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Familiarizing with local biodiversity

Notes on Systematics of Plants and Insects

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CHAPTER- 21

BOTANICALS AS BIOPESTICIDES: ACTIVE CHEMICAL CONSTITUENTS AND BIOCIDAL ACTION

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INTRODUCTION

Pesticides are synonymous with modern agriculture and provide the most effective and economically efficient means of controlling thousands of species of insect pests, weeds, fungi and nematodes that compete for our food and fibre. Chemical pesticides in general and broad spectrum pesticides in particular have provided convincing means of controlling the pests, since 1950 (Ennis and McClellan, 1964). The estimated 30% losses from pests that would occur in the absence of pesticides, would spell economic and human disaster for many developing countries around the world. Outbreaks of forest insects alone damage some 35 million hectares of forests annually, primarily in the temperate and boreal zones (FAO, 2010a). Chemical, biological and technological advancements in agriculture have successfully boosted the production of food grains and vegetables for ever growing population and saved mankind from hunger and pestilence. This has been achieved through high-tech agro-practices supported by heavy use of chemical fertilizers and pesticides. Several examples highlight the value of pesticides in reducing crop losses. In Ghana, which is the world's premier cocoa exporting country, the application of insecticides has almost trebled the yields by effectively controlling the damage to the crop by the capsid bug, and in Pakistan extensive use of insecticides on the sugar crop increased the yield by 50% (Tripathi, 1998).

The United Nations Food and Agricultural Organisation (FAO) have remarked that without the use of pesticides a considerable amount of agricultural production in developing countries would be destroyed by pests. Green revolution boosted the agricultural production in India making the country self-sufficient in food supplies (Swaminathan, 1995) that highlight the value of pesticides in reducing crop losses. Thus, the use of pesticides has gradually become a part of our modern agriculture practices (Levitan *et al.*, 1995) and their consumption has also increased remarkably in the recent past causing serious ecological and health problems all over the world.

Current views are therefore to examine and introduce ecologically sound and environmentally safer alternative means of plant protection that help sustained agricultural production and forest productivity in future.

ORIGIN OF SYNTHETIC PESTICIDES

Synthetic pesticides, developed during the World War II dramatically increased the potential for controlling pests and till the first two decades of this pesticide revolution emphasis was placed on their positive and beneficial aspects. Dr. Paul Muller in 1939 discovered the powerful insecticidal properties of Dichloro-diphenyl-trichloro ethane (DDT) which soon became the most widely used single insecticide in the world. Although, the 1930 represents the beginning of modern era of synthetic organic pesticides namely, alkyl thiocyanate (1930), salicylanilide (1931), the first organic fungicide, dithiocarbamate (1934), chloranil (1938) and phenyl crotonate or dinocap (1946). Other organic compounds developed during this period were azobenzene, ethylene dibromide, ethylene oxide, methyl bromide and carbon disulphide as fumigants; phenothiazine, p-dichlorobenzene, naphthalene and thiodiphenylamine as insecticide. Spurred on by the success of DDT, the chemical industry began an intensive search for other synthetic organic pesticide and a steady stream of new insecticides, herbicides, fungicides and other pesticidal products began to appear in the market. Several useful synthetic insecticides viz., chlorinated hydrocarbon cyclodiene (benzene hexa chloride, aldrin, dieldrin, heptachlor and eldrin etc.); organophosphorous compounds (schradan, parathion, malathion, menazon); carbamate esters (sevin); herbicides (2-methyl-4-chloro and 2,4-dichloro-2,4-D-phenoxyacetic acid); fungicides (captan, oxathiins, benzamidazoles, thiophanates, pyrimidines) have been developed during 1950-66 (Cremlyn, 1978). In 1967, benzimidazole fungicides and in 1975 photo-stable pyrethroids were important additions in the world of pesticides. Since then the discovery, use and increase in types and their production started very fast. Over 1 billion pounds of pesticides are used in the United State (US) each year and approximately 5.6 billion pounds are used worldwide (Donaldson *et al.,* 1999, Michael and Alavanja, 2009).

In India, the plant protection became effective with the popularity of BHC and DDT in the early 1950's which was further supported by the introduction of organophosphorous and carbamates. Now, India after Japan is the largest manufacturer of pesticides in South Asian and African countries.

PESTICIDAL ABUSE AND HAZARDOUS CONSEQUENCES

Indiscriminate use of synthetic pesticides over the years has resulted different types of hazards and toxicity. Pesticides residue may constitute a significant source of contamination of air water, soil and food which could become a threat to the plant and animal communities. A large amount of pesticides is released into atmosphere during use thereby inviting adverse climatic changes. A variety of undesirable environmental effects of pesticides has been reported from many countries. The effects include excessive mortality and reduced reproductive potential in organisms, changes in the abundance of species and the diversity of ecosystem, reduction in the productive potential of natural resources and the development of pesticide resistance in target and non-target species (Koeman, 1978). Irrespective of the method of application (soil incorporation, broadcasting, dusting or foliar spray), soil serves as the ultimate sink for all the pesticide applied (Flury, 1996). After reaching the soil, the pesticides are decomposed either by leaching, surface runoff, absorption/desorption, volatilization, microbial metabolism or a combination of these processes. As a result, world soils are accumulating ever increasing amount of residues of wide variety of pesticides which can move into the bodies of invertebrates, pass into air or water, absorbed by plants or broken down into other toxic products. The presence of pesticides in soil therefore, continues to be of interest to environmental scientists. Leaching of pesticides to groundwater or nearby rivers, simultaneous non-selective killing of pests, accidents with toxic pesticides, pesticide residues of food crops and the disappearance of certain vertebrates have become more or less synonymous with modern intensive agriculture. Less than 0.1% pesticides reach the target pest and remainder negatively affects humans, livestock and natural biota (Pimentel, 1992). In general the indiscriminate and heavy use of pesticides in agriculture and forestry plantations has contaminated the food grains, dairy products, fruits, vegetables, fodders, horticulture land, drinking water and the living environment as a whole. Aquatic living species die as the pesticides washed down from the fields to rivers, tanks and other water reservoirs.

Majority of synthetic pesticides are not easily degradable and tend to enter food chains. They spread their toxic effects through ecological cycling and biological magnification and cause serious health problems in human and animal subjects. Organochlorine and organophosphorous compounds are now predominately used. The former is stable and extremely slow degradable under various environmental conditions. The environmental half-life of such chemicals has been reported to be 10 years or more (Brooks, 1976). The stability and persistence of these materials in the environment, their accumulation in the tissues of living organisms and their lack of selectivity were major factors in the development of pest resistance and in their deleterious impact on beneficial species. The pesticidal residue in plants produce, soil, water, wildlife and animal tissues is responsible for various carcinogenic, mutagenic, teratogenic and catratogenic defect in human society. Liver and kidney damages are observed in response to a long exposure to organochlorine pesticides whereas organo-phosphorous toxicity results decline of memory (Korsak and Sato, 1977). Sometimes they may even result in mutation of genes and these changes become prominent only after a few generations. According to an estimate, heavy use of chemical pesticides cause about 50,000 cases of pesticide poisoning every year in the under developed countries. According to WHO estimate, pesticide related deaths in developing nations are 10,000 per year and about 2 million people suffer from acute pesticidal poisoning.

Increased use of organochlorine pesticides in agriculture is causing severe damages to the environment. These chemicals liberate chlorine which enters into stratosphere above the atmosphere and diminishes the volume of ozone allowing more ultraviolet rays of the sun to penetrate into the atmosphere which is very harmful to the human health. Another problem with the use of chemical pesticide is the resistance developed by a number of pests as a result of their prolong use. Most pesticides have a limited effective life. Resistance has been reported in almost 500 species of insects and mites, 100 species of plant pathogens, 50 species of insects and rodents and 2 species of nematodes (Georghiou, 1986). Synthetic pyrethroids have induced resistance in bollworm, one of the most destructive pests of cotton. Further the use of these chemical insecticides has also resulted in secondary pest outbreaks. Insects such as the whitefly, mites and aphids, which had never been a serious threat to cotton, are now emerged as major pests. Residues of DDT and other toxic insecticides have been found not only in the fat and blood of the people in the various part of India but also in the breast milk of lactating mother (Tripathi, 1998).

GLOBAL APPREHENSION

Despite the appearance of pest resistance and recognition of some adverse effects on non-target species, little serious thought was given to the potential long-term consequences of pesticide use in terms of human health. The continual addition of large amount of persistent pesticides to the environment has caused widespread destruction of soil fertility and endangered the ecological security of food, farmer and farmland. In the most natural situation, the plants, animals and micro-organisms of the soil are absolutely essential for its fertility. The soil contains microorganisms that are responsible for the conversion of nitrogen, phosphorous and sulphur to the forms available for plants. Use of these pesticides has either been banned or discouraged in developed countries as they create several environmental and health hazards. Recognizing the fact that most of the complex physical and chemical processes responsible for soil fertility are dependent on soil microorganisms, use of DDT has been banned in many countries. DDT registered for use on some 334 crops and agricultural commodities in 1961, was banned in the USA in 1972 and the use of most other chlorinated hydrocarbon insecticide were either banned or severely restricted during the next decades. The environmental biologists are opposed to the continuing treatment of soil with heavy doses of deadly and persistent toxicants. In Netherlands several pesticides have been removed from the market and the overall uses of crop protection agents has to diminish by at least 50 %.

This situation has led to much greater emphasis on the judicious use of pesticides and to develop the methods that are capable of reducing the large scale utilization of chemical pesticides by encouraging eco-friendly biopesticides (Zechendorf, 1996). To overcome the problem of pesticidal hazards, there is a growing appreciation about biopesticides, which only attack the target pests and also harmless to animals, fish, human beings and wildlife as well. One of the best control measures is the use of plant origin chemicals in the form of antifeedants, repellents, protectants, growth disrupting hormones and insecticides because of their biodegradability, least persistence and least toxic to non-target organisms. The presence of biologically active principles in certain plants and their extraordinary pest management traits have, in recent years, raised considerable interest among the scientists all over the world and a fairly good amount of data has been generated on several plant species regarding their pest control potential.

BOTANICALS AS BIOPESTICIDES – AN ECOFRIENDLY AND SAFE OPTION

The development and promotion of eco-friendly bio-pesticides which only attack the target pest and harmless to beneficial biota are being stressed all over the world. Plants have evolved over some 400 million years and they have developed a number of protective, genetically acquired inbuilt mechanisms, such as repellency and insecticidal action etc to protect themselves from pest attack. As such, plant products are regarded as an effective substitute for chemical pesticides. Botanicals or their derivatives of plant origins have good capability to regulate and control of harmful pests.

Plants are known to provide a vast reservoir of biologically active chemical constituents. However, not more than 10% of these have so far been examined in detail for their biological activity against human diseases (Nitya Nand, 1977) and much less against plant diseases. The earliest mention of poisonous plants or those with pest control properties is found in ancient Indian literatures. Democritus tried plant extract for controlling plant diseases as early as in 470 BC (Sherville, 1960). Pest control through pesticides of plant origin has a long history and farmers have used pesticides prepared from seeds of resistant plants. Thus, a large number of different plant species contain natural insecticidal materials. Some of these have been used by man as insecticides since very early times. But many of them can not be profitably extracted. However, several of these extracts have provided valuable contact insecticides which possess the advantage that their use does not appear to result in the emergence of resistant insect strains in the same degrees as the application of synthetic insecticides do. As early as in 1690, the water extract of tobacco leaves was being used to kill the sucking insects of garden pest and against mildew diseases of trees (Forsyth, 1802). Plants are known to biosynthesize a dazzling array of structural variety which exhibit an almost equally dazzling array of anti-insect biological activities. The grain protection activity of neem seeds and tobacco extract is in practice for more than 300 year in Indian and Europe (Jotwani and Sirkar, 1965; Pathak *et al*., 1995a, Kulkarni and Joshi, 1998b). The farmers in Tamilnadu and Karnataka use *Vitex negundo* and Karanja as grain protectants (Ahmed and Koppel, 1987). Kulkarni (2001) in a detailed review, has discussed biological activities exhibited by some important plant species known till date, against insect pests, either in the form of crude extracts or purified isolated compounds.

Pesticidal products of plant origins have been found remarkably effective in the form of antifeedant, repellent, protectants and growth disrupting hormones and as other biocides (Kulkarni, 2001). The active principle in tobacco extract was later shown to be the alkaloid nicotine which is the first naturally occurring insecticide isolated in 1828. Nicotine functions as a non-persistent contact insecticide against aphids, capsids, leaf miner, codling moth and thrips on a wide variety of crops (Busbey, 1950-51). Around 1850, two important natural insecticides were introduced namely rotenone and dihydrorotenone from the roots of the plant *Derris elliptica* (Fukami and Nakajima, 1971) and they were being used for the control of caterpillars. Pyrethrum extracted from the flower heads of *Chrysanthemum cinerariaefolium* was used for pest control in the past and it is still one of the important pesticides at present (Matsui and Yamamoto, 1971). Bradely (1983) used pepper dust to protect trees against blight to their blossoms. A real breakthrough in pesticidal applications of plants and plant produces occurred during early sixties when Pradhan *et al.* (1962) first reported the antifeedant properties of Neem seed kernel against desert locust *Schistocerca gregaria* (Kulkarni, 2001).

BOTANICAL PRODUCT EXPLOITATION

Contrary to the problems associated with the use of synthetic chemicals, botanicals are environmentally non-pollutive, renewable, inexhaustible, indigenously available, easily accessible, largely non-phytotoxic, systemic ephemeral thus readily biodegradable, relatively cost effective and hence find a very promising role as a plant protectant in the strategy of integrated pest management. A large number plant species containing natural insecticidal material have also been examined for their pesticidal properties. There are approximately 2000 plant species all over the world which have been found to exhibit biocidal activity (Grainge and Ahmed, 1988) and some of them have been recommended for the control of pest and diseases of various agricultural, horticultural, fruit, other economical crops and plant species (Table 1).

Neem finds an important place amongst plant origin pesticides by virtue of multifacial biological activities exhibited against wide range of insect pests in the world (Schmutterer, 1995). The eco-friendliness, easy availability and renewable nature helped to prepare different pesticides from its various parts and major chemical constituent, azadirachtin. Azadirachtin is found to be effective as feeding deterrent, repellent, toxicant, sterilant and growth disruptant for insects at a dosage as low as 0.1 ppm (Miana *et al.,* 1996). Neem extracts have been reported as quite effective against more than 300 insect pests of different orders (Marippan, 1995). In India neem has been evaluated against 195 species of insects belonging to ten different orders viz. *Orthoptera, Dictyoptera, Lepidoptera, Hemiptera, Diptera, Coleoptera, Hymenoptera, Isoptera, Thysanoptera,* and *Siphnoptera*. The diversified biocidal activities of neem are highly influenced by the chemically diverse and structurally complied tetranortrierpenoids (limonoids) isolated and characterized from different parts of neem. Various workers have examined bio-efficacy of its pure individual principles. Almost every parts of the neem are bitter but the seeds possess maximum detergency. Keeping the pesticide potential of Neem and its domestic as well as international market in view, some Indian companies have launched neem-based pesticides during past few years (Tripathi, 2000). Schmutterer (1995) in his report included a few insect pests of forestry importance, susceptible to neem and its products. Recent reports on the efficacy of neem extracts and some marketed products against some major forest insect pests damaging forest nurseries, plantations and natural forests (Meshram *et al*., 1994, Kulkarni *et al*., 1995, 1996a,b, 1998b).

The presence of biologically active principles in seed and other parts and their extraordinary pest management traits have in recent years raised considerable interest among the scientists all over the world and a fairly good amount of data has been generated on several plant species regarding their pest control potential (Tripathi and Tripathi, 1999). Scientists from all over the world have evaluated a number of plants chemically and biologically and a fairly good amount of data has been generated on several plant species regarding their pest control potential.

The most promising botanical pesticides for use at present and probably in future, are derived from species of the families *Meliaceae, Rutaceae, Asteraceae, Annonaceae, Labiateae and Canellaceae* (Miana *et al.*, 1996). Aphicidal properties of crude aqueous extract of *Aconitum ferox* has been reported against red pumpkin beetle, wheat aphid, mustard fly, kharif grasshopper, radish aphid and mustard aphid (Jacobson, 1975). Leaf extract of *Acorus calamus* has been found to possess insecticidal, antifeedant and repellent properties. Leaf extract of *Aegle marmelos* and seed extract of *Annona squamosa* exhibited antifeedant activity and significantly protect grains from storage pests. Crude extract of bulb of *Allium cepa* and *Allium sativum* showed insecticidal, repellent, nematicidal and fungicidal activities (Prakash Rao, 1987). Leaf extract of *Artemisia vulgaris* was reported to act as repellent against stored grain pests and flour beetle.

Aqueous and alcoholic extracts and powder of *Balanite egyptica* bark showed insecticidal activity against the aphids and the grasshoppers (McIndoo, 1983). Oil cake of Indian mustard, *Brassica juncea* show repellency to rice weevil and reduce its oviposition in stored maize grain and its seed extract shows antifeedant activity against the hairy caterpillar on groundnut crop (Bowry *et al.,* 1984). Extract of whole plant of *Calotropis procera, Datura metel* and *D. strumanium* in water, alcohol and petroleum ether has been reported to have insecticidal activity when tested against red pumpkin beetle and the cabbage butterfly (Khanvilkar, 1983). Leaf of *Cannabis sativa*, *Lanatana camara, Jatopha carcus* and *Nerium indicum* act as protectants against stored grains. Methanolic extract of various parts of *Capparis deciduas* have shown aphidicidal activity against peach aphid (Sundasraraj *et al.*, 1998). Crude seed extract of *Cassia fistula* is reported to inhibit the metamorphosis of the 5^{th} instar larvae of cotton strainer (Jaipal *et al*., 1983). Aqueous extract of *Catharanthus roseus* was reported to show insecticidal activity against the yellow stem borer of rice, cotton strainer and act as an antifeedant when sprayed on black gram pod borer. Extracts of its leaf, flower and whole plant showed repellent activity when tested against stored grain pests. Leaf extract of the plant can also reduce the infestation of the sweet potato weevil in the crop. Turmeric powder (*Curcuma longa*) has been reported as a repellent and protectants of stored grains. Spray of its rhizome extract on moth bean crop provides leaf protection against the attack of moth bean defoliator.

Leaf extract of *Eucalyptus* sp. showed repellency to the woolly apple aphid and screw worn and reported to realty impair the fecundity of the pulse beetle. Its powder admixtures with rice grains reduces the populations of the paddy moth and checks the cross infestation of the lesser grain borer. Seed oil of *Gossypium hirsutum* protects stored bean seed against the bruchid, maize, sorghum and wheat grains from the infestation of Angoumois grain moth and rice weevil without affecting their viability (Oca *et al.*, 1978). Leaf and flower extracts of *Ipomea cornea* in benzene showed repellency to pulse beetle and reduce their oviposition and multiplication in stored green gram (Pandey, 1986). Its wood, leaf, fruit and seed extracts in water were reported to be toxic to the leaf cutting larvae. Its seed extract is reported to reduce oviposition of the potato tuber moth (Shelke, 1987). Aqueous suspension of stem extract (1%) of *Lantana camara* showed inhibitory activity against 4^{th} instar larvae of silk moth (Gopalkumer, 1993). Refined linseed (*Linum usitatissimum*) oil acts as surface coating agent for endosulfan encapsulated formulations and increases efficacy of the chemical against the sorghum stalk borer (Srivastava and Saxena, 1986). Whole plant extract of *Nerium indicum* as well as extracts of its various parts in water, ether and alcohol are toxic to the vinegar fly and rice weevil (Jacobson, 1975). Volatile oil from the leaves of *Ocimum sanctum* inhibits oviposition of the cotton leafhopper (Saxena and Basit, 1982). Petroleum ether extracts of the whole plant and leaves of *Parthenium hysterosphorus* showed juveno - mimetic activity to the 5th instar larvae of the cotton stainer resulting morphogenetic changes in the larvae (Rajendran and Gopalan, 1979) and antifeedant activity to the cotton leaf armyworm, brinjal leaf beetle, cabbage leaf webber and migratory grasshopper also.

Root and bark extracts of *Plumbago zeylanica* in alcohol and ether show toxicity to aphid, cotton stainer, Mexican bean beetle and hairy caterpillar (Mclndoo, 1983). Oil of castor (*Ricinus communis*) has been found to inhibit the multiplication of pulse beetle and the storage weevil and showed repellent activity to the rice weevil and is toxic to the leaf cutting ants and inhibits the oviposition of leafhopper. Leaf extract of *Swertia chirata* inhibited the development and growth of sun-hemp pest (Singh and Pandey, 1979) and has been found to be toxic to the Japanese beetle (McIndoo, 1983). Root and leaf extracts of *Teprosia purpurea* in water and ether have been reported to be toxic and act as repellent to the hairy caterpillar and cotton leaf armyworm. Leaf, flower and bud extracts of *Thevetia peruiana* show repellency to pulse beetle and reduce their oviposition and multiplication (Pandey *et al.*, 1986). Its leaf and fruit extracts in water show toxicity against cowpea aphid and jute hairy caterpillar. Leaf extract of *Toona ciliata* has been reported to show antifeedant activity against the attack of the Mahogany shoot borer. Its oil acts as protectants against the stored wheat grains. Ethereal extract of flowers *Tribulus terrestris* was reported to show insecticidal and antifeedant activities against the cotton strainer, the fall armyworm and the gram pod borer. Root extract of Khus (*Vetiver zizanioides*) shows inhibition in growth and development of the cotton stainer and also reduces the longevity of the cotton leaf armyworm. Aqueous and alcoholic extract of branch, leaf and seeds of *Vitex negundo* and its oil reported to be insecticidal, repellent, juvenile hormone mimetic and antifeedant activities against a wide range of storage and Lepidoptereran pests (David *et al.*, 1988)

Besides the above, some natural forest products have long been known to possess insecticidal, insect growth regulating and antifeedant properties. Effecacy of ethanol, acetone and ether extracts of *Acorus calamus, Lantana camara, Adhatoda vasica* and *Melia* *azadarach* reported in killing Ailanthus webworm, *Atteva fabriciella* (Ahmed, *et al.*, 1991). Acetone and alcoholic extracts of bark and roots of *Dalbergia stipulacea*, leaves of *Eucalyptus hybrid* and *Adina cordifiolia*, ursolic acid and bryonolic acid were evaluated as insect antifeedant against Poplar defoliator *Clostera cupreta* (Ahmed *et al.*, 1991). Aqueous leaf extracts of leaf and roots of *Linostoma decundrum* wall (Thymelaeaceae) were reported to have antifeedant, insecticidal, antiovipositional and ovicidal properties against red spider mite (RSM), *Oligonychus coffeae* (Tetranychidae), a major pest of tea and chrysomelid beetle, *Calopepla leyana* Latr. (Chrysomelidae: Coleoptera), a serious pest of Gamari (*Gmelina arborea*) a valuable timber species of northeast region of India (Bora *et al.*, 1999).

BOTANICAL FUNGICIDES

Although, there have been reported many insecticides of plant origin, it is also worth considering the potential of higher plant as fungicides. The production of phyto-fungicides is found to be more complex than the phyto-insecticides. Secondary metabolites that produced by certain higher plants are being reported to have antifungal properties (Benner, 1996). The alcoholic extract of the plant *Tiliacora racemosa* which is regarded as an antidote to snake bite, found to show a mild antifungal activity (Tripathi and Dwivedi, 1989). Its alkaloidal constituent, tiliacorinine showed promising antifungal activity against *Alternaria* leaf blight of pigeon pea (Singh *et al.*, 1991). Capillin obtain from *Artemisia capillaries* Thunb is being reported as effective to a range of plant pathogens (Benner, 1996). Sclareol produced by *Salvia scarea* L. And *Nicotiana glutinosa* is claimed to show *in vivo* control of plant pathogens by Bailey *et al.*, 1975 (as quoted by Benner, 1996) including *Uromyces fabae*. Many essential oils extracted from higher plants have shown fungi-toxicity against fungal pathogens (Fawcett *et al.,* 1990; Dewedi *et al.*, 1990 Singh, *et al.*, 1993 and Singh, 1996). The essential oils have been reported as a good source of phyto-fungicides.

Essential oils derived from medicinal and aromatic plant species, such as *Citrus sinensis, Cuminum cyminum, Hyptis suaveolens, Aegle marmalos, Seseli indicum* etc. have been reported to have the potentiality to act as fungicides against a broad spectrum of fungi such as *Aspergillus spp, fuserium spp, Helmenthsporium spp, Rhizocotonia solani, Pythium spp, Colletrotium spp. curviularia lunata, Periconia artopurpuria*, etc. (Singh *et al.*, 1999). The antifungal activity of polyphenolic complex of 50% extract of *Acacia nilotica* Bark has inhibitory effect on *Fusarium oxysporum* (Bhargava *et al.*, 1998). Plant saponins, Medicagogenic acid of *Medicago sativa* L., pterocarpans in *Erythrina crista galli* L., and allicin in Garlic (*Allium sativum,* L.) have been reported to have antifungal properties by different workers as quoted by Benner, 1996). Narayan Bhat *et al,* (1994) reported a few plant species for their antifungal activity against the Brinjal damping off disease caused by *Pythium aphanidermatium,* of which cold-water leaf extract of *Polylthia longifolia* inhibited 56.6%, *Ceasalpinia pauciflora* inhibited 85.5%, *Minikara kauki* (78.8%) and hot water extract of *Eucalyptus microtheca* showed 90% inhibition of mycelial growth. Gupta *et al.*, (1996) reported inhibitory affect of leaf extracts of *Azadirachta indica*, *Calotropis gigantean*, *Eucalyptus sp., Parthenium hystrophorous* and *Pongamia pinnata* against *Fusarium pallidorosum* and *F. Moniliformis* that caused leaf blight and *F. oxysporum* that caused leaf spot diseases in mulberry (*Morus alba*).

Biocidal properties of some other plants viz. *Abelmoshus esculentus, Amaranthus spinosus, Andropogone sorghum, Apios Americana, Brassica nigra, Carica papaya, Cassia sophera, Chrysanthumum cinerarietolium, Cocos nuifera, Corchous capsularis Andrographis peniculata, Curcumon domestica, Cymbopogon nardus, Datura metel, Euphorbia pulsherrima, Faericulum vulgare, Holarrena antidysenterica, Hydrocarpus kuzil, Lonchocarpus spp, Madhuca indica, Mentha spp, Michelia champaca, Moringa oelifera, Nictiana tibacum, Ocimum basillicum, Opuntia spp., Piper nigram, Prosopis cineraria, Ryania speciosa, Semecarpus anacardium, Trigonella foenumgraecum* etc. have also been investigated by several researchers.

ADVANTAGES AND LIMITATIONS

Botanical pesticides have certain advantages/characters over synthetic chemicals. Such pesticidal products are reported to cause no adverse effects on non-target biota. They are unstable as deriving from plants extract and therefore, biodegradable, particularly when exposed to light. They pose no threat to the environment and harmless to beneficial insects. They are soluble in water, highly biodegradable and therefore, low persistence as they start degrading soon after applied. Thus most of the crops sprayed with botanical pesticides are quite safe for consumption after a short period after spraying (Chomchalow, 1993). There is no such evidence reported so far that the disease pests have developed resistance over phytopesticides (Cameron, 1974). Phytopesticides even those derived from a single plant has many active ingredients of low potency. This may be one of the reason that disease pest unable to develop resistance against these phytopesticides since it requires several simultaneous mutations to acquire genetic constituents to overcome all active ingredients of botanical pesticides (Chomchalow, 1993). Phytopesticides are highly selective and therefore, effective against a specific pest species only, while other non-target species (*e.g.* beneficial insects and predators etc.) are not affected, thus minimizing the impact on natural environment. However some exceptions have been also reported. For example, neem seed extract has been reported to be effective against 200 species of insects, mites and nematodes, including major pests such as locust, rice and maize borers, pulse beetles (Chomchalow, 1993). Phytopesticides are reported to have very low mammalian toxicity except a few such products e.g. from *Derris* sp., tobacco, etc. Some extracts, for example neem seed does not harm birds and beneficial insects such as bees (Chomchalow, 1993). Phytopesticides are commonly applied as extracts, suspensions in water base, spray formulation etc. Various additives as anivaporants, pH regulators and other ingredients are used in the spray formulation. The spray formulations are atomized into drops by conventional nozzles producing various drop - size spectra (Boving *et al*, 1971). The research and development cost and the time required for the discovery of phytopesticides is much lesser as compared to chemical pesticides. The raw materials for the production of phytopesticides are the agro-byproduct and plants, which are affordable and production technology is relatively simple. Therefore phytopesticides are much cheaper than chemical pesticides.

Inspite of so many benefits of phytopesticides, they have some limitations as well. Phytopesticides have a short shelf life and must be used soon after preparation. Normal self-life of botanical pesticides is ranged from one week to one day only, if not stabilized by chemical process (Chomchalow, 1993). Some active ingredients of certain phytopesticides may also be lost during production and processing while over crude process. The effectiveness of these active ingredients may also be lost due to lack of quality control, short self-life and low concentration of active ingredients. Therefore, the claim for effectiveness in certain cases may not exist up to their promising level. Availability of raw materials in large scale and imbalance among the production, demand and market availability are some common constrains of botanical pesticides.

CONCLUSION

Utilization of botanical pesticides in agriculture and plantation forestry is now emerging as one or the prime means to protect crop produce and plantations to save the environment from pesticidal pollution. They are preferred over chemical pesticides on account of their low mammalian toxicity, no hazards to environment and human health. To fulfill the demand of food for ever-growing population, agricultural productivity enhancement is essential; hence use of pesticides seems to be indispensable. However use of harmful chemical pesticides should be managed in such a way that it will not pose any serious threat to environment and human life (Fig. 1). Moreover, plant products from diverse plant genetic resources of tropical & sub – tropical countries must be formulated and their shelf-life, thermal and phytolytic activity must be evaluated for developing more effective biopesticides.

Table30: Botanical with their probable active chemical constituents responsible for Insecticidal, Herbicidal, Fungicidal & other pesticidal activities

S. No.	Plant species	Common Names	Plant part used	Probable active chemical constituents (s)	Biological activity
1.	*Abies balsamea*	Balsam fir	Leaves	Juvabione, dehyojuvabione	Hormonal (JH)
2.	*Aconitum ferox*	Indian Aconite, Bishnag	Whole plant	Psuedaconitine, chasmaconitine, indaconitine, bikhaconitine & diacetyl pseudaconitine	Aphicidal, toxic to beetles
3.	*Acorus calamus*	Bachh	Leaves	Trans - asarone, cis - asarone, isoasarone	Repellent, antifeedant
4.	*Adhatoda vasica*	Adusa	Leaves	Vasicine, vasicinone, vasicinol, limonene,	Insecticidal, antifeedant
5.	*Aegle marmelos*	Bael/ Bilva	Essential oil from leaves	Limonene, α pinene, sabinene, ocimene and p -caryophyllene	Feeding deterrence, fungicidal
6.	*Allium sativum*	Wild Pyaj	Bulbs	Diallyl di-sulfide, diallyl tri-sulfide	Insecticidal
7.	*Allium cepa*	Pyaj	Bulbs and leaves	Quercetin & phenolic compounds	Insecticidal
8.	*Andrographis paniculata*	Kalmegh	Leaves	Andrographolide	Insecticidal

9.	*Anethum sowa*	Dill	Seeds, leaves, stem	Carvone, dillapiole	Insecticidal
10.	*Anacardium occidentale*	Kaju	Cashew nut shell oil	Phenolic constituents	Insecticidal
11.	*Annona reticulata*	Ramphal	Roots, stems, leaves, seeds	Anonaine, liriodenine, reticuline, norushinsunine	Insecticidal
12.	*Annona squamosa*	Sharifa	Fruit & Seed Exts.	Annonacin, annonin, Annonelliptine, asimicin, annonidines	Antifeedant, repellent
13.	*Aquilaria malaccensis*	Agar-wood	Agarwood dust	α- guaiene, caryophellene oxide, eudesmol	Protection, repellent
14.	*Argemone maxicana*	Satyanashi	Leaves	Protopine nitrate, Berberine nitrate, Ceryl alcohol, β-sitostero	Protection
15.	*Artemisia vulgaris*	Mugwort	Leaves	1,8-cineole, camphor and α-terpineol	Repellent, insecticidal
16.	*Artemisia capillaris*	Seeta-bani	Leaves	Bornyl acetate, capillarin, capillen	Feeding deterrent
17.	*Azadirachta indica*	Neem	Leaves and diff. parts	Limonoids, azadirachtins, salanin, nimbin	Insecticidal, Hormonal (JH), antifeedant, multifacial
18.	*Bambusa arundinacea*	Bamboo	Fresh & young shoots	Benzoic acid, cyanogenic glucoside	Insecticidal
19.	*Bixa orellana*	Latkan, Annatto	Seed coats	Bixin	Repellent
20.	*Brassica comprastis*	Sarson	Seeds	2- Phenylethyl isothiocyanate	Fecundity reducing
21.	*Butea monosperma*	Palash	Flowers	Chalcones and Aurones	Termicide
22.	*Caesalpinia crista*	Latakaranja	Seeds	Karajin, fatty acids	Antifeedant, insecticidal, repellant
23.	*Calotropis procera*	Aak	Leaves	Latex containing poisonous constituents	Antifeedant
24.	*Camellia spp.*	Camellia	Leaves	Shikinic acid, caeffin & tannins	Insecticidal, repellent
25.	*Cannabis sativa*	Bhang	Leaves	Resinoid tetrahydrocannabinol, a phenolic type substance	Protectant
26.	*Capsicum frutescens*	Lal mirch	Fruits	Capsaicin	Insecticidal
27.	*Carica papaya*	Papaya	Leaves	Carpaine	Insecticidal

28.	*Cassia nigricans*	Cassia	Leaves	Emodin	Insecticidal
29.	*Cassia occidentalis*	Chakunda, Kasonda	Leaves	Emodin	Insecticidal
30.	*Cassia alata*	Dadmurdan	Seeds	Cassiaxanthone, kaempferol and its glycosides, aloeemodin, chrysophanol, isochrysophanol, β – sitosterol rhein physicion – 1-glucoside	Meamorphosis inhibitor
31.	*Cassia tora*	Charota	Leaves	Chrysophanic – 9 - anthrone	Antifeedant
32.	*Catharanthus roseus*	Sadabahar	Whole plant	Several alkaloids	Insecticidal, Antifeedant
33.	*Chenopodiun anthelminticum*	Chenopodium	Seeds	Essential oil having ascaridole	Insecticidal
34.	*Chrysanthemum spp.*	Guldaudi	Flowers	Pyrethrins I & II, cinerins I & II, and jasmolins I & II	Antifeedant
35.	*Cinchona officinalis*	Cinchona	Bark	Quinine, quinidine, cinchonine & cinchonidine	Insecticidal
36.	*Cinnamomum camphora*	Kapur	All parts of tree	Camphor oil	Insecticidal
37.	*Citrus limon*	Nimbu	Leaves and fruits	Limonin, nomilin, obacunone	Antifeedant, toxicant
38.	*Citrus spp.*	Nimbu	Leaves, twigs & peels	Citropin, dl- limonens, linalool, glucosides, acids, terpenes etc.	Insecticidal
39.	*Cymbopogan spp.*	Nimbu ghas	Leaves	γ – cardiaene, elemicin, citral	Insecticidal, repellent
40.	*Curcuma longa*	Haldi	Turmeric powder	Curcumene, Termerone, dehydro-termerone, α- phellandrene	Repellent, protectant
41.	*Curcuma longa*	Turmeric	Essential oil from leaves	α-Phellandrene	Growth inhibition and larval mortality
42.	*Datura metel*	Datura	Leaves	Hyoscine	Antifeedant
43.	*Derris elliptica*	Derris	Roots	Rotenone and dihydrorotenone	Insecticidal
44.	*Eucalyptus hybrid*	Safeda	Leaves	1,8 - Cineole, α-phellandrene, linalyl isovalerate, isoamyl isovalerate etc.	Antifeedant
45.	*Eucalyptus globulus*	Blue Eucalyptus	Leaf ext.	1,8 - Cineole, caryophyllene, globul ol, α-phellandrene, β-	Protection

				eudesmol etc.	
46.	*Eucalyptus rostrata*	Murray red gum	Leaves	1,8 - Cineole, α-phellandrene etc.	Anti-Fecundity
47.	*Euphorbia antiquorum*	Tridhara	Latex	Latex contains 4.0 – 6.4 % caoutchouc	Antifeedant
48.	*Foeniculam vulgare*	Moti Saunf	Leaves	Fenicularin	Repellent
49.	*Ginkgo biloba*	Balkuwari	Leaves	Salicylic acid derivatives, bilobalide, ginkgolide – A and B	Feeding detterent
50.	*Glycine max*	Soybean	Leaves	Glyceollins, daidzein	Antifeedant, toxicant
51.	*Hydrocarpus spp.*	Calmogara , Jangli badam	Seeds	Hydnocarpic acid, Chaulmoogric acid, Gallic acid & other fatty acids	Repellent, oviposition reducer
52.	*Ipomea carnea*	Behaya	Leaves	Essential oil having alantolactone	Insecticidal
53.	*Jatropha carcus*	Ratanjot	Leaves and seeds	Isovitexin, vitexin, β – sitosterol Curcine, curcasin, fatty acids etc.	Protectant, repellent
54.	*Lantana camera*	Raimuniya	Leaves	Caryophyllene, cineol and β - pinene	Protectant
55.	*Lawsonia inermis*	Mehandi	Leaves	Tannin, saponin, anthraquinone flavonoids, glucosides and alkaloids	Antifeedant
56.	*Lycopersicon hirsutum*	Jangli Tamatar	Leaves	2-tridecanone, trans - caryophyllene	Repellency, toxicity
57.	*Melia azedarach*	Bakain	Leaves	Tetraterpenoids, toosendanin, meliandiol, melianone, meliantriol, nimbolidin A, volkensin	Antifeedant, ovipositon deterrent, antifertility, toxicant
58.	*Mentha spicata*	Pudina	Flowering tops	Cineole, carvone, caryophyllene, menthol	Antifeedant, toxicant
59.	*Moringa oleifera*	Senjana	Leaves	Niazirin, niazirinin	Growth inhibitor
60.	*Nerium oleander*	Kaner	Leaves	Cardiotonic, oleandrin, neridin	Inhibit oviposition
61.	*Nicotiana tabacum*	Tambaku	Seeds	Nicotine, nornicotine, anabasine	Insecticidal, antifeedant
62.	*Ocimum basillicum*	Ram Tulsi	Leaves and seeds	Juvocimene I, II, linalool, methyl chavicol, eugenol,	Antifeedant, toxicant

				methyl eugenol, geraniol, geranial, neral	
63.	*Ocimum sanctum*	Tulsi	Leaves, seeds	Linalool, chavicol, eugenol, eugenol methyl ether, cineole, caryophyllene	Insecticidal, repellent
64.	*Parthenium hysterophorus*	Gajar ghas	Whole plant	Parthenin, 1,8-cineole, coronopilin	Feeding deterrent, growth inhibitor
65.	*Piper nigrum*	Kali Mirch	Fruits or seeds	Piperine, piperitine	Insecticidal, repellent
66.	*Plumbago zeylanica*	Chitrak	Roots and leaves	Pumbagin, juglone	Antifeedant, repellent
67.	*Pongamia pinnata*	Karanj	Leaves	Karanjin	Insecticidal, aphicidal
68.	*Pidium guajava*	Amrood	Leaves	β- sitosterol, maslinic acid, guijavalic acid	Insecticidal, repellent
69.	*Ricinus communis*	Arandi	Leaves and seeds	Ricinine & fatty acids	Repellent
70.	*Sapindus mukorossi*	Ritha	Seeds	Saponins	Insecticidal
71.	*Sesamum indicum*	Safed til	Roots	Fatty oil contains sesamin, sesamolin, sesangolin etc.	Antifeedant
72.	*Tagetes minuta*	Genda	Flowers	Tagetes oil having terthienyl - (2,2',5',2''-terthiophene), E-ocimenone	Larvicidal, repellent
73.	*Tephrosia purpurea*	Sharpunkh a	Roost & seeds	Ratenoids	Insecticidal
74.	*Tephrosia vogelii*	Fish bean	Leaves	Ratenoids	Insecticidal
75.	*Vinca rosea*	Sadabaha	Leaves	Toxic alkaloids & Phenolics	Repellent
76.	*Vetiveria zizanioides*	Khas	Roots	Vetiver oil having β- vetivene, azulene, zizanene leavojujenol etc.	Growth disrupter, repellent
77.	*Vitex negundo*	Nirgundi	Leaves & seed	Rotundial	Repellent, insecticidal
78.	*Zanthoxylum monophyllum*	Yellow Prickle	Bark	Zanthophylline	Feeding deterrent
79.	*Zanthoxylum monophyllum*	Yellow Prickle	Fruits	Essential oil having 1,8 - cineole,*trans* - sabinene hydrate and *cis* - sabinene hydrate	Insecticidal
80.	*Zinziber officinale*	Adrak	Rhizomes	Gingerdione, paradol,	Antifeedant,

				gingerol, shogaol	growth inhibitior

Source: Subramaniam, 1993, Tripathi, 1998, Kulkarni, 2001 and Dhaliwal & Koul, 2007

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