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Review

The potential of secondary metabolites in plant material as deterents against insect pests: A review

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The potential of using plant material as deterrent against pest in crops, on the field and during post-harvest period, is a study that is presently gaining acceptance as a result of the indiscriminate use of chemical pesticides which has given rise to many well-known problems, including genetic resistance of pest species, toxic residues in stored products, increasing costs of application, hazards from handling and environmental pollution. This paper explores the anti-feedant properties of some of these plants and also discusses the advantages and disadvantages of using anti-feedant compounds isolated from plant material.

Key words: Secondary metabolites, plant material, deterrent.

INTRODUCTION

Plants were first recorded as being used against biting insects by the ancient Greeks and are still used by enormous number of people today as biopesticides. The use of plant and plant-derived products to control pests in the developing world is well known and prior to the discovery of synthetic pesticides, plant or plant-based products were the only pest-managing agents available to farmers around the world (Owen, 2004). Biopesticides are a group of naturally occurring, often slow-acting protecting agents that are usually safer to humans with minimal residual effects to the environment than conventional pesticides. Biopesticides can be biochemical or microbial. Biochemical pesticides include plant-derived pesticides (botanicals) that can interfere with the growth, feeding or reproduction of pests or insect pheromones applied for mating disruption, monitoring or attract-and-kill strategies.

The pool of plants possessing insecticidal substances is enormous. These have generated extraordinary interest in recent years, as potential sources of natural insect control agents. Today over 2000 species of plants are known that possess some insecticidal activity (Jacobson, 1975, 1989). Insect pest management is facing the economic and ecological challenge worldwide due to the human and environmental hazards caused by majority of the synthetic pesticide chemicals. Identification of novel effective insecticidal compounds is essential to combat increasing resistance rates. Botanicals containing active insecticidal phytochemicals, appear to be promising to address some of these problems. Therefore, there is a continuous need to explore new active molecules with different mechanisms of action. Secondary metabolites present in plants apparently function as defense (toxic), which inhibits reproduction and other processes (Rattan, 2010).

Though, over the last fifty years, insect pests have mainly been controlled with synthetic insecticides. There are problems of pesticide resistance and negative effects on non-target organisms, including man and the environment, hence negating the wide spread acceptance of the use of these synthetic compounds. The indiscriminate use of chemical pesticides has given rise to many well-known and serious problems, including genetic resistance of pest species, toxic residues in stored products, increasing costs of application, hazards from handling, environmental pollution and so on (Rembold, 1994; FAO, 1992). The botanical insecticides are generally pest-specific and are relatively harmless to non-target organisms including man. They are also biodegradable and harmless to the environment.

Furthermore, unlike conventional insecticides which are based on a single active ingredient, plant derived insecticides comprise an array of chemical compounds which act concertedly on both behavioural and

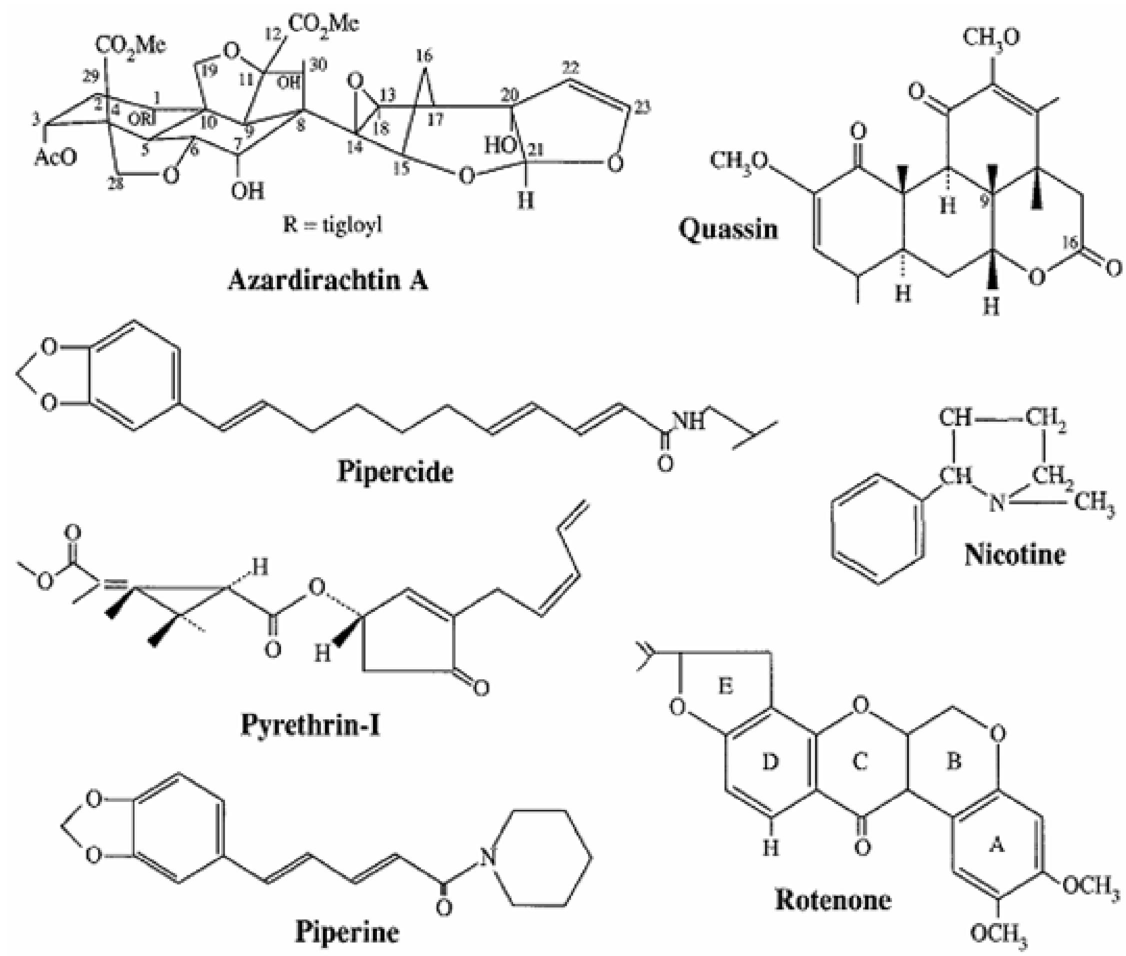

Figure 1. Secondary plant compounds of selected plants.

physiological processes. Thus the chances of pests developing resistance to such substances are less likely (Saxena, 1987; Schery, 1954).

Plant-derived insecticides

Plant-derived insecticides definitely have great potential for the natural control of insect pests, particularly in tropical countries like Papua New Guinea, Nigeria, etc. Currently, more than 860 plant species with insecticidal properties, mostly originating from the Tropical rain forest, have been identified, as well as 150 plant species with compounds effective against nematodes, beetles, rodents, mites and molluscs. The significance of these plant genetic resources, as potential insecticides becomes evident when looking at the perspective of an increasing number of insects, showing resistance against chemical insecticides.

Finally, the use of local resources for the manufacture of plant-derived insecticides, could make a developing country like Nigeria more independent of pesticide imports and furthermore, be of potential economic value. Plant-derived insecticides are certainly able to replace chemical insecticides to a greater extent in small-scale agricultural and agro forestry systems; presently, their use for large-scale agricultural and forestry plantations is being looked into. Plant-derived insecticides contain natural insecticides, deterrents or repellents that belong to various groups of chemicals such as alkaloids, rotenoids and pyrethrins. Some of these compounds are shown in Figure 1.

The Neem tree *Azadirachta indica*, belonging to the family Meliaceae originating from the Indian subcontinent, is a well known example of one of the plants with potential to serve as an anti-feedant against insects and pests. Other examples include *Detarium microcarpum*, *Sclerocarya birrea*, *Piper guineense* as seed protectants for maize (*Sitophilus zeamais*), *Cassia nigricans* Vahl oil and the plant as grain protectants of stored wheat weevil, *Tribolium casteneum*, as well as containing biologically active compounds, that may serve as candidates for new formulations in the treatment and prevention of livestock diseases and pest management (Ayo, 2010); *Lantana* *camara* as grain protectants of cowpea seeds *Causus maculates* (Schery, 1954; Champagne et al., 1989).

Although this information has been available for hundreds of years, scientific investigations to determine the parts of the plants and trees which have toxic activity against insects or the mode of action of the active substances are limited.

What are anti-feedants?

These are substances that reduce consumption (feeding) by an insect (N.B the terms anti-feedant and feeding deterrent are used synonymously). They are behaviour modifying substances that deter feeding, through a direct action on peripheral sensilla (= taste organs) in insects (Isman, 2002). This definition excludes chemicals that suppress feeding by acting on the central nervous system (following ingestion and absorption) or a substance that has sub-lethal toxicity to the insect. Anti-feedant activity is generally demonstrated through laboratory bioassays, consisting of either choice or non-choice tests conducted over a short duration, using standard binary leaf disc choice tests or wafer disc choice tests.

Many well documented insect anti-feedants are triterpenoids. Based on a 30-carbon skeleton, these substances often occur as glycosides (conjugated with sugars) and are often highly oxygenated. Especially well studied in this regard are the limonoids from the neem (*A. indica*) and chinaberry (*Melia azedarach*) trees, exemplified by azadirachtin, toosendanin and limonin from *Citrus* species.

Other anti-feedant triterpenoids include cardenolides, steroidal saponins and withanolides. Several types of diterpenes (based on a 20-carbon skeleton) are well known as antifeedants, including the clerodanes and the abietanes. Sesquiterpenes (15-carbon skeleton) with potent anti-feedant action include the drimanes, e.g. drimane polygodial, which occurs in foliage of the water pepper, *Polygonum hydropiper* and the sesquiterpene lactones. Monoterpenes (based on a 10-carbon skeleton) which are major constituents of many plant “essential oils” deter insect feeding. Among the plant phenolics, the best known antifeedants are the furanocoumarins and the neolignans. Alkaloids with well documented anti-feedant effect on insects include certain indoles and the solanaceous glycol alkaloids. Specific examples of well documented anti-feedants from plants are listed in Table 1 with the structures of some of these compounds in Figure 1.

Potential uses of anti-feedants

The simplest method of using an antifeedant as a crop protectant is to apply it as a water or oil-based spray, in the same manner used to apply an insecticide. However, apart from neem products, there are few actual demonstrations of antifeedant efficacy in the field. John Pickett and collaborators at the IARC-Rothamsted, have shown that application of polygodial or methyl salicylate, resulted in reduced aphid populations with concomitant increase in yields of winter wheat, in one case comparable to that achieved with the pyrethroid insecticide cypermethrin (Picket et al., 1997; Griffiths et al., 1991).

Given that many anti-feedants do not kill pests outright and even their behavioural effects may be ephemeral under field conditions, their utility may ultimately depend on deploying them with more creative strategies. For example, investigation of the joint effects of an antifeedant, leaf extract of *Ajuga* spp. and the Insect Growth Regulator [IGR] teflubenzuron, on the mustard beetle, *Phaedon cochleariae* and larvae of the diamondback moth, *Plutella xylostella,* feeding on mustard plants led to the observation that the anti-feedant, suppressed beetle and caterpillar feeding for several days but with minimal mortality after two weeks whereas the IGR did not prevent feeding in the first 48 h after application but did kill all beetles and larvae after two weeks.

In applying the two protectants in combination, foliar consumption was reduced by at least 50% and pest mortality was greater than 75%. As the tender, upper leaves are more valuable than the older, lower ones, leaf damage can be better tolerated on the lower leaves. With that in mind, the investigators utilized the two protectants in an even more intriguing manner. They sprayed the upper parts of mustard plants with the anti-feedant and the lower parts with the IGR. Under this treatment regime, beetles were quickly driven to the lower leaves where they came in contact with the IGR. The result was virtually no damage to the upper parts of the plants and modest damage to the lower portions but with complete mortality of beetles, using a reduced amount of the insecticide (Griffiths et al., 1991).

Prospects for commercial use

Given the aforementioned limitations to the use of insect antifeedants, namely differences in response between pest species, potential desensitization of pests and rapid environmental degradation, it is most unlikely that an anti-feedant will emerge with sufficient field efficacy, to act as a stand alone crop protectant.

Presently, research effort includes the use of Integrated Pest Management [IPM] Techniques and Green Pesticides Technology [GPT]. The use of Integrated Pest Management [IPM] tactics including physical, biological and selective chemical control, has gained prominence in recognition of the concept of co-evolution between herbivorous insects and their host plants, as well as its practical implications. IPM also promotes the search and

Table 1. Some examples of potent insect anti-feedants isolated from terrestrial plants.

Chemical type	Compound	Plant source
Monoterpene	Thymol	*T. vulgaris* (Lamiaceae)
Sesquiterpene	lactone (germacranolide type) Glaucolide A	*Vernonia* species (Asteraceae)
Sesquiterpene (drimane type)	Polygodial	*P. hydropiper* (Polygonaceae)
Diterpene (abietane type)	Abietic acid	*Pinus* species (Pinaceae)
Diterpene (clerodane type)	Ajugarin I	*A. remota* (Lamiaceae)
Flavonoid	Quercetin	*B. madagascariensis* (Caesalpiniaceae)
Triterpene (limonoid type)	Azadirachtin	*A. indica* (Meliaceae)
Triterpene (cardenolide type)	Digitoxin	*D. purpurea* (Scrophulariaceae)
Triterpene (ergostane type)	Withanolide E	*W. somnifera* (Solanaceae)
Triterpene (spirostane type)	Aginosid	*A. porrum* (Liliaceae)
Alkaloid (indole type)	Strychnine	*S. nuxvomica* (Loganiaceae)
Alkaloid (steroidal glycoside)	Tomatine	*L. esculentum* (Solanaceae)
Phenolic (furnanocoumarin)	Xanthotoxin (= 8-methoxy psoralen)	*P. sativa* (Apiaceae)
Phenolic (lignan)	Podophyllotoxin	*P. peltatum* (Berberidaceae)
Phenolic (benzoate ester)	Methyl salicylate	*G. procumbens* (Ericaceae)

utilization of natural active principles (insecticides, repellents, attractants, etc.) which could be helpful in dealing with insect pests of crops and forest plantations.

The concept of “Green Pesticides” is also one that is gaining a lot of attention presently. It refers to all types of nature-oriented and beneficial pest control materials, which can contribute to reduce the pest population and increase food production. They are safe and ecofriendly. They are more compatible with the environmental components than synthetic pesticides (Isman and Machial, 2006). It involves the development of green pesticide technology, using oil-in-water micro-emulsions as a nano-pesticide delivery system to replace the traditional emulsifiable concentrates (oil), in order to reduce the use of organic solvent and increase the dispersity, wettability and penetration properties of the droplets. (Koul et al., 2008). These are some of the areas in which effort is geared presently, to ensure maximum production and yield in food supply while reducing the insect infestations usually observed.

Though, there are insect anti-feedants with minimal bioactivity in mammals and other non-target organisms available on a commercial scale, there are likely specific crop-pest combinations where an anti-feedant can play a significant role, as part of an integrated pest management system. Whether the market(s) for such a specific protectant can justify the costs of development, remains to be seen. Ongoing research work into insect sensory systems, neuro-pharmacology, and organic chemistry may ultimately mitigate the limitations to antifeedants observed at present and lead to a suite of new crop protectants, based on deterrence of insect feeding and oviposition in the nearest future.

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