BOTANICAL PESTICIDES AND THEIR APPLICATIONS IN INSECT PEST MANAGEMENT

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Abstract

Pest management is facing economic and ecological challenge worldwide due to human and environmental hazards caused by majority of the synthetic pesticide chemicals. Identification of novel effective insecticidal compounds is essential to combat increasing resistance rates. Botanical pesticides have long been touted as attractive alternatives to synthetic chemical pesticides for pest management because botanicals reputedly pose little threat to the environment or to human health. Botanical pesticides are naturally occurring chemicals extracted or derived from plants that are used to control pests. They play a vital role in integrated pest management (IPM) by offering a safer, more environmentally friendly alternative to synthetic pesticides. A number of plant substances have been considered for use as pest antifeedants, repellents and toxicants, but apart from some natural mosquito repellents, a little commercial success has ensued for plant substances that modify arthropod behaviour.

Keywords: insecticidal compounds, botanical pesticides, repellents, human health

1. Introduction

Climate change, biodiversity loss, and growing needs for food production are just a few of the many issues facing agriculture worldwide (Rockstrom et al., 2009; Tilman et al., 2011; Deutsch et al., 2018). Up to 40% of the world's food crops are destroyed annually by pests and diseases. This causes hunger, disrupts rural income, and costs the agricultural trade more than $220 billion year (Vandana and Uniyal, 2021; Table 1). As long as there are affordable and efficient chemicals available, pesticides will probably continue to be the mainstay of pest management strategies (Haynes, 1988). Significant ecological effects result from intensive agriculture, which is linked to high inputs of synthetic pesticides. These effects include the loss of essential ecosystem services, such as insect-mediated pest reduction. In order to manage pests sustainably, efforts have been made in recent years to find safer alternatives to conventional insecticides. The goal of habitat management, a component of conservation biological control, is to promote and maintain natural pest suppression by giving predators and parasitoids shelter, alternative prey, and floral resources. Another significant provisioning ecosystem service is the use of plant extracts as botanical pesticides. Ancient Egypt, China, Greece, and India were among the first countries to use plant derivatives, or botanical pesticides as we currently know them, in agriculture at least two thousand years ago (Ware, 1983; Thacker, 2002).

Over 6,500 plant species are thought to have had their anti-insect qualities investigated. Of these, 235 families and over 2,500 species have demonstrated biopesticide action (Celis et al., 2008; Walia et al., 2012). Herbal medicines have long been made from whole plants or their extracts.

In addition to producing a wide range of secondary metabolites for other uses, plants also create critical molecules needed for growth and development (Rosenthal and Berenbaum, 1991).

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

Sr. No.	Crops/ Commodities	Major Pests
01.	Rice	*Acrida exaltata, Ampittia dioscorides, Chilopoly chrysa, Cnaphalo crocistrapezalis, Lenodora vittata, Leptocorisa acuta, Nephotet tixparvus* and many more.
02.	Maize	*Agonos celisnubilis, Aloa albistriga, Anomala dimidiate, Mythimna loreyi, Myllocerus viridanus* and many more
03.	Sugarcane	*Abda startusatrus, Chilosac chariphagusindicus, 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, Bemisiata baci, 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.

These secondary metabolites are bioactive substances that have a wide range of effects on bacterial, fungal, viral, insect, and human cells. They are also essential for interactions with other living things (Schäfer and Wink, 2009). The function of botanical pesticides in pest management will be covered in this chapter, along with how they are superior than synthetic pesticides in terms of biodegradability and the fact that they pose little to no risk to non-target creatures, the environment, or people. The future of botanical pesticides is also covered, since more research on their stability, efficacy, safety, modes of action, and cost-effectiveness may make them a viable substitute for synthetic pesticides.

2. Conventional Pest and Human Health

The majority of conventionally manufactured chemical pesticides are extremely dangerous to human health since they can cause harmful and significant medical problems in humans when consumed or in trace amounts. Chemical pesticides like organochlorines, organophosphates, and carbamates can disturb the body's neuronal coordination, create adult neurotransmitter synthesis errors, and cause neurological disorders including Alzheimer's and Parkinson's disease. Due to hormonal imbalances and DNA disruption during development, pesticide exposure during fetal development might result in congenital problems, hereditary diseases, or disorders. Chemical pesticides have the greatest detrimental effects on both adults and children since they can cause cancer. This may result in brain, thyroid, bladder, and leukemia cancer (Asghar *et al*., 2016).

3. Botanical Pesticides – A Rich resource

Natural substances that are taken from plants are known as botanical insecticides. Although they can be used as a substitute for synthetic chemical formulations, natural pesticidal treatments are not always less harmful to people. Naturally occurring substances include some of the most lethal, rapidly acting poisons and strong carcinogens (Regnault-Roger et al., 2005; Regnault-Roger and Philogène, 2008). Significant research on botanical pesticides from various plant sources has been prompted by the pesticides' distinctive qualities, which include minimal toxicity to humans, selectivity towards beneficial insects, and lack of persistence and bioaccumulation in the environment (Grdisa and Grsic, 2013). Compared to traditional chemical pesticides, they are typically safer for both people and the environment (Dimetry, 2014). 15 (33.3%) were found using the phrases "botanical insecticide," "plant extracts," "biopesticides," "insecticidal activity," or "pesticidal activity (Apiaceae, Apocynaceae, Asteraceae, Boraginaceae, Brassicaceae, Campanulaceae, Fabaceae, Lamiaceae, Myrtaceae, Papaveraceae, Polygonaceae, Primulaceae, Proteaceae, Rosaceae, Rubiaceae and Scro-phulariaceae; Table 2) out of 44 plant families that have been involved in habitat manipulation studies, had at least one plant genus or species with insecticidal activity. Pro- teaceae had one plant used in habitat manipulation in the same genus as another plant used as a biopesticide. All other plant families had at least one plant species tried for its insecticidal activity and tested in habitat manipulation studies (Fiedler *et al.,* 2008; Lavandero *et al.,* 2006; Vattala *et al.,* 2006).

Table – 2: Important group of pesticidal plants

Scientific name	**Common name**	**Botanical insecticide activity**	**Order of insects controlled**	**Ref as botanical species**	**Ref as HM species**
Apiaceae					
Ammi majus L.	Bishop's flower	+	Lepidoptera	1	*
Ammi visnaga (L.) Lamarck	Toothpick ammi	+	Diptera	2, 3	*
Anethumgra veolens L.	Dill	+	Coleoptera, Blattodea, Diptera	4, 5, 6	*
Angelica atropurpurea L.	Angelica	o			*
Anthriscus cerefolium (L.)	Chervil	+	Coleoptera, Diptera	7	*
Anthriscus sylvestris (L.) Hoff-	Cow parsley	+	Lepidoptera, Diptera	63	*
Apium graveolens L.	Celery	+	Diptera	8	*
Carum carvi L.	Caraway	+	Coleoptera	9	*
Conium maculatum	Poison hemlock	+	Thysanoptera, Trombidiformes,	10, 11	10
Conopodium majus	Pignut	o			13
Coriandrum sativum L.	Coriander/cilantro	+	Coleoptera	12, 13	13
Daucus carota L.	Wild carrot	+	Diptera, Coleoptera	14, 15	*
Foeniculum vulgare Mill.	Fennel	+	Coleoptera	12, 16, 17	*
Heracleum sphondylium L.	Eltrot	o			*
Heracleum maximum Bartr.	Cow parsnip	x	Coleoptera	18	*
Pastinaca sativa L.	Wild parsnip	+	Lepidoptera	19	2
Pimpinella anisum	Aniseed	+	Diptera	20, 21	10

Zizia aurea (L.) Koch	Golden alexanders	o			*
Apocynaceae *Apocynum cannabinum* L.	Indian hemp	o	*		
Asclepsia syriaca	Common milkweed	o	22		
Asclepia stuberosa	Butterfly weed	o	22		
Asclepia sfascicularis Dcne.	Milkweed	o	*		
Asclepia sincarnata L.	Swamp milkweed	o	*		
Asclepias syriaca L.	Common milkweed	o	*		
Asclepia stuberosa L.	Butterfly weed	o	*		
Asparagaceae					
Asparagus acutifolius	Wild asparagus	o	13		
Asteraceae					
Achilleamil lefolium L.	Yarrow	+	Lepidoptera, Coleoptera	22, 24	*
Achillea spp.	Yarrow	+	Lepidoptera, Coleoptera	23, 24	*
Ageratina aromatic	Lesser snakeroot	x	Diptera	25	14
Andryala integrifolia	Common andryala	o			11
Anthemis arvensis L.	Corn chamomile	x	Lepidoptera	26	*
Artemisia ludoviciana	Louisiana wormwood	+	Hemiptera, Orthoptera	27, 28	16
Aster nova-angliae L.	Smooth aster	x	Lepidoptera	26	*
Aster novi-belgii L.	New England aster	+	Lepidoptera	26	*
Bacchari spilularis	New York aster	o			*

DC.					
Baccharis viminea DC.	Coyotebrush	o			*
Cacalia atriplicifolia L. H. Rob.	Mule fat	o			*
Calendula arvensis	Field marigold	x	Lepidoptera	29	7
Calendula officinalis L.	Calendula	+	Hemiptera	30	*

4. Types of Botanicals Insecticides and their effects

Essential oils

Natural compounds that are isolated from plants and utilized as a great substitute for chemical or synthetic pesticides are known as plant secondary natural products (Regnault- Roger and Philogène, 2008; Sithisut et al., 2011). Furthermore, the United States Food and Drug Administration (FDA) recognized botanical pesticides (essential oils) as safer than synthetic pesticides, which increased the risk of ozone depletion, neurotoxicity, carcinogenic, teratogenic, and mutagenic effects in non-targets, as well as cross- and multi-resistance in insects. Additionally, insecticide resistance to synthetic pesticides resulted in significant food losses due to chemical failure in pests and annually caused economic losses of several billion dollars worldwide (Elzen and Hardee, 2003; Pereira et al., 2006; Shelton et al., 2002) (Regnault- Roger *et al.,* 2012).

Because essential oils derived from aromatic plants are so popular with organic farmers and eco-conscious customers, their use as pesticides has grown significantly. Their effects on a range of insects include growth inhibitors, oviposition inhibitors, ovicides, antifeedants, repellents, insecticidal, and growth-reducing properties (Don-Perdo, 1996; Elzen and Hardee, 2003; Koshier and Sedy, 2001; Lu, 1995; Pereira *et al.,* 2006; Regnault-Roger *et al.,* 2012; Shelton *et al.,* 2002; Sithisut *et al.,* 2011; Tripathi *et al.,* 2003).

Alkaloids

The most significant class of natural compounds with an important insecticidal function is alkaloids (Balandrin et al., 1985; Rattan, 2010). According to Wachira et al. (2014), pyridine alkaloids isolated from Ricinus communis have antimalarial properties against Anopheles gambiae. Rutacha lepensis leaves were used to extract furocoumarin and quinolone alkaloids, which demonstrated larvicidal and antifeedant properties against Spodoptera littoralis larvae (Emam et al., 2009). Alkaloids extracted from Pergularia tomentosa were discovered to have larvicidal and antifeeding properties by Acheuk and Doumandji-Mitiche (2013). Lee (2000) came to the conclusion that the alkaloids pipernonaline and piperidine had larvicidal properties against mosquitoes. Alkaloids from the extract of Arachis hypogaea exhibit larvicidal efficacy against the vectors of malaria and chikungunya (Velu *et al.,* 2015).

Flavonoids

Flavonoids might be helpful in a plan to control pests. According to Acheuk and Doumandji-Mitiche (2013), flavonoids are crucial in protecting plants against herbivores and insects that feed on plants. By affecting the behavior, growth, and development of insect pests, flavonoids and isoflavonoids both shield the plant from harm (Simmonds, 2003; Simmonds and Stevenson, 2001). In Pinus banksiana, rutin and quercetin-3-glucoside prevent L. dispar from growing and raise its death rate (Gould and Lister, 2006). The tobacco armyworm (Spodoptera litura) died more frequently when exposed to quercetin and rutin glycosides found in peanuts (Mallikarjuna et al., 2004). Three flavone glucosides found in rice prevent insects from digesting food and act as deterrents for herbivores and Nilaparva talugens (Acheuk and Doumandji-Mitiche, 2013).

Glycosides

Flax, bamboo, cassava, and other plants contain cyanogenic glycosides, which are referred to as plant defense compounds. As fumigants, they work well against insects found in stored products. Cyanohydrins can be utilized as soil fumigants and as an alternative fumigant because of their insecticidal action on insects (Park and Coats, 2002). Anthraquinones that were extracted from Cassia species were discovered to have insecticidal and antimalarial properties by Dave and Lediwane (2012). Glycosides from the extract of A. hypogaea exhibit larvicidal efficacy against the vectors of malaria and chikungunya (Velu *et al.,* 2015). Juvenogens have a potential application in insect pest control (Wimmer *et al.,* 2007).

Esters and Fatty acids

Larvicidal effectiveness against the vector C. quinquefasciatus is demonstrated by fatty acid methyl esters that were derived from Solanum lycocarpum (Silva et al., 2015). The utilization of saturated fatty acids, specifically C8, C9, and C10, as antifeedants or repellents against houseflies, horn flies, and stable flies was demonstrated by Mullens et al. (2009). The main malaria vector, Anopheles funestus, has strains that are both susceptible to and resistant to insecticides. Samuel et al. (2015) found that the fatty acid mixture (C8910) is both poisonous and repellent to these varieties. Yousef et al. (2013) found that linoleic acid was harmful to S. littoralis larvae and reduced their body weight.

5. Mode of Action of Botanicals

Depending on the physiological traits of the insect species and the type of insecticidal plant, botanical pesticides have varying effects on insect pests. Repellants, growth retardants, toxicants, chemosterilants, attractants, and feeding deterrents/antifeedants are the six categories into which the constituents of different botanical insecticidal products can be divided (Rajashekar et al., 2012). The particular enzyme, protein, or biological step that is impacted is typically included in the method of action. Although the majority of botanical pesticides' modes of action are categorized according to the pests they control, their physical attributes, or their chemical makeup (Khambay *et al.,* 2003; Bloomquist *et al.,* 2008).

Repellents

Through the stimulation of olfactory or other receptors, botanical pesticides have the ability to repel insect pests and protect crops (Isman, 2006) with little harm to the environment (Talukder, 2006; Talukder et al., 2002). Due to their minimal or nonexistent pesticide residue, botanical pesticides are regarded as safe for use in pest management, protecting people, the environment, and ecosystems (Talukder et al., 2004). According to Ghavami et al. (2017), essential oils of Achillea wilhelmsii, Myrtus communis, Ziziphora tenuiore, and M. piperita have the ability to repel human fleas. Because essential oils have a repellent effect on Tribolium confusum, Rahdari and Hamzei (2017) showed that oils from M. piperita, R. officinalis, and Coriandrum sativum are effective when used to safeguard organic produce. The repellent properties of six Zanthoxylum species—Z. armatum, Z. dimorphophyllum, Z. dimorphophyllum var. spinifolium, Z. piasezkii, Z. stenophyllum, and Z. dissitum—against two storage pests, namely Tribolium castaneum and Lasioderma serricorne adults, were documented by Zhang et al. (2017). The essential oils of these six species demonstrated notable repellent properties against these two storage pests.The different repellent activities on two insects might be attributed to the different anti-insect mechanism and different non persistent volatility of essential oil sample (Kimutai *et al.,* 2017).

Feeding deterrents/antifeedants

Botanical pesticides that make the treated materials unappealing or unpalatable in order to prevent or interfere with insect feeding (Rajashekar et al., 2012; Talukder, 2006). Eventually, the insects die from starvation after remaining on the treated material indefinitely. Liao and colleagues (2017) showed that M. alternifolia oil and its chemical components had clear antifeedant properties against Helicoverpa armigera Hubner. According to Loko et al. (2017), the phytoconstituents in Khayas enegalensis leaf extract, which contain tannins, saponins, flavonoids, steroids, and alkaloids, may have contributed to Dinoderus porcellus's demise. Azadirachtin, a major component of neem, has been identified as a crucial insecticidal element by Chaudhary et al. (2017) and Ghoneim and Hamadah (2017). It acts as an antifeedant, repellent, and repugnant agent and induces sterility in insects by preventing oviposition and interrupting sperm production in males.

Toxicity

Certain botanical insecticides are poisonous and kill insects that are preserved in products (Padin et al., 2013). According to Hollingworth et al. (1994), rotenone is regarded as a poisonous substance because it poisons the mitochondria, blocking the electron transport chain and preventing the production of energy. Its ingestion is necessary for its effectiveness as an insecticide, making it a stomach poison (Isman, 2006). The essential oil of Lavandula angustifolia demonstrated good contact toxicity and fumigant properties against adult granary weevils. Granary weevil orientation to an alluring host substrate can also be altered by a potent repellent action (Germinara et al., 2017). According to Trivedi et al. (2017), fumigants are harmful to Callosobruchus chinensis, a pest of stored grains.The essential oils of cinnamon, clove, rosemary, bergamot, and Japanese mint showed potential to be developed as possible natural fumigants or repellents for control of the pulse beetle.

6. Growth retardants and development inhibitors

The growth and development of insects were negatively impacted by botanical pesticides, which lengthened the stages of development and decreased the weight of the larva, pupa, and adult stages (Talukder, 2006). Additionally, plant derivatives lower the rates of adult emergence and larval and pupal survival (Koulet al., 2008). Both neem seed oil and azadirachtin have been shown to considerably increase aphid nymphal mortality, at 80 and 77%, respectively, while also lengthening the development period of those that survive to adulthood (Kraissand Cullen, 2008).

Sterility/reproduction inhibitors

A chemosterilant, which is a chemical agent that prevents sexually reproducing organisms from reproducing, or the sterile insect method (SIT) can both cause sterility (Morrison et al., 2010). By rendering one or both sexes temporarily or permanently sterile or by preventing the development of the young to a sexually functional adult stage, chemesterilants are used to control economically damaging or disease-causing pests (mostly insects) (Navarro-Llopis, et al., 2011; Wilke et al., 2009). Plant components, oil, extracts, and powder combined with grain have been shown to decrease insect oviposition, egg hatchability, postembryonic development, and offspring development (Asawalam and Adesiyan, 2001; Shaalan *et al.,* 2005).

Attractants

Insect attractants are botanical compounds that make insects travel in a specific direction toward their source. They affect the olfactory (smell) and gustatory (taste) receptors or sensilla. Bark beetles and other Cruciferaea insects are naturally attracted to iso-thiocyantes from Crucifera seeds, sugar and molasses, and terpenes from bark combined with pheromones. Carrot fly (Psilarosae) and Lepidoptera are drawn to onions by propylmercapton from Umbelliferae and phenylacetaldehyde from Araujia serisofera flowers, respectively. There are three methods for controlling insects with insect attractants. When surveying or tracking insect populations, the size of the infestation is determined, and the appropriate control measure is chosen to divert insects from their typical mating, aggregation eating, or oviposition behaviors and attract them to insecticide-coated traps or poison baits. Since they don't destroy insects, they don't disrupt the ecology. By leading insects to the incorrect oviposition sites, they can reduce the quantity of insects by causing them to starve or produce unfertilized eggs. They are unreliable when utilized as the only control measure in an integrated control scheme (Arora *et al.,* 2012).

7. Resources of Botanical Pesticides

Insect control currently involves four main categories of botanical products: pyrethrum, rotenone, neem, and essential oils, in addition to three others that are used sparingly: ryania, nicotine, and sabadilla. There is limited (low volume) regional use of other plant extracts and oils in different nations, such as garlic oil and capsicum oleoresin. Table 3 shows that the functional and biological active plant constituents of several botanical pesticides differed from one product and source to another. Exemption from registration for some items routinely used in processed foods has substantially aided the commercial development of plant-based insecticides (Quarles, 1996). This opportunity has spurred the development of botanical insecticides, acracides, fungicides, bactericides, nematicides and herbicides for agricultural and industrial applications and for the consumer market as described by Thibout*et al.,* (1986); Thibout and Auger (1997); Auger and Thibout (2002).

Table - 3: Pesticidal plants and their parts used

Species	**Families**	**Parts**
Abrus precatorius L	Fabaceae	L, S
Allium sativum L	Alliaceae	L
Anacardium occidentale L	Anarcadiaceae	L
Annonasen egalensis Pers.	Asteraceae	S, B
Artemisia annua L	Asteraceae	L, B
Azadirachta indica A. Juss	Meliaceae	L,B,R, F
Balanites aegyptiaca Linn Bel.	Zypophyllaceae	R
Biden spilosa L	Asteraceae	L
Cannabis sativa L	Cannabaceae	L, S, F
Capsicum frutescens L	Solanceae	F
Carica papaya L	Caricaceae	R, B
Chrysanthemum coccineum Wild	Asteraceae	L, F
Clausenaa nisata	Rutaceae	L, R
Dalbergia saxatilis	Fabaceae	L, B
Dannettia tripetala	Annonaceae	L
Eucalyptus globules Labill	Myrtaceae	L, B
Gmelina arborea Juss.	Verbenaceae	L
Hyptis sauvcolens Poit.	Labiate	shoot
Jatropha curcas L	Euphorbiaceae	sap, F, S, B
Khayas enegalensis A. Juss	Meliaceae	S, B
Lannea acida	Anacardiaceae	B
Lawsonia inermis	Lythraceae	L
Melia azadarach L	Meliaceae	L, R, B
Mitra carpusscaber Zucc	Rubiaceae	shoot
Nicotiana tabacum L	Solanaceae	L
Ocimum gratissimum L	Liminaceae	L

Parkiaclap pentoniana Keay.	Mimosaceae	S, B
Phytolaccadod ecandra L'Herit	Phytolaceae	L, F
Piper guineense Schum & Thonn	Piperaceae	F
Piliostigma thonningii	Caesalpiniaceae	R,B
Prosopis africana Linn.	Mimosaceae	S, B
Spenoclea zeylanica Gearth	Sphenocleceae	shoot
Tagetes minuta L	Asteraceae	L
Tephrosa vogelii Hook	Fabaceae	L
Vernovia amygdalina L	Asteraceae	L

R-Root, B-bark, S-Stem, L-Leaves, F-Flowers

8. Commercialized Botanical Pesticides

The major commercially used botanical pesticides in the agricultural pest management are shown in Figure 1.

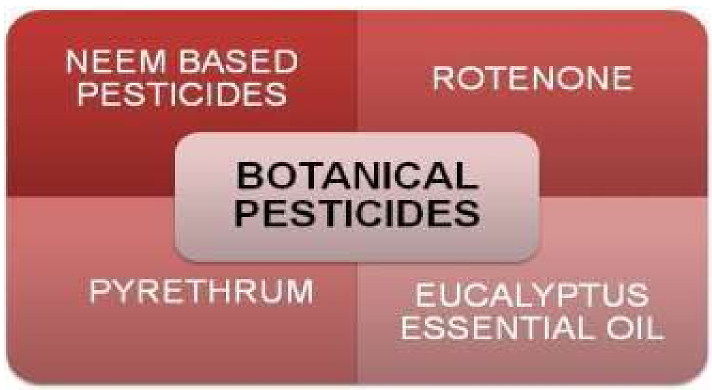

Figure- 1: Major Botanical Pesticides

Neem based products

The neem tree, Azadirachta indica, which belongs to the Meliaceae family, is the source of neem-based goods (Campos et al., 2016). Azadirachtin, meliantriol, salannin, desacetylsalannin, nimbin, desacetylnimbin, and nimbidin are the powerful active components of neem. One of the neem tree's most powerful active substances is azadirachtin, a tetranortriterpenoid limonoid (Mordue (Luntz) and Blackwell, 1993). According to Govindchari (1992), neem seeds have a higher content of azadirachtin (0.2–0.6%) than other sections of the neem tree. When compared to other azadirachtin analogs, azadirachtin A is the most potent biological component that exhibits insecticidal activity (Koul et al., 2004; Sola et al., 2014). Azadirachtin has a variety of effects on insects, including anti-feedant, anti-repellent, anti-ovipositional, and insect growth-regulating qualities (Schmutterer, 1990; Bramhachari, 2004). 550 insect species, primarily from the orders Dictyoptera, Orthoptera, Heteroptera, Isoptera, Lepidoptera, Diptera, Coleoptera, Homoptera, Siphonaptera, and Hemiptera, are its most successful targets (Sadre et al., 1983; Mordue (Luntz) and Blackwell, 1993). The whitefly that spirals, Aleurodicus dispersus In tropical and sub-tropical portions of the world, russell (Hemiptera: Aleyrodidae) is a significant pest that affects a range of agricultural crops. It was recently discovered that neem ethanolic extract was quite successful against the test pest, Aleurodicus disperses (Table 4).

Table - 4: Major Target Insects of Neem Based Botanical Pesticides

Target Insect Species	**References**
Anopheles stephensi	Lucantoni *et al.* (2006)
Anopheles culicifacies	Chandramohan *et al.* (2016)
Ceraeochrysa claveri	Scudeler *et al.* (2013); (2014)
Cnaphalocrocis medinalis	Senthil Nathan *et al.* (2006)
Diaphorina citra	Weathersbee and McKenzie (2005)
Helicoverpa armigera	Ahmad *et al.* (2015)
Mamestra brassicae	Seljasen and Meadow (2006)
Nilapar vatalugens Stal	Senthil Nathan *et al.* (2009)
Pieris brassicae	Hasan and Ansari (2011)
Spodopteraf rugiperda	Tavares *et al.* (2010)

Rotenone

The roots and stems of tropical legumes Derris (Derris elliptica, Derris involuta), Lonchocarpus (Lonchocarpus utilis, Lonchocarpusurucu), and Tephrosiavirginiana are the source of rotenone, a broad-spectrum botanical pesticide (Weinzierl, 2000; Isman, 2006). Rotenone is the isoflavonoid in terms of chemistry. The acute toxicity of pure rotenone to mammals is similar to that of the synthetic chemical pesticide DDT (rat oral LD50 is 132 mg/kg) (Isman, 2006; El-Wakeil, 2013). Derris species, Lonchocarpus species, and Tephrosia species are the sources of its extraction. The powdered dried root is sprayed or utilized. Rotenone is the active component; it inhibits cellular respiratory enzymes, causes food and contact poisoning, and causes stomach poisoning.

Pyrethrum

One of the most significant botanical insecticides in India is pyrethrum, which is taken from Chrysanthemum cinerariaefolium flowers (El-Wakeil, 2013). Compared to other plant parts, the flowers of the plant have a higher concentration of pyrethrum (Rhoda et al., 2006; Isman, 2006; Sola et al., 2014). Six active ingredients—pyrethrin I, pyrethrin II, cinerin I, cinerin II, jasmolin I, and jasmolin II—combine to form pyrethrum. The Insecticide Act of 1968 has authorized the commercial use of pyrethrum and eucalyptus leaf extract as botanical pesticides for a variety of uses. 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 (Table - 5).

Table – 5: Major Target Pests of Pyrethrum

Sl.No	Target Pests	References
01.	Mosquitoes, saw fly larvae, Caterpillars, Leafhoppers, Aphids and Beetles.	Todd *et al.*, 2003
02.	*Culicoides variipennis* (Coquillett)	Woodward *et al.,* 1985
03.	Houseflies	Sheppard and Swedlund, 1999
04.	Flour beetle	Arthur and Campbell, 2008

9. *Eucalyptus* Essential Oil

Eucalyptus oil is a complex blend of several phytochemicals, including alcohols, aldehydes, ketones, ethers, monoterpenes, sesquiterpenes, aromatic phenols, and oxides. Different species have different chemical ingredient proportions and compositions. The compounds 1, 8-cineole (eucalyptol), citronellal, citronellol, citronellyl acetate, p-cymene, eucamalol, limonene, linalool, and α-pinene are responsible for the pesticidal action of eucalyptus oil (Batish et al., 2006; Su et al., 2006; Batish et al., 2008). 1, 8-cineole is the most significant characteristic molecule for the pesticidal activity among the many components of essential oil (Batish et al., 2008). The various chemical components act synergistically to bring the overall pesticide activity (Cimanga *et al*., 2002).

Mode of Actions

Rotenone

Rotenone is a contact and gastrointestinal poison that slows down the electron transport chain in insect pests' mitochondria (Henn and Weinzierl, 1989; Hinson, 2000; El-Wakeil, 2013; Khater, 2012). It interferes with Nicotinamide Adenine Dinucleotide Hydride (NADH) during the production of useable cellular energy Adenosine Triphosphate (ATP) and prevents electrons from moving from iron-sulfur centers in complex I to ubiquinone (Belmain et al., 2012). A backup of electrons is therefore produced within the mitochondrial matrix when Complex I is unable to transfer its electron to Complex Q. Cellular oxygen is converted to the reactive species known as the radical during this limiting process. Deoxyribonucleic acid (DNA) and other mitochondrial components may sustain harm from this reactive species (Hinson, 2000).

Azadirachtin

According to Khalil (2013), azadirachtin exhibits potent antifeedant properties on insect chemoreceptors, discouraging insect pests from consuming the plant. Azadirachtin inhibits the release of peptide hormones in crops treated with neem tree extracts, causing severe growth problems and aberrant molting in insect pests (Aerts and Mordue, 1997). Last but not least, azadirachtin damages most insects' muscles, fat, and digestive systems (Aerts and Mordue, 1997; Mordue and Blackwell, 1993).

Pyrethrins

Pyrethrins function similarly to DDT and pyrethroids, attacking the neurological systems of all insects (Henn and Weinzierl, 1989). The electrical transmission of impulses along the axon is impacted by axonic toxic compounds (Khater, 2012). Pyrethrins interfere with the proper transmission of nerve impulses by disrupting the sodium and potassium ion exchange mechanism in insect nerve fibers (Henn and Weinzierl, 1989). In insect nerve cells, pyrethrins cause prolonged and recurrent nerve firings by delaying the closure of voltage-gated sodium ion channels (Khater, 2012). The insect dies as a result of paralysis and lack of motor coordination brought on by this overexcitation.

10. Factors affecting the use of Botanical Pesticides

- ✓ Raw material availability.
- ✓ Standardization of botanical extracts containing a complex mixture of active constituents 3. Solvent types, plant species and part of plant.
- ✓ Rapid degradation.
- ✓ State registration.
- ✓ Market opportunities for botanical pesticides.
- ✓ Weather conditions (Henn *et al.,* 1991; Dosemeci *et al.,* 2002).

11. Advantages and Disadvantages of Botanical Pesticides

Advantages

- The farmer is familiar with the plants that produce the aforementioned substances because they typically grow in the same geographical area.
- These plants frequently have additional functions, such as being used as insect repellents around the house or for medical purposes.
- The active product's quick breakdown could be useful because it lowers the possibility of residues on food.
- Some of these products may be used shortly before harvesting.
- Despite not killing insects over the long run, several of these chemicals work extremely rapidly to prevent them from feeding.
- These products may be less aggressive with natural enemies and more selective with insect pests due to their stomach action and quick decomposition.
- Most of these compounds are not phytotoxic.
- ✓ Resistance to these compounds is not developed as quickly as with synthetic pesticides (El-Wakeil, 2014).

Disadvantages

- ✓ Most of these products are not truly pesticides since many are merely insect deterrents and their effect is slow.
- ✓ They are rapidly degraded by UV light so that their residual action is short.
- ✓ Not all plant pesticides are less toxic to other animals than the synthetic ones.

- ✓ They are not necessarily available season long.
- ✓ Most of them have no established residue tolerances.
- ✓ There are no legal registrations establishing their use.
- ✓ Not all recommendations followed by growers have been scientifically verified. (El-Wakeil 2013).

12. Conclusion

Natural botanical pesticides are more widely used both domestically and internationally since they are relatively safe, readily biodegradable, and have a variety of effects on insect pests. The botanicals have a wide range of sources, and many pesticidal plants have not yet been thoroughly investigated. Finding workable substitutes has become necessary due to growing concerns about insect resistance to chemical pesticides. Botanicals have the advantage of being inexpensive and easy for farmers to prepare without the need for advanced methods. Many companies have developed botanical formulations that are easily accessible in the market for a broader reach.

However, we cannot completely rule out the possibility that botanicals also have a broad range of action, which is why they must pass safety testing before being used in the field. Despite claims that there are over 2500 different types of pesticidal plants, about ten or fewer are the most widely used. The portion of the plant that possesses pesticidal qualities occasionally has its own usage restrictions. Botanicals are a significant part of Integrated Pest Management and are effective when combined with both chemical and microbial insecticides.

Botanical pesticides (essential oils, flavonoids, alkaloids, glycosides, esters and fatty acids) have various chemical properties and modes of action and affect a wide array of insect pests in different ways namely; repellents, feeding deterrents/antifeedants, toxicants, growth retardants, chemosterilants, and attractants.

The results of the study demonstrate that over the past ten years, there has been a consistent and ongoing rise in the preference for botanicals. Therefore, for improved performance, future focus should be on creating a variety of botanical formulations with the specific compounds. In addition to ensuring sustainable agriculture, this will improve beneficial insects and preserve the biotic balance. However, not all botanicals are safe for humans, so when applying botanical pesticides in the field, appropriate safety precautions must be taken. Plant-based pesticides are predominantly used in low-income and emerging nations to control pests because of their cost-effectiveness, availability, accessibility, and easy-to-use.

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