2015 [38]
Tomato	*Tuta absoluta*	Neem seed oil	Salem and Abdel-Moniem, 2015 [65]
Phaseolus vulgaris	*Bemisia tabaci*	Neem oil	de Almeida Marques *et al*., 2015 [20]

8.6.1. Insect growth regulation
Regulation of the insects' growth is a very interesting property of neem products which is unique in nature, since the products work on juvenile hormones. The insect larva feeds and as it grows, it sheds its old skin. This particular shedding of old skin is the phenomenon of ecdysis or moulting and is governed by an enzyme, ecdysone (Ramarethinam and Marimuthu, 1998) [60]. When the neem components, especially azadirachtin, enter the body of the larva, the activity of ecdysone is suppressed and the larva fails to moult, remains in the larval stage and ultimately dies (Ramarethinam *et al*., 2000) [59]. If the concentration of azadirachtin is not high enough, the larva will die only after it has entered the pupal stage. If the concentration is lower still, the adult emerging from the pupa will be 100% malformed, and absolutely sterile.

8.6.2. Feeding deterrent
The most important property of neem is feeding deterrence. When an insect larva sits on a leaf, it will want to feed on it. This particular trigger of feeding is given through the maxillary glands (Dethier, 1980) [21]. Peristalsis in the alimentary canal is thus speeded up, and the larva feels hungry and starts feeding on the surface of the leaf. If the leaf is treated with a neem product, because of the presence of azadirachtin, salanin and melandriol, there will be an anti-peristaltic wave in the alimentary canal which produces something similar to a vomiting sensation in the insect (Schoonhoven, 1980) [68]. Because of this sensation, the insect does not feed on the neem-treated surface. Its ability to swallow is also blocked.

8.6.3. Oviposition deterrent
Another way in which neem controls pests is by preventing the females from depositing eggs. This property is known as oviposition deterrence, and comes in very handy when the seeds in storage are coated with neem kernel powder and neem oil (Dethier, 1980; Saxena, 1989; Ramarethinum and Marimuthu, 2000) [21, 67, 58]. The seeds or grains obtained from the market may already be infested with some insects. Even these grains could be treated with neem seed kernel extract or neem oil. After this treatment, the insects will not feed on them. Further damage to the grains will be halted and the female will be unable to lay its eggs during the egg-laying period of its life cycle.

Mode of Action
Neem acts as a biopesticide at different levels and in various ways. Primarily it acts as antifeedant *ie*., when an insect larva is hungry and it wants to feed on the leaf but if the leaf is treated with neem product, because of the presence of azadirachtin, salanin and melandriol there is an antiperistalitic wave in the alimentary canal 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. Secondly it acts as oviposition deterrent *ie*., by not allowing the female to deposits eggs comes in very handy when the seeds in storage are coated with neem kernel powder and/or neem oil. It also acts as insect growth regulator. It is a very interesting property of neem product and unique in nature, *ie*., it works on juvenile harmone.

9. Conclusion
There is a need of cost effective, biodegradable, potential, ecofriendly and safe sustainable agricultural products alternating to the chemical fertilizers and pesticides. As neem act as the most reliable source of pro-pesticide having no adverse effect on human and animals. Thus neem based products play a crucial role in organic agriculture.

10. Reference

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