Chapter 12
Botanicals in Pest Management: Current Status and Future Perspectives

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Abstract The problems caused by synthetic pesticides and their residues have increased the need for effective biodegradable pesticides with greater selectivity. Alternative strategies have included the search for new types of pesticides which are often effective against a limited number of specific target species, are biodegradable into nontoxic products and are suitable for use in integrated pest management programs. The natural plant products derived from plants effectively meet this criterion and have enormous potential to influence modern agrochemical research. When extracted from plants, these chemicals are referred to as botanicals. The use of botanical pesticides is now emerging as one of the prime means to protect crops and their products and the environment from pesticide pollution. Botanicals degrade more rapidly than most chemical pesticides, and are, therefore, considered relatively environment friendly and less likely to kill beneficial pests than synthetic pesticides with longer environmental retention. Most of the botanical pesticides generally degrade with in few days and some times with in a few hours, these pesticides needs to be applied more frequently. More frequent application coupled with higher costs of production makes botanicals more expensive to use than conventional pesticides. Moreover, in spite of wide recognition that many plants possess pesticidal properties, only a handful of pest control products obtained from plants (pyrethrum, neem, rotenone) are in use because commercialization of botanicals is hindered by several issues discussed in this chapter.

Keywords Botanicals · Pest management · Neem · Essential oils · Plant extracts · Commercialization

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12.1 Introduction

Pests are one of the serious problems faced by agriculture today. Although there are many ways to reduce or kill pests, every pest management method has certain drawbacks. Synthetic pesticides that have been commercialized are halogenated hydrocarbons or organophosphates which have long environmental half lives and are suspected to possess toxicological properties than most of natural compounds. Considering above and several other factors there is growing need for alternative, environmentally benign, toxicologically safe, more selective and efficacious pesticides. Botanicals being plant secondary metabolites, thus offer an attractive and favourable alternative for pest management (McLaren, 1986). Documented scientific literature also support the fact that plant secondary metabolites are involved in the interaction of plant with other species- primarily in the defence response of plant against pests. Thus the secondary compounds called botanicals represent a large reservoir of chemical structures with pesticidal activity (Klocke, 1987). This resource is largely untapped for use as pesticides. There are several advantages of botanical pesticides like fast degradation by sun light and moisture or by detoxifying enzymes, target specific nature and less phytotoxicity which provokes researcher to use botanicals in pest management. Higher plants produce diverse array of secondary metabolites which include phenolics, terpenes, alkaloids, lignans and their glycosides. These play significant role in plant defence system and offer an array of structural prototypes for development of lead molecules which can serve as new pest control agents (Lydon and Duke, 1989).

The knowledge of pest to which particular plant is resistant may provide useful information for predicting what pests may be controlled by secondary metabolites derived from a particular plant species. This approach has led to the discovery of several commercial pesticides such as pyrethroid insecticides. Botanicals have been classified into herbicides, insecticides, fungicides, nematicides, molluscides, and rodenticides. These pesticides have variable mode of action. Some act as direct toxicant, sterilant where as others act as antifeedant/repellant or behavior modifiers. The discovery process for botanical pesticides is more cumbersome as compared to synthetic counterparts but less environmental load caused by botanical pesticides makes them an attractive alternative. In spite of relatively small previous efforts in the development of botanical pesticides they have made large impact in the area of insecticides. Minor success has been achieved in herbicides, nematicides, rodenticides, fungicides and molluscides (Duke, 1990).

The number of options that must be considered in discovery and development of a natural product as pesticide is larger than for a synthetic pesticide. Further more complexity, limited environmental stability and low activity of many biocides from plants, compared to synthetic pesticides are discouraging. However, advances in chemistry and biotechnology are increasing the speed and ease with which man can discover and develop secondary compounds of plants as pesticides. All these advances combined with increasing need and environmental pressures are greatly increasing the interest for production of botanical pesticides.

12.2 Botanicals vs. Synthetic Chemicals

For self-defense purposes, many plants generate chemicals that are toxic to insects. Because these naturally occurring insecticides are derived from plants, they are called botanical insecticides or botanicals. Before World War II, botanical insecticides were commonly used throughout the world to defend against insect pests. However, just before the war, a highly effective "synthetic" (man-made) insecticide called DDT was introduced which changed the nature of pest control worldwide. Because these chemicals were cheaper, easier to apply and longer lasting, other synthetic insecticides soon followed, which quickly displaced botanicals in the marketplace and greatly slowed the research and development of natural, botanical compounds. Unfortunately, these synthetic insecticides target a nervous system common to people and animals, and can be toxic to fish and the environment. In addition, many of the chemicals persist for long periods and cause residual problems (Coats, 1994). Insect pests have also developed resistance to many of the synthetic chemicals over time (Roush, 1989). As awareness of the potential health and environmental hazards of many residual synthetic pesticides increases, and as pests become resistant to more and more synthetic compounds, interest in plant-derived pesticides is increasing (Isman, 2006).

Botanicals degrade rapidly in sunlight, air and moisture and by detoxification enzymes. Rapid breakdown means less persistence and reduced risk to non target organisms. However precise timing and/or more frequent applications may be necessary. Botanical insecticides are fast acting. Although death may not occur for several hours or days, insect may be immediately paralyzed or stop feeding. Most botanicals have low to moderate mammalian toxicity. Some botanicals quickly breakdown or are metabolized by enzymes inside bodies of their target pests. Breakdown may occur rapidly, so that the insecticide only temporarily stuns the insect but does not kill it (Rice, 1983). A synergist may be added to a compound to inhibit certain detoxification enzymes in insects. This enhances the insecticidal action of the product. Synergists are low in toxicity, have low or no inherent insecticidal properties, and have very short residual activity. Pyrethrins are often mixed with a synergist such as piperonyl butoxide (PBO) to increase their effectiveness. Rapid breakdown and fast action make botanicals more selective to certain plant feeding pests and less harmful to beneficial insects.

Most botanicals are not phytotoxic (toxic to plants). However nicotine sulfate may be toxic to some vegetables and ornamentals. Botanicals tend to be more expensive than synthetics and some are no longer commercially available (e.g. Nicotine). The potency of some botanicals may vary from one source or batch to the next. Data on effectiveness and long term (chronic) toxicity to mammals are unavailable for some botanicals. Tolerance for residues of some botanicals on food crops has not been established. Botanical insecticides include nicotine from tobacco, pyrethrum from chrysanthemums, derris from cabbage, rotenone from beans, sabadilla from lilies, ryania from ryania shrub, limonene from citrus peel, and neem from the tropical neem tree. Most, other than nicotine have low levels of toxicity in mammals and birds and create few adverse environmental effects (Prakash and Rao, 1997).

Major classes of synthetic insecticides are chlorinated hydrocarbons, organophosphates, carbamates and pyrethroids. Although, synthetic insecticides (e.g., chlorinated hydrocarbons, organophosphates and pyrethroids) have been an important part of pest management for many years, the disadvantages and risks of using them have become apparent. Some synthetic insecticides leave unwanted residues in food, water and environment. Some are suspected carcinogens and low doses of many synthetic insecticides are toxic to mammals. As a result, many people are looking for less hazardous alternatives to conventional synthetic insecticides. Organochlorines act by blocking an insect's nervous system, causing malfunction tremors, and death. All organochlorines are relatively insoluble, persist in soils and aquatic sediments, can bio- concentrate in the tissues of invertebrates and vertebrates from their food, move up trophic chains, and affect top predators (Brooks, 1974). These properties of persistence and bioaccumulation led eventually to the withdrawal of registration and use of organochlorine insecticides, from the late 1990s, in industrialized nations, although they continued to be used in developing countries. Organophosphate insecticides originated from compounds developed as nerve gases by Germany during World War II. Thus those developed as insecticides, such as tetra ethyl pyrophosphate (TEPP) and parathion, had high mammalian toxicities. In insects, as in mammals they act by inhibiting the enzyme cholinesterase (ChE) that breaks down the neurotransmitter acetylcholine (Ach) at the nerve synapse, blocking impulses and causing hyperactivity and titanic paralysis of the insect, then death. Some are systemic in plants and animals, but most are not persistent and do not bioaccumulate in animals or have significant environmental impacts. Carbamyl, the first carbamate insecticide, acts on nervous transmission in insects also through effects on cholinesterase by blocking acetyl choline receptors. Carbamates are broad spectrum insecticides, of moderate toxicity and persistence, they rarely bioaccumulate or cause major environmental impacts (Kuhr and Dorough, 1976).

Synthetic pyrethroid insecticides, with structures based on natural compound pyrethrum, were introduced in the 1960s and include tetramethrin, resmethrin, fenvalerate, permethrin and delta methrin, all used extensively in agriculture. They have very low mammalian toxicities and potent insecticidal action, and are photostable with low volatilities and persistence. They are broad-spectrum insecticides and may kill some natural enemies of pests. They do not bioaccumulate and have few effects on mammals, but are very toxic to aquatic invertebrates and fish (Elliot et al., 1978).

12.3 Botanicals as Fungicides and Insecticides

Pre-harvest losses due to fungal diseases in world crop production can amount to 11.8% or even higher in developing countries (Agrios, 1997). Most of the efforts in the past few years for the effective control of plant diseases have been focused on effective eradication or prevention through the development of synthetic chemical fungicides (Bajpai et al., 2004). However, increasing concern over the environmental load caused by the currently used synthetic fungicides has necessitated the search for fungicides of biological origin with the germane assumption that bio-products are more specific in their action and mechanisms, do exist in nature for their disposition and are thus less hazardous. Therefore, recently there is an upsurge of interest in natural plant products to be used as fungicides. Although it is difficult to define the ecological significance of most synthetic fungicides, there is good reason to suppose that a secondary plant metabolism has evolved to protect plants against attack of microbial pathogens (Benner, 1993).

Plant extracts or phytochemicals provide attractive alternative to currently used synthetic fungicides as regards controlling phytopathogenic fungi, since they constitute a rich source of bioactive molecules (Wink, 1993). They are often active against a limited number of specific target pests, are biodegradable into non-toxic products, and are, therefore, potentially useful in integrated pest management programs. Therefore, recent efforts have been directed towards the development of secondary metabolites as potentially useful products for commercial fungicides or lead compounds (Kim et al., 2003; Yoo et al., 1998).

Biologically active natural products have the potential to replace synthetic fungicides. Biologically active natural products such as flavour compounds, glucosinolates, chitosan, essential oils and plant extracts have been exploited for the management of fungal rotting of fruits and vegetables (Tripathy and Dubey, 2004). Botanical fungitoxicants are used for the protection of stored food commodities from fungal infestation (Kumar et al., 2007). Monoterpene isolated from essential oil of *Carum carvi* exhibited fungicidal activity in protecting the potato tubers from rotting (Anonymous, 1994). The essential oil and methanol extract and derived fractions of *Metasequoia glyptostroboides* showed great potential of antifungal activity against *Fusarium oxysporum, Fusarium solani* and *Sclerotinia sclerotiorum* (Bajpai et al., 2007). α-cedrol isolated from essential oil of *Thuja orientalis* possess antifungal activity against *Alternaria alternata* (Guleria et al., 2008a). Volatile oils from *Eucalyptus citriodora* showed complete inhibition of *Rhizoctonia solani* and *Helminthosporium oryzae* at 10 and 20 ppm respectively (Ramezani et al., 2002). Guleria et al., (2008b) reported toxicity of *Solanum xanthocarpum* leaf extract against *Alternaria brassicae*. Neem formulations have been used for controlling the damping off in brinjal and chilli (Bohra et al., 2006). Aqueous leaf extracts of *Datura metel* and *Lawsonia inermis*, known for their high antifungal activity against *Phaeoisariopsis personata*, completely inhibited the germination of urediniospores of *Puccinia arachidis* in vitro. In the greenhouse, extracts of *D. metel* (25 g/L) and *L. inermis* (50 g/L) applied as a prophylactic spray reduced the frequency of late leaf spot lesions and rust pustules by 65–74% compared with controls (Kishore and Pande, 2005). Saponin rich extracts (SREs) can also play an important role in controlling phyto-pathogenic fungi, especially under organic management (Chapagain et al., 2007; Guleria and Kumar, 2007).

The use of natural products as insecticides against crop pests is gaining importance in recent years. The organic synthetic insecticides are more hazardous, leave toxic residues in food products, and are not easily biodegradable; besides their influence on the environment and public health is deleterious. Unlike synthetic chemicals that kill both pests and predators outright, the natural insecticides are relatively inactive against the later. Most of the botanical insecticides are easily biodegradable and their supply can be made at cheaper rate by regular cultivation.

Though, botanical insecticides may not match synthetic insecticides in efficacy, but the natural insecticides extracted from plants in their semi purified form have slow releasing action and are prophylactic. Among the natural insecticides rotenone from *Derris elliptica*, nicotine from tobacco leaf, pyrethrins from pyrethrum flowers (*Chrysanthemum cinerariaefolium*) and azadirachtin from neem (*Azadirachta indica*) have attained commercial importance. Intensive chemical investigation on neem seeds reveal that azadirachtin, a complex and highly oxygenated compound belonging to tetranortriterpenoid class is the most potent antifeedant and growth disruptant to many insects. Antifeedant chemicals do not kill insects straightway but when sprayed on crops or applied to stored grains, the insect rather prefer to die of starvation than consume the treated food. Among the well represented plant insecticides is “Pyrethrums” obtained from *C. cinerariaefolium* which is mainly used as a domestic insecticide because it is non toxic to man and warm blooded animals and is highly sensitive to light. There are four main principal ingredients in *Chrysanthemum* viz., pyrethrum I and II and cinerin I and II (Verma and Dubey, 1999). Photostable pyrethroids synthetically prepared from pyrethrins are chemically similar to pyrethrins but are more stable outdoors to heat and light. Pyrethroids are neuroexcitatory, producing heightened repetitive nerve activity especially in the sensory nervous system (Vijverberg and Bercken, 1990). Pyrethrum is a predominant botanical in use, accounting for 80% of the world botanical insecticide market (Isman, 2005).

Terpenes isolated from Rutales have been shown as effective against stored grain pests (Omar et al., 2007). Essential oils of cumin (*Cuminum syminum*), anise (*Pimpinella ansium*), oregano (*Origanum syriacum* var. *bevanii*) and eucalyptus (*Eucalyptus camaldulensis*) were effective as fumigants against the cotton aphid (*Aphis gossypii*) and carmine spider mite (*Tetranychus cinnabarinus*) (Tuni and Sahinkaya, 1998). Contact, fumigant and antifeedant effects of a range of essential oil constituents (cinnamaldehyde, and α-pinene) against the maize weevil (*Sitophilus zeamais*) and the red flour beetle (*Tribolium castaneum*) have been demonstrated (Huang and Ho, 1998; Huang et al., 1998). In the United States, exemption from registration of some insecticides based on plant essential oils has greatly facilitated their commercial development (Quarles, 1996).

In search of botanical pesticides, toosendanin, an antifeedant limonoid from the bark of the trees *Melia toosendan* and *Melia azedarach* (Meliaceae) has gained a considerable attention as potential botanical pesticide (Chiu, 1989; Chen et al., 1995; Koul et al., 2002). Production of toosendanin based botanical insecticide containing approximately 3% toosendanin (recemic mixture) as the active ingredient has already commenced in the P.R. China (Koul, 2008).

12.4 Botanical Insecticides in Use and their Mode of Action

Pyrethrins (Pyrethrum/Pyrenone) – Pyrethrum is an extract from *Chrysanthemum cinerariaefolium* daisies. Pyrethrins act on insects by rapidly causing paralysis, and they are widely used in fast knockdown aerosol sprays. Pyrethrins affect the insect's central nervous system by moving through the insect's skin or through its gut after ingestion. They do not inhibit the choline esterase enzyme. Pyrethrins (Fig. 12.1) change the permeability of sodium channels in the nerve axon. This typically results in excitation, lack of coordination and paralysis.

In order to improve their killing ability, they are generally mixed with synergist (s) (e.g., piperonyl butoxide or PBO or n-octyl bicyclotheptone dicarboximide). PBO protects the pyrethrins from enzymatic degradation by insect's enzyme system. They have an oral LD_{50} of approximately 1,500 mg/kg (Casida and Quistad, 1995).

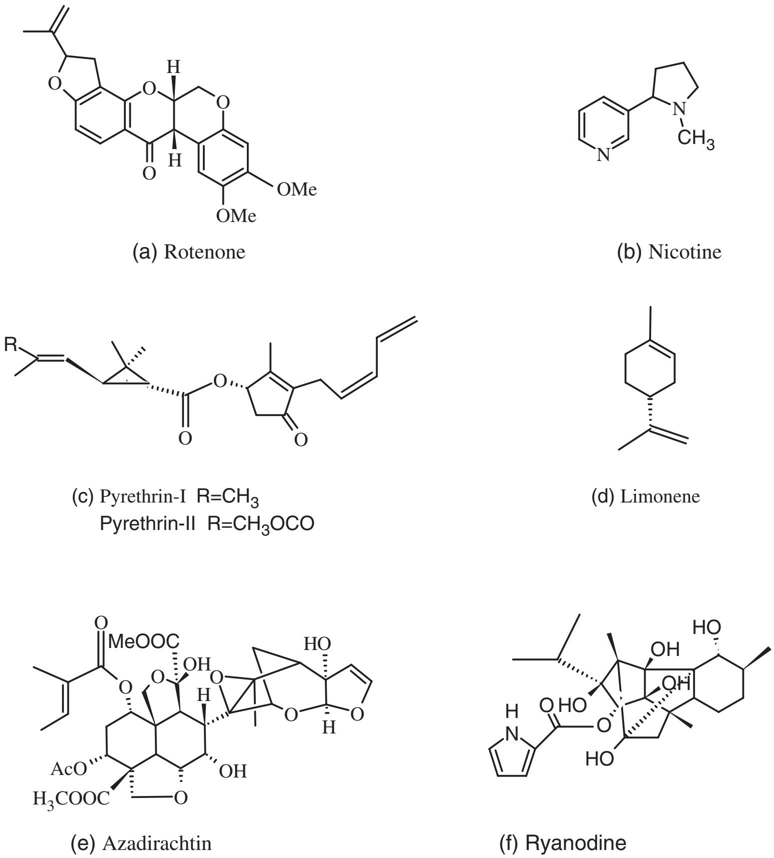

Fig. 12.1 Active constituent of some botanical insecticides from different plant sources discussed in this chapter. (**a**) Rotenone, (**b**) Nicotine, (**c**) Pyrethrin I and II, (**d**) Limonine, (**e**) Azadirachtin and (**f**) Ryanodine

As the pyrethrum mammalian toxicity is very low, it can be applied to food crops close to harvest. Pyrethrins knockdown, "flush out" or kill most insects, beneficial or otherwise. This can leave the plants to re-infestation in a milieu devoid of natural predators. It is toxic to bees and fish.

Rotenone – Rotenone is one of the most toxic of the commonly used botanical insecticides. It is extracted from the roots of two tropical legumes *Lonchocarpus* and *Derris*. Rotenone is a cell respiratory enzyme inhibitor and acts as a stomach poison in insects (Fields et al., 1991). Its mode of action involves disruption of cellular metabolism, acting between NAD^+ (a co-enzyme involved in oxidation and reduction in metabolic pathways) and Co-enzyme Q (a respiratory enzyme responsible for carrying electrons in electron transport chains), resulting in failure of respiratory function (Ware, 2000). Essentially, rotenone (Fig. 12.1) inhibits a biochemical process at the cellular level making it impossible for the target organism to use oxygen in the release of energy needed for body processes and hence conduction of nerve impulses (Hollingworth et al., 1994). Rotenone is extremely toxic to fish and other aquatic life and is commonly used as fish poison. It has an oral LD_{50} of approximately 350 mg/kg.

Rotenone basically slows nerve transmission to the point where the insect's body does not function. Rotenone degrades rapidly when exposed to air and sunlight (1–3 days). As rotenone is not absorbed through skin or gut, making it relatively "safe" for human. Rotenone is more toxic to mammals by inhalation than by ingestion, skin irritation and inflammation of mucous membranes may result from skin contact.

Nicotine – Nicotine is a natural insecticide from *Nicotiana spp*. (tobacco) stems and leaves and is most commonly available as nicotine sulfate. It is a fast acting nerve toxin and is highly toxic to mammals. It is generally absorbed through the eyes, skin and mucous membranes. Nicotine (Fig. 12.1) affects insects by decreasing the heart beat at high doses but increases the heart beat at low doses by interfering with the nervous system. It is highly toxic to all warm blooded animals as well as insects. It is having an oral LD_{50} of 50 mg/kg (Isman, 2006). Nicotine sulfate is also easily absorbed through the gut but not the skin. Generally the death is due to respiratory failure due to the chest muscles not functioning. Neither nicotine alkaloid nor nicotine sulfate affects choline esterase.

Sabadilla – Sabadilla comes from the ripe seeds of the tropical lily *Schoenocaulon officinale*. The alkaloids in sabadilla affect nerve cells, causing loss of nerve function, paralysis and death. Pure extracts are very toxic if swallowed or absorbed through skin and mucous membranes. It breaks down rapidly in sunlight and air, leaving no harmful residues. Sabadilla is a broad spectrum contact poison, but has some activity as a stomach poison. It has an oral LD_{50} of 5,000 mg/kg and acts as both a contact and stomach poison on insects. To humans, sabadilla is very irritating to the upper respiratory tract, causing sneezing. It is also irritating to the skin, and it is absorbed through the skin and the gut if ingested. Sabadilla is photosensitive and breaks down rapidly in sunlight. It contains alkaloids (primarily cevadine and veratridine) that act as nerve poisons.

Ryania – Ryania is an extract from the roots of *Ryania speciosa*. It has relatively low toxicity to mammals. It breaks down fairly slowly. It has an oral LD_{50} of approximately 750 mg/kg and affects insect's nervous system but it is not a choline esterase inhibitor. Ryanodine (Fig. 12.1) acts as a muscular poison by blocking the conversion of ADP to ATP in striated muscles (NRC, 2000).

Limonene – An extract from citrus oils. The oral LD_{50} is reported to be greater than 5,000 mg/kg. Linalool is a closely related material that is also an extract from orange and other citrus fruit peels. Citrus oil extracts have been combined with insecticidal soap for use as contact poisons against aphids and mites. Limonene (Fig. 12.1) and linalool are contact poisons (nerve toxins). They have low oral and dermal toxicities. Both the compounds evaporate readily from treated sufaces and have no residual effect.

Neem – The primary active ingredient in most neem based pesticides is a compound called azadirachtin (Isman, 2005). Azadirachtin (Fig. 12.1) a liminoid or more specifically as tretranor triterpenoid possess considerable insecticidal activity. Azadirachtin being chemically complicated has not been synthesized. Its major modes of action are that of powerful insect growth regulator (IGR), a feeding and an oviposition deterrent. It is structurally similar to the natural insect hormone ecdysone. Azadirachtin interferes with the production and reception of this insect hormone during insect's growth and molting. Thus azadirachtin blocks the molting cycle causing the insect to die (Mordue and Blackwell, 1993).

12.5 Factors Affecting Use of Botanical Pesticides

12.5.1 Raw Material Availability

Plants represent a vast store house of potentially useful chemical molecules. Many laboratories around the world are engaged in screening of plants not only for therapeutic purposes but also for useful natural products which have wider implications in the development of pest control agents for use in agriculture. These studies speak volume about the plant species possessing potential pest controlling activity under laboratory conditions but the step from the laboratory to field eliminates many contenders.

For commercial scale production of botanical pesticides there should be continuous supply of raw material and more importantly the source plant should be amenable to cultivation. Efforts for production of botanicals through tissue culture are yet to bear fruit. This further call for the selective production of certain novel molecules endowed with biological activity through genetic engineering of potential candidate plants.

12.5.2 Standardization of Botanical Extracts Containing a Complex Mixture of Active Constituents

The crude plant extract contains a mixture of chemical molecules belonging to different chemical class of compounds and all may not possess biological activity. Therefore, for a botanical pesticide to be effective, there should be chemical standardization in order to concentrate the chemical molecules possessing biological activity. This can be achieved through the use of standard procedures meant for particular class of chemical molecules followed by an appropriate analysis to ensure the desired level of biological activity. Complex mixtures of active ingredients in botanicals may help in mitigating the problem of resistance development. In a laboratory experiment green peach aphid, *Myzus persicae* was shown to evolve nine fold resistance to azadirachtin over 35 generation when selected agent was pure azadirachtin applied to plants at LC_{50} level; whereas, a parallel aphid line selected with neem seed extract, containing the same amount of azadirachtin but as a part of complex mixture did not evolve resistance to azadirachtin over the same period (Feng and Isman, 1995).

The exorbitant costs and cumbersome procedures involved in the isolation of bioactive constituents make it a difficult venture. The only exception to this statement is pyrethrum, where not only the bioactive molecule was isolated in pure form but also served as lead for the development of photo stable pyrethroids. There are certain disadvantages associated with complex mixtures, as it is difficult to standardize a product containing a mixture of active constituent of differing preparation and bioactivity.

12.5.3 Market Opportunities for Botanical Pesticides

Low market share of botanical pesticides in industrialized countries as compared to multimillion dollar regulatory costs prevent many botanical pesticides from reaching the market place. The registration of new active ingredient in the USA can be to the tune of US$ 250,000 or more. Further more, regulatory procedures presently in place are tailored specifically for synthetic chemicals. On the other hand complex mixtures of bioactive constituents in botanicals make their registration difficult. Hence, registration requirement needs to be modified in order to accommodate the environmentally benign botanical pesticides (Isman, 2006). In India for instance applicants are allowed to market new products up to a period of five years before final registration.

12.6 Future Perspective

Application of synthetic pesticides is a regular practice to ward off infestation of insect pests and diseases from field crops. However, as these conventional chemicals are reported to cause environmental load and threat to public health, the world trends in pesticide research now a day calls for discovery of safer and eco-friendly chemicals for pest control. Plants are rich resource of chemicals that are toxic to pests. When extracted from plants these chemicals are called botanicals. Botanicals are endowed with a spectrum of properties such as insecticidal activities, repellence to pest, insect behavior modifier, antifeedent activity, toxicity to mites, snails, slugs, nematodes and other agricultural pests (Duke, 1990). Apart from this, they also possess antifungal, antiviral and antibacterial properties. They have variable toxicity to non target organisms, although as a group they tend to be less toxic to mammals (with + ve exception to nicotine), than non botanicals.

The use of botanicals is now emerging as one of the prime means to protect crops and their products and the environment from pesticide pollution, which is a global problem. Since most of them generally degrade within few days, and some times within a few hours, these insecticides must be applied more often. More frequent application coupled with exorbitant cost of production usually makes botanicals more expensive to use than their synthetic counterparts.

In spite of the wide recognition that many plants possess insecticidal properties, only a handful of pest control products directly obtained from plants including pyrethrum (pyrethrin), neem (*Azadirachta indica*), rotenone, quassia and tomato leaf extract are in use because the commercialization of new botanicals can be hindered by a number of issues. Further more, regulatory protocols being designed, keeping in view the synthetic chemicals, constitute a barrier to the commercialization of potentially useful botanicals, mainly due to the presence of complex mixtures of active ingredients in them. However, in view of the negative effects of the synthetic chemicals on human health, environment and ecosystem the regulatory authorities are likely to look more favourably on the alternative products so that these new products can be mobilized into the market with less hurdles (Isman, 2006).

Insects have developed widespread insecticide resistance to many synthetic insecticides, and the industry may not have enough resources to continually develop and supply the market with new products precisely when needed to replace the old ones. Therefore, there is a growing need to develop insecticides with newer modes of action not leading to the development of resistance. In this regard, botanicals consisting of mixtures of active principles have an advantage over conventional synthetic insecticides.

The benefits of botanical insecticides can be best translated into practice in developing countries where farmers may not afford synthetic insecticides, due to their exorbitant costs and where the traditional use of plants for protection of stored products is long established (Kumar et al., 2007). Also thousands of pesticide related accidents occur, where farmers can afford synthetic insecticides, due to lack of protective equipment and limited literacy.

Future research efforts, therefore, should be directed not only towards the development and application of known botanicals but also on screening more plants and isolate new and novel bioactive molecules which have pest controlling properties or can serve as leads for the development of eco-friendly pesticides.

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