

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; Ucinini 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, anthelmintic, molluscicidal, nematocidal, insecticidal, larvicidal, antifeedant, and insect repellent) and pharmacological activities (antioxidant, anticancer, antiulcer, spermicidal, antidiabetic, anti-implantation, immunomodulating and immun contraceptive 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/multi-purpose 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 Nemeč 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 anti-feedant 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 Orthoptera 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 Nemeč (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 *Melanchnra 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 anti-feedant 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 *Macrostoteles 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 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, anti-malarial, 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 anthelmintic, 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 $\hat{\alpha}$ -unsaturated ζ -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 non-polar 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
<i>A. muricata</i>	Seeds	Bullatalicin	<i>Anticarsia gemmatalis</i> <i>Pseudaletia sequax</i>	Feeding deterrence and growth inhibition	Fontana et al. (1998)
		Squamocin	<i>M. persicae</i> <i>Leptinotarsa decemlineata</i>	Insecticide	Guadano et al. (2000)
		Annonacin	<i>Rhodnius pallescens</i>	Insecticide	Parra-Henao et al. (2007), Robledo-Reyes et al. (2008),
			<i>R. prolixus</i>	Insecticide and repellency	Leatemia and Isman (2004)
		<i>Periplaneta americana</i> <i>S. litura</i>	Insecticide		
<i>A. squamosa</i>	Seeds	Squamocin	<i>T. castaneum</i>	Insecticide	Khalequzzaman and Sultana (2006), Seffrin et al. (2010), Khalequzzaman and Sultana (2006), Leatemia and Isman (2004)
		Methanolic extract	<i>T. ni</i>	Insecticide and feed deterrent	
		Crude extract	<i>S. litura</i> and <i>H. armigera</i>	Insecticide	
			<i>T. castaneum</i>	Insecticide	
		Annonins	<i>S. litura</i>	Insecticide	
		Annotemoyin-1	<i>T. castaneum</i>	Insecticide	
	Neoannonin	<i>P. xylostella</i>		Parvin et al. (2003), Laetamia and Isman (2004)	
<i>A. cherimolia</i>	Seeds	Squamocin	<i>S. frugiperda</i>	Insecticide and antifeedant activity	Álvarez et al. (2007)
		Itrabin			
		Cherimolin-1			
		Neoannonin			
		Asimicin			
		Squamocin	<i>O. fasciatus</i>	Insecticide	Álvarez et al. (2008)
	Almunequin				
	Itrabin				
	Molvizarin				
<i>A. montana</i>	Leaves and branch	Annonacin	<i>O. fasciatus</i>	Insecticide	Álvarez et al. (2008)
		Cis-annonacin 10-one			
		Densicomacin-1			
		Annonacin-a			
		Gigantetronenin	<i>S. frugiperda</i>	Antifeedant and toxic	Di Toto Blessing et al. (2010)
	Murihexocin				
	Tucupentol				
<i>Oxandra cf xylopioides</i>	Leaves	Berenjenol	<i>S. frugiperda</i>	Insecticide	Rojano et al. (2007)
<i>A. atemoya</i>	Seeds	Methanolic extract	<i>T. ni</i>	Insecticide and feed deterrent	Seffrin et al. (2010)

3.3 Pongamia

Pongamia pinnata (Linn.) Pierre (syn: *P. glabra* Vent; *Derris indica* (Lam) Bennett; *Milletia*

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 ponga 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 anti-nutritional 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 tigliane 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. gossypifolia*, 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 minimizing 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 cochinchensis*; 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, *Podagriscus* 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 LC₅₀ 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 ICT (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 range 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

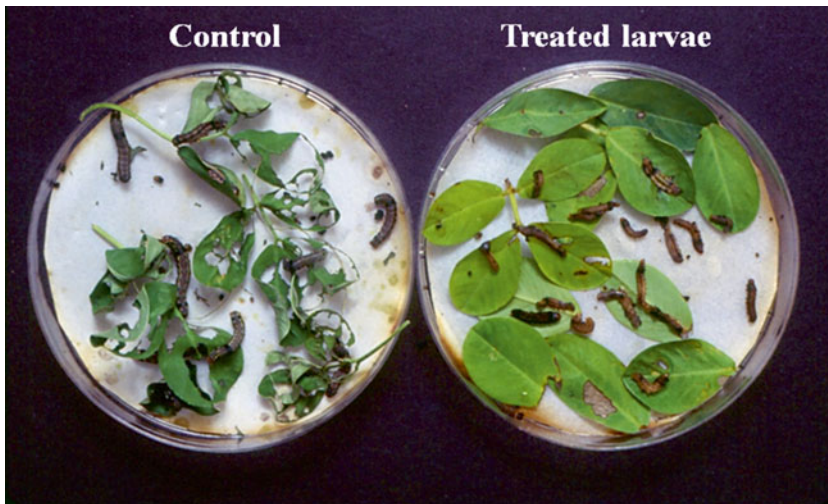


Fig. 5.1 Effect of botanical extracts on *Spodoptera litura*

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

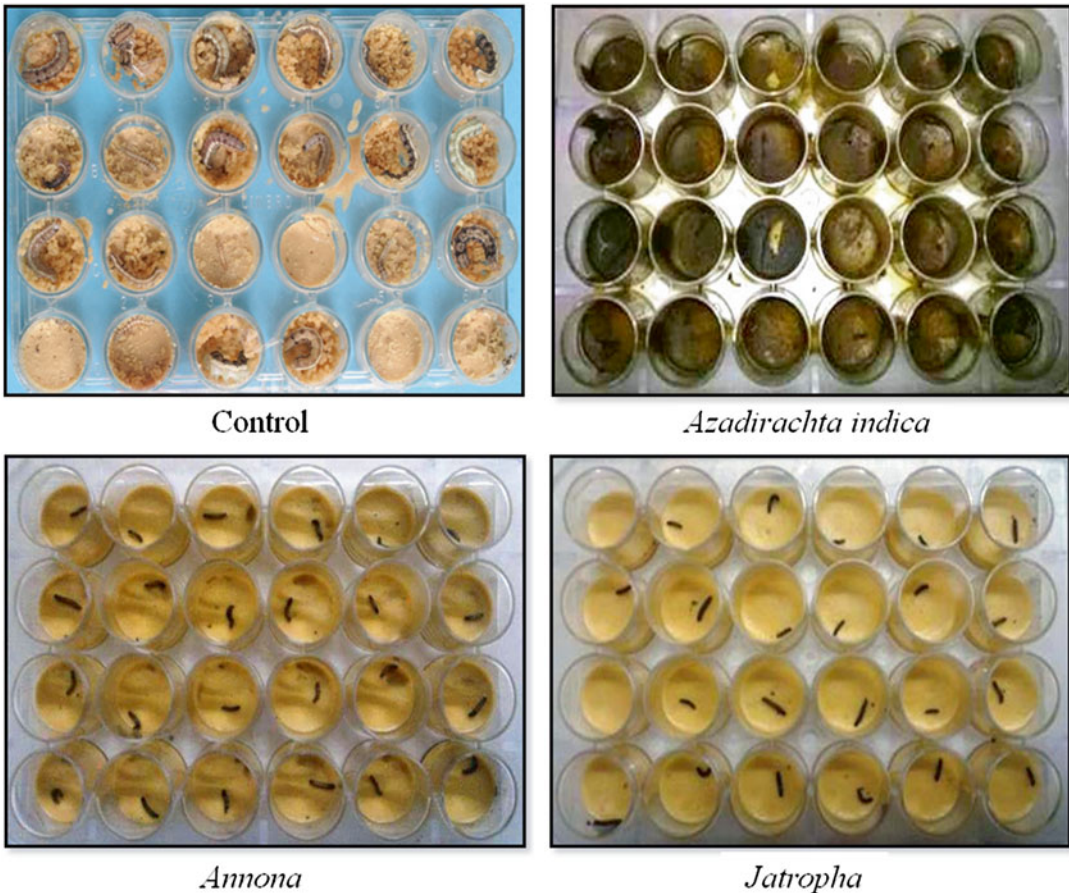
Scientific name	Mortality (%)		Repellency/ovipositional deterrence (%)	
	<i>H. armigera</i>	<i>S. litura</i>	<i>H. armigera</i>	<i>S. litura</i>
<i>A. squamosa</i>	20	40	47	96
<i>A. squamosa</i>	28	46	79	90
<i>A. squamosa</i>	25	34	45	93
<i>C. gigantea</i>	18	12	33	66
<i>C. domestica</i>	38	32	65	55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

(continued)

Table 5.2 (continued)

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

ND not determined

**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 bio-wash (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

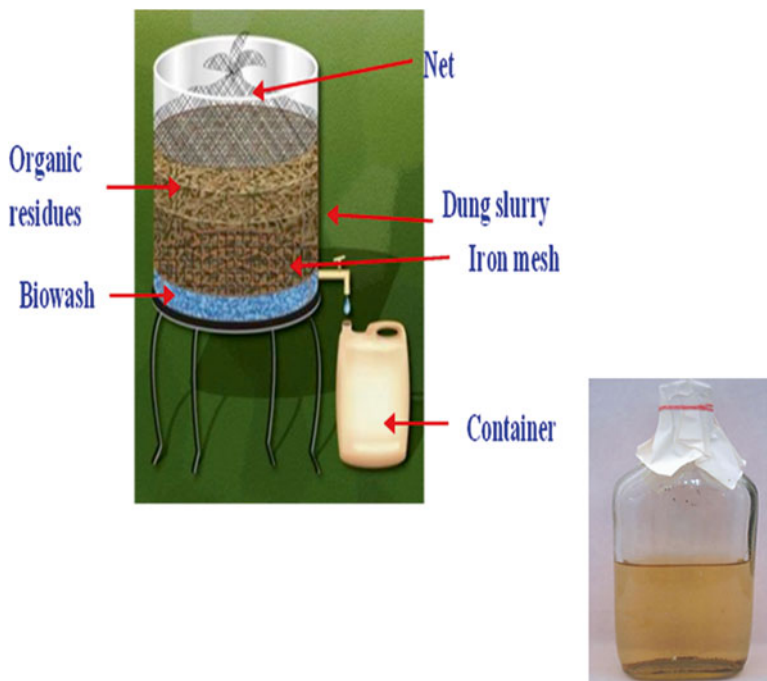


Fig. 5.4 The protocol for biowash preparation and the final product (*inset*)

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

Treatments	<i>H. armigera</i>		<i>S. litura</i>	
	Mortality (%)	Weight reduction (%)	Mortality (%)	Weight reduction (%)
<i>Annona</i>	58	60	57	70
<i>Chrysanthemum</i>	43	43	49	47
<i>Datura</i>	42	56	58	77
<i>Jatropha</i>	86	53	62	53
<i>Neem</i>	71	60	60	52
<i>Parthenium</i>	69	32	57	59
<i>Pongamia</i>	76	58	74	56
<i>Tridax</i>	45	54	46	54
<i>Vitex</i>	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)

Treatment	Adsorbed fraction		Nonadsorbed fraction	
	Mortality (%)	Weight reduction (%)	Mortality (%)	Weight reduction (%)
<i>Annona</i>	91	89	65	80
<i>Datura</i>	88	76	64	89
<i>Jatropha</i>	87	84	72	97
<i>Neem</i>	81	79	69	89
<i>Parthenium</i>	93	73	65	91
<i>Pongamia</i>	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.

References

- Acda MN (2009) Toxicity, tunneling and feeding behavior of the termite, *Coptotermes vastator*, in sand treated with oil of the Physic nut, *Jatropha curcas*. *J Insect Sci* 6:1–8
- Adabie-Gomez DA, Monford KG, Agyir-Yawson A, Owusu-Biney A, Osae M (2006) Evaluation of four local plant species for insecticidal activity against *Sitophilus zeamais* Mots (Coleoptera:Curculionidae) and *Callosobruchus maculatus* (F) (Coleoptera: Bruchidae-). *Ghana J Agric Sci* 39:147–154
- Adebowale KO, Adedire CO (2006) Chemical composition and insecticidal properties of the underutilized *Jatropha curcas* seed oil. *African J Biotech* 5(10):901–906
- Adolf W, Opferkuch HJ, Hecker E (1984) Irritant phorbol derivatives from four *Jatropha* species. *Phytochemistry* 23:129–132
- Aerts RJ, Mordue (Luntz) AJ (1997) Feeding deterrence and toxicity of neem triterpenoids. *J Chem Ecol* 23(9):2117–2132
- Ahmad G, Yadav PP, Maurya R (2004) Furanoflavonoid glycosides from *Pongamia pinnata* fruits. *Phytochemistry* 65:921–924
- Ahmad N, Ansari MS, Hasan F (2012) Effects of neem based insecticides on *Plutella xylostella* (Linn.). *Crop Prot* 34:18–24
- Akanbi WB, Adebayo TA, Togun OA, Adeyeye AS, Olaniran OA (2007) The use of compost extract as foliar spray nutrient source and botanical insecticide in *Telfairia occidentalis*. *WJAS* 3(5):642–652
- Alali FQ, Rogers LL, Zhang Y, McLaughlin JL (1998) Unusual bioactive annonaceous acetogenins from *Goniothalamus giganteus*. *Tetrahedron* 54:5833–5844
- Alali FQ, Liu X, McLaughlin JL (1999) Annonaceous acetogenins: recent progress. *J Nat Prod* 62:504–540
- Alam S, Sarkar Z, Islam A (2004) Synthesis and studies of antibacterial activity of pongaglabol. *J Chem Sci* 116:29–32
- Alao FO, Adebayo TA, Olaniran OA, Akanbi WB (2011) Preliminary evaluation of the insecticidal potential of organic compost extracts against insect pests of Okra (*Abelmoschus esculentus* (L.) Moench). *Asian J Plant Sci Res* 1(3):123–130
- Al-Khafaji AS, Omar AD, Eskander T (2003) Effect of plant extracts on the control of some important agricultural pests. In: Eighth Arab congress of plant protection, 12–16 October, El-Beida, Libya, pp 87–91
- Álvarez O, Neske A, Popich S, Bardón A (2007) Toxic effects of annonaceous acetogenins from *Annona cherimolia* (Magnoliales: Annonaceae) on *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *J Pestic Sci* 80:63–67
- Álvarez O, Barrachina I, Ayala I, Goncalvez M, Moya P, Neske A, Bardón A (2008) Toxic effects annonaceous acetogenins on *Oncopeltus fasciatus*. *J Pestic Sci* 81:85–89
- Alves DS, Oliveira DF, Carvalho GA, Dos Santos JRHM, Carvalho DA, Santos MAI, De Carvalho HWP (2011) Plant extracts as an alternative to control *Leucoptera coffeella* (Guérin-Mèneville) (Lepidoptera: Lyonetiidae). *Neotrop Entomol* 40(1):123–128
- Aneja R, Khanna RN, Seshadri TR (1963) 6-Methoxyfuroflavone, a new component of the seeds of *Pongamia glabra*. *J Chem Soc*: 163–168
- Anita S, Sujatha P, Prabhudas P (2012) Efficacy of pulverised leaves of *Annona squamosa* (L.), *Moringa oleifera* (Lam.) and *Eucalyptus globulus* (Labill.) against the stored grain pest, *Tribolium castaneum* (Herbst.). *Recent Res Sci Technol* 4(2):19–23
- Antonious GF, Meyer JE, Rogers JA, Hu YH (2007) Growing hot pepper for cabbage looper, *Trichoplusia ni* (Hübner) and spider mite, *Tetranychus urticae* (Koch) control. *J Environ Sci Health B* 42(5): 559–567
- Atawodi ES, Joy C, Atawodi JC (2009) *Azadirachta indica* (neem): a plant of multiple biological and pharmacological activities. *Phytochem Rev* 8:601–620
- Barnby MA, Yamasaki R, Klocke JA (1989) Biological activity of azadirachtin, three derivatives, and their

- ultraviolet radiation degradation products against tobacco budworm (Lepidoptera, Noctuidae) larvae. *J Econ Entomol* 82:58–63
- Bermejo A, Figadere B, Zafra-Polo MC, Barrachina I, Estornell E, Cortes D (2005) Acetogenins from Annonaceae: recent progress in isolation, synthesis and mechanisms of action. *Nat Prod Rep* 22:269–303
- Bilton JN, Broughton HB, Ley SV, Lidert A, Morgan ED, Rzepa HS, Seppard RN (1985) Structural reappraisal of the limonoid insect antifeedant azadirachtin. *J Chem Soc Chem Commun* 14:968–971
- Biswas K, Chattopadhyay I, Banerjee RK, Bandyopadhyay U (2002) Biological activities and medicinal properties of neem (*Azadirachta indica*). *Curr Sci* 82(11): 1336–1345
- Blaney WM, Simmonds MSJ, Ley SV, Anderson JC, Toogood PL (1990) Antifeedant effects of azadirachtin and structurally related compounds on lepidopterous larvae. *Entomol Exp Appl* 55:149–160
- Bobadilla M, Zavaleta G, Gil F, Pollack L, Sisniegas M (2002) Efecto bioinsecticida del extracto etanólico de las semillas de *Annona cherimolia* Miller (chirimoya) y *A. muricata* Linnaeus (guanábana) sobre larvas del IV estadio de *Anopheles sp.*. *Rev Peru Biol* 9:64–73
- Boursier CM, Bosco D, Coulibaly A, Negre M (2011) Are traditional neem extract preparations as efficient as a commercial formulation of azadirachtin A? *Crop Prot* 30(3):318–322
- Bozsik A (1996) Studies on aphicidal efficiency of different stinging nettle extracts. *Anz Schädli kd Pflanzenschutz Umweltschutz Appita* 69:21–22
- Brinji NV (1987) Non-traditional oil seeds and oils in India. Oxford/IBH Publishing, New Delhi, pp 143–166
- Broughton HB, Ley SV, Slawin AMZ, Williams DJ, Morgan ED (1986) X-ray crystallographic structure determination of detigloyldihydroazadirachtin and reassignment of the structure of the limonoid insect antifeedant azadirachtin. *J Chem Soc* 1:46–47
- Bullangpoti V, Wajnberg E, Feyereisen PAR (2012) Antifeedant activity of *Jatropha gossypifolia* and *Melia azedarach* senescent leaf extracts on *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and their potential use as synergists. *Pest Manag Sci* 68:1255–1264
- Bunker GK, Rana BS, Ameta OP (2006) Efficacy of some plant products against mustard aphid, *Lipaphis erysimi* (Kaltenbach). *Pestology* 30:28–32
- Butterworth JH, Morgan ED (1968) Isolation of a substance that suppresses feeding in locusts. *J Chem Soc Chem Commun* 1:23–24
- Butterworth JH, Morgan ED (1971) Investigation of the locust feeding inhibition of the seeds of the neem tree, *Azadirachta indica*. *J Insect Physiol* 17:969–977
- Cabone P, Sarais G, Angioni A, Lai F, Dedola F, Paolo Cabras P (2009) Fate of azadirachtin A and related azadirachtoids on tomatoes after greenhouse treatment. *J Environ Sci Health B* 44:598–605
- Carcache-Blanco EJ, Kang YH, Park EJ, Su BN, Kardono LB, Riswan S, Fong HH, Pezzuto JM, Kinghorn AD (2003) Constituents of the stem bark of *Pongamia pinnata* with the potential to induce quinone reductase. *J Nat Prod* 66:1197–1202
- Castillo LE, Jimenez JJ, Delgado MA (2010) Secondary metabolites of the Annonaceae, Solanaceae and Meliaceae families used as biological control of insects. *Trop Subtrop Agroecosyst* 12:445–462
- Cavé A, Figadere B, Laurens A, Cortes D (1997) Acetogenins from annonaceae. In: Herz W, Kirby GW, Moore RE, Steglich W, Tamm C (eds) *Progress in the chemistry of organic natural products*. Springer, New York, pp 81–287
- Chandel BS, Pandey UK, Kumar A (1987) Insecticidal evaluation of some plant extracts against *Epilachna vigintioctopunctata* Fabr. (Coleoptera: Coccinellidae). *Indian J Entomol* 49(2):294–296
- Chang FR, Yang PY, Lin JY, Lee KH, Wu YC (1998) Bioactive kaurane diterpenoids from *Annona glabra*. *J Nat Prod* 61:437–439
- Chatrou LW, Rainer H, Maas PJM (2004) Annonaceae (Soursop family). In: Smith N et al (eds) *Flowering plants of the neotropics*. New York Botanical Garden, New York, pp 18–20
- Chatterjee A, Pakrashi S (eds) (1994) *The treatise on Indian medicinal plants*, vol 3. Publications and information directorate. CSIR, New Delhi, p 76
- Chauhan D, Chauhan JS (2002) Flavonoid glycosides from *Pongamia pinnata*. *Pharm Biol* 40:171–174
- Chávez D, Acevedo LA, Jimenez MR (1998) A novel annonaceous acetogenin from the seeds of *Rollinia mucosa* containing adjacent tetrahydrofuran-tetrahydropyran ring systems. *J Nat Prod* 61:419–421
- Chitra KC, Reddy PVR, Rao KP (1991) Effect of certain plant extracts in the control of brinjal spotted leaf beetle, *Henosepilachna vigintioctopunctata* Fabr. *J Appl Zool Res* 2(1):37–38
- Chopra RN, Bhadwan RL, Gosh S (1949) *Poisonous plants in India*. Scientific monograph no. 17, ICAR, New Delhi, pp 10–12
- Chowdhuri H (1996) Effect of curcumin and turmeric oil on photostability and efficacy of azadirachtin. Ph.D. thesis, PG School, Indian Agricultural Research Institute, New Delhi, India
- Colman-Saizarbitoria T, Johnson HA, Alali FQ, Hopp DC, Rogers LL, McLaughlin JL (1998) Annojahnin from *Annona jahnii*: a possible precursor of mono-tetrahydrofuran acetogenins. *Phytochemistry* 49:1609–1616
- Cóloom OA, Barrachina I, Mingol IA, Mass CG, Sanz PM, Neske A, Bardon A (2008) Toxic effects of annonaceous acetogenins on *Oncopeltus fasciatus*. *J Pest Sci* 81:81–85
- Cóloom OA, Neske A, Chahboune N, Zafra-Polo MC, Bardón A (2009) Tucupentol, a novel mono-tetrahydrofuranic acetogenin from *Annona montana*, as potent inhibitor of mitochondrial complex I. *Chem Biodivers* 6:335–340
- Cordell GA, Quinn-Beattie ML, Farnsworth NR (2001) The potential of alkaloids in drugs discovery. *Phytother Res* 15:183–205
- CSIR (1969) *The wealth of India – a dictionary of Indian raw materials*, vol 8. Publications and Information Directorate, Council of Scientific and Industrial Research, New Delhi, pp 206–211

- Da Rocha AI, Luz AIR, Rodrigues WA (1981) A presença de alcaloides em espécies botânicas da Amazônia. III – Annonaceae. *Acta Amazon* 11:537–546
- Dalwadi MM, Korat DM, Tank BD (2008) Bio-efficacy of some botanical insecticides against major insect pests of Indian bean, *Lablab purpureus* L. *Karnataka J Agric Sci* 21(2):295–296
- Devakumar C, Sukh Dev (1996) In: Randhawa NS, Parmar BS (eds) *Neem*, 2nd edn. New Age, pp. 77–110. ISBN 10: 812242046X/ISBN 13:9788122420463
- Devappa RK, Maes J, Makkar HPS, Greyt WD, Becker K (2009) Isolation of phorbol esters from *Jatropha curcas* oil and quality of produced biodiesel. In: 2nd international congress on biodiesel: the science and the technologies, Munich, Germany.
- Devappa RK, Makkar HPS, Becker K (2010) *Jatropha* toxicity – a review. *J Toxicol Environ Health B Crit Rev* 13:476–507
- Devappa RK, Makkar HPS, Becker K (2011) *Jatropha* diterpenes: a review. *J Am Oil Chem Soc* 88:301–322
- Devappa RK, Makkar HPS, Becker K (2012) Localisation of antinutrients and qualitative identification of toxic components in *Jatropha curcas* seed. *J Sci Food Agric* 92:1519–1525. doi:10.1002/jsfa.4736
- Devappa RK, Bingham JP, Khana SK (2013) High performance liquid chromatography method for rapid quantification of phorbol esters in *Jatropha curcas* seed. *Ind Crops Prod* 49:211–219
- Dhandapani N, Rajendran NS, Abul KA (1985) Plant products as anti-feedants to control insects. *Pesticides* 19(11):53–60
- Di Toto Blessing L, Álvarez Colom O, Popich S, Neske A, Bardón A (2010) Antifeedant and toxic effects of acetogenins from *Annona montana* on *Spodoptera frugiperda* L. *J Pest Sci* 83:307–310
- El Shafie HAF, Basedow T (2003) The efficacy of different neem preparation for control of insects damaging potatoes and eggplants in the Sudan. *Crop Prot* 22:1015–1021
- Enan EE (2005) Molecular and pharmacological analysis of an octopamine receptor from American cockroach and fruit fly in response to plant essential oils. *Arch Insect Biochem Physiol* 59:161–171
- Ermel K (1995) Azadirachtin content of neem seed kernels from different regions of the world. In: Schmutterer H (ed) *The neem tree, source of unique natural products for integrated pest management, medicine, industry and other purposes*. Weinheim, VCH, pp 89–92
- Fang XP, Rieser MJ, Gu GX, McLaughlin JL (1993) Annonaceous acetogenins: an updated review. *Phytochem Anal* 4:27–49
- Feldhege M, Schmutterer H (1993) Investigations on side effects of Margosan-O on *Encarsia Formosa* Gah. (Hym., Aphelenidae), parasitoid of the greenhouse whitefly, *Trialeurodes vaporariorum* Westw. (Hom., Aleyrodidae). *J Appl Entomol* 115:37–42
- Fontana J, Lancas F, Pasos M, Cappelaro E, Villegas J, Baron M, Nosedá M, Pomiiio M, Vitale A, Webber A, Maul A, Foerster LPW (1998) Selective polarity- and adsorption-guided extraction/purification of *Annona* sp. polar acetogenins and biological assay against agricultural pests. *Appl Biochem Biotechnol* 70:67–76
- Garg GP (1979) New component from leaves of *Pongamia glabra*. *Planta Med* 37:73–74
- Gelbic I, Nemeč V (2001) Developmental changes caused by metyrapone and azadirachtin in *Spodoptera littoralis* (Boisd.) (Lep., Noctuidae) and *Galleria melonella* (L.) (Lep., Pyralidae). *J Appl Entomol* 125:417–422
- GEXSI (2008) <http://www.Jatropha-platform.org/documents/GEXSI>
- Goel G, Makkar HPS, Francis G, Becker K (2007) Phorbol esters: structure, biological activity, and toxicity in animals. *Int J Toxicol* 26:279–288
- Gopalakrishnan S, Rupela OP, Humayun P, Kiran BK, Sailasree J, Alekhya G, Sandeep D (2009) Bio-active metabolites from PGPR and botanicals. In: Reddy MS, Sayyed RZ, Sarma YR, Reddy KRK, Desai S, Rao VK, Reddy BC, Podile AR, Kloepper JW (eds) *Proceedings of first Asian PGPR congress on plant growth promotion by rhizobacteria for sustainable agriculture*, Andhra Pradesh, India. Scientific Publishers, Jodhpur, pp 44–51
- Gopalakrishnan S, Kannan IKG, Alekhya G, Humayun P, Sree Vidya M, Deepthi K (2010) Efficacy of *Jatropha*, *Annona* and *Parthenium* biowash on *Sclerotium rolfsii*, *Fusarium oxysporum* f. sp. *ciceri* and *Macrophomina phaseolina*, pathogens of chickpea and sorghum. *Afr J Biotechnol* 9(47):8048–8057
- Gopalakrishnan S, Ranga Rao GV, Humayun P, Rameshwar Rao V, Alekhya G, Simi J, Deepthi K, Sree Vidya M, Srinivas V, Mamatha L, Rupela O (2011) Efficacy of botanical extracts and entomopathogens on control of *Helicoverpa armigera* and *Spodoptera litura*. *Afr J Biotechnol* 10(73):16667–16673
- Govindachari TR (1992) Chemical and biological investigations on *Azadirachta indica* (the neem tree). *Curr Sci* 63:117–122
- Govindachari TR, Sandhya G, Ganeshraj SP (1991) Isolation of novel azadirachtin H and I by high-performance liquid chromatography. *Chromatographia* 31:303–305
- Govindachari TR, Suresh G, Gopalakrishnan G, Wesley SD (2000) Insect antifeedant and growth regulating activities of neem seed oil the role of major tetrenotriterpenoids. *J Appl Entomol* 124:287–291
- Green PWC, Stevenson PC, Simmonds MSJ, Sharma HC (2003) Phenolic compounds on the pod-surface of pigeonpea, *Cajanus cajan*, mediate feeding behavior of *Helicoverpa armigera* larvae. *J Chem Ecol* 29(4):811–821
- Gu ZM, Zhao GX, Oberlies NH, Zeng L, McLaughlin JL (1995) Annonaceous acetogenins: potent mitochondrial inhibitors with diverse applications. In: Arnason JT, Mata R, Romeo JT (eds) *Recent advances in phytochemistry*, vol 29. Plenum Press, New York, pp 249–310

- Guadaño A, Gutiérrez C, De la Peña E, Cortés D, González A (2000) Insecticidal and mutagenic evaluation of two annonaceous acetogenins. *J Nat Prod* 63:773–776
- Haas W, Sterk H, Mittelbach M (2002) Novel 12 deoxy-16-hydroxyphorbol diesters isolates from the seed oil of *Jatropha curcas*. *J Nat Prod* 65:1434–1440
- Habou ZA, Haougui A, Mergeai G, Haubruge E, Toudou A, Verheggen FJ (2011) Insecticidal effect of *Jatropha curcas* oil on the aphid *Aphis fabae* (Hemiptera: Aphididae) and on the main insect pests. associated with cowpeas (*Vigna unguiculata*) in Niger. *Tropicultura* 29(4):225–229
- Hasan F, Ansari MS (2011) Toxic effects of neem-based insecticides on *Pieris brassicae* (Linn.). *Crop Prot* 30:502–507
- He K, Zeng L, Ye Q, Shi G, Oberlies NH, Zhao GX, Njoku CJ, McLaughlin JL (1997) Comparative SAR evaluations of annonaceous acetogenins for pesticidal activity. *Pestic Sci* 49:372–378
- Heywood VH (1978) Flowering plants of the world. University Press, Oxford (Cortes D 1991)
- Hodin J (2009) On the origins of insect hormone signaling, phenotypic plasticity of insects. Science Publishers, Enfield, New Hampshire, USA, pp 817–839
- Hoelmer KA, Osborne LS, Yokomu RK (1990) Effect of neem extracts on beneficial insects in greenhouse culture. In: USDA neem workshop on neem's potential in pest management programs. USDA, Beltsville, pp 100–105
- Irulandi S, Balasubramanian G (2000) Report on the effect of botanicals against *Megalurothrips distalis* (Karny) (Thripidae: Thysanoptera) and *Lampides boeticus* Linn. (Lycaenidae: Lepidoptera) on greengram. *Insect Environ* 5(4):175–176
- Isman MB (1993) Growth inhibitory and antifeedant effects of azadirachtin on six noctuids of regional economic importance. *Pestic Sci* 38:57–63
- Isman MB (1995) Lepidoptera: butterflies and moths. In: Schmutterer H (ed) The neem tree, source of unique natural products for integrated pest management, medicine, industry and other purposes. VCH Verlagsgesellschaft, Weinheim, pp 229–318
- Isman MB (2006) Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annu Rev Entomol* 51:45–66
- Isman MB, Akhtar Y (2007) Plant natural products as a source for developing environmentally acceptable insecticides. In: Shaaya I, Nauen R, Horowitz AR (eds) Insecticides design using advanced technologies. Springer, Berlin/Heidelberg, pp 235–248
- Isman MB, Koul O, Luczynski A, Kaminski J (1990) Insecticidal and antifeedant bioactivities of neem oils and their relationship to azadirachtin content. *J Agric Food Chem* 38:1408–1411
- Jadhau KB, Jadhua LD (1984) Use of vegetable oils, plant extracts and synthetic products as protectants from pulse beetle. *Callosobruchus maculatus* in stored grain. *J Food Sci Technol* 21:110–113
- Jarvis AP, Johnson S, Morgan ED, Simmonds MSJ, Blaney WM (1997) Photooxidation of nimbin and salannin, tertranortriterpenoids from the neem tree (*Azadirachta indica*). *J Chem Ecol* 23(12):2841–2860
- Jarvis AP, Johnson S, Morgan ED (1998) Stability of the natural insecticide azadirachtin in aqueous and organic solvents. *Pestic Sci* 53:217–222
- Jarvis AP, Morgan ED, Edwards C (1999) Rapid separation of triterpenoids from neem seed extracts. *Phytochem Anal* 10:39–43
- Jing L, Fang Y, Ying X, Wenxing H, Meng X, Syed MN, Fang C (2005) Toxic impact of ingested jatropherol-I on selected enzymatic activities and the ultrastructure of midgut cells in silkworm, *Bomboxy mori* L. *J Appl Entomol* 129:98–104
- Johnson S, Morgan ED, Peiris CN (1996) Development of the major triterpenoids and oil in the oil and seeds of neem (*Azadirachta indica*). *Ann Bot* 78:383–388
- Johnson HA, Oberlies NH, Alali FQ, McLaughlin JE (2000) Thwarting resistance: annonaceous acetogenins as new pesticidal and antitumor agents. In: Cutler SJ, Cutler JG (eds) Biological active natural products: pharmaceuticals. CRC Press, Boca Raton, pp 173–183
- Jolad SD, Hoffman JJ, Schram KH, Cole JR, Tempesta MS, Kriek GR, Bates RB (1982) Uvaricin a new antitumor agent from *Uvaria accuminata*, (Annonaceae). *J Org Chem* 47:3151–3153
- Katekhaye SD, Kale MS, Laddha KS (2012) A simple and improved method for isolation of karanjin from *Pongamia pinnata* Linn. seed oil. *Indian J Natl Prod Resour* 3(1):131–143
- Katoune HI, Malam Lafia D, Salha H, Doumma A, Drame AY, Pasternak D, Ratnadass A (2011) Physic nut (*Jatropha curcas*) oil as a protectant against field insect pests of cowpea in Sudano-Sahelian cropping systems. *J SAT Agric Res* 9:1–6
- Khalequzzaman M, Nahar J, (2003) Toxicity of azadirachtin to larvae and adults of *Tribolium castaneum* (Herbst). *J Biol Sci* 11:19–24
- Khalequzzaman M, Sultana S (2006) Insecticidal activity of *Annona squamosa* L. seed extracts against the red flour beetle, *Tribolium castaneum* (Herbst). *J Bio-Sci* 14:107–112
- Khani M, Awang RM, Omar D, Rahmani M (2012) Bioactivity effect of *Piper nigrum* L. and *Jatropha curcas* L. extracts against *Corcyra cephalonica* [Stainton]. *Agrotechnol* 2:1
- Khumrungsee N, Bullangpoti V, Pluemanupat W (2009) Efficiency of *Jatropha gossypifolia* L. (Euphorbiaceae) against *Spodoptera exigua* Hübner (Lepidoptera: Noctuidae): toxicity and its detoxifying enzyme activities. *KKU Sci J* 37:50–55
- Klenk A, Bokel M, Kraus W (1986) 3-Tigloylazadiractl, an insect growth regulating constituent of *Azadirachta indica*. *J Chem Soc Chem Commun* 7:523–524
- Kotkar HM, Prashant SM, Sangeetha VGSS, Shipra RJ, Shripad MU, Maheshwari VL (2001) Antimicrobial and pesticidal activity of partially purified flavonoids of *Annona squamosa*. *Pest Manag Sci* 58:33–37

- Koul O (1999) Insect growth regulating and antifeedant effects of neem extracts and azadirachtin on two aphid species of ornamental plants. *J Biosci* 1:85–90
- Koul O, Isman MB, Ketkar CM (1990) Properties and uses of neem, *Azadirachta indica*. *Can J Bot* 68:1–11
- Koul O, Shankar JS, Kapil RS (1996) The effect of neem allelochemicals on nutritional physiology of larval *Spodoptera litura*. *Entomol Exp Appl* 79:43–50
- Koul O, Multani JS, Singh G, Daniewski WM, Berlozecki S (2003) 6 beta-hydroxygedunin from *Azadirachta indica*. Its potentiation effects with some non-azadirachtin limonoids in neem against lepidopteran larvae. *J Agric Food Chem* 51:2937–2942
- Kraus W (1995) In: Schmutterer H, Ascher KRS (eds) The neem tree: source of unique natural products for integrated pest management, medicine, industry and other purposes. VCH Publishers Inc., New York, pp 35–88. ISBN 3-527-30054-6
- Kraus W, Bokel M, Cramer R, Klenk A, Poehnl H (1985) Constituents of neem and related species. A revised structure of azadirachtin. *Abstr 3rd Int Conf Chem Biotechnol Biol Act Nat Prod* 4:446–450
- Krishnamurthi A (1969) The wealth of India, vol VIII. Publication and Information Directorate CSIR, New Delhi
- Kumar J, Parmar BS (1997) Neem oil content and its key chemical constituents in relation to the agro-ecological factors and regions of India. *Pestic Res J* 9:216–225
- Kumar A, Sharma S (2008) An evaluation of multipurpose oil seed crop for industrial uses (*J. curcas* L.): a review. *Ind Crops Prod* 28:1–10
- Kumar M, Singh R (2002) Potential of *Pongamia glabra* Vent as an insecticide of plant origin. *Biol Agric Hort* 20:29–50
- Kumar V, Chandrashekar K, Sidhu OP (2006) Efficacy of karanjin and different extracts of *Pongamia pinnata* against selected insect pests. *J Entomol Res* 30(2):103–108
- Lal L (1987) Studies on natural repellents against potato tuber moth. *Phthorimaea operculella* Zell in country stores. *Potato Res* 30(2):329–334
- Leatemia J, Isman M (2004) Efficacy of crude seed extracts of *Annona squamosa* against diamondback moth, *Plutella xylostella* L. in the greenhouse. *Int J Pest Manag* 50:129–133
- Leboeuf M, Cavé A, Bhaumik PK, Mukherjee B, Bukherjee R (1982) The phytochemistry of Annonaceae. *Phytochemistry* 21:2783–2813
- Ley SV, Anderson JC, Blaney WM, Jones PS, Lidert Z, Morgan ED, Robinson NG, Santafianos D, Simmonds MSJ, Toogood PL (1989) Insect antifeedants from *Azadirachta indica*: chemical modification and structure–activity relationships of azadirachtin and some related limonoids. *Tetrahedron* 45:5175–5192
- Li L, Li X, Shi C, Deng Z, Fu H, Proksch P, Lin W (2006) Pongamone A–E, five flavonoids from the stems of a mangrove plant, *Pongamia pinnata*. *Phytochemistry* 67:1347–1352
- Liang GM, Chen W, Liu TX (2003) Effects of three neem-based insecticides on diamondback moth (Lepidoptera: Plutellidae). *Crop Prot* 22:333–340
- Lindquist RK, Casey ML (1990) Evaluation of oils, soaps and natural product derivatives for miner, foxglove aphid, western flower thrips and greenhouse whitefly control. *Ohio Flor Assoc Bull* 727:3–5
- Liu SY, Sporer F, Wink M, Jourdane J, Henning R, Li YL, Ruppel A (1997) Anthraquinones in *Rheum palmatum* and *Rumex dentatus* (Polygonaceae) and phorbol esters in *J. curcas* (Euphorbiaceae) with molluscicidal activity against the schistosome vector snails *Oncomelania*, *Biomphalaria* and *Bulinus*. *Trop Med Int Health* 2:179–188
- Macedo ME, Consoli RA, Grandi TS, Dos Anjos AM, Oliveira AB, Mendes NM, Queiroz RO, Zani CL (1997) Screening of Asteraceae (Compositae) plant extracts for larvicidal activity against *Aedes fluviatilis* (Diptera: Culicidae). *Mem Inst Oswaldo Cruz* 92:565–570
- Mahey S, Sharma P, Seshadri TR (1972) Structure and synthesis of globrochromene, a new constituent of *Pongamia glabra*. *Indian J Chem* 10:585–588
- Maia MF, Moore SJ (2011) Plant-based insect repellents: a review of their efficacy, development and testing. *Malaria J* 10(1):S11
- Makkar HPS, Becker K (2009) *Jatropha curcas*, a promising crop for the generation of biodiesel and value-added coproducts. *Eur J Lipid Sci Technol* 111:773–787
- Makkar HPS, Becker K, Sporer F, Wink M (1997) Studies on nutritive potential and toxic constituents of different provenances of *J. curcas*. *J Agric Food Chem* 45:3152–3157
- Makkar HPS, Francis G, Becker K (2007) Bioactivity of phytochemicals in some lesser known plants and their effects and potential applications in livestock and aquaculture production systems. *Animal* 1:1371–1391
- Makkar HPS, Maes J, Becker K (2009) Removal and degradation of phorbol esters during pre-treatment and transesterification of *Jatropha curcas* oil. *J Am Oil Chem Soc* 86:173–181
- Malik SB, Seshadri TR, Sharma P (1976) Minor component of the leaves of *Pongamia glabra*. *Indian J Chem* 14B:229–230
- Martinez SS, Van Emden HF (2001) Growth disruption, abnormalities and mortality of *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae) caused by azadirachtin. *Neotrop Entomol* 30:113–125
- Mazid M, Khan TA, Mohammad F (2011) Role of secondary metabolites in defense mechanisms of plants. *Biol Med* 3(2):232–249
- McLaughlin JL, Zeng L, Oberlies NH, Alfonso D, Johnson HA, Cummings BA (1997) In: Hedin PA, Hollingworth RM, Miyamoto J, Thompson DG (eds) *Phytochemicals for pest control*, ACS symposium series 658. American Chemical Society, Washington, DC, pp 117–133
- Meera B, Kumar S, Kalidhar SB (2003) A review of the chemistry and biological activity of *Pongamia pinnata*. *J Med Aromat Plant Sci* 25:441–465

- Mengual L (1997) Extraction of bioactive substances from *J. curcas* L. and bioassays on *Zonocerus variegatus*, *Sesamia calamistis* and *Busseola fusca* for characterisation of insecticidal properties. In: Gübitz GM, Mittelbach M, Trabi M (eds) Biofuel and industrial products from *Jatropha curcas*. Dbv-Verlag University, Graz, pp 211–215
- Mohanty KK, Chakraborty DP, Roy S (1988) Antifeedant activity of oil fractions of some leguminous plants against *Diacrisia obliqua*. Indian J Agric Sci 58(7):579–580
- Mondal A, Walia S, Shrivastava C, Kumar B, Kumar J (2010) Synthesis and insecticidal activity of karanj ketone oxime and its ester derivatives against the mustard aphid (*Lipaphis erysimi*). Pestic Res J 22(1):39–43
- Mordue AJ, Blackwell A (1993) Azadirachtin, an update. J Insect Physiol 39:903–924
- Mordue AJ, Nisbet AJ (2000) Azadirachtin from the neem tree *Azadirachta indica*: its action against insects. An Soc Entomol Bras 29:615–632
- Murray B, Isman (1997) Neem and other botanical insecticides: barriers to commercialization. Phytoparasitica 25(4):339–344
- Murugan K, Jeyabalan D, Kumar SN, Babu R, Sivaramakrishnan S, Nathan SS (1998) Antifeedant and growth inhibitory potency of neem limonoids against *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae). Insect Sci Appl 1:157–162
- Narasimhan V, Mariappan V (1988) Effect of plant derivatives on green leaf hopper (GLH) and rice tungro (RTV) transmissions. Int Rice Res Newsl 13(1):28–29
- Nathan SS, Kalaivani K (2006) Combined effects of azadirachtin and nucleopolyhedrovirus (SplNPV) on *Spodoptera littoralis* Fabricius (Lepidoptera: Noctuidae) larvae. Biol Control 39:96–104
- Nathan SS, Kalaivani K, Murugan K (2005) Paul Gene Chung. Efficacy of neem limonoids on *Cnaphalocrocis medinalis* (Guenée) (Lepidoptera: Pyralidae) the rice leaf folder. Crop Prot 24:760–763
- Nathan SS, Chunga PG, Murugan K (2006) Combined effect of biopesticides on the digestive enzymatic profiles of *Cnaphalocrocis medinalis* (Guenée) (the rice leaf folder) (Insecta: Lepidoptera: Pyralidae). Ecotoxicol Environ Saf 64:382–389
- Ngiefu CK, Paquot C, Vieux A (1976) Oil-bearing plants of Zaire. II. Botanical families providing oils of medium unsaturation. Oleagineux 31(12):545–547
- National Research Council (NRC) (1992) Neem: tree for solving global problems. National Academy Press, Washington, DC
- Nwosu MO, Okafor JI (1995) Preliminary studies of the antifungal activities of some medicinal plants against *Basidiobolus* and some other pathogenic fungi. Mycoses 38:191–195
- Ocampo D, Ocampo R (2006) Bioactividad de la familia Annonaceae. Rev Univ Caldas 5:135–155
- Okonkwo EO (2005) Plant materials used for controlling insect pests of stored products in Nigeria, Families Annonaceae, Piperaceae, and Rutaceae. J Herbs Spices Med Plants 11:47–69
- Onunkun O (2012) Evaluation of aqueous extracts of five plants in the control of flea beetles on okra (*Abelmoschus esculentus* (L.) Moench). J Biopest 5(Suppl):62–67
- Packiam SM, Ignacimuthu S (2013) Effect of botanical pesticide formulations against the chilli trips (*Scirtothrips dorsalis* Hood) on peanut ecosystem. Int J Nat Appl Sci 2(1):1–5
- Packiam SM, Anbalagan V, Ignacimuthu S, Vendan SE (2012) Formulation of a novel phytopesticide PONNEEM and its potentiality to control generalist herbivorous Lepidopteran insect pests, *Spodoptera litura* (Fabricius) and *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). Asian Pac J Trop Dis 2(2):S720–S723
- Pappas ML, Broufas GD, Koveos DS (2011) Chrysopid predators and their role in biological control. J Entomol 8(3):301–326
- Parmar BS, Gulati KC (1969) Synergists for pyrethrins (II)-karanjin. Indian J Entomol 31:239–243
- Parra-Henao G, García C, Cotes J (2007) Actividad insecticida de extractos vegetales sobre *Rhodnius prolixus* y *Rhodnius pallescens* (Hemiptera: Reduviidae). Bol Malariai Salud Ambient 47:125–137
- Parvin S, Islam E, Rahman M, Haque E (2003) Pesticidal activity of pure compound Annotemoyin-1 isolated from chloroform extract of the plant *Annona squamosa* Linn. against *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). Pak J Biol Sci 6:1088–1091
- Paul J, Gnanam R, Jayadeepa RM, Arul L (2013) Anti cancer activity on graviola, an exciting medicinal plant extract vs various cancer cell lines and a detailed computational study on its potent anti-cancerous leads. Curr Top Med Chem 13(14):1666–1673
- Pavanaram SK, Ramachandra Row L (1955) New flavones from *Pongamia pinnata* (L.) Merr.: identification of compound D. Nature 176:1177
- Pavela R (2012) Efficacy of three newly developed botanical insecticides based on pongam oil against *Plutella xylostella* L. larvae. J Biopest 5(1):62–70
- Pavela R, Herda G (2007a) Effect of pongam oil on adults of the greenhouse whitefly *Trialeurodes vaporariorum* (Homoptera: Trialeurodidae). Entomol Gen 30:193–201
- Pavela R, Herda G (2007b) Repellent effects of pongam oil on settlement and oviposition of the common greenhouse whitefly *Trialeurodes vaporariorum* on *Chrysanthemum*. Insect Sci 14:219–224
- Pawar PV, Joseph M, Sen A, Joshi SP (2011) Growth regulatory and toxic effects of non-edible oil seed extracts and purified extracts against *Helicoverpa armigera* (Hübner). J Agric Technol 7(5):1275–1282
- Pereira J (1983) The effectiveness of six vegetable oils as protectants of cowpeas and banbara groundnuts against infestation by *Callosobruchus maculatus* (F.). Indian J Agric Sci 51:910–912
- Pérez-Pacheco R, Rodríguez C, Lara J, Montes R, Valverde G (2004) Toxicidad de aceites, esencias y extractos vegetales en larvas de mosquito *Culex quin-*

- quefasciatus* Say (Diptera: Culicidae). *Acta Zool Mex* 20:141–152
- Pineda S, Martínez AM, Figueroa JI, Schneider MI, Del Estal P, Viñuela E, Gómez B, Smaghe G, Budia F (2009) Influence of azadirachtin and methoxyfenozide on life parameters of *Spodoptera littoralis* (Lepidoptera: Noctuidae). *J Econ Entomol* 102(4):1490–1496
- Prakash A, Rao J, Nandagopal VN (2008) Future of botanicals in rice, wheat, pulses and vegetables pest management. *J Biopest* 1(2):154–169
- Premchand (1989) Presence of feeding deterrent in the velvet bean, *Mucuna cochinchensis* Roxb. *Indian J Entomol* 51(2):217
- Priestley CM, Williamson EM, Wafford KA, Sattelle DB (2003) Thymol, a constituent of thyme essential oil, is a positive allosteric modulator of human GABA receptors and a homo-oligomeric GABA receptor from *Drosophila melanogaster*. *Braz J Pharmacol* 140:1363–1372
- Prijono D, Gani MS, Syahputra E (1997) Insecticidal activity of annonaceous seed extracts against *Crociodolomia binotalis* Zeller (Lepidoptera: Pyralidae). *Bull Plant Pest Dis* 9:1–6
- Raintree Nutrition (2004) Graviola monograph. www.rain-tree.com/Graviola-Monograph.pdf. Visitado 26 Feb 2009
- Rajasekaran B, Jayraj S, Raghuramman S, Narayanswamy T (1987) Use of neem products for the management of certain rice pests and diseases. In: Mid-term appraisal works on botanical pest control of rice based cropping system, p 13
- Rajguru M, Sharma AN, Banerjee S (2011) Assessment of plant extracts fortified with *Bacillus thuringiensis* (Bacillales: Bacillaceae) for management of *Spodoptera litura* (Lepidoptera: Noctuidae). *Int J Trop Insect Sci* 31(1–2):92–97
- Rakshit KD, Darukeshwara J, Rathina RK, Narasimhamurthy K, Saibaba P, Bhagya S (2008) Toxicity studies of detoxified *J. curcas* meal (J. curcas) in rats. *Food Chem Toxicol* 46:3621–3625
- Rao GVR, Gopalakrishnan S (2009) Biopesticides research at ICRISAT: a consortium model. In: “Expert consultation on biopesticides and biofertilizers for sustainable agriculture” APAARI and council of research, Taiwan, 22–29 Oct
- Rao NVS, Rao JV (1941) A note on glabrin: a new component of the seeds of *Pongamia glabra*. *Proc Indian Acad Sci* 14:123–125
- Ratnadas A, Togola M, Cissé B, Vassal JM (2009) Potential of sorghum and physic nut (*Jatropha curcas*) for management of plant bugs (Hemiptera: Miridae) and cotton bollworm (*Helicoverpa armigera*) on cotton in an assisted trap-cropping strategy. http://ejournal.icrisat.org/Volume7/Sorghum_Millets/SG703.pdf. Accessed 13 Dec 2011
- Ratnakumari B, Chandrasekaran S (2005) Efficacy of neem products against cotton stem weevil (*Pempherulus affinis* Faust) in Coimbatore. *Andhra Agric J* 52(1,2):295–297
- Ravindra V, Kshirsagar (2010) Insecticidal activity of *Jatropha* seed oil against *Callosobruchus maculatus* (Fabricius) infesting *Phaseolus aconitifolius* Jacq. *Bioscan* 5(3):415–418
- Reddy AV, Singh RP (1998) Fumigant toxicity of neem (*Azadirachta indica* A. Juss.) seed oil volatiles against pulse beetle, *Callosobruchus maculatus* Fab. (Col., Bruchidae). *J Appl Entomol* 122:607–611
- Reddy AV, Devi RS, Reddy DVV (2012) Evaluation of botanical and other extracts against plant hoppers in rice. *J Biopest* 5(1):57–61
- Reena SR, Sinha BK (2012) Evaluation of *Pongamia pinnata* seed extracts as an insecticide against American bollworm *Helicoverpa armigera* (Hübner). *Int J Agric Sci* 4(6):257–261
- Rembold H (1988) Azadirachtins: their structures and mode of action. In: Jacobson M (ed) Focus on phytochemical pesticides: the neem tree. CRC Press, Boca Raton, pp 47–67
- Rembold H (1989) Azadirachtins, their structure and mode of action. In: Arnason JT, Philogene BJR, Morand P (eds) Insecticides of plant origin, ACS symposium series 387. American Chemical Society, Washington, DC, pp 150–163
- Rembold H (1990) Isomeric azadirachtins and their mode of action. In: Jacobson M (ed) Focus on phytochemical pesticides 1: the neem tree. CRC Press, Boca Raton, pp 47–67
- Ribeiro LP, Vendramim JD, Bicalho KU, Andrade MS, Fernandes JB, Moral RA, Demétrio CGB (2013) *Annona mucosa* Jacq. (Annonaceae): A promising source of bioactive compounds against *Sitophilus zeamais* Mots. (Coleoptera: Curculionidae). *J Stored Prod Res* 55:6–14
- Richard AW (2000) Botanical insecticides, soaps and oils. In: Recheigl JE, Recheigl NA (eds) Biological and biotechnological control of insect pests. Lewis Publishers, London, pp 101–121
- Ríos MY, Castrejun F, Robledo N, León I, Rojas G, Navarro V (2003) Chemical composition and antimicrobial activity of the essential oils from *Annona cheromola* (Annonaceae). *J Mex Chem Soc* 47:134–142
- Robledo-Reyes P, González R, Jaramillo G, Restrepo J (2008) Evaluación de la toxicidad de acetogeninas annonáceas sobre ninfas de *Periplaneta americana* L. (Dyctioptera: Blattidae). *Bol Museo Entomol Univ Valle* 9:54–61
- Rojano B, Gaviria C, Sáez J, Yepes F, Muñoz F, Ossa F (2007) Berenjenol aislado de *Oxandra cf xylopioides* (Annonaceae) como insecticida. *Vitae* 14:95–100
- Roy DC, Pande YD (1991) Effect of *hyptis suaveolens* (L.) Poit. leaf extract on the population of *Lipaphis erysimi* Kalt. In: IV National symposium on growth, development and control techniques of insect pests. Zoological Society, Muzaffarnagar, p 37
- Roy D, Sharma NN, Khanna RN (1977) Structure and synthesis of iso-pongaflavone, a new component of the seeds of *Pongamia glabra*. *Indian J Chem* 15:1138–1139
- Rozman V, Kalinovic I, Korunic Z (2007) Toxicity of naturally occurring compounds of Lamiaceae and Lauraceae to three stored product insects. *J Stored Prod Res* 43:349–355

- Rupprecht JK, Hui YH, McLaughlin JL (1990) Annonaceous acetogenins: a review. *J Nat Prod* 53(2):237–278
- Sabandar CW, Ahmat N, Jaafar FM, Sahidin I (2013) Medicinal property, phytochemistry and pharmacology of several *Jatropha* species (Euphorbiaceae): a review. *Phytochemistry* 85:7–29
- Sathyaseelan V, Bhaskaran V (2010) Efficacy of some native botanical extracts on the repellency property against the pink mealy bug, *Maconellicoccus hirsutus* (Green). in Mulberry crop. *Recent Res Sci Technol* 2(10):35–38
- Sauerwein M, Sporer F, Wink M (1993) Insect-toxicity of phorbol esters from *Jatropha curcas* seed oil. *Planta Med* 59:A686
- Savard J, Espil L (1951) Centre Tech For Trop Nogent Marne Publ 3:7
- Schmahl G, Al-Rasheid KAS, Abdel-Ghaffar F, Klimpel S, Mehlhorn H (2010) The efficacy of neem seed extracts (Tre-san®, MiteStop®) on a broad spectrum of pests and parasites. *Parasitol Res* 107:261–269
- Schmutterer H (1985) Which insect pests can be controlled by application of neem seed kernel extract under field conditions. *Z Angew Entomol* 100:468–475
- Schmutterer H (1988) Potential of azadirachtin-containing pesticides for integrated pest control in developing and industrialized countries. *J Insect Physiol* 34:713–719
- Schmutterer H (1990a) Future tasks of neem research in relation to agricultural needs worldwide. In: Locke JC, Lawson RH (eds) Proceedings of workshop on neem's potential in pest management programs. USDA–ARS, Beltsville, ARS-86, pp 15–22
- Schmutterer H (1990b) Properties and potential of natural pesticides from the neem tree, *Azadirachta indica*. *Annu Rev Entomol* 35:271–297
- Schmutterer H (2002) The neem tree. Neem Foundation, Mumbai
- Schroeder DR, Nakanishi KA (1987) Simplified isolation procedure for azadirachtin. *J Nat Prod* 50:241–244
- Scudeler EL, Dos Santos DC (2013) Effects of neem oil (*Azadirachta indica* A. Juss) on midgut cells of predatory larvae *Ceraeochrysa claveri* (Navás, 1911) (Neuroptera: Chrysopidae). *Micron* 44:125–132
- Secoy DM, Smith AE (1983) Use of plants in control of agricultural and domestic pests. *Econ Bot* 37:28–57
- Seffrin RC, Shikano I, Akhtar Y, Isman MB (2010) Effects of crude seed extracts of *Annona atemoya* and *Annona squamosa* L. against the cabbage looper, *Trichoplusia ni* in the laboratory and greenhouse. *Crop Prot* 29:20–24
- Shameel S, Usmanghani K, Ali MS (1996) Chemical constituents from seeds of *Pongamia pinnata* (L.) Pierre. *Pak J Pharm Sci* 9:11–20
- Sharma INS, Singh AK, Singh SP (1982) Allelopathic potential of some plant substances as anti-feedants against insect pests of jute. In: Proc. first national symposium on allelopathy in agro-ecosystems. Indian Society of Allelopathy, HAU, Hisar, pp 157–176
- Sharma HC, Leuschner K, Sankaram AVB, Gunasekhar D, Marthandamurthi M, Bhaskaraiah K, Subrahmanyam M, Sultana N (1983) Insect antifeedants and growth inhibitors from *Azadirachta indica* and *Plumbago zeylanica*. In: Schmutterer H, Ascher KRS (eds) Natural pesticides from neem tree and other tropical plants: proceedings of the 2nd international neem conference, 1986, GTZ, Eschborn. German Society for Technical Cooperation, Eschborn
- Sharma HC, Sankaram AVB, Nwanze KF (1999) Utilization of natural pesticides derived from neem and custard apple in integrated pest management. In: Juss A, Singh RP, Saxena RC (eds) *Azadirachta Indica* A. Juss. Oxford/IBH, New Delhi, pp 199–213
- Sharma PR, Sharma OP, Saxena BP (2003a) Effect of Neem gold on haemocytes of tobacco armyworm, *Spodoptera littoralis* (Fabricius) (Lepidoptera; Noctuidae). *Curr Sci* 84:690–695
- Sharma V, Walia S, Kumar J, Nair MG, Parmar BS (2003b) An efficient method for the purification and characterization of nematicidal azadirachtins A, B and H using MPLC and ESIMS. *J Agric Food Chem* 51:3966–3972
- Sharma V, Walia S, Dhingra S, Kumar J, Balraj SP (2006) Azadirachtin-A and tetrahydroazadirachtin-A concentrates: preparation, LC-MS characterization and insect antifeedant/IGR activity against *Helicoverpa armigera* (Hübner). *Pest Manag Sci* 62:965–975
- Shelke SS, Jadhav LD, Salunkhe GN (1985) Ovipositional and adult repellent action of some vegetable oils/extracts against potato tuber moth. *Maharashtra Agric Univ* 10:284–286
- Shelke SS, Jadhav LD, Salunkhe GN (1987) Ovicidal action of some vegetable oils and extracts in the storage pest of potato, *Phthorimaea operculella*. *Zell Biovigyanam* 13:40–41
- Shi GE, Alfonso D, Fatope MO, Zeng L, Gu ZM, Zhao GX, He K, MacDougal JM, McLaughlin JL (1995) Mucocin: a new annonaceous acetogenin bearing a tetrahydropyran ring. *J Am Chem Soc* 117:10409–10410
- Shi G, Kozlowski JF, Schwedler JT, Wood KV, MacDougal JM, McLaughlin JL (1996) Muconin and mucoxin: additional non-classical bioactive acetogenins from *Rollinia mucosa*. *J Org Chem* 61:7988–7989
- Shrinivas M, Balikai S (2009) Evaluation of plant products in combination with cow urine and panchagavya against sorghum shootfly, *Atherigona soccata* Rondani. *Karnataka J Agric Sci* 22:618–620
- Shukla S, Arora R, Sharma HC (2005) Biological activity of soybean trypsin inhibitor and plant lectins against cotton bollworm/legume pod borer, *Helicoverpa armigera*. *Plant Biotechnol* 22(1):1–6
- Sidhu OP, Behl HM (1996) Seasonal variations in azadirachtins in seeds of *Azadirachta indica*. *Curr Sci* 70(12):1084–1086
- Sidhu OP, Kumar V, Behl HM (2003) Variability in neem (*Azadirachta indica*) with respect to azadirachtin content. *J Agric Food Chem* 51:910–915
- Silva GN, Faroni LRA, Sousa AH, Freitas RS (2012) Bioactivity of *Jatropha curcas* L. to insect pests of stored products. *J Stored Prod Res* 48:111–113

- Simin K, Ali Z, Khaliq-Uz-Zaman SM, Ahmad VU (2002) Structure and biological activity of a new rotenoid from *Pongamia pinnata*. *Nat Prod Res* 16:351–357
- Singh YP (2007) Efficacy of plant extracts against mustard aphid, *Lipaphis erysimi* on mustard. *Indian J Plant Prot* 35(1):116–117
- Singh D, Singh AK (1991) Repellent and insecticidal properties of essential oils against housefly *Musca domestica* L. *Insect Sci Appl* 12(4):487–491
- Singh D, Siddiqui MS, Sharma S (1989) Reproduction retardant and fumigant properties in essential oils against rice weevil (Coleoptera: Curculionidae) in stored wheat. *J Econ Entomol* 83(3):727–733
- Singh R, Rup PJ, Koul O (2008) Bioefficacy of *Eucalyptus camaldulensis* var. *obtusa* and *Luvanga scandens* essential oils against *Spodoptera litura* (Lepidoptera: Noctuidae). *Biopestic Int* 4:128–137
- Sinha SH (1993) Neem in the integrated management of *Helicoverpa armigera* Hubn. in chickpea. In: World neem conference. Indian Society of Tobacco Science, Bangalore, p 6
- Sláma K, Williams CM (1965) Juvenile hormone activity for the bug *Pyrrhocoris apterus*. *Proc Natl Acad Sci U S A* 54(2):411–414
- Solsoloy AD (1995) Pesticidal efficacy of the formulated physic nut, *Jatropha curcas* L. oil on pests of selected field crops. *Philipp J Sci* 124:59–74
- Solsoloy AD, Solsoloy TS (1997) Pesticidal efficacy of formulated *J. curcas* oil on pests of selected field crops. In: Gubitz GM, Mittelbach M, Trabi M (eds) Biofuels and industrial products from *J. curcas*. DBV Graz, Graz, pp 216–226
- Solsoloy AD, Solsoloy TS (2000) Insecticide resistance management in cotton in the Philippines. *Philipp J Crop Sci* 25:26
- Stokes JB, Redfern RE (1982) Effect of sunlight on azadirachtin antifeeding potency. *J Environ Sci Health A* 17:57–65
- Suliman R, Saker I, Namora D (2003) Importance of plant extracts in managing acarids damaging to crops. In: Eighth Arab congress of plant protection, 12–16 October, El-Beida, Libya, pp 87–91
- Sundaram KMS (1996) Azadirachtin biopesticide: a review of studies conducted on its analytical chemistry, environmental behaviour and biological effects. *J Environ Sci Health Part B* 31:913–948
- Sundaram KMS, Curry J (1996a) Effect of some UV-light absorbers on the photostability of azadirachtin of a neem based pesticide. *Chemosphere* 32:649–659
- Sundaram KMS, Curry J (1996b) Photostabilization of the botanical insecticide azadirachtin in the presence of lecithin as UV protectants. *J Environ Sci Health B* 31:1041–1060
- Sundaram KMS, Sundaram A, Curry J, Sloane L (1997) Formulation selection, and investigation of azadirachtin – a persistence in some terrestrial and aquatic components of a forest environment. *Pestic Sci* 51:74–90
- Susarla RS, Murthy MM, Rao BVSK, Chakrabarti PP, Prasad RBN, Kanjilal S (2012) A method for isolation of karanjin from the expelled cake of *Pongamia glabra*. *Eur J Lipid Sci Technol* 114:1097–1101
- Talopatra B, Malik AK, Talopatra SK (1985) Triterpenoids and flavonoids from the leaves of *Pongamia glabra* Vent. Demethylation studies on 5-methoxyfuranoflavone. *J Indian Chem Soc* 62:408–409
- Taylor DAH (1984) The chemistry of the Limonoids from Meliaceae *Prog Chem Org Nat Prod* 45:1–101
- Thebtaranonth C, Thebtaranonth Y, Wanauppathamkul S, Yuthavong Y (1995) Antimalarial sesquiterpenes from tubers of *Cyperus rotundus*: structure of 10, 12-peroxy-calamenene, a sesquiterpene endoperoxide. *Phytochemistry* 540:125–128
- Tormo JR, Gallardo T, González MC, Bermejo A, Cabedo N, Andreu I, Estornell E (1999) Annonaceous acetogenins as inhibitors of mitochondrial complex I. *Curr Top Phytochem* 2:69–90
- Tripathi AK, Rao SM, Singh D, Chakraborty RB, Bhakuni DS (1987) Antifeedant activity of plant extracts against *Diacrisia oblique* walk. *Curr Sci* 56(12):607–608
- Unicini Manganeli RE, Zaccaro L, Tomei PE (2005) Antiviral activity in vitro of *Urtica dioica* L., *Parietaria diffusa* M. and K., and *Sambucus nigra* L. *J Ethnopharmacol* 98:323–327
- Valencia A, Frérot B, Guénego H, Múnera DF, Grossi De Sá MF, Calatayud PA (2006) Effect of *Jatropha gossypifolia* leaf extracts on three lepidoptera species. *Rev Colomb Entomol* 32(1):45–48
- Veitch GE, Boyer A, Ley SV (2008) The azadirachtin story. *Angew Chem Int Ed* 47:9402–9429
- Venkataramireddy P, Chitra KC, Rao PK (1990) Efficacy of plant extracts in the control of brinjal spotted leaf beetle, *Henosepilachna vigintioctopunctata* F. In: Proc of symposium of botanical pesticides in IPM, Rajahmundry, pp 225–227
- Venkateswarlu B, Katyal JC, Choudhari J, Mukhopadhyay K (1997) Azadirachtin content in the neem seed samples collected from different dry land regions. *Neem Newsl (IARI)* 14(1):7–11
- Vismayaa SEW, Manjunatha JR, Srinivas P, Kanyaa S TC (2010) Extraction and recovery of karanjin: a value addition to karanja (*Pongamia pinnata*) seed oil. *Ind Crops Prod* : 118–122 (32pp)
- Warthen JD, Stokes JR, Jacobson M, Kozempel MF (1984) Estimation of azadirachtin content in neem extract and formulations. *J Liq Chromatogr* 7:591–598
- Williams LAD, Mansingh A (1996) The insecticidal and acaricidal actions of compounds from *Azadirachta indica* (A. Juss.) and their use in tropical pest management. *Integr Pest Manag Rev* 1(3):133–145
- Willis TE (1967) Textbook of pharmacognosy. J. and A Churchill Ltd, pp 513–524
- Wink M (2000) Interference of alkaloids with neuroreceptors and ion channels. In: Rahman XA (ed) Bioactive natural products. Elsevier, Amsterdam, Netherlands, pp 3–129

- Wink M, Koschmieder C, Sauerweien M, Sporer F (1997) Phorbol esters of *J. curcas* – biological activities and potential applications. In: Gubitz GM, Mittelbach M, Trabi M (eds) Biofuel and industrial products from *Jatropha curcas*. DBV, Graz, pp 160–166
- Yadav PP, Ahmad G, Maurya R (2004) Furanoflavonoids from *Pongamia pinnata* fruits. *Phytochemistry* 65:439–443
- Yamasaki RB, Klocke JA (1987) Structure bioactivity relationship of azadirachtin, a potent insect control agent. *J Agric Food Chem* 35:467–471
- Yamasaki RB, Klocke JA, Lee SM, Stones GA (1986) Darlington, M. V. Isolation and purification of azadirachtin from neem (*Azadirachta indica*) seeds using flash chromatography and high performance liquid chromatography. *J Chromatogr* 18:467
- Yin H, Zhang S, Wu J, Nan H, Long L, Yang J, Li Q (2006) *Ponga flavonol*: a prenylated flavonoid from *Pongamia pinnata* with a modified ring A. *Molecules* 11:786–791
- Yule S, Srinivasan R (2013) Evaluation of bio-pesticides against legume pod borer, *Maruca vitrata* Fabricius (Lepidoptera: Pyralidae), in laboratory and field conditions in Thailand. *J Asia Pac Entomol* 16:357–360
- Zeng L, Ye Q, Oberlies NH, Shi G, Gu ZM, He K, McLaughlin JL (1996) Recent advances in Annonaceous acetogenins. *Nat Prod Rep* 13:275–306
- Zoubiri S, Baaliouamer A (2011) Potentiality of plants as source of insecticide principles. *J Saudi Chem Soc.* doi:[10.1016/j.jscs.2011.11.015](https://doi.org/10.1016/j.jscs.2011.11.015)