Pharmacologia 3 (12): 641-656, 2012
ISSN 2044-4648 / DOI: 10.5567/pharmacologia.2012.641.656
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Prospects of Botanical Biopesticides in Insect Pest Management

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Abstract: Conventional insecticides possess inherent toxicities that endanger the health of the farm operators, consumers and the environment. Negative effects on human health led to a resurgence in interest in botanical insecticides because of their minimal costs and ecological side effects. Botanicals are encouraging over broad-spectrum conventional pesticides. They affect only target pest and closely related organisms, effective in very small quantities, decompose quickly and provide the residue free food and a safe environment to live. When incorporated in integrated pest management programs, botanical pesticides can greatly decrease the use of conventional pesticides or used in rotation or in combination with other insecticides, potentially lessening the overall quantities applied and possibly mitigating or delaying the development of resistance in pest populations. Although the use of rotenone and nicotine appears to be waning, pyrethrum and neem are well established commercially, pesticides based on plant essential oils have recently entered the marketplace. Plant- based insecticides induce not only acute toxicity to pests but also deterrence and/or repellence which may contribute to overall efficacy against some pests that cause great economic losses at the pre- as well postharvest stages of the crop production and transmit diseases to animals and humans. This review provides information about pyrethrum, rotenone, nicotine and other traditional botanicals, as well as the newer botanicals, neem and essential oils. I discussed their effectiveness, uses, safety, commercialization and future trends of plant- based insecticides. Botanical insecticides are desirable alternatives to synthetic chemical insecticides for controlling pests. They are best suited for use in organic food production in industrialized countries but can play a much greater role in developing countries as a new class of ecofriendly products for controlling pests.

Key words: Plant-based insecticides, pyrethrum, nicotine, rotenone, neem, essential oils, nanotechnology

INTRODUCTION

The use of locally available plants, such as *Derris, Nicotiana* and *Ryania*, is an ancient way to control pests during prehistoric period. Pesticidal plants were used widely until 1940s, then they were alternated by synthetic pesticides as they are easier to handle and lasted longer. Pesticides are the substances or mixture of substances used to prevent, destroy, repel, attract, sterilize or mitigate the pests. The consumption of pesticide in some of the developed countries is almost 3000 g ha^{-1}. Overenthusiastic use of synthetic insecticides led to problems unforeseen at the time of their introduction. Pesticides are generally persistent in nature. The World Health Organization (WHO) estimates that 200,000 people are killed worldwide, every year, as a direct result of pesticide poisoning. Moreover, the use of synthetic chemicals has also been restricted because of their carcinogenicity, teratogenicity, high and acute residual toxicity, ability to create hormonal imbalance, spermatotoxicity, long degradation period and food residues (Dubey *et al*., 2011; Pretty, 2009; Feng and Zheng, 2007; Khater, 2011).

Repetitive use has resulted in pesticide residue hazards, upsetting the balance of nature through disruption of natural enemies, pollinators and other wild life, extensive groundwater contamination, evolution of resistance and resurgence of treated populations, outbreaks of secondary pests, i.e., those normally kept under control by their natural enemies (Dubey *et al*., 2011). It was reported by the World Resources Institute that more than 500 insect and mite species are immune to one or more insecticides (WRI, 1994). Pests becoming tolerant to insecticides, resulting in the use of double and triple application rates (Stoll, 2000). Integrated Pest Management (IPM) can be defined as the use of all available means to maintain pest populations below levels that would cause economic loss while minimally impacting the environment. Achieving a zero pesticide strategy in tropical agroecosystems may be easier than in temperate zones, as in many instances farmers have not yet begun the generalized use of pesticides (Pretty, 2009). The plant kingdom is recognized as the most efficient producer of chemical compounds, synthesizing many products that are used in defense against different pests (Isman and Akhtar, 2007). Such plants have been in nature for millions of years without any adversative effects on the ecosystem. Botanical pesticides are also very close chemically to those plants from which they are derived, so they are easily decomposed by a variety of microbes common in most soils, their use maintains the biological diversity of predators (Grainge and Ahmed, 1988), as a result, they reduces environmental contamination and human and animal health hazards.

As a form of allelopathy, some botanicals serve as control agents for pests and diseases after intercropping or mix-cropping with the main crop, ex., *N. tabaccum* and some other plant species, especially grasses (Ogunnika, 2007) have been found to possess this attribute. *Eucalyptus camaldulensis* and some other botanicals are also used as weed control in farmlands to maximize yields (Oyun and Agele, 2009). Farming population in the tropics has included intercropping and mix-cropping of main crops with the botanicals, ex., planting *Manihot esculenta* (cassava) with *Ocimum gratissimum* (camphor basil), *Theobromae cacao* (cocoa) with *Carica papaya* (pawpaw) and so on (Ogunnika, 2007). Accordingly, crops are protected naturally and simply through pesticidal plants without the carrying out formulation and application processes for pest and disease control.

Botanical extracts induce insecticidal activity, repellence to pests, antifeedant effects and insect growth regulation, toxicity to nematodes, mites and other pests, as well as antifungal, antiviral and antibacterial properties against pathogens (Prakash and Rao, 1986, 1997). In developing countries, pesticidal plants offer unique and challenging opportunities for exploration and development of their own botanicals. Following is an overview pointing out the effectiveness, uses, safety and commercialization of the plant- based insecticides.

TRADITIONAL INSECTICIDES

Pyrethrum: Pyrethrum is the most widely and heavily used botanical insecticide worldwide and it is well known as fast knockdown household aerosols. The flowers of *Tanacetum cinerariaefolium* (Asteraceae) are ground to a powder and then extracted with hexane or a similar nonpolar solvent; removal of the solvent yields an orange-colored liquid that contains the active principles (Casida and Quistad, 1995). The majority (>75%) of the world's supply of pyrethrum was produced in Kenya and Tanzania but its production began in Tasmania (Australia) in 1996 and it recently produces almost one-half of the world supply. Technical grade pyrethrum, the resin used in formulating commercial insecticides, typically contains from 20-25% pyrethrins (Casida and Quistad, 1995). Recently, Australia produces produces a technical grade material comprising 50% pyrethrins by weight. Pyrethrins are common active ingredients in the insecticide products. Without formulation with one of the synergists, most of the paralyzed insects recover. A synergist such as piperonyl butoxide (PBO), derived from sassafras or n-octyl bicycloheptane dicarboximide, increase insect mortality and extend the shelf life of the product.

In purity, pyrethrins are moderately toxic to mammals (rat oral acute LD_{50} values range from 350-500 mg kg^{-1}) but technical grade pyrethrum is considerably less toxic (almost 1500 mg kg^{-1}) (Casida and Quistad, 1995). The half-lives of pyrethrins on field-grown tomato and bell pepper fruits were 2 h or less (Antonious, 2004). Natural pyrethrum has seldom been used for agricultural purposes because of its cost and instability in sunlight. Development of synthetic derivatives apyrethroids@ that are more stable in sunlight solve this problem.

Pyrethroids: Pyrethroids are synthetic materials designed to imitate natural pyrethrum but they are much more toxic and long lasting (Singh and Srivastava, 1999). Sunlight does not break them down and they stick to leaf surfaces for weeks, killing any bypassing insect. Even though pyrethroids can be useful insecticides, they induce some deleterious effects as they irritate the human skin; some of them are extremely toxic to natural enemies, honey bees and fish. They are more harmful to the environment than pyrethrin (Dubey *et al*., 2011).

Mode of action: Pyrethrum is an axonic poison, as are the synthetic pyrethroids and DDT. Axonic poisons affect the electrical impulse transmission along the axons, the elongated extensions of the neuron cell body. They affect both the peripheral and central nervous system of the insect. Pyrethrum initially stimulates nerve cells to produce repetitive discharges, leading eventually to paralysis. Such effects are caused by their action on the sodium channel, a tiny hole through which sodium ions are permitted to enter the axon to cause excitation. These effects are produced in insect nerve cord which contains ganglia and synapses, as well as in giant nerve fiber axons (Ware and Whitacre, 2004).

Types of pyrethroids: There are two types of pyrethroids. Type I have a negative temperature coefficient, similar to that of DDT; whereas Type II have a positive temperature coefficient, showing increased kill with increase in ambient temperature. The stimulating effect of pyrethroids is much more pronounced than that of DDT. Pyrethroids dominated world insecticide use from the 1980s to the start of the current century representing an example of synthetic pesticide chemistry based on botanical model.

As modern pyrethroids bear little structural resemblance to the natural pyrethrins, their molecular mechanism of action differs as well (Ware and Whitacre, 2004; Dubey *et al*., 2011; Khater, 2011).

Rotenone: Rotenone is an isoflavonoid obtained from the roots or rhizomes of tropical legumes in the genera *Derris, Lonchocarpus* and *Tephrosia*. It is a traditional botanical insecticide in declining use in agriculture. Use of rotenone is limited to organic food production. In California, about 200 kg are used annually, mostly on lettuce and tomato crops (Isman, 2006). Rotenone continues to be sold for home and garden use. It has been used, 350 years, in South-east Asia to paralyze fish, causing them to surface and be easily captured. It kills all fish at dosages that are relatively nontoxic to fish food organisms and is degraded rapidly. Accordingly, it is used to reclaim lakes for game fishing. It commonly sold as a dust containing 1-5% active ingredients for home and garden use but liquid formulations used in organic agriculture can contain as much as 8% rotenone and 15% total rotenoids (Isman, 2006).

Mode of action: Rotenone is a contact and stomach poison. It is a broad-spectrum cytotoxin, as it inhibits the electron transport chain in mitochondria. Rotenone is a respiratory enzyme inhibitor, acting between NAD+ (a coenzyme involved in oxidation and reduction in metabolic pathways) and coenzyme Q (a respiratory enzyme responsible for carrying electrons in some electron transport chains), resulting in failure of the respiratory functions (Ware and Whitacre, 2004).

Safety: Pure rotenone is relatively toxic to mammals; the oral acute LD50 in rats is 132 mg kg^{-1}. The safety of rotenone is a very controversial issue because acute exposure in rats produces brain lesions consistent with those observed in humans and animals with Parkinson's disease (Betarbet *et al*., 2000) and its persistence on food crops after treatment, the half-life of rotenone is 4 days and at harvest residue levels were above the tolerance limit of treated olives (Cabras *et al*., 2002).

Nicotine: Nicotine and the related alkaloids nornicotine and anabasine are obtained from aqueous extracts of tobacco (*Nicotiana* spp.; Solanaceae) and *A. aphylla* (Chenopodiaceae). They induce highly insecticidal effects as they are synaptic poisons, mimic the neurotransmitter acetylcholine. Therefore, they cause symptoms of poisoning similar to those seen with organophosphate and carbamate insecticides (Hayes, 1982). Nicotine has seen declining use as it is quite toxic to humans through ingestion, dermal exposure or inhalation. An oral human lethal dose is 60 mg. As a result, it is seldom used today in North America or Europe, although it continues to be used in China and crude tobacco extracts are used in Africa (Morse *et al*., 2002). Nicotine is used mostly as a fumigant in greenhouses against soft-bodied pests. Nevertheless, preparation of stable nicotine fatty acid soaps, presumably with reduced bioavailability and toxicity to humans (Casanova *et al*., 2002) will resolve this problem.

Nicotinoids: Nicotinoids are similar to and modeled after the natural nicotine. They have been previously referred to as *nitro-quanidines*, *neonicotinyls*, *neonicotinoids*, *chloronicotines* and more recently as the *chloronicotinyls*. Nicotinoids include Imidacloprid, Admire7, Confidor7, Gaucho7 and Merit7, acetamiprid (Assail7), thiamethoxam (Actara7, Platinum7), nitenpyram (Bestguard7), clothianidin (Poncho7 and dinotefuran (Starke7). The nicotinoids act on the central nervous system of insects, leading to irreversible blockage of postsynaptic nicotinergic acetylcholine receptors.

Other traditional botanicals: Few other plant materials have seen declining commercial use as insecticides, such as wood of the Caribbean tree *Ryania speciosa* (Flacourtiaceae) contains a suite of unique alkaloids that block neuromuscular junctions. The ground stem wood, containing <1% ryanodine and its alkaloid analogues, has been used in organic fruit production. *Quassia amara* (Simaroubaceae), a small tree from Brazil, contains bitter triterpenoids. Woodchips and ground bark of this species and its related tree, *Ailanthus altissima* have been used traditionally as an insecticide. Sabadilla is a powder based on the ground seeds of *Schoenocaulon officinale* (Liliaceae), a South American plant. Pure active principles, steroidal-type alkaloids, are quite toxic to mammals but, as with rotenone, the concentration of alkaloids in the powdered seeds is quite low, providing a margin of safety to the user (Ware and Whitacre, 2004; Isman, 2005, 2006, 2010; Isman and Akhtar, 2007; Gilbert and Gill, 2010; Kumar *et al.,* 2010; Dubey *et al*., 2011; Khater, 2011; Mehlhorn *et al*., 2011).

NEWER BOTANICAL INSECTICIDES

Neem: Neem (*Azadirachta indica* A. Juss: Meliaceae) is a newer botanical insecticide, native to the Indian sub-continent and well known their as the 'Botanical Marvel' 'Village Pharmacy' 'Wonder Tree' 'all- can- treat- tree' and 'Gift of Nature'. Neem is widely grown in other Asian countries and tropical and subtropical areas of Africa, America and Australia. It grows well even in poor, shallow, degraded and saline soil. Neem is used in the introduced countries as a shade tree, windbreak, or source of firewood than for its medicinal or insecticidal purposes.

Biological activities: The discovery of neem is attributed to Heinrich Schmutterer, who observed that swarming desert locusts in Sudan defoliated almost all local flora except for some introduced neem trees (National Research Council, 1992). Crude neem, extracts and products induce antifeedant effect. Azadirachtin, isolated in 1968, is the most potent locust antifeedant discovered to date. Furthermore, neem possess fungicidal, nematicidal, bactericidal (Schmutterer, 1995; Mehlhorn *et al.*, 2011), molluscidial, diuretic and antiarthritic properties (Mehlhorn *et al.*, 2011). It also exhibit immunomodulatory, anti-inflammatory, antihyperglycaemic, antiulcer, antimalarial, antiviral, antioxidant, antimutagenic and anticarcinogenic effects (Subapriya and Nagini, 2005). On the other hand, azadirachtin has systemic action in certain crop plants, greatly enhancing its efficacy and field persistence (Schmutterer, 2002a).

Mode of action: The efficacy of neem is linked to the physiological action of azadirachtin ($C_{35}H_{44}O$)$_{16}$ a nortriterpenoid belonging to the limonoids. It is the most biologically active constituent of neem. It acts as an Insect Growth Regulator (IGR) on larval insects like disruption of moulting, growth inhibition, malformation which may contribute to mortality. This is attributed to a disruption of endocrine events as the down-regulation of haemolymph ecdysteroid level through the blockage of release of PTTH, prothoracicotropic hormone, from the brain-corpus cardiacum complex, or to a delay in the appearance of the last ecdysteroid peak showing a complete moult inhibition. There are also effects on allatropin and juvenile hormone titres (Mordue and Blackwell, 1993). In addition, its antifeedant effect is highly variable among pest species and even those species initially deterred are often capable of rapid desensitization to azadirachtin (Bomford and Isman, 1996).

Neem controls gypsy moths, leaf miners, sweet potato whiteflies, western flower thrips, loopers, caterpillars and mealybugs as well as some of the plant diseases, including certain mildews and rusts (Dubey *et al.*, 2011). Neem is also effective against arthropods of medical and veterinary importance, such as lice, mite, tick, fleas, bugs, cockroaches and flies (Mehlhorn *et al.*, 2011).

Production: Neem seeds contain 0.2-0.6% azadirachtin by weight, so solvent partitions or other chemical processes are required to concentrate to be 10-50% as in the technical grade material used for commercial production. Worldwide, there are over 100 commercial neem formulations such as Margosan-O, Bio-neem, Azatin, Neemies, Safer's ENI, Wellgro, RD-Repelin, Neemguard, Neemark and Neemazal. Neem derivatives have been applied against pests as leaves, oil, cake, extracts and as formulations in neem oil. Refined neem products have been expensive to produce which may account for their limited penetration into the market place thus far (Isman, 2004). However, several commercial products are sold in the United States and the European Union. Azadirachtin-based insecticides represented about one third of the botanicals used in agriculture in 2003 (about 600 kg) in California. After forty one years or its isolation and twenty one years of full solution of its chemical structure, a landmark in the chemistry of azadirachtin was reached in 2007 and its synthesis was completed. This means that synthetic azadirachtin will be available in the future (Veitch *et al.*, 2007a, b; Mordue *et al.*, 2010).

Precautions for effective application: Worldwide, there are over 100 commercial neem formulations. In order to produce and use efficacious neem pesticide, some points should be distinguished by the user to avoid reduction in bioefficacy. Contaminated neem seeds with aflatoxin should not be picked from the ground but seeds that are greenish yellow in colour should be picked from the trees or swept regularly under the tree. Neem materials should be efficiently and quickly dried after harvest so that they can be stored ready for use during off season period. Neem leaf extracts are less effective than seed extracts due to lower azadirachtin content, neem preparations should be kept away from sunlight to avoid photodegradation of active ingredients by UV light and formulations are better applied at dusk when sun is weak. Sun screens such as Para Amino Benzoic Acid (PABA) could be added to reduce the photo-oxidation of azadirachtin by UV light. Azadirachtin is more effective when formulated in a neem oil medium together with the other natural products of neem. Solvent such as methanol and ethanol have been found to extract the active ingredients better than water. limnoids could be added to inert compounds to produce a neem product with a known stable azadirachtin concentration (Salako *et al.*, 2008).

Safety: Azadirachtin is nontoxic to mammals, rat oral acute LD50 is >5000 mg kg^{-1} (Raizada *et al.*, 2001). A 90-day oral feeding of rats with 10,000 ppm of azadirachtin did not show chronic toxicity (Mehlhorn *et al.*, 2011). Neem products were neither mutagenic nor carcinogenic and they did not produce any skin irritations or organic alterations in mice and rats, even at high concentrations.

The adverse effects are reversible reproduction disturbances. Reproductive effects of aqueous leaf extract 6 weeks daily feeding led to infertility of rats at 66.7%, for 9 weeks: 100%. (Mehlhorn *et al.*, 2011). If applied with care, the use of unprocessed and aqueous neem-based products should not be discouraged (Boeke *et al.*, 2004; Khater, 2011) for more details.

The pure compound azadirachtin, the unprocessed materials, the aqueous extracts and the seed oil are the most safe to use as an insecticide to protect stored consumption seeds for human consumption (estimated safe daily doses, ESD, of 15, 0.26 and 0.3 mg kg^{-1} b.wt., 2 μL kg^{-1} b.wt. day^{-1}, respectively). On the other hand, non-aqueous extracts turn out to be relatively toxic (ESD 12.5 μg kg^{-1} b.wt.). The application modes, crude plant parts, seed oil and aqueous extracts, most feasible for low-resource farmers in tropical countries, where no complex extractions can be performed due to a lack of solvents and equipments, are also the most advisable from a health risk viewpoint (Boeke *et al.*, 2004).

Form Ecological and environmental stand points, azadirachtin is non toxic to fish (Wan *et al.*,1996), natural enemies and pollinators (Naumann and Isman, 1996), birds, other wild life and aquatic organisms as azadirachtin, breaks down in water within 50B100 h. It is harmless to non-target insects (bees, spiders and butterflies). The effect of azadirachtin on natural enemies is highly variable (Hohmann *et al.*, 2010; Kumar *et al.*, 2010). Timing of treatment before parasitism is less deleterious to parasitoid emergence (Hohmann *et al.*, 2010). Azadirachtin induce no accumulations in the soil, no phytotoxicity and accumulation seen in plants and no adverse effect on water or groundwater (Mehlhorn *et al.*, 2011). Like the pyrethrins, azadirachtin is rapidly degraded by sunlight as the half-life of azadirachtin is only one day (Kleeberg and Ruch, 2006), leaving no residues. Consequently, neem is preferred over chemical pesticides. Azadirachtin is classified by the Environmental Protection Agency (EPA) in class IV. Neem can be considered as the most important among all biopesticides for controlling pests due to its non-toxicity, environmental safety and so on, thereby replacing synthetic pesticides.

Other plants with antifeedant and insect regulation effects: Many plant chemicals deter insects from feeding, thereby showing an antifeedant effect. Azadirachtin and limonoids such as limonin and nomilin from different plant species in Meliaceae and Rutaceae (e.g., from *Citrus* fruits) have long been used successfully for insect control, especially in India. Azadirachtin protects newly grown leaves of crop plants from feeding damage, thereby showing systemic antifeedant properties (Varma and Dubey, 1999).

Some plants contain insect growth regulatory chemicals (IGRs) which disrupt insect maturation and emergence as adults. *Ocimum basilicum* contain juvocimenes, an analogue of insect juvenile hormones (Balandrin *et al.*, 1985). Essential oils of *Matricaria recutita contain* precocenes which interfere with the normal function of insect glands that produce juvenile hormones resulting in the suppression of insect growth while moulting. Juvabione, found in the wood of balsam fir, was discovered by accident when paper towels made from this source were used to line insect-rearing containers resulting in a suppression of insect development (Varma and Dubey, 1999; Dubey *et al.*, 2011; Khater, 2011) for more details.

Essential oils: Essential Oils (EO) are complex mixtures of volatile organic compounds produced as secondary metabolites in plants. Steam distillation of aromatic plants yields essential oils, long used as fragrances and favoring in the perfume and food industries, respectively. More recently they have become popular as agents for aromatherapy.

Eos are characterized by a strong odor and have a generally lower density than that of water. Among higher plants, there are 17,500 aromatic plant species (Bruneton, 1999) and approximately 3,000 essential oils are known out of which 300 are commercially important for cosmetics, perfume and pharmaceuticals industries (Bakkali *et al.*, 2008) apart from pesticidal potential (Chang and Cheng, 2002). Several plant families, ex. Myrtaceae, Lauraceae, Rutaceae, Lamiaceae, Asteraceae, Apiaceae, Cupressaceae, Poaceae, Zingiberaceae and Piperaceae, are highly targeted for anti-insect activities. To defend themselves against herbivores and pathogens, plants naturally release a variety of volatiles including various alcohols, terpenes and aromatic compounds. These volatiles can deter insects or other herbivores from feeding, can have direct toxic effects, or they may be involved in recruiting predators and parasitoids in response to feeding damage. They may also be used by the plants to attract pollinators, protect plants from disease, or they may be involved in interplant communication (Pichersky and Gershenzon, 2002).

Biological activities: Since, the middle ages, essential oils have been widely used for bactericidal, virucidal, fungicidal, antiparasite, insecticidal, medicinal and cosmetic applications, especially nowadays in the pharmaceutical, sanitary, cosmetic and agricultural and food industries. In nature, essential oils play an important role in the protection of the plants as antibacterials, antivirals, antifungals, insecticides and also against herbivores by reducing their appetite for such plants.

They also may attract some insects to favor the dispersion of pollens and seeds, or repel undesirable others.

Some essential oils have been recognized as an important natural source of pesticides. Aromatic plants produce many compounds that are insect repellents or act to alter insect feeding behavior, growth and development, ecdysis (moulting) and behavior during mating and oviposition. Recently researchers have demonstrated such compounds showing larvicidal and antifeedant activity, capacity to delay development, adult emergence and fertility, deterrent effects on oviposition and arrestant and repellent action. Plants with strong smells, such as French marigold and coriander, act as repellents and can protect the crops nearby (Khater, 2011; Dubey *et al*., 2011).

Essential oils cause direct toxicity to insects, oviposition and feeding deterrence, repellence and attraction against the insects of the several orders like lepidoptera, coleoptera, diptera, isopteran and hemiptera.

Traditionally, Eos are used for protection of stored commodities, especially in the torpical and Mediterranean region and in southern Asia but there is a growing interest in EOs as fumigant and contact insecticidal activities to a wide range of pests in the 1990s.

Chemistry: Monoterpenoids (90% of the essential oils) allow a great variety of structures with diverse functions. They are ten carbon hydrocarbon or their related compounds such as acyclic alcohols (e.g., linalool, geraniol, citronellol), cyclic alcohols (e.g., menthol, isopulegol, terpeniol), bicyclic alcohols (e.g., borneol, verbenol), phenols (e.g., thymol, carvacrol), ketones (carvone, menthone, thujone), aldehydes (citronellal, citral), acids (e.g., chrysanthemic acid) and oxides (cineole). The main group is composed of terpenes and terpenoids and the other of aromatic and aliphatic constituents, all characterized by low molecular weight terpenes mainly the monoterpenes (C10) and sesquiterpenes (C15) but hemiterpenes (C5), diterpenes (C20), triterpenes (C30) and tetraterpenes (C40) also exist. Aromatic compounds occur less frequently than the terpenes and are derived from phenylpropane e.g., aldehyde: cinnamaldehyde; alcohol: cinnamic alcohol; phenols: chavicol, eugenol; methoxy derivatives: anethole, elemicine, estragole, methyl eugenols; methylene dioxy compounds: apiole, myristicine, safrole, (Isman, 2006; Tripathi *et al*., 2009).

It worth to mention that the composition of these oils can vary dramatically, even within species according to the part of the plant from which the oil is extracted (i.e., leaf tissue, fruits, stem, etc.), the phenological state of the plant, the season, the climate, the soil type and other factors, ex., rosemary oil collected from plants in two areas of Italy were demonstrated to vary widely in the concentrations of two major constituents, 1,8-cineole (7-55%) and a-pinene (11-30%) (Flamini *et al*., 2002). Such variation is common and has also been described for the oils derived from *Ocimum basilicum* (Pascual-Villalobos and Ballesta-Acosta, 2003) and *Myrtus communis* (Flamini *et al*., 2004).

Mode of action: Essential oils interfere with basic metabolic, biochemical, physiological and behavioral functions of insects. Insects inhale, ingest or skin absorb essential oils. The rapid action against some pests is indicative of a neurotoxic mode of action and there is evidence for interference with the neuromodulator octopamine (Enan, 2005) or GABA-gated chloride channels (Priestley *et al*., 2003; Khater, 2011). Some essential oils have larvicidal effect and the capacity to delayed development and suppress emergence of adults of insects of medical and veterinary importance (Khater, 2003; Shalaby and Khater, 2005; Khater and Shalaby, 2008; Khater and Khater, 2009; Khater *et al*., 2009, 2010; Khater, 2011). Citronellal, cotronellol, citronellyl or a mixture of these have been patented as pest treatment composition against human louse (Ping, 2007).

Fumigant effect: The currently used fumigants, phosphine, methyl bromide and DDVP (2,2-dichlorovinyl dimethyl phosphate) provoke some safety concerns. Phosphine is the major cause of suicidal deaths in India. Methyl bromide has ozone-depleting potential (UNEP, 2000) and DDVP has a possible human carcinogen potential (Lu, 1995). As a consequence, there is an increasing necessitates for development of safe alternative that could replace the toxic fumigants against stored product pests.

Insect resistance to phosphine is a matter of serious concern (Athie and Mills, 2005; Dubey *et al*., 2008).

Many plant essential oils have fumigant action, such as those of *Artemisia* sp., *Anethum sowa*, *Curcuma long* and *Lippia alba*. Clove, rosemary, thyme, eucalyptus and various mint species have demonstrated contact and fumigant toxicity to a wide spectrum of insects, including human head lice (Toloza *et al*., 2008). Isolates like d-limonene, carvones and 1,8-cineole have been well documented as fumigants.

Some essential oils with bioactivity against stored product pests, such as oils of basil, citrus peel, eucalyptus, various mint species, lavender and rosemary but not all essential oils are active against all the insect pests (Don-Pedro, 1996; Papachristos and Stamopoulos, 2002). Nutmeg oil has been determined to significantly impact both the maize weed, *Sitophilus zeamais* and the red-flour beetle, *Tribolium castaneum* and demonstrates both repellent and fumigant properties (concentration dependent) (Huang *et al*., 1997). The exact mode of action of these oils as fumigant is unknown but the oils mainly act in the vapor phase via respiratory system (Tripathi *et al*., 2009; Isman, 2010; Dubey *et al*., 2011; Khater, 2011).

Chemosterilant: Some of the essential oils and their components induce sterility in the insect pests, chemosterilants. Alkaloids isolated from *Annona squamosa* have shown larvicidal growth-regulating and chemosterilant activities against *Anopheles stephensi* at concentrations of 50-200 ppm. (Saxena *et al*., 1993). A compound 1, 3, 7-Trimethylxanthine, was isolated from seed extract of *Coffea arabica*. It proved effective as a chemosterilant for *Callosobruchus chinensis*, causing nearly 100% sterility at a concentration of 1.5%. At similar concentration the compound had no phytotoxic effect on the crop plant *Vigna mungo*. Possible use of the compound for control of stored-grain pests is suggested (Rizvi *et al*., 1980). The compound β-asarone extracted from rhizomes of *Acorus calamus*, possesses antigonadial activity causing the complete inhibition of ovarian development of different insects (Varma and Dubey, 1999). It is important to note that chemosterilants are highly required in integrated pest management programs to reduce the occurrence of pest resistant.

Repellents: Repellents are substances that act locally or at a distance, usually by providing a vapor barrier deterring the arthropod from coming into contact with the surface. Global warming has moved the mosquitoes that transmit malaria, yellow fever and dengue into some temperate and higher altitudes, affecting people who are vulnerable to these diseases. It has been predicted an increase from approximately 45B60% in the proportion of the world's population living within the potential zone for malaria transmission (EPA, 1997). Synthetic chemicals have been developed in order to protect human from mosquito bites. DEET (N,N-diethyl-m-toluamide) is a broad spectrum repellent and the most effective and persistent on skin. Unfortunately, it may cause environmental and human health risks (Pitasawat *et al*., 2003). For that reason, search efforts are directed towards natural repellents.

Repellent metabolites: The repellent activity of essential oils contributed to some metabolites such as, monoterpenes (α-pinene, cineole, eugenol, limonene, terpinolene, citronellol, citronellal, camphor and thymol) against mosquitoes; sesquiterpenes, β-caryophyllene, repellent against *A. aegypti*; phytol, a linear diterpene alcohol, against *Anopheles gambiae*; phenylethyl alcohol, β-citronellol, cinnamyl alcohol, geraniol and α-pinene, isolated from the essential oil of *Dianthus caryophyllum*, against ticks (*Ixodes ricinus*). Most of the arthropod-repellent compounds are oxygenated, having the hydroxyl group linked to a primary, secondary or aromatic carbon. More importantly, some metabolites with the hydroxyl group linked to a tertiary carbon (linalool, α-terpineol and limonene), such activity is suppressed against *Anopheles gambiae*, suggesting the possibility that the type of carbon where the hydroxyl substitution is present modulates repellency (Nerio *et al*., 2010). Most insect repellents are volatile terpenoids such as terpenen-4-ol. Other terpenoids can act as attractants. In some cases, the same terpenoid can repel certain undesirable insects while attracting more beneficial insects, ex., geraniol will repel house flies while attracting honey bees (Duke, 1990).

Action as repellents: The repellent molecules interact with the female mosquito olfactory receptors and block the sense of smell. Lactic acid plays a role in host seeking behavior. It has been found that following a blood meal, the sensitivity of lactic acid sensitive neurons drops and this drop is co-incident with the cessation of host-seeking behavior and lactic acid sensitivity returns to normal after oviposition (Davis, 1984). In behavioral studies, lactic acid is essential to attraction of *Aedes aegypti* but lactic acid by itself is only mildly attractive, indicating synergism with other unidentified human odor components (Geier *et al*., 1996).

It is unclear if repellents work by common mechanisms in different arthropods. DEET is effective against many other Diptera of medical importance, as well as hematophagous Hemiptera, Siphonaptera, Hymenoptera, Acarina and Gnathobdellidae (an annelid family), suggesting that DEET operates on a fundamental physiological basis common to members of the arthropod-annelid evolutionary line (Peterson and Coats, 2001).

Mosquito repellency caused by DEET is thought to be due to the blocking of lactic acid receptors, abolishing upwind flight, resulting in the insect Alosing@ the host (Davis and Sokolove, 1976). Lactic acid is present in warm-blooded animal body odor and sweat and is attractive to female mosquitoes. Some botanical are comparable to, or even better than synthetic repellents; nonetheless, repellents based on EOs tend to being short-lived in their effectiveness, due to their volatility. Consequently, there is an egret need for effective ecofriendly repellents.

Large number of essential oils repel arthropod species. A neem extract proprietary product, AG1000, has been shown to be repellent to the biting midge *Culicoides imicola* which can spread cattle diseases (Braverman *et al*., 1999). Similarly, essential oils of *Cinnamomum camphora*, *C. cassia* and *C. zeylanicum* have been found to have repellent action against mosquitoes (Kim *et al*., 2003). Oils obtained from soybean, lemongrass, cinnamon and the compounds 3,8-p-menthane-diol (from lemon eucalyptus), citronellal (from lemongrass) and 2-phenethylpropionate (from groundnut). All of these materials appear effective against mosquitoes based on short-term tests with humans, although their duration of effect has been the subject of some debate (Fradin and Day, 2002). Flea and tick control products for companion animals based on d-limonene, a constituent of citrus peel oil, or oils of peppermint, cinnamon, clove, thyme and lemongrass, have been introduced recently.

The most patented natural repellent is based on nepetalactone and dihydronepetalactone from *Nepeta cataria* against cockroaches, mosquitoes, mites, ticks and other household insects (Scialdone, 2006; Hallahan, 2007). Nootkatone from Vetiver oil and its derivatives, tetrahydronootkatone and 1,10-dihydronootkatone have been patented as repellent against mosquitoes, cockroaches, termites and ants (Zhu *et al*., 2005; Henderson *et al*., 2005a, b).

Essential oils have pronounced *in vitro* and *in vivo* pediculicidal activity as the number of lice infesting water buffaloes in Egypt was significantly reduced 3, 6, 4 and 6 days after treatment with the essential oils of camphor (*Cinnamomum camphora*), peppermint (*Mentha piperita),* chamomile (*Matricaria chamomilla*) and onion (*Allium cepa*), respectively. Surprisingly, the same oils repelled flies (*Musca domestica, Stomoxys calcitrans, Haematobia irritans* and *Hippobosca equine*) infecting buffaloes for almost 6 days post-treatment. No adverse effects were noted on either animals or pour-on operators after exposure to the applied oils (Khater *et al*., 2009).

Pioneers in the American West placed the ripe fruit of the osage orange (hedgeapple) (*Muclura pomifera*) in cupboards to repel cockroaches and other insects. The fruit has a compound irritating to the feet of an insect will cause that insect to spend less time in a treated area. Its oil contain numerous sesquiterpenoids many of them were repellent to the German cockroach (Peterson and Coats, 2001). In addition, Cineole, geraniol and piperidine found in bay leaves (*Laurus nobilis*, Lauraceae) possess repellent properties towards cockroaches (Verma and Meloan, 1981).

d-Limonene is heavily used for controlling structural pests as termite in California and other plant oils (clove, peppermint, etc.) are used in the USA by professional pest control operators as ‘flushing agents’ for cockroach control and for ‘perimeter treatments’ of homes against ants and termites, suggesting that repellence makes a strong contribution to the efficacy of these products (Isman *et al*., 2011). Repellent activity may also underlie the use of these oils in the long-term protection of foods and food products through their incorporation into packaging materials (Wong *et al*., 2005).

Very little is known about the receptors responsible for the repellent responses in cockroaches but oleic acid and linoleic acid have been indicated in death recognition and death aversion (repellency) in cockroaches and the term ‘necromone’ has been proposed to describe a compound responsible for this type of behavior (Rollo *et al*., 1995).

Female Caribbean fruit flies, *Anastrepha suspense*, lay their eggs readily in ripe grape fruit but do not oviposit in immature grape fruit because of the presence of linalool which is toxic to the eggs and larvae of insects. Limonene found in sour oranges (*Citrus aurantium*) is toxic to adult bean weevils (*Callosobruchus phasecoli*) but highly attractive to male Mediterranean fruit flies (Jacobson, 1982). β-Ocimene is repellent to the leaf cutter ant, *Attacephalotis* in both field and laboratory experiments (Harborne, 1987). Experiments with the aphid *Carvariella aegopodii* which feeds on *umbelliferae* species in summer, indicate that the aphid can be captured in traps baited with carvone but is repelled by linalool (Chapman *et al*., 1981; Harborne, 1987). Carvone occurs in the essential oils of several plants of the Apiaceae.

Carvone is a monoterpene of the essential oil of *Carum carvi.* It is a non-toxic botanical insecticide under the trade name TALENT. It enhances the shelf life of stored fruits and vegetables and inhibits microbial deterioration without altering the taste and odor of the fruits after treatment (Varma and Dubey, 1999). The LD50 value of carvone (in mice) is reported to be 1640 mg kg^{-1} (Isman, 2006).

Synergistic phenomena: A synergistic phenomenon among metabolites of EOs may result in a higher bioactivity as minor constituents found in low percentages may act as synergists, enhancing the effectiveness of the major constituents through a variety of mechanisms (Berenbaum, 1985) for reducing the dose of polluting substances and the risk of developing resistance. Repellent activity of the mixture of essential oils from *Artemisia princeps* and *Cinnamomum camphora* against Thyme, anise and saffron oils have been demonstrated for synergistic activity (Youssef, 1997). Mixtures of different monoterpenes produced a synergistic effect on mortality and they developed a proprietary monoterpene mixture containing 0.9% active ingredient for use against foliar feeding pests (Hummelbrunner and Isman, 2001).

Essential oils act as a wood preservative solution by mixing eucalyptus essential oils with pyrethroids and borax (Urabe, 1992). Damage to cotton by the bollworm, *Helicopverpa armigera* (Hubner), can be minimized by mixtures of conventional insecticides at one half the recommended rate by combining extracts of three local plants (*A. indica, Khya senegalensis* and *Hyptis suaveolens*) which provided greater efficacy than the conventional products alone at their recommended rate. Yet, none of the plant extracts alone provided adequate crop protection (Sinzogan *et al*., 2006). Note that negative synergism can occur between the essential oil or their components and the other ingredients present in the total formulation.

Improving the efficacy: The pH and the salinity of base may significantly impact the activity of the essential oil. A low pH and saline (5% NaCl) environment can potentiate the activity of the whole product (Lachowicz *et al*., 1998). The effectiveness of a mosquito repellency of a product in a topical application that contains *C. citratus* oil, was tested on different formulations. Efficacy decreased in the order hydrophilic base>emulsion base>oleaginous base (Oyedele *et al*., 2000). *Zanthoxylum limonella* oil was successfully microencapsulated in glutaraldehyde crosslinked gelatin (a polymer), in order to improve mosquito repellent properties (Maji *et al*., 2007).

Although, natural active ingredients are some times more expensive than synthetic products, the essential oil of *Zanthoxylum piperitum* is only one example for which there is a potential to be used on the development of combined repellents, especially in situations when DEET is ineffective and impractical (Kamsuk *et al*., 2007).

In order to increase the EO repellent efficiency, some fixative materials such as liquid paraffin, vanillin, salicyluric acid, mustard and coconut oils have been used. Formulations based on creams, polymer mixtures, or microcapsules for controlled release, resulted in an increase of repellency duration. Essential oils can also be incorporated with polymers into sheets. Attractant adhesive films with essential oils were prepared to control insects, see Nerio *et al*. (2010) and Khater (2011) for more details.

Commercialization: Today essential oils represent a market estimated at US $700.00 million and a total world production of 45,000 tons. Almost 90% of this production is focused on mint and citrus plants (Verlet, 1993). Several private companies produce EOs- based insecticides for controlling greenhouse pests and diseases and for controlling domestic and veterinary pests. EcoSMART Technologies, Inc., United States, is one of the leading companies for essential oil-based pesticides. They currently produce aerosol and dust formulations containing proprietary mixtures of essential oil compounds, including eugenol and 2-phenethyl propionate aimed at controlling domestic pests (cockroaches, ants, fleas, flies, wasps, etc.). A mixture of essential oil trademarked hexahydroxyl (EcoPCO EcoSMART Technologies, Franklin, Tennessee) and based on distinct combinations of different plant essential oils that significantly enhance the activity of these oils against insect was formulated. This patented technology demonstrates rapid insecticidal activity by combining oils with common molecular structure (a six membered carbon ring with an oxygenated functional group attached) and since they are directed at octpaminergic sites, they are also classified as GRAS (Isman and Akhtar, 2007).

Safety and advantages: In general, the essential oils and their major constituents are relatively nontoxic to mammals, with acute oral LD50 values in rodents ranging from 800-3,000 mg kg^{-1} for pure compounds and _5,000 mg kg^{-1} for formulated products. Insecticides based on plant essential oils are useful where there is a premium on human and animal safety. So products offer alternatives to professional pest managers in case of controlling: structural pests (viz., termites, carpenter ants), flies, cockroaches and mosquitoes. Owing to their volatility, the oils and their constituents are environmentally nonpersistent, with outdoor half lives of 24 h on surfaces, in soil and in water (Isman *et al*., 2011). There are no harvest restrictions or worker re-entry restrictions for treated crops; they are compatible with biological control agents and indigenous natural enemies of pests. They bring about reduce risks to honeybees and other foraging pollinators.

Many of the commercial products that include essential oils are on the ‘Generally Recognized as Safe’ (GRAS) list fully approved by the Food and Drug Administration (FDA) and Environmental Protection Agency (EPA) in USA for food and beverage consumption (Burt, 2004).

Regarding the advantages of using essential oil-based pesticides, mosquito management/abatement, is done through large-scale urban fogging, or for individual property “perimeter” treatments, using controlled-release timers (“puffers”). For treatment of waterways and standing water using essential oil as larvicides and repellents has been a very active field of investigation in recent years. They are used for home and garden use for flying and crawling insects and related pests; management of turfgrass and landscape pests; for ectoparasite (viz., flea and tick) control on dogs and cats; and as personal repellents for application to the skin and/or clothing to prevent/limit attack by blood-feeding flies and ticks (Isman *et al*., 2011).

Eos based can be used as “stand alone” products for some pests, especially soft-bodied and sucking insects and mites. They are effective under low pest pressure, e.g., early in a growing season. More importantly, they can be used in rotation or in combination (tank-mixed) with other crop protectants, including conventional (synthetic or microbial) pesticide products.

Some of the essential oils effectively controlled pests that are resistant towards synthetic pesticides. These essential oils are a complex mixture of components including minor constituents, in contrast to synthetic pesticides based on single products and they act synergistically within the plant as a defense strategy (Feng and Ishman, 1995). Thus natural insecticides could solve this problem.

In contrast to the previous advantages, environmental non persistence of EOs could be a disadvantage when used as stand-alone products as two or more carefully timed applications may be required to effect satisfactory management of pests. EOs have limited efficacy against large chewing insects, as lepidopterans, coleopterans and can be phytotoxic if misused (e.g., applied at rates exceeding that recommended on the product label). The disadvantages of limited persistence and phytotoxicity could be lessened through microencapsulation of essential oils when formulated (Yang *et al*., 2009).

BARRIERS TO COMMERCIALIZATION OF BOTANICALS

There are several barriers to commercialization of botanical insecticides, such as production of plant resources on a commercial scale, standardization of chemically complex extracts, regulatory approval, the slow action of many botanicals and the lack of residual action and the availability of competing products (newer synthetics, fermentation products and microbials) that are cost-effective and relatively safe compared with other available products. In addition, other drawbacks are related to physical properties of essential oils, ex., as high boiling point, high molecular weight and low vapor pressure, hinder them form large scale application. These challenges should be overcome for botanicals to be of particular use for human and high value animals and crops. For more information about standardization, regulatory approval and commercialization (Tripathi *et al*., 2009; Isman, 2006, 2010; Dubey *et al*., 2011).

RESOURCE AVAILABILITY

Regarding sustainability of botanical resources, the used plants should be abundant in nature, or produced on a commercial scale, ex., pyrethrum, rotenone, neem and aromatic plants. Neem is introduced to other Asian countries as well as tropical and subtropical areas of Africa, America and Australia for multi purposes other than medicinal and insecticidal purposes. Neem seed oil had a long history of use in India for the production of soaps and low grade industrial oil. When extraction companies began purchasing neem seeds in bulk to produce insecticides, the price of seeds increased 10-fold. In contrast, certain plant essential oils have numerous uses as fragrances and flavorings and the massive volumes required to satisfy these industries maintain low prices that make their use as insecticides attractive (Isman, 2006).

As an alternative search strategy, waste or by-products of plant-based industries are extremely helpful, such as extraction and screening of sawdust from tropical timber operations led to the discovery of potent insecticides in the stem wood of the Malaysian tree, *Azadirachta excelsa*, a close relative of the Indian neem tree (Schmutterer, 2002b).Using of biomass that is a waste product of another industry, e.g., citrus peel (*Citrus x sinensis*) from orange juice production as the starting material for extraction of *d*-limonene, can be an economical and efficient source (Isman, 2010).

Recently, attention has been paid towards the exploitation of higher plant products as novel chemotherapeutics in plant protection. Such plant products have also been formulated for their large-scale application in crop protection (Dubey *et al*., 2009). Research aimed at producing azadirachtin from neem tissue culture provided proof of concept but economic feasibility has yet to be attained (Allan *et al*., 2002). Production of botanical insecticides by phytopharming, through genetic engineering of an existing field crop to produce high-value natural products originally isolated from a different botanical source (Isman, 2006) but such technologies are expensive implying that the traditional means of obtaining botanicals will continue for the near future.

BOTANICALS IN THE FUTURE

Botanicals are incorporated in IPM programs as products in crop protectant rotations. Currently, botanicals are facing fewer competitions in organic food production which estimated to be growing by 8-15% per annum in Europe and in North America (National Research Council, 2000). Botanicals are helpful in case of the documented resistance of the diamondback moth to *Bacillus thuringiensis* and spinosad due to overuse (Tang *et al*., 1997; Zhao *et al*., 2002). In contrast, botanicals face tremendous competition in conventional agriculture from the newest generation of Areduced risk@ synthetic insecticides such as the neonicotinoids. Between 1998 and 2003, use of reduced risk pesticides in California increased more than threefold (from 138-483 tons), whereas biopesticide use declined (from 652-472 tons) (CDPR, 2005).

Nanotechnology has become one of the most promising new technologies pests for pest control. Thus nanotechnology will revolutionize pest management in the near future. Nanoparticles help to produce new pesticides, insecticides and insect repellants (Owolade *et al*., 2008). Nanoencapsulation is a process through which a chemical (ex. an insecticide) is slowly but efficiently released to a particular host for insect pest control. Release mechanisms include diffusion, dissolution, biodegradation and osmotic pressure with specific pH (Vidhyalakshmi *et al*., 2009). Such process can also deliver DNA and other desired chemicals into plant tissues for protection of host plants against insect pests (Torney, 2009). Nanoparticles loaded with garlic essential oil are efficacious against *T. castaneum* Herbst (Yang *et al*., 2009). Aluminosilicate filled nanotube can stick to plant surfaces while nano ingredients of nanotube have the ability to stick to the surface hair of insect pests and ultimately enters the body and influences certain physiological functions (Patil, 2009).

Nanotechnology is used widely in Agriculture and Food (Joseph and Morrison, 2006). One of the world's largest agrochemical corporations, Syngenta, is using nanoemulsions in its pesticide products. Encapsulated product from Syngenta delivers a broad control spectrum on primary and secondary insect pests of cotton, rice, peanuts and soybeans. Marketed under the name Karate7 ZEON, a quick release microencapsulated product containing the active compound lambda-cyhalothrin (a synthetic insecticide based on the structure of natural pyrethrins) which breaks open on contact with leaves. The encapsulated product Agutbuster@ only breaks open to release its contents when it comes into contact with alkaline environments, such as the stomach of certain insects. Furthermore, the new technology improve pesticide and fertilizer delivery systems which can take action to environmental changes, ex. they will release their cargo in a controlled manner (slowly or quickly) in response to different signals e.g., heat, moisture, ultrasound, magnetic fields, etc. Recently, nanotechnology is widely acceptable publicly because it is not yet linked to any toxicological and ecotoxicological risks. Research on nanoparticles and insect control should be directed toward production of faster and ecofriendly pesticides to deliver into the target host tissue through nanoencapsulation. This will control pests efficiently and accelerate the Green Revolution. For more information about usages of nanoparticles, (Yang *et al*., 2009; Bhattacharyya *et al*., 2008, 2010; Hashim, 2011; Khater, 2011).

CONCLUSION

Chemical pesticide induces development of pest resistance to applied agents and nontarget environmental impacts. IPM programs have demonstrated that current levels of pesticide use in many circumstances are not necessary and, frequently, are even counter-productive (Pretty, 2009). Consequently, excessive and otherwise inappropriate pesticide use is an unnecessary burden on farmers= health and income, on public health and on the environment. Farmers in the developing countries may not be able to afford synthetic insecticides; traditional use of plants and plant derivatives for protection of stored products is long established. When conventional insecticides are affordable to growers through government subsidies, limited literacy and a lack of protective equipments give rise to thousands of accidental poisonings annually.

Botanicals help in preventing the dumping of thousands of tons of pesticides on the earth; they are safer to the user and the environment because they are biodegradable and break down into harmless compounds within hours or days in the presence of sunlight. Although botanical insecticides are not helpful in controlling major agronomic crops (cotton, maize, soybean, rice, oilseeds) (Isman, 2010), they are promising alternatives to conventional insecticides in the developed world where a premium is placed on human and animal safety for controlling pest of medical and veterinary importance (at homes, schools, restaurants, hospitals and garden) and in developing countries where they constitute an affordable tool for crop protection. There is a wide scope for the use of plant-based pesticides in the integrated management of different insect pests. Enhancement of the shelf-life, the speed of kill, the field efficacy and reliability and the cost of these natural insecticides are very curtailed for botanicals to be pro-poor and cost-effective.

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