REWIEW ARTICLE

Botanical pesticides – a major alternative to chemical pesticides: A review

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ABSTRACT

Pest management is one of the essential components in the agriculture. Conventional pesticides caused various environmental issues such as imbalances in the ecosystem, loss of soil fertility, and deterioration of marine life. Conventional pesticides also caused various harmful and serious issues on the humans and animal health leading to severe cancers, neurological disorders, hormonal disturbances, and reproductive issues. Botanical pesticides obtained naturally from plant based chemicals were found to be an effective alternative to conventional pesticides. Neem based pesticides are one of the most important botanical pesticides used widely in India for agricultural pest management followed by pyrethrum, and Eucalyptus oil based pesticides. Various botanical pesticides are used in the conventional, sustainable and integrated pest management.

Keywords: Pest management, conventional pesticides, botanical pesticides, azadirachtin, pyrethrin.

INTRODUCTION

Pest management is one of the important component of agricultural management due to harmful effects and economic losses of agricultural crops and commodities. Around 10 – 15% of the yield of the major agricultural crops such as rice, wheat, maize, and potato is lost every year globally due to pest induced plant diseases leading to major impact on economic of that particular nation. This major threat to financial and quality losses of agricultural crops led to major insights in the field of research and new discoveries of pest controlling agents. Pests can be controlled and managed by the application of various pesticides in the different ways and at the different time period, according to the standard guidelines laid down by the nation. The first pesticide, DDT was discovered in 1939 which brought wide revolution in the area of pesticide research. Thus, pesticides are now a major part of the agricultural sector in order to prevent the economic losses and crop quality deterioration. The purpose of this review article is to provide the significance of biopesticides, especially, botanical pesticides over conventional synthetic chemical pesticides. The major botanical pesticides commonly used in the market have been discussed this review article.

Table 1: Major Indian Agricultural Crops/ Commodities and its associated major pests

Sr. No.	Crops/ Commodities	Major Pests
01.	Rice	*Acrida exaltata, Ampittia dioscorides, Chilo polychrysa, Cnaphalocrocis trapezalis, Lenodora vittata, Leptocorisa acuta, Nephotettix parvus, and many more.*
02.	Maize	*Agonoscelis nubilis, Aloa albistriga, Anomala dimidiate, Mythimna loreyi, Myllocerus viridanus, and many more*
03.	Sugarcane	*Abdastartus atrus, Chilo sacchariphagus indicus, Cofana spectra, Mocis frugalis, Mythimna separate, and many more.*
04.	Groundnut	*Agrius convolvuli, Atractomorpha crenulata, Caryedon serratus, Dudua aprobola, Sphenoptera perroteti, Spodoptera litura, and many more.*
05.	Cotton	*Aloa albistriga, Anomis flava, Bemisia tabaci, Ferrisia virgata, Helicoverpa armigera, Phenacoccus solenopsis, Plautia crossota, and many more.*
06.	Banana	*Aleurodicus rugioperculatus, Aularches miliaris, Bactrocera dorsalis, Cosmopolites sordidus, Hishimonus phycitis, Odoiporus longicollis, Prodromus clypeatus, Parasa lepida, and many more.*

Source: Insects in Indian Agroecosystems, ICAR – NBAIR, Government of India.

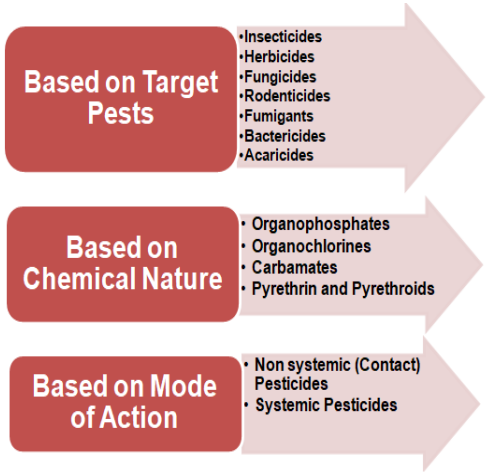

Figure 1: Classification of Pesticides on the Basis of Target Pests, Chemical Nature and Mode of Action.

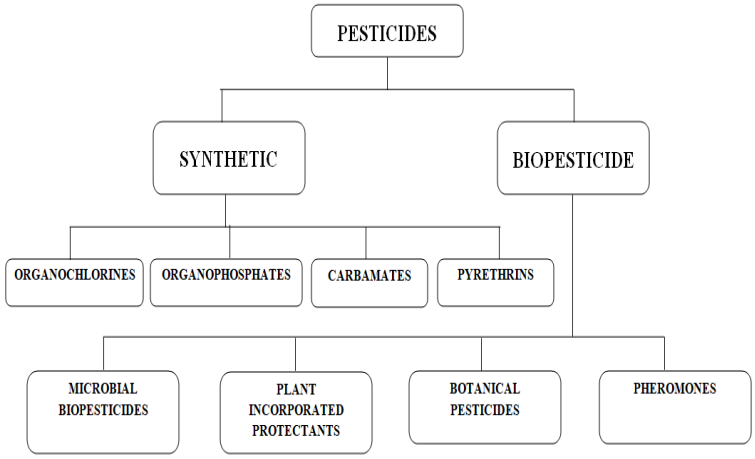

Figure 2: Classification of Pesticides (Council on Scientific Affairs, AMA)

2. Pests of Agricultural Crops and Commodities:

Agricultural crop productivity depends on various parameters such as soil quality, climate, availability of water, seeds, high yielding variety seeds, and much more. The one of the major parameters of the crop productivity and management is to prevent the attacks and infections by pests. The major crops and its associated major pests are tabulated in the Table 1.

3. Pesticides: Classification and Significance:

According to Food and Agriculture Organization (FAO) of the United Nations (2002), a pesticide is any substance or mixture of substances intended for preventing, destroying, or controlling any pest including vectors of human or animal diseases, unwanted species of plants or animals causing harm during, or otherwise interfering with, the production, processing, storage, or marketing of food, agricultural commodities, wood and wood products, or animal feedstuffs, or which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies. In simple terms, a pesticide is a chemical or biological agent that interferes with the growth pattern or physiological system of pests or kills the pests thus preventing the attack to the agricultural crops or commodities which in turn increases crop yield (quality) and prevents economic losses.

3.1. Classification of Pesticides:

The pesticides are most commonly classified on the basis of the target pests; mode of action; and chemical nature (Figure 1). Furthermore, Council on Scientific Affairs, American Medical Association (1997) classified the pesticides into two broad categories, namely, synthetic pesticides and biopesticides (Figure 2).

Synthetic pesticides are further divided into four subgroups as illustrated in the Figure 2, whereas biopesticides are further categorized into four subgroups, namely; microbial biopesticides, plant incorporated protectants, botanical pesticides and pheromones (See Figure 2). This review article emphasizes on the biopesticides mainly, botanical pesticides, which will be discussed briefly in the further sections.

3.2. Significance of Pesticides in Agriculture:

The enhancement of agricultural crop yield with good farming practices by using the concept of agricultural management is very essential and crucial component of agriculture. Since pests can cause significant loss in crop yield by attacking the agricultural crops and commodities which can lead to economic losses of the farmers and nation. In order to abate and eradicate the pests from attacking the crops, pesticides can be used for the crop protection from pests in pre harvest, harvest and post harvest (storage) periods. Prevention of pests during the pre harvest period is very crucial for the growth of crops depends on it and thus it can increase crop production. Thus, the major significance of the pesticide is to protect the agricultural crops and commodities from the pests by killing or by making the plant resistible to the pests in order to increase the crop production along with the superior high quality, pest free crops.

3.3. Conventional Pesticides and Human Health:

Most of the conventional synthesized chemical pesticides are highly toxic to human health since the consumption of these pesticides or traces of pesticides can cause harmful and serious medical issues in the humans. Chemical pesticides such as organochlorines, organophosphates, and carbamates can cause neural defects such as Alzheimer Disease, Parkinson's disease, disruption of neural coordination in the body, defects in the neurotransmitter synthesis in adults. Pesticide exposure during foetal development can cause congenital disorders, genetic diseases or disorders due to disruption in their DNA during development, and hormonal imbalance in the foetus. The most harmful effects of chemical pesticides for both adults and children are due to their carcinogenic effects. This can cause leukemia, bladder, thyroid, and brain cancer (Asghar *et. al.*, 2016).

HARMFUL EFFECTS OF CHEMICAL PESTICIDES ON HUMAN HEALTH

• Neurological, Psychological and Behavioural Dysfunctions.
• Hormonal Imbalances.
• Immune System Dysfunctions.
• Reproductive System Defects.
• Infertility.
  • Genotoxicity.
  • Cancer
  • Blood Disorders.
  • Kidney Disorders.
  • Liver Disorders.

Source: Adapted from Asghar *et. al.*, 2016.

3.4. Conventional Pesticides and Environmental Effects:

Chemical pesticides are one of the major causes of the water pollution, and some pesticides are persistent organic pollutants such as Aldrin, Chlordane, DDT, Dieldrin, Endrin, Heptachlor, and Mirex, and can contribute to soil pollution. Since these pesticides are non biodegradable, and persistent, they can get accumulated in the environment causing ecosystem disturbances. The major environmental effects are tabulated in the following table.

EFFECTS OF CHEMICAL PESTICIDES ON ENVIRONMENT
• Environmental Pollution. • Reduction of Biodiversity and nitrogen fixation. • Destruction of marine life. • Changes in the ecosystem balances. • Rapid development of resistance in pests. • Suppression of parasitoids and predators. • Adverse effects on non target organisms.

4. Biopesticides – Alternative to Chemical Pesticides:

The harmful effects of chemical pesticides on human health and the environment led to the discovery of the alternatives to the chemical pesticides. Biopesticides are one of the most important alternatives to the

conventional pesticides. Biopesticides are biochemical pesticides that are naturally occurring substances that control pests by non toxic mechanisms (Dutta, 2015). Biopesticides are certain types of pesticides derived from natural materials such as plants, microbes (bacteria, fungus, viruses, and protozoa), and animals which can abate and/ or control the pests. Living organisms, phytochemicals, microbial products or byproducts (semiochemicals) can be used as biopesticides. The classification of biopesticides has been illustrated in the Figure 2. Researches and developments in the field of biopesticides are due to the following advantages of the biopesticides which proved (Kandpal, 2014) to be very beneficial alternative to the chemical pesticides:

- Less harmful than conventional pesticides and less environment load (eco – friendly);
- Designed to affect only one pest (target specific);
- Small doses of biopesticides are effective against pests;
- Biodegradable and non persistent.

In India, only 12 biopesticides have been registered under the Insecticide Act, 1968 (Thakore, 2006). Neem based pesticides, *Bacillus thuringensis*, Trichoderma and NPV are the major biopesticides produced and used commercially in India.

5. Botanical Pesticides:

Botanical pesticides or botanicals are one of the alternatives to conventional pesticides and sub group of biopesticides in agricultural pest management. The characteristic features of the botanical pesticides such as lack of persistence and bioaccumulation in the environment, selectivity towards beneficial insects and low toxicity to humans (Grdisa and Grsic, 2013) led to the significant studies of botanical pesticides from different plant sources. Botanical pesticides are the naturally occurring secondary metabolites (phytochemicals) extracted from the plant sources which can control and kill the pests thus helping in the agricultural pest management. They are generally safer to humans and the environment than conventional chemical pesticides (Dimetry, 2014). Thus, they are of great importance in the field of research of pest management.

5.1. Commercialized Botanical Pesticides:

The major commercially used botanical pesticides in the agricultural pest management are shown in Figure 3.

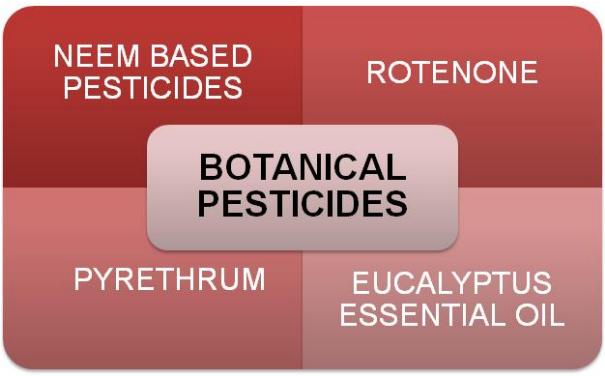

Figure 3: Major Botanical Pesticides

5.1.1. Neem Based Pesticides:

Neem based products are extracted from the neem tree, *Azadirachta indica*, a member of the Meliaceae family (Campos *et. al.*, 2016). The potent active ingredients of the neem are azadirachtin, meliantriol, salannin, desacetyl salannin, nimbin, desacetyl nimbin, and nimbidin. Azadirachtin, a tetranortriterpenoid limonoid, is one of the most potent active compounds of the neem tree [Mordue (Luntz) and Blackwell, 1993]. Azadirachtin is present in higher concentration (0.2 – 0.6%) in the seeds of the neem compared to other parts of the neem tree (Govindchari, 1992). Azadirachtin A is the most active biological ingredient which shows insecticidal activity compared to other analogs of azadirachtin (Koul *et. al.*, 2004; Sola *et. al.*, 2014). Azadirachtin has a wide spectrum of actions on insects such as repellents, antifeedant, insect growth regulatory, and anti – ovipositional properties (Schmutterer, 1990; Bramhachari, 2004). It is most effective against 550 insect species, mostly relating to orders Dictyoptera, Orthoptera, Heteroptera, Isoptera, Lepidoptera, Diptera, Coleoptera, Homoptera, Siphonaptera and Hemiptera [Sadre *et. al.*, 1983; Mordue (Luntz) and Blackwell, 1993]. The spiralling whitefly, *Aleurodicus dispersus* Russell (Hemiptera: Aleyrodidae) is one of the major pests affecting a variety of agricultural crops in the tropical and subtropical regions of the world. Recently, it was found that ethanolic extract of neem was highly effective against test pest, *Aleurodicus dispersus*. The combination of ethanolic extract of neem and acetone extract of crown flower in the ratio 1: 3 showed highest synergistic insecticidal effect against *Aleurodicus dispersus* compared to other combinations formulated in their study (Alim et. al., 2017). Ali *et. al.* (2017) found that *Azadirachta indica* (neem) extract was the most effective insecticide against sucking insect pests, namely, white fly, jassid, and mites compared to other plant extracts used in their study.

Table 2: Major Target Insects of Neem Based Botanical Pesticides.

Sr. No.	Target Insect Species	References
01.	*Anopheles stephensi*	Lucantoni *et. al.*, 2006
02.	*Anopheles culicifacies*	Chandramohan *et. al.*, 2016
03.	*Ceraeochrysa claveri*	Scudeler *et. al.*, 2013; 2014
04.	*Cnaphalocrocis medinalis*	Senthil Nathan *et. al.*, 2006
05.	*Diaphorina citra*	Weathersbee and McKenzie, 2005
06.	*Helicoverpa armigera*	Ahmad *et. al.*, 2015
07.	*Mamestra brassicae*	Seljasen and Meadow, 2006
08.	*Nilaparvata lugens Stal*	Senthil Nathan *et. al.*, 2009
09.	*Pieris brassicae*	Hasan and Ansari, 2011
10.	*Spodoptera frugiperda*	Tavares *et. al.*, 2010

Common Target Pests of Azadirachta (Neem Based Pesticides)

Powdery mildew, White flies, Bollworm, Thrips, Stem borer, Brown Plant Hopper, Leaf Folder, American bollworm, Red Spider mites, Fruit borer (*Helicoverpa armigera*), fruit and shoot borer, leaf roller, pod borer, white flies, leaf hopper, caterpillar, pink mite. (Table 2).

Table 3: Major Target Pests of Pyrethrum.

PYRETHRUM AND MAJOR TARGET PESTS		
Sr. No.	**Target Pests**	**References**
01.	Mosquitoes, sawfly larvae, caterpillars, leafhoppers, aphids, and beetles.	Todd *et. al.*, 2003
02.	*Culicoides variipennis* (Coquillett)	Woodward *et. al.*, 1985
03.	House flies	Sheppard and Swedlund, 1999
04.	Flour beetle	Arthur and Campbell, 2008

5.1.2. Rotenone:

Rotenone is one of the broad spectrum botanical pesticide that is extracted from the roots and stems of tropical legumes *Derris* (*Derris elliptica*, *Derris involuta*), *Lonchocarpus (Lonchocarpus utilis*, *Lonchocarpus urucu*) and *Tephrosia virginiana* (Weinzierl, 2000; Isman, 2006). Chemically, rotenone is the isoflavonoid. Pure rotenone is comparable to synthetic chemical pesticide, DDT in terms of its acute toxicity to mammals (rat oral LD_{50} is 132 mg/ kg) (Isman, 2006; El - Wakeil, 2013).

It is extracted from *Derris* spp., *Lonchocarpus* spp., and *Tephrosia* spp. The dried root powder is used or sprayed. The active ingredient is Rotenone, which acts as a contact and food poison, cellular respiratory enzyme inhibitor, stomach poison.

5.1.3. Pyrethrum:

Pyrethrum is one of the most important botanical pesticides used in India, which is extracted from the flowers of *Chrysanthemum cinerariaefolium* (El - Wakeil, 2013). The higher concentration of pyrethrum is found mainly in the flowers of the plant compared to other parts of the plant (Rhoda *et. al.*, 2006; Isman, 2006; Sola *et. al.*, 2014). Pyrethrum is the mixture of six active ingredients, namely, pyrethrin I, pyrethrin II, cinerin I, cinerin II, jasmolin I, and jasmolin II. Pyrethrin I, cinerin I, and jasmolin I are the esters of chrysanthemic acid, whereas pyrethrin II, cinerin II, and jasmolin II are the esters of pyrethric acid (Head, 1973; Grdisa and Grsic, 2013). The typical pyrethrum extract contains pyrethrins, cinerins, and jasmolins in the ratio 10: 3: 1 (Grdisa and Grsic, 2013). Thus, pyrethrins are the most dominant form of active ingredients compared to cinerins and jasmolins in

terms of concentrations. The major target insect pests of Pyrethrum is shown in Table 3.

5.1.4. Eucalyptus Essential Oil:

The eucalyptus oil is a complex mixture of various phytochemicals such as monoterpenes, sesquiterpenes, aromatic phenols, oxides, ethers, alcohols, aldehydes, and ketones. The composition and proportion of the chemical constituents vary with the species. The pesticidal activity of eucalyptus oil is due to 1, 8 – cineole (eucalyptol), citronellal, citronellol, citronellyl acetate, p – cymene, eucamalol, limonene, linalool, and α – pinene (Batish *et. al.*, 2006; Su *et. al.*, 2006; Batish *et. al.*, 2008). Among the various components of essential oil, 1, 8 – cineole is the most important characteristic compound for the pesticidal activity (Batish *et. al.*, 2008). The various chemical components act synergistically to bring the overall pesticide activity (Cimanga *et. al.*, 2002). In addition to the essential oil of Eucalyptus, leaf extracts of Eucalyptus also has insecticidal activity against various pests. Koul *et. al.* (2008) showed that essential oil of *Eucalyptus globulus* Labill, consisting of eucalyptol, α – pinene, and α – cymene were effective repellent against target pests. It was found that the leaf powder of *Eucalyptus globulus* L., showed insecticidal activity against *Prostephanus trunatus* (Mukanga *et. al.*, 2010). Singh *et. al.* (2012) found that the leaf extracts of three plants, namely, *Azadirachta indica*, *Ocimum sanctum* L., and *Eucalyptus globulus* showed insecticidal activity significantly against test insects, namely, *Asphis gossypi* Glover (aphids) and *Phenacoccus solenopsis* Tinsley (mealy bugs) *in vitro*.

5.2. Current Status of Botanical Pesticides in India:

In order to use pesticides for the agricultural or any purpose, the pesticides and its formulations must be registered under the Insecticide Act, 1968 according to the guidelines and regulations prescribed by the Central Insecticide Board & Registration Committee (CIBRC), Department of Agriculture and Farmer's Welfare in India. In India, only three botanical pesticides namely Azadirachtin (Neem Based Formulations), Pyrethrum, and Eucalyptus Leaf Extract has been registered and allowed to use as botanical pesticides commercially for various purposes under Insecticide Act, 1968. Out of three, Azadirachtin or neem based pesticides are mostly used as the botanical pesticides in the agricultural pest management system followed by pyrethrum, and Eucalyptus Leaf Extract.

6. Recent Advances of Botanical Pesticides Studies:

Heliothis armigera (Hubner) (Lepidoptera: Noctuidae) is one of the major agricultural pests which affects a variety of agricultural crops and commodities such as soybeans, corn, sunflower, peanuts, potatoes, and many more. It was found that the effect of 5% *Nigella sativa* extract (72.99% mortality) was significantly effective against *Heliothis armigera* (fruit borer), followed by 5% *Jatropha curcas* extracts (62.64% mortality), (Awasthi and Avasthi, 2017). Diamond back moth, *Plutella xylostella* Linn., and cabbage butterfly, *Pieris brassicae* Linn., are the major agricultural pests affecting profitable crops, particularly cabbage in India. Neem (*Azadirachta indica*) seed kernel extracts, plant extracts of 0.5% *Alpinia galanga* and *Gomphrena globosa* extracts proved to be superior in reducing the larval density of *Plutella xylostella.* Plant extracts of *Artemisia brevifolia*, *Azadirachta indica*, and *M. azedarach* Linn was found to be most effective (larvicidal activity) against *Pieris brassicae* larvae (Dey *et. al.*, 2017). Botanical pesticides such as *Azadirachta indica*, Pyrethrin, *Datura metel*, *Mirabilis jalapa*, *Targetes minuta*, *Hyptis suaveolens*, *Lantana camara*, *Ryania speciose*, and *Allium sativum* L., has been successfully employed against common bean (*Phaseolus vulgaris* L.) pests such as aphids, bruchid beetle, pink stalk borer, common bean leaf spot, bollworm, grasshoppers, armyworms, cabbage loppers, potato aphids, thrips, and caterpillars (Karani *et. al.*, 2017). Khan *et. al.* (2017) concluded that *Isodon rugosus* and *Daphne mucronata* plant extracts can serve as a potential pesticide against *Acyrthosiphon pisum* (pea aphid; Hemiptera) based on the results obtained in their study.

CONCLUSION

Botanical pesticides are the major alternatives to the conventional synthetic chemical pesticides due to various advantages over conventional pesticides. Neem based pesticides are more common botanicals in India than remaining botanical pesticides. It is essential to prevent the development of pest resistance to the botanical pesticides by formulating various novel mixtures of botanical pesticides as per the directions and regulations of the regulatory bodies or by using different botanical pesticides periodically so that pests would not be able to recognize the compounds and develop resistance mechanism against the botanical pesticides.

Conflicts of interest: The authors stated that no conflicts of interest.

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