# Efficacy of Major Plant Extracts/ Molecules on Field Insect Pests

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**Abstract**

Insect pests are considered the major hurdle in enhancing the production and productivity of any farming system. The use of conventional synthetic pesticides has led to the emergence of pesticide-resistant insects, environmental pollution, and negative effects on natural enemies, which have caused an ecological imbalance of the predator-prey ratio and human health hazards; therefore, eco-friendly alternative strategies are required. The plant kingdom, a rich repertoire of secondary metabolites, can be tapped as an alternative for insect pest management strategies. A number of plants have been documented to have insecticidal properties against various orders of insects in vitro by acting as antifeedants, repellents, sterilant and oviposition deterrents, etc. However, only a few plant compounds are applicable at the field level or presently commercialised. Here, we have provided an overview of the broad-spectrum insecticidal activity of plant compounds from neem, *Annona*, *Pongamia*, and *Jatropha*. Additionally, the impact of medicinal plants, herbs, spices, and essential oils has been reviewed briefly.

**Keywords**

Insect pests • Field crops • Botanicals • Plant extracts • Secondary metabolites • Insecticidal properties

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## 1 Introduction

The plant kingdom is recognised as the most efficient producer of chemical compounds that are used to defend plants against different insect pests (Isman and Akhtar 2007). The literature focusing on the effects of plant secondary compounds on insects is voluminous. As many as 2,121 plant species are reported to possess pest management properties, and 1,005 species of plants exhibit insecticidal properties, which includes 384 species with antifeedant properties, 297 species with repellent properties, 27 species with attractant properties, and 31 species with growth-inhibiting properties (Singh et al. 2008). The biological activity of plant extracts against bacteria, fungi, viruses, and insects has been discussed adequately (Bozsik 1996; Macedo et al. 1997; Unicini Manganelli et al. 2005; Gopalakrishnan et al. 2010, 2011). Botanical insecticides can be made from roots, flowers, seeds, stems, leaves, fruits, and bark in water or in organic solvents. Botanicals used as insecticides presently constitute 1 % of the world insecticide market (Rozman et al. 2007). In this chapter, the importance of botanicals in agriculture with an emphasis on field pests is reviewed.

## 2 History of Botanicals Used as Pesticides

Botanicals have been in nature for millions of years with no adverse effects on the ecosystem. The repellency of plant material has been exploited for thousands of years by mankind by hanging bruised plants in houses, a practice that is still in wide use throughout developing countries. The use of plant extracts and plant parts in the form of powder as insecticides dates back at least as far as the Roman Empire. For instance, during the reign of Persian king Xerxes (400 BC), children were deloused with a powder obtained from the dry flowers of a plant known as pyrethrum, *Tanacetum cinerariaefolium* (family – Compositae). In India, a poisonous plant is mentioned in the Rig Veda, the classic book of Hinduism, which was composed during the second millennium BC (Chopra et al. 1949). Today, in Mexico and several Central American countries, it is common practice to treat pests with plants known for their insecticidal properties. Crude botanical insecticides have been used for several centuries and have been known in tribal or traditional cultures around the world (Richard 2000). Plants have also been used for centuries in the form of crude fumigants, where plants were burned to drive away mosquitoes and later as oil formulations applied to the skin or clothes (Maia and Moore 2011). Mixing grain with plant oils is an ancient Indian and African approach of protecting grains against insect attack (Pereira 1983). The first botanical insecticide used as such, i.e., tobacco, dates back to the seventeenth century. A plant insecticide known as rotenone, which was obtained from the roots of the timbo plant, was introduced circa 1850. In 1965, Sláma and Williams made a surprising discovery that paper towels made from the wood of the balsam fir (*Abies balsamea*) released vapours that elicited a potent effect on hemipteran bugs of the Pyrrhocoridae family (Hodin 2009; Sláma and Williams 1965).

## 3 Insect Pest Management with Botanicals: A Depiction

### 3.1 Neem

*Azadirachta indica* A. Juss (syn: *Melia azadirachta, M. indica,* and *Antelaea azadirachta*), also known as the Indian neem tree, belongs to the family Meliaceae (mahogany) and was first described by the French botanist Adrian Henri Laurent de Jussieu in 1830. The botanical name *M. azadirachta* is sometimes confused with *M. azedarach*, a West Asian tree commonly known as chinaberry, Persian lilac, bakain, and dharak (National Research Council (NRC) 1992).

Every part of the neem tree has been used extensively as household remedies and also in ayurvedic, unani, and homeopathic medicine. Hence, it has been described as a ‘cynosure of modern medicine’ by Biswas et al. (2002). Broad-spectrum biological effects (antibacterial, antifungal, antiviral, antiplasmodial, antitrypanosomal, anthelminthic, molluscicidal, nematicidal, insecticidal, larvicidal, antifeedant, and insect repellent) and pharmacological activities (antioxidant, anticancer, antiulcer, spermicidal, antidiabetic, anti-implantation, immunomodulating and immunocontraceptive activities, etc.) attested by various parts and extracts of neem have been reviewed (Atawodi et al. 2009). Hence, the neem tree has received attention from the international scientific community, and authors from different countries have referred to this tree as a 'miracle tree/multipurpose crop/village dispensary/living pharmacy' (Biswas et al. 2002). The importance of the neem tree was been recognised years ago by the US National Academy of Sciences, which published a report entitled 'Neem – a tree for solving global problems' (NRC 1992).

### 3.1.1 Azadirachtin and Related Compounds

*A. indica* produces a plethora of triterpenoids. The first bitter compound isolated from neem oil is nimbin, and it is found to be one of the most abundant limonoids in seeds (Johnson et al. 1996). Subsequently, azadirachtin ($C_{35}H_{44}O_{16}$), a complex compound, was extracted from neem seeds by Butterworth and Morgan (1968, 1971) followed by its identification as a highly oxygenated tetranortriterpenoid by Kraus et al. (1985) and Broughton et al. (1986). In later years, Rembold (1989) isolated six related compounds (azadirachtins B–G), whereas Govindachari et al. (1991) reported seven compounds (azadirachtins A, B, D, F, H, I, and K) of closely related structures from neem kernels.

The ratio between these complex compounds has been reported differently by various authors. Klenk et al. (1986) and Rembold (1990) have stated that the ratio of azadirachtin B to azadirachtin A is 1:5, whereas the others compounds (azadirachtins C-G) occur at a ratio of 1 to 100 parts of azadirachtin A. Sidhu et al. (2003) studied the intra-provenance and inter-provenance variations of azadirachtin content in neem trees and found that azadirachtin A is 13–16-fold higher than azadirachtin B and that this difference varies among the natural populations. He also stated that climatic factors have no influence on azadirachtin content and that the observed differences might be due to the individual genetic compositional variations among the trees. Studies by Kumar and Parmar (1997) on neem ecotypes also affirm the variations in azadirachtin content and the non-impact of climatic factors on the same. In contrast, Ermel (1995) and Venkateswarlu et al. (1997) revealed the influence of humidity, rainfall, temperature, or season on azadirachtin content variations. It is also found that seasonal variations contribute to the synthesis of specific azadirachtins (Sidhu and Behl 1996). However, azadirachtins A and B are the major active metabolites of neem seeds/kernels. More than 135 compounds have been isolated from different parts of neem, and several reviews have been published on the chemistry and structural diversity of these compounds (Taylor 1984; Koul et al. 1990; Govindachari 1992; Chatterjee and Pakrashi 1994; Kraus 1995; Devakumar and Sukh Dev 1996).

Various methods have been reported for the isolation and purification of azadirachtins from neem seeds and/or kernels (Warthen et al. 1984; Schroeder and Nakanishi 1987; Govindachari et al. 1991; Sharma et al. 2003a, b). Yamasaki et al. (1986) and Schroeder and Nakanishi (1987) isolated azadirachtins by flash chromatography and reported different concentrations. Jarvis et al. (1999) isolated 11 triterpenoids including azadirachtins by supercritical fluid chromatography.

### 3.1.2 Neem Products as Pesticides/Insecticides

Voluminous reports on extracts, purified compounds/formulations, and traditional preparations of neem indicate their versatility and broad-spectrum insecticidal activity. The chemistry, environmental behaviour, and biological effects of neem products have been reported widely (Mordue and Blackwell 1993; Sundaram 1996; Williams and Mansingh 1996; Veitch et al. 2008). Because there is a vast amount of data, we have presented an overview of the potential of neem products. Laboratory testing has indicated that neem extract-based insecticides are effective against more than 400 pest species (Koul 1999), which has generated wide agricultural and environmental interests. Natural neem preparations have shown anti-insecticidal activity against the noctuid moths *Spodoptera littoralis* (Gelbic and Nemec 2001; Sharma et al. 2003a, b) and *S. litura* (Kumar and Parmar 1997; Govindachari et al. 2000), *Peridroma saucia*, the heteropteran bug *Oncopeltus fasciatus* (Isman et al. 1990), the leafhopper *Jacobiasca lybica*, and the whitefly *Bemisia tabaci* (El Shafie and Basedow 2003). Apart from the neem extract/formulations, published reports have also established that azadirachtin A, the major triterpenoid, and its related compounds possess insecticidal activity.

This broad-spectrum pesticidal/insecticidal activity is exerted by their phago and oviposition deterrent, repellent, antifeedant, growth retardant, moulting inhibitor, and sterilant properties. It was also reported that neem products prolong larval developmental times and prevent larval maturation. These effects might be influenced by neem products acting both as systemic and as contact poisons (Schmutterer 1990a, b; Mordue and Blackwell 1993), which was demonstrated by the treatment of *S. litura* with azadirachtin and other terpenoids (salannin, nimbinene, and nimbin) (Koul et al. 1996). Additionally, the broad-spectrum insecticidal attributes have been reported in *Plutella xylostella* (Schmutterer 1990a, b; Isman 1995; Liang et al. 2003), *Pieris brassicae* (Hasan and Ansari 2011), *S. littoralis* (Pineda et al. 2009), and other insects (Isman et al. 1990). Broad-spectrum insecticidal activity has also been demonstrated by neem seed kernel extracts under field conditions against Lepidoptera, Coleoptera, and Orthoptera insects (Schmutterer 1985).

However, insects from different orders differ markedly in their behavioural/physiological responses to azadirachtin/related compounds/neem extracts. This difference was demonstrated in a study conducted by Aerts and Mordue (1997), which showed strong toxicity and antifeedant activity of azadirachtin against *O. fasciatus* (Hemiptera), *S. littoralis* (Lepidoptera), and *Schistocerca gregaria* (Orthoptera). The study also stated that the lower structural forms of azadirachtin, such as azadirone, azadiradione, nimbin, and salannin, exhibit only the antifeedant activity, specifically on the lepidopteran pest *S. littoralis*. Therefore, the lepidopteran insect pest shows higher sensitivity than Orthopoda to neem compounds, and the combination of toxicity and antifeedant activity of azadirachtin renders it a strong insecticide. The malformation of *S. littoralis* at various developmental stages by azadirachtins has been substantiated by Martinez and Van Emden (2001), Gelbic and Nemec (2001), and Nathan and Kalaivani (2006). Inter-genus variation has also been demonstrated by neem compounds on lepidopteran members, where salannin was active against *S. littoralis* and nimbin was active against *Heliothis virescens* and *H. armigera* (Blaney et al. 1990). Interfamily variations on Noctuidae members, which includes the black army cutworm *Actebia fennica*, bertha armyworm *Mamestra configurata*, variegated cutworm *P. saucia*, zebra caterpillar *Melanchra picta*, Asian armyworm *S. litura,* and cabbage looper *Trichoplusia ni*, by azadirachtin have also been documented, where *A. fennica* and *S. litura* are less inhibited than the other species (Isman 1993). Nathan and colleagues recorded the antifeedant and growth inhibition activity of various neem limonoids (azadirachtin, salannin, deacetylgedunin, gedunin, 17-hydroxyazadiradione, and deacetylnimbin) against the rice leaf folder *Cnaphalocrocis medinalis* (Nathan et al. 2005) and legume pod borer *H. armigera* (Murugan et al. 1998). Apart from the major tetranortriterpenoids (nimbin and salannin) of neem seeds, the photo-oxidation products of tetranortriterpenoids, such as nimbinolide, isonimbinolide, salanninolide, and isosalanninolide, have also shown anti-insect properties, as demonstrated on *S. littoralis* (Jarvis et al. 1997).

Neem seed kernel extract (NSKE) has a profound effect on the rice leaf folder and sorghum shootfly *Atherigona soccata* (Shrinivas and Balikai 2009). The effect of NSKE was also reported on the potato tuber moth *Phthorimaea operculella* (Shelke et al. 1987), *H. armigera* (Sinha 1993), and *Lampides boeticus* (Irulandi and Balasubramanian 2000). Sap feeders, such as White Backed Plant

Hopper (WBPH) (Reddy et al. 2012), *Aphis craccivora*, *Empoasca kerri*, *Megalurothrips distalis* (Irulandi and Balasubramanian 2000; Dalwadi et al. 2008), pink mealy bug *Maconellicoccus hirsutus* (Sathyaseelan and Bhaskaran 2010), and the cotton stem weevil *Pempherulus affinis* (Ratnakumari and Chandrasekaran 2005), were subdued with NSKE. NSKE is effective not only against agriculturally important pests but also against parasites and pests that affect humans and animals, which further validates the broad-spectrum activity of NSKE (Schmahl et al. 2010).

Although azadirachtin is the major active constituent of neem extracts, the effects observed from such extracts could be due to the sum or synergy of azadirachtin and the other terpenoids present in the extract mixture (Boursier et al. 2011; Martinez and Van Emden 2001). Azadirachtin is one of the main active ingredients in neem extracts, but non-azadirachtin compounds (e.g., 6-β-hydroxygedunin or different volatiles from neem) isolated from *A. indica* seem to be involved in the toxicity and antifeedant activity of neem extracts (Reddy and Singh 1998; Koul et al. 2003).

### 3.1.3 Mechanism of Action

Schmutterer 1990a, b suggests that the well-established antifeedant and growth-inhibitory properties of azadirachtin is attributed to the disruption of endocrine events. Mordue and Blackwell (1993) stated that there are three modes of action of azadirachtin in insects: (i) feeding inhibition by the blockage of input receptors for phagostimulants or by the stimulation of deterrent receptor cells, or both; (ii) growth inhibition by the blockage of morphogenetic peptide hormone release, which affects ecdysteroid and juvenile hormone titers; and (iii) direct detrimental and histopathological effects on insect muscles, fat body, and gut cuticular epithelial cells. Azadirachtin has demonstrated its negative effects by reducing hemocyte count, degenerating organelles, and destroying plasma membranes (Sharma et al. 2003a, b). Recently, Nathan et al. (2006) revealed the impact of neem extracts on digestive enzymes, such as amylase, protease, and lipase.

### 3.1.4 Boundaries/Barriers for Commercialisation

In general, the principal barriers affecting the commercialisation of botanical pesticides include the scarcity of natural resources, standardisation, quality control, and registration (Murray and Isman 1997), which are each less of a concern for conventional insecticides. The limited stability of azadirachtins and related compounds under natural conditions, such as temperature, light, UV radiation, rainfall, pH, etc., has been addressed by studies conducted by Barnby et al. (1989), Schmutterer (1988 and 1990b), Stokes and Redfern (1982), Warthen et al. (1984), and Jarvis et al. (1998). Other azadirachtoids, such as deacetylnimbin, deacetylsalannin, nimbin, and salannin, disappeared rapidly when they were exposed to sunlight. Notably, azadirachtin A and B are less photostable in formulations than their corresponding pure forms (Cabone et al. 2009). This instability of azadirachtin has been attributed partly to the presence of unsaturation in the tiglate and enol ether moieties. Hence, the hydrogenation of the labile olefinic moieties is crucial to obtain more stable reduced products (Bilton et al. 1985; Yamasaki and Klocke 1987). Though structural change is an option to overcome this problem, structure-activity relationship studies have indicated that modifications of the basic molecule lead to altered insecticidal activity (Yamasaki and Klocke 1987; Rembold 1988). Alternatively, the use of stabilisers, such as antioxidants and UV/sunscreens, has been contemplated (Chowdhuri 1996; Sundaram and Curry 1996a, b).

Azadirachtin A is resistant to hydrogenation at ambient conditions of temperature and pressure. However, Bilton et al. (1985) and Ley et al. (1989) have reduced the azadirachtins using high pressure with selected catalysts to dihydroazadirachtin-A (reduction of the 22,23 double bond) and tetrahydroazadirachtin-A (reduction of the 2′,3′ double bond of tiglic acid of dihydroazadirachtin-A). Dihydroazadirachtin-based products have been registered by the Environment Protection Agency for use in the USA. Sharma et al. (2006) tested the structurally altered compound tetrahydroazadirachtin-A and the native compound azadirachtin against *H. armigera*. They found that tetrahydroazadirachtin has equal stability and effectiveness on comparison with azadirachtin, which validates its use as commercial neem biopesticides in the future.

Another barrier affecting neem compounds/formulations is the compatibility with biological control. Hoelmer et al. (1990) recorded no detrimental effects of the commercial neem product Margosan-O on *Encarsia formosa* and *E. transvena*, the parasitoids/natural enemies of *B. tabaci*. They observed no significant effect on the degree of parasitism on any of the natural enemies. Feldhege and Schmutterer (1993) recorded a considerable reduction in the degree of parasitism by *E. formosa* against azadirachtin-exposed *T. vaporariorum* pupae. A recent study by Scudeler and Dos Santos (2013) on *Ceraeochrysa claveri*, a natural enemy of several pests, such as whiteflies, thrips, lepidopteran pests, aphids, and mites (Pappas et al. 2011), demonstrated severe alterations in their midgut cells by the indirect ingestion of neem oil-treated prey. In contrast to these mild negative effects, neem products contribute to a favourable prey/predator ratio and help provide a healthy functioning ecosystem (El Shafie and Basedow 2003).

### 3.1.5 Commercialisation

Although purified neem compounds/formulations exhibit instability and produce negative effects on natural enemies, its role as a broad-spectrum insecticide at very low concentrations with desirable residual properties and reduced insect resistance has made these compounds valuable tools in insect pest management and commercialisation in countries such as the USA, Canada, Mexico, European Union, and New Zealand and in Asian countries, such as India and China. In fact, neem is the most commercially exploited plant for insect pest management (Schmutterer 2002). Some of the examples of neem products include NeemAzal-T/S®, Neemix, Neemexcel (Ahmad et al. 2012), Thai neem 111® (Yule and Srinivasan 2013), Margosan-O (Lindquist and Casey 1990), Neem-EC® (Sundaram et al. 1997), Neem gold (Sharma et al. 2003a, b), Tre-san®; MiteStop®; Wash Away Louse®, and Picksan LouseStop® (Schmahl et al. 2010), which have proved their efficacy against various pests and insects. Boursier et al. (2011) compared traditional neem preparations with commercial formulations of azadirachtin-A against the leafhopper *Macrosteles quadripunctulatus* and *S. littoralis* and found that there was equivalent activity between both of the preparations. However, in the same study, whitefly *B. tabaci* required a higher concentration of traditional neem extract, which indicated species specificity.

## 3.2 *Annona*

The largest species in the family of angiosperm is Annonaceae, which includes approximately 135 genera with 2,500 species (Chatrou et al. 2004). Annonaceae are tropical trees and shrubs found in Central America, Africa, and Southeast Asia and are one of the main sources of edible fruits and edible oils (Ngiefu et al. 1976; Heywood 1978) in those regions. Some of the fruits from Annona species include pawpaw, chirimoya, sweetsop, soursop, and custard apple (Isman 2006). Annona species also possess medicinal properties. The wood of the Annonaceous trees is used in alcohol production (Savard and Espil 1951). Studies conducted on Annona reveal diverse chemical compounds in various species (Leboeuf et al. 1982; Chang et al. 1998; Kotkar et al. 2001). A complex mixture of acetogenins with 30 compounds has been identified in each of the species. In particular, sesquiterpenes and monoterpenes are the main compounds of the oils of *Annona* spp. (Ríos et al. 2003). Many genera from the family viz. *Annona, Asimina, Goniothalamus, Rollinia*, and *Uvaria* have been studied, and, to date, approximately 400 compounds have been explored (Alali et al. 1999; Johnson et al. 2000). These compounds have been found to possess cytotoxic, antitumor, antimalarial, insecticidal, and parasiticidal properties (Rupprecht et al. 1990; Fang et al. 1993; Alali et al. 1999; Ocampo and Ocampo 2006). In small farms worldwide, some species of Annona have been used as botanical insecticides by traditional home made preparations (Secoy and Smith 1983; Okonkwo 2005; Castillo et al. 2010).

### 3.2.1 The Annonaceous Acetogenins (ACGs)

ACGs are the most rapidly growing class of natural products that possess a wide range of biological activities, such as anthelminthic, antimalarial, antimicrobial, antiprotozoal, antitumor, and cytotoxic actions (Fang et al. 1993; Gu et al. 1995; Zeng et al. 1996; Cavé et al. 1997). In 1982, uvaricin was the first ACG discovered, and it was found to possess antileukemic activity (Jolad et al. 1982). ACGs have a series of C-35/C-37 derived from C-32/C-34 fatty acids combined with a 2-propanol unit. 'A long aliphatic chain with a terminal methyl substituted R, an *â-unsaturated* ç-lactone ring with one, two, or three tetrahydrofuran rings along with hydrocarbon chain, and a number of oxygenated moieties (hydroxyls, acetoxyls, ketones, epoxides) and/or double bonds' is the characteristic feature of ACG (Shi et al. 1995, 1996; Alali et al. 1998; Chávez et al. 1998; Colman-Saizarbitoria et al. 1998; Paul et al. 2013).

Among the Annona genus, two species have outstanding insecticidal properties, *A. muricata* and *A. squamosa*. The following acetogenins are found in *A. muricata* and *A. squamosa*: annocatalin, annohexocin, annomonicin, annomontacin, annomuricatin, annomuricin, annonacin, coronin, corossolin, corossolone, gigantetrocin, gigantetronenin, montanancin, muracin, muricatalicin, muricin, robustosin, solamin, squamocin, and uvariamicin (Raintree Nutrition 2004). These compounds can range from polar to nonpolar and, hence, can be extracted using various solvents, such as water (Pérez-Pacheco et al. 2004), ethanol (Bobadilla et al. 2002), acetone (Khalequzzaman and Sultana 2006), chloroform (Parvin et al. 2003), petroleum ether (Álvarez et al. 2008), and hexane (Fontana et al. 1998).

### 3.2.2 Biology of ACGs

ACGs have been reported to be potent inhibitors of NADPH/ubiquinone oxidoreductase (complex I), an enzyme of the electron transport chain system of mitochondria. This inhibition deprives the cell's ATP and induces apoptosis (Tormo et al. 1999; Alali et al. 1999). These bioactive effects of ACGs have also been confirmed against other species of insects including sap-sucking Lepidoptera larvae such as *Myzus persicae*, spider mites, mosquito larvae, striped cucumber beetles, melon aphids, Colorado potato beetles, Mexican bean beetles, bean leaf beetles, European corn borers, blowfly larvae, and free-living nematodes (Ahammadsahib et al. 1993; He et al. 1997; McLaughlin et al. 1997; Guadaño et al. 2000; Leatemia and Isman 2004; Álvarez et al. 2007; Cólom et al. 2008). The incorporation of ACGs in the diet of *S. frugiperda* led to morphological changes, which reflected the interference of ACGs with hormonal activity (Di Toto Blessing et al. 2010). Annonaceous extracts have been evaluated in several groups of medically and agriculturally important insects. Thus, the biological activity of acetogenins is similar to that of limonoid azadirachtin isolated from seeds of *A. indica* (Mordue and Nisbet 2000). Similarly, there are various insecticidal ACGs (Table 5.1). Recent reports have also revealed that these ACGs are more effective against stored grain pests. In developing countries, postharvest grain loss is a major problem because of stored-grain pest infestations. Anita et al. (2012) and Ribeiro et al. (2013) showed that the extracts of *A. squamosa* and *A. mucosa* are toxic to *Tribolium castaneum* and *Sitophilus zeamais*, respectively. Isoquinoline alkaloids are another class of compounds associated with plant defence against herbivorous insects (Da Rocha et al. 1981; Cordell et al. 2001; Bermejo et al. 2005; Cólom et al. 2009). Isoquinoline alkaloids interact with neural signal transduction networks and interfere with neuroreceptors via enzymes involved in neurotransmission metabolism and ion channels (Wink et al. 1997; Wink 2000); however, no studies are available regarding the biological activity of isoquinoline alkaloids. To date, Annona products are not available commercially, and studies have not addressed the commercial use of these products. Hence, this is one area where more work needs to be performed.

**Table 5.1** Active compounds with biological activity from the Annonaceae family (Modified from Castillo-Sanchez et al. 2010)

| Botanical name | Plant part | Active compound | Insect | Biological activity | Reference |
|---|---|---|---|---|---|
| *A. muricata* | Seeds | Bullatalicin | *Anticarsia gemmatalis*<br>*Pseudaletia sequax* | Feeding deterrence and growth inhibition | Fontana et al. (1998) |
| | | Squamocin | *M. persicae* | Insecticide | Guadano et al. (2000) |
| | | | *Leptinotarsa decemlineata* | | |
| | | Annonacin | *Rhodnius pallescens* | Insecticide | Parra-Henao et al. (2007), Robledo-Reyes et al. (2008), Leatemia and Isman (2004) |
| | | | *R. prolixus* | Insecticide and repellency | |
| | | | *Periplaneta americana* | Insecticide | |
| | | | *S. litura* | | |
| *A. squamosa* | Seeds | Squamocin | *T. castaneum* | Insecticide | Khalequzzaman and Sultana (2006), Seffrin et al. (2010), Khalequzzaman and Sultana (2006), Leatemia and Isman (2004) |
| | | Methanolic extract | *T. ni* | Insecticide and feed deterrent | |
| | | Crude extract | *S. litura* and *H. armigera* | Insecticide | |
| | | | *T. castaneum* | Insecticide | |
| | | Annonins | *S. litura* | Insecticide | |
| | | Annotemoyin-1 | *T. castaneum* | Insecticide | Parvin et al. (2003), Laetamia and Isman (2004) |
| | | Neoannonin | *P. xylostella* | | |
| *A. cherimolia* | Seeds | Squamocin | *S. frugiperda* | Insecticide and antifeedant activity | Álvarez et al. (2007) |
| | | Itrabin | | | |
| | | Cherimolin-1 | | | |
| | | Neoannonin | | | |
| | | Asimicin | | | |
| | | Squamocin<br>Almunequin | *O. fasciatus* | Insecticide | Álvarez et al. (2008) |
| | | Itrabin | | | |
| | | Molvizarin | | | |
| *A. montana* | Leaves and branch | Annonacin | *O. fasciatus* | Insecticide | Álvarez et al. (2008) |
| | | Cis-annonacin 10-one | | | |
| | | Densicomacin-1 | | | |
| | | Annonacin-a | | | |
| | | Gigantetronenin | *S. frugiperda* | Antifeedant and toxic | Di Toto Blessing et al. (2010) |
| | | Murihexocin | | | |
| | | Tucupentol | | | |
| *Oxandra cf xylopioides* | Leaves | Berenjenol | *S. frugiperda* | Insecticide | Rojano et al. (2007) |
| *A. atemoya* | Seeds | Methanolic extract | *T. ni* | Insecticide and feed deterrent | Seffrin et al. (2010) |

## 3.3 *Pongamia*

*Pongamia pinnata* (Linn.) Pierre (syn: *P. glabra* Vent; *Derris indica* (Lam) Bennett; *Millettia novo-guineensis* Kane & Hat) belongs to the family Fabaceae, which is an indigenous plant of the Indian subcontinent and Southeast Asia (Krishnamurthi 1969; CSIR 1969). It is known as the poonga oil tree, pongam tree, karanja, karanj, karum, kanji, Indian beech, etc. and has been used traditionally in ayurvedic, siddha, and folk medicines. The impact of chemical, biological, and pharmacological aspects of this tree has been reviewed (Meera et al. 2003). Pongam seed oil contains 5–6 % flavonoids. Karanjin, a furanoflavonoid compound, is the main constituent of the flavonoids (Brinji 1987) and known for its insecticidal properties (Kumar and Singh 2002). The isolation of this compound from oil and de-fatted oil cakes has been detailed in the work of Vismaya et al. (2010) and Katekhaye et al. (2012) and the work of Susarla et al. (2012), respectively. The insecticidal property of Karanjin was enhanced through structural modifications that converted Karanjin into karanj ketone, karanj ketone oxime esters, and karanj ketone oxime N-O-nonanoate. This enhanced insecticidal property was demonstrated on the aphid *Lipaphis erysimi* (Mondal et al. 2010).

For approximately 70 years, natural product chemists have studied the complex organic compounds of karanj, especially the flavone-like molecules kanjone, pongamol, pongapinnols A–D, pongagalabrone, pongapin, pinnatin, pongone, pongacoumestan, glabrachalcone, isopongachromene, isopongaflavone, galbone, pongalabol, pongagallone A and B, and 6-methoxyfuroflavone (Rao and Rao 1941; Pavanaram and Ramachandra Row 1955; Aneja et al. 1963; Mahey et al. 1972; Malik et al. 1976; Roy et al. 1977; Garg 1979; Talopatra et al. 1985; Shameel et al. 1996; Chauhan and Chauhan 2002; Simin et al. 2002; Carcache-Blanco et al. 2003; Ahmad et al. 2004; Alam et al. 2004; Yadav et al. 2004; Li et al. 2006; Yin et al. 2006).

The compounds, either as oil or as an extract from methanol/aqueous/chloroform/acetone, are biologically active against insect pests. They act as insecticides, repellents, oviposition deterrents, antifeedants, and larvicides (Parmar and Gulati 1969; Kumar and Singh 2002; Pavela and Herda 2007a, b). The extract of *P. pinnata* is also toxic against *S. litura* and *H. armigera* as well as the stored grain pests *Trogoderma granarium* and *T. castaneum* (Kumar et al. 2006; Pawar et al. 2011; Reena and Sinha 2012). Karanj oil and Karanj leaf extract have been used against mustard aphid *L. erysimi* in field conditions (Bunker et al. 2006; Singh 2007).

Karanj extract is a constituent of commercially available insecticidal formulations, such as Plexin, Karrich, Salotrap, RD Repelin, and RD9 Repelin, for the control of various insect pests. PONEEM, which is discussed further in the latter part of this chapter, is a patented insecticidal formulation of pongam oil and neem oil. However, compared with neem products, the reduced efficiency of Karanj extract in aqueous solutions is a limiting factor for their wider applications; therefore, this area requires further research attention.

## 3.4 *Jatropha*

*Jatropha curcas*, also known as physic nut, is a tropical plant that belongs to Euphorbiaceae and is native to North America but now thrives in Africa and Asia (Willis 1967). The seeds of this plant consist of 47 % fat and various antinutritional factors such as saponin, phytate, trypsin inhibitor, and cyanogenic glycosides (Makkar et al. 1997; Kumar and Sharma 2008; Rakshit et al. 2008). *Jatropha* have an immense potential to generate a large amount of feedstock oil for biodiesel production. The global jatropha oil production is proposed to be approximately 28 MT/annum and is the major oil produced in Asia (GEXSI 2008).

There are various terpenoids present as secondary metabolites of *Jatropha*. To date, 65 types of terpenes have been explored (Devappa et al. 2011). Phorbol esters (PEs), a group of tigilane diterpenes, are a major toxic constituent of *Jatropha* (Adolf et al. 1984; Makkar et al. 1997). Approximately six PEs have been identified so far, and 70–75 % of the PEs are in an extractable form in *J. curcas* kernels, whereas 25–30 % are non-extractable (Haas et al. 2002). The non-extractable PEs remain tightly bound to the matrix of the kernel (Makkar et al. 2009; Makkar and Becker 2009). Goel et al. (2007) have investigated the structure along with the biological activity and toxicity of PEs in animals, while the medicinal property, phytochemistry, and pharmacological properties of *Jatropha* spp. have been studied by Sabandar et al. (2013).

The toxic constituents of PEs present in the seed extract and leaf extract of *J. curcas* possess insecticidal, fungicidal, and molluscicidal properties (Nwosu and Okafor 1995; Liu et al. 1997; Solsoloy and Solsoloy 1997). The PEs contained in jatropha oil are effective against many insects and pests of both field crops and stored grains, including *Callosobruchus maculatus*, *C. chinensis*, *C. maculatus*, *Clavigralla tomentosicollis*, *Sitophilus zeamais*, *Rhyzopertha dominica*, *T. castaneum*, *Oryzaephilus surimanensis*, *L. erysimi*, *P. rapae*, *Phthorimaea operculella*, *Tetranychus urticae*, *O. fasciatus*, *Coptotermes vastator*, *Amrasca biguttula*, *Aphis gossypii*, and *Aphis fabae* (Shelke et al. 1985, 1987; Solsoloy 1995; Solsoloy and Solsoloy 1997; Wink et al. 1997; Solsoloy and Solsoloy 2000; Jing et al. 2005; Adabie–Gomez et al. 2006; Adebowale and Adedire 2006; Acda 2009; Devappa et al. 2010; Habou et al. 2011; Katoune et al. 2011; Ravindra and Kshirsagar 2010; Silva et al. 2012), by antifeedant, oviposition deterrent, ovicidal, and antibirth properties.

The PE-enriched fraction has been studied broadly against various insect pests, such as viz. *S. frugiperda* (Devappa et al. 2012), *C. maculatus* (Adebowale and Adedire 2006; Jadhau and Jadhua 1984), *Corcyra cephalonica* (Khani et al. 2012), *Busseola fusca*, *Sesamia calamistis*, *H. armigera*, and *Manduca sexta* (Sauerwein et al. 1993; Mengual 1997; Makkar et al. 2007; Ratnadass et al. 2009). The PE fractions are susceptible to oxidation and, hence, the addition of antioxidants/storage at cold temperatures is necessary for an increased shelf life (Devappa et al. 2013). The PE fraction has been found to be stable even after 2 years at 4 °C (Devappa et al. 2009). The extract from another species, *J. gossypiifolia,* has been shown to have toxic effects on three lepidopteran pests, *B. fusca*, *Ostrinia nubilalis*, and *S. nonagrioides* (Valencia et al. 2006). Additionally, the PE fraction has been shown to possess antifeedant properties and insecticidal activity against *S. exigua* (Khumrungsee et al. 2009) and *S. frugiperda* (Bullangpoti et al. 2012). Only a limited number of insects have been evaluated under controlled conditions, so the evaluation of broad-spectrum insecticidal activity is crucial. In addition, the fate of PEs under field conditions with the impact of water, soil, plants, and environmental risks has to be investigated. PE toxicity testing on natural enemies, mammalian systems, and modes of action of the insecticidal activity is another prerequisite. Apart from PEs, other secondary metabolites of *Jatropha* sp., such as saponins, lectins, and cyanogenic glycosides, should also be evaluated for their insecticidal activity.

## 3.5 Weeds as Plant Protection Tools

A plant considered undesirable, troublesome, and growing where it is not wanted is a weed. Here, it is worth considering the importance of weeds as botanical insecticides. *Lantana* is an invasive species in the tropical and subtropical regions of the world. However, the plant exhibits insecticidal properties on insects such as aphids, mites (Suliman et al. 2003), potato tuber moths (Lal 1987), and *S. obliqua* (Sharma et al. 1982). The most common weeds, such as *Parthenium* and *Cyperus*, were found to be successful in minimising the *Epilachna* beetle, diamond back moth, and cabbage head caterpillar in vegetables (Dhandapani et al. 1985; Venkataramireddy et al. 1990; Thebtaranonth et al. 1995; Prijono et al. 1997). *Calotropis* is reported to be active on rice plant hoppers (Prakash et al. 2008).

## 3.6 Medicinal Herbs as Plant Protectants

Medicinally valued herbs can also control agriculturally important insects. Herbs such as *Gynandropsis gynandra*, *Catharanthus roseus*, *Vitex*, *Ocimum*, and *Euphorbia royleana* were found to be effective against the *Epilachna* beetle, *H. armigera*, *M. hirsutus*, mustard aphid, and mesta hairy caterpillars (Sharma et al. 1982; Chandel et al. 1987; Rajasekaran et al. 1987;

Roy and Pande 1991; Prakash et al. 2008; Sathyaseelan and Bhaskaran 2010). Furthermore, the *Epilachna* beetle can be regulated by medicinal herbs such as *Solanum xanthocarpum* and *Strychnos nux-vomica* (Dhandapani et al. 1985; Chitra et al. 1991). Other plants, such as the bitter gourd and *Vernonia amygdalina*, known for their bitterness, have demonstrated efficacy against the flea beetle on okra and the coffee leaf miner *Leucoptera coffeella* (Alves et al. 2011; Onunkun 2012). *Passiflora mollissima*, popularly known as banana passion fruit, is not only used in the food industry for ice cream production but also for the control of insect pests such as the Mesta hairy caterpillar (Tripathi et al. 1987).

## 3.7 Spices and Condiments with Insecticidal Action

Homemade botanicals from spices and condiments, such as peppers and garlic, have shown particular promise as a source of botanical pesticides. For instance, powdered chilli pepper deters the onion fly, *Delia antiqua*, *Earias insulana*, *T. ni*, and *T. urticae* (Antonious et al. 2007). Garlic shows its effect on soft-bodied insects, such as aphids, and cumin (*Nigella sativa*) has been shown to be effective against the *Epilachna* beetle (Chandel et al. 1987).

## 3.8 Essential Oils

Essential oils (EOs) are complex mixtures of volatile organic compounds produced as secondary metabolites in plants to defend themselves against herbivores and pathogens. The major plant families from which EOs are extracted include Myrtaceae, Lauraceae, Lamiaceae, and Asteraceae. EOs have repellent, antifeedant, reproduction retardant, fumigant toxicity, and growth-reducing effects on a variety of insects (Singh et al. 1989; Singh and Singh 1991). EOs are neurotoxic, and there is evidence for interference with the neuromodulator octopamine (Enan 2005) or GABA-gated chloride channels (Priestley et al. 2003). Zoubiri and Baaliouamer (2011) performed a detailed literature survey on 230 plants and listed the insecticidal activity of their essential oils along with the major active compounds.

## 3.9 Miscellaneous

Plantago (Alves et al. 2011), *Zea mays* male flowers (not important after pollination; Al-Khafaji et al. 2003), and velvet bean (*Mucuna cochinensis*; Premchand 1989) are also considered to contain insecticidal activity. Other plants such as mahua, *Psoralea corylifolia,* and *Lindenbergia grandiflora* were indicated to possess insecticidal principles (Tripathi et al. 1987; Mohanty et al. 1988; Narasimhan and Mariappan 1988). Plant extracts of cassava, papaya, sweet potato, tea, *Solanum nigrum*, *Solanum incanum*, Mexican tea, Mexican marigold, blackjack (*Bidens pilosa*), thorn apple, and *Aloe* are known to have insecticidal properties.

## 3.10 Botanical Pesticides from Herbal Compost

In addition to insecticides derived from leaf and seed extracts of plants, the compost made out of plants also contributes to insect pest control. Biowashes of crude extracts of *Annona*, *Jatropha*, and *Pongamia* vermicompost were reported to kill *H. armigera* and *S. litura* (Gopalakrishnan et al. 2011). Maize stover compost demonstrated very good control of whiteflies, *Podagrica* species, *Zonocerus variegatus*, and *B. tabaci* with its efficacy ranging from 60 to 80 % control. Organic composts, especially maize stover compost, can be used as an insecticide in organic farming systems to raise okra plants (Alao et al. 2011). Akanbi et al. (2007) reported that the foliar application of organic composts effectively controlled the level of insect infestation of *Telfairia occidentalis.* In the field, organic compost extracts did not kill the observed insects but had a repellent and/or barrier effect.

## 4 Synergism

Biological activity can be enhanced by combinations of biomolecules. An extensive study has been carried by Packiam et al. (2012) with formulations of pongam oil and neem oil. This formulation, PONEEM, has been patented in India. The phytochemicals present in PONEEM karanjin and azadirachtin have controlled *Scirtothrips dorsalis* in chilli thrips efficiently by acting as a feeding deterrent (Packiam and Ignacimuthu 2013). The same phytopesticide formulation has been evaluated against *S. litura* and *H. armigera*. The oviposition deterrent activities at different concentrations with different formulations were studied extensively by Packiam et al. (2012). A formulation with pongam oil and *Thymus vulgaris*/*Foeniculum vulgare* has showed lower $LC_{50}$ values against *P. xylostella* than pongam oil alone indicates the syndergism between the botanicals (Pavela 2012). A combination of *Bacillus thuringiensis* subsp. *kurstaki* (Btk) with extracts of *Acacia arabica*, *A. squamosa*, *Datura stramonium*, *Eucalyptus globulus, Ipomoea carnea, Lantana camara*, *Nicotiana tabacum* and *P. pinnata* was prepared by Rajguru et al. (2011). They investigated the efficacy and synergistic activity against *S. litura* larvae and revealed that high mortality using the fortified extracts was due to synergistic action. In particular, the leaf extracts of *N. tabacum* and the seed extracts of *A. arabica*, *A. squamosa*, and *D. stramonium* showed a promising result and were compatible with Btk. Hence, it might be important to explore microbial combinations with insecticides from plants in field conditions.

## 5 Research at ICRISAT on Botanical Pesticides

During the process of evolution, plants have developed some defence systems to compete against biotic (herbivores, insects, microorganisms, etc.) and also abiotic stresses. One such system is the production of secondary metabolites, such as protease inhibitors, lectins, terpenoids, nonprotein amino acids, alkaloids, cyanogenic glycosides, saponins, tannins, etc. (Mazid et al. 2011). In the past few years, ICRISAT research has been focused on the molecules responsible for host-plant resistance and their corresponding effect on pests to develop efficient biopesticides. In ICRISAT, several studies have been conducted on various botanicals to identify potential and cost-effective strategies for the control of insects. Sharma and colleagues have worked on various plant materials/metabolites for the control of the major devastating crop pest *H. armigera* and also against other insect pests. Earlier, they worked on various solvent extracts of unripened seeds, ripened seeds, kernels, and leaves of the neem tree against *Mythimna separata* and reported an antifeedant compound, which has differed from earlier reports on *A. indica* and *M. azedarach* (Sharma et al. 1983). In long-term collaboration with IICT (Indian Institute of Chemical Technology, Hyderabad, India), active fractions of neem and custard apple extracts were tested under laboratory and field conditions against various insect pests (Sharma et al. 1999). In the past few years, they have analysed the effect of lectins from leguminous and nonleguminous plants, such as field bean, pigeon pea, chickpea, soybean, peanut, lentil, canavalia (concanavalin A), garlic, snowdrop, and jackfruit (jacalin), and trypsin inhibitors from soybean against *H. armigera*. All of the tested plant metabolites affected survival and developmental parameters (Shukla et al. 2005). A phenolic compound (stilbene) from pigeon pea with antifeedant activity against *H. armigera* was also documented by their research group (Green et al. 2003).

Eleven indigenous plant materials (*Cleistanthus collinus*, *C. gigantea*, *P. glabra*, *Artemisia dubia*, *Sphaeranthus indicus*, *Cassia occidentalis*, *Chloroxylon swietenia*, *Vitex negundo*, *Madhuca indica*, *Strychnos nux-vomica*, and *S. potatorum*) known for insecticidal properties collected from Andhra Pradesh and Chhattisgarh states of India were evaluated against *S. litura* larvae. The water extract of these products against second/fourth instar larvae clearly indicated the superiority of *C. collinus*, *C. gigantea* (leaf extract), and *P. glabra* (seed extract) in suppressing the larval growth and development of *S. litura* (Fig. 5.1). The above list of plant materials, excluding *A. dubia*, against second instar larvae of *H. armigera* clearly indicated the superiority of *C. collinus* and *S. indicus* with 57 % larval mortality one week after exposure and with others recording 10–48 % mortality (Rao and Gopalakrishnan 2009). Further observations 2 weeks after exposure revealed a similar trend with a range of 17–63 % larval mortality (Gopalakrishnan et al. 2009).

Furthermore, experiments were conducted to evaluate 18 different botanical extracts against *S. litura* and *H. armigera.* The larvicidal activity of the botanical extracts produced a ranged of mortality between 52 % and 86 %, with the maximum found in neem fruit powder. Studies on larval mortality and oviposition deterrence of various botanicals against *H. armigera* produced the highest larval mortality in neem extracts, followed by *Datura*, rain tree pod, and *Chrysanthemum*. For *S. litura*, the maximum mortality was recorded with neem fruit extract followed by *Pongamia*, rain tree pod, *Datura*, and *Annona*. The oviposition of the two species was severely affected by the plant extract sprays, which reflected the potential of the botanicals in the suppression of key pests (Table 5.2) (Gopalakrishnan et al. 2009).

Bioactive compounds from 17 different botanicals, particularly *Annona, Datura, Pongamia, Parthenium, Gliricidia,* neem, and *Jatropha*, which are capable of managing

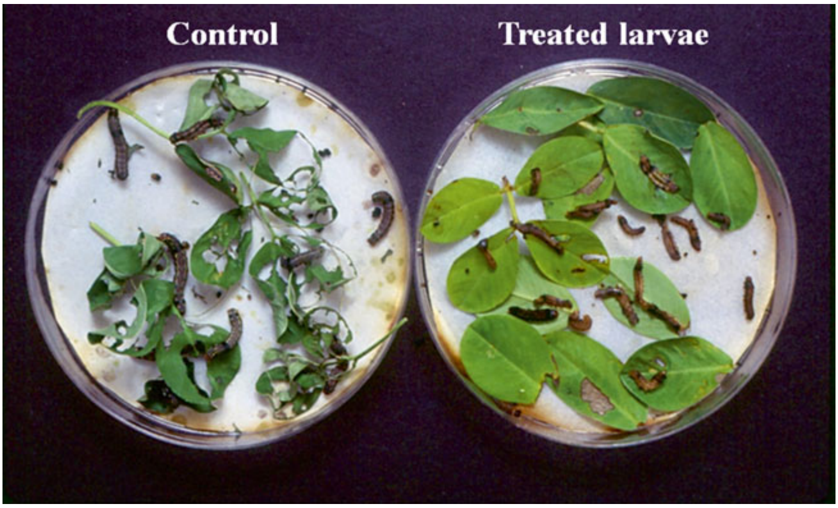


**Fig. 5.1** Effect of botanical extracts on *Spodoptera litura*

**Table 5.2** Evaluation of one percent botanical extract against neonates of *H. armigera* and *S. litura* (Gopalakrishnan et al. 2009)

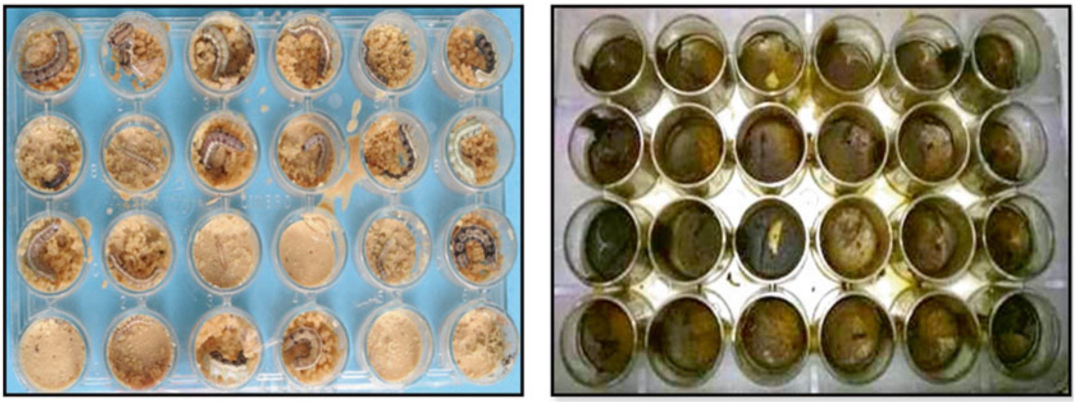
| | Mortality (%) | | Repellency/ovipositional deterrence (%) | |
|---|---|---|---|---|
| Scientific name | *H. armigera* | *S. litura* | *H. armigera* | *S. litura* |
| *A. squamosa* | 20 | 40 | 47 | 96 |
| *A. squamosa* | 28 | 46 | 79 | 90 |
| *A. squamosa* | 25 | 34 | 45 | 93 |
| *C. gigantea* | 18 | 12 | 33 | 66 |
| *C. domestica* | 38 | 32 | 65 | 55 |
| *D. metel* | 40 | 46 | 32 | 46 |
| *J. curcas* | 24 | 26 | 8 | 95 |
| *Tagetes erecta* | 35 | 34 | 66 | 96 |
| *M. azedarach* | 22 | 30 | 93 | 87 |
| *A. indica* | 42 | 48 | 9 | 73 |

(continued)

**Table 5.2** (continued)

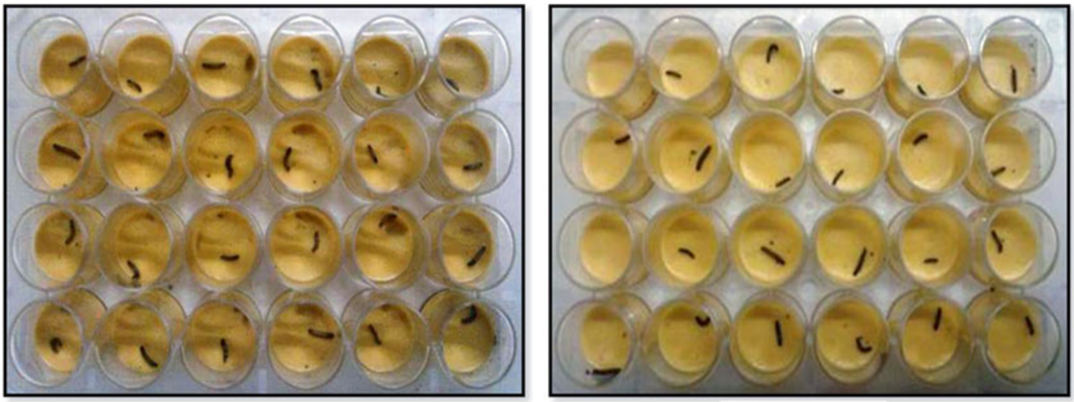
| | Mortality (%) | | Repellency/ovipositional deterrence (%) | |
|---|---|---|---|---|
| Scientific name | *H. armigera* | *S. litura* | *H. armigera* | *S. litura* |
| *A. indica* | 21 | 74 | 84 | 100 |
| *P. hysterophorus* | 10 | 26 | 13 | 75 |
| *P. pinnata* | 30 | 64 | 92 | 56 |
| *P. pinnata* | 29 | 32 | 4 | 77 |
| *Prosopis juliflora* | 16 | 44 | 34 | 37 |
| *Samanea saman* | 31 | 44 | 43 | ND |
| *S. saman* | 39 | 52 | 21 | 73 |
| *Tridax procumbens* | 32 | 34 | 32 | 85 |
| *V. negundo* | 10 | 44 | 1 | 93 |

*ND* not determined



Control

*Azadirachta indica*



*Annona*

*Jatropha*

**Fig. 5.2** Effect of botanical extracts on *Helicoverpa armigera* larvae

*H. armigera* and *S. litura*, were identified. When the feed was treated with crude biowash (Figs. 5.2 and 5.3) for healthy larvae (4-day old), 42 and 86 % mortality and 32 and 71 % weight reduction compared with the control were reported for *H. armigera*, while *S. litura* exhibited 46 and 74 % larval mortality and 47 and 77 % weight reduction compared with the untreated control (Fig. 5.4).

**Fig. 5.3** Preparation of herbal biowash

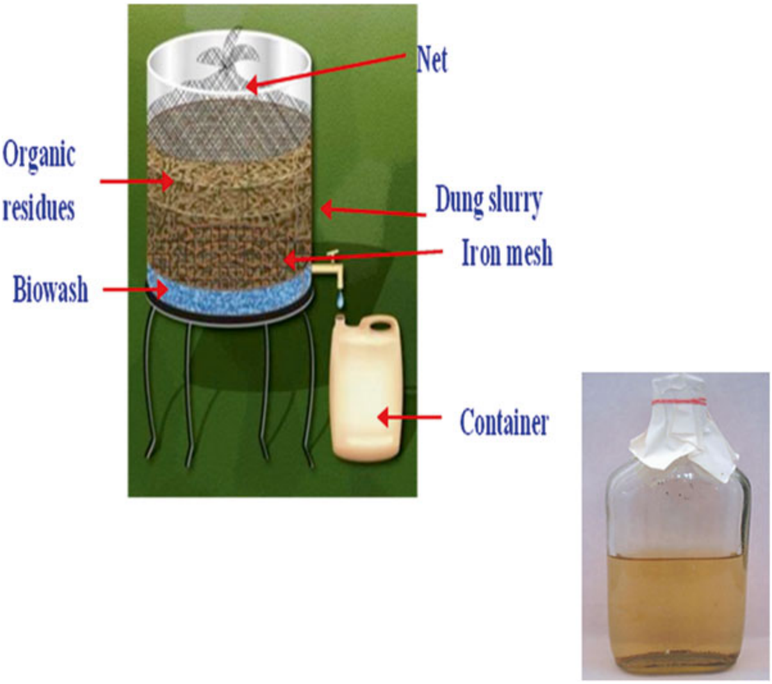


**Fig. 5.4** The protocol for biowash preparation and the final product (*inset*)

**Table 5.3** Influence of various botanical extracts on *H. armigera* and *S. litura* (Gopalakrishnan et al. 2011)

| | *H. armigera* | | *S. litura* | |
|---|---|---|---|---|
| Treatments | Mortality (%) | Weight reduction (%) | Mortality (%) | Weight reduction (%) |
| *Annona* | 58 | 60 | 57 | 70 |
| *Chrysanthemum* | 43 | 43 | 49 | 47 |
| *Datura* | 42 | 56 | 58 | 77 |
| *Jatropha* | 86 | 53 | 62 | 53 |
| *Neem* | 71 | 60 | 60 | 52 |
| *Parthenium* | 69 | 32 | 57 | 59 |
| *Pongamia* | 76 | 58 | 74 | 56 |
| *Tridax* | 45 | 54 | 46 | 54 |
| *Vitex* | 45 | 71 | 52 | 58 |
| SE± | 13.1** | 9.6** | 5.5*** | 8.3*** |
| CV% | 42 | 34 | 24 | 36 |

*SE* standard error, *CV* coefficient of variance
** statistically significant at 0.01 (*p* values); *** statistically significant at 0.001 (*p* values)

**Table 5.4** The effect of adsorbed and nonadsorbed fractions of potential crude biowash samples on *H. armigera* larvae (Gopalakrishnan et al. 2011)

| | Adsorbed fraction | | Nonadsorbed fraction | |
|---|---|---|---|---|
| Treatment | Mortality (%) | Weight reduction (%) | Mortality (%) | Weight reduction (%) |
| *Annona* | 91 | 89 | 65 | 80 |
| *Datura* | 88 | 76 | 64 | 89 |
| *Jatropha* | 87 | 84 | 72 | 97 |
| *Neem* | 81 | 79 | 69 | 89 |
| *Parthenium* | 93 | 73 | 65 | 91 |
| *Pongamia* | 93 | 91 | 73 | 91 |
| *SE*± | 1.6* | 6.0 (NS) | 1.7* | 2.9* |
| *CV*% | 3 | 13 | 4 | 6 |

*NS* nonsignificant, *SE* standard error, *CV* coefficient of variance
*statistically significant at 0.001

The adsorbed and nonadsorbed fractions of crude biowash from open column chromatography of the promising botanicals (*Annona, Datura, Jatropha,* neem, *Parthenium,* and *Pongamia*) showed significant mortality on *H. armigera* (Tables 5.3 and 5.4) (Gopalakrishnan et al. 2011). The compatibility of botanical extracts (such as *Annona*, *Datura*, neem fruit, and *Parthenium*) and some selected entomopathogenic microorganisms (such as *Bacillus subtilis* [BCB-19] and *Metarhizium anisopliae*) were assessed. Neem fruit and *Datura* were found to be compatible with *B. subtilis* (BCB-19). None of the four botanical powder extracts suppressed *M. anisopliae* up to 8 days. In another study, three botanicals (*Annona, Datura*, and neem fruit powder) and three entomopathogens (viz. *Bacillus megaterium* (SB-9), *B. pumilus* (SB-21), and *Serratia marcescens* (HIB28)) were evaluated for their compatibility. There were no definite signs of suppression by any of the botanicals on the bacteria. However, there were some signs of improved growth in the case of SB-9 + neem fruit, SB-9 + *Annona*, and HIB-28 + *Datura* (Gopalakrishnan et al. 2011).

## 6 Conclusion

The inherent toxicity and unforeseen environmental problem intensified by the extended use of synthetic pesticides have been addressed by regulatory agencies from time to time via banning/restricting the use of toxic pesticides in agriculture. As a result, much attention is being paid to the exploration of plant biodiversity because plants produce a rich repertoire of phytochemicals, which evolved partly as defence molecules against attacking organisms. However, they are non-phytotoxic, are easily biodegradable, and have a minor impact on environmental and human health. Therefore, natural products are generally regarded as safe. Safe insecticides are presently in demand because insects are becoming resistant to existing products at a greater rate than new insecticides can be developed. However, the appropriate protection of species and ecological communities has to be considered to protect biodiverse resources from threats.

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