PEST CONTROL: INSECTS AND OTHER ARTHROPODS

Divender Gupta
Department of Entomology, Dr. Y.S. Parmar University of Horticulture & Forestry, Nauni (Solan), India

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Summary

Insect pests and mites account for 15% loss of our agricultural produce out of a total of 40% caused by various pests. Initially, for their control, insecticides of plant origin were mainly in use. Later, inorganic insecticides came into the scene, but these declined with the advent of synthetic organic insecticides, which started with the discovery of the insecticidal properties of DDT. Within few years of their use, however, their detrimental effects on human health, other organisms, environment and problem of resistance necessitated the exploration of alternate methods like biological control, cultural control, use of semiochemicals, IGR's, novel insecticides etc. Every method has its advantages and disadvantages and individually none of them is equivalent to insecticides in effectiveness, at least in most situations. But in combination they can help in reducing pesticide use and protecting the environment.

1. Introduction

Insects came on this earth about 250 million years ago, whereas human beings appear only one million years back, so in the real sense, human beings are competitors of insects and not the reverse. But as the human being sits at the top of the evolutionary ladder, his life is effectively superior to that of any other organism, and in that sense, the insects become competitors. A pest is an organism whose activity causes it to be inimical to the welfare of humans. Of the approximate total of 8 million insects, roughly 2% constitute the pests, is the remainder being either useful or harmless. But these 2% insects are responsible for a crop loss of 10-15%. World food and fiber losses caused by pests (principally insect pathogens and weeds) are estimated to be about 40% of which 15% are attributable to insects and mites.

Well before 2500 BC, the Sumerians were using sulfur compounds to control insects and mites. By 1200 BC, botanical insecticides had been used for seed treatments and as fungicide in China. The earlier insecticides were mainly of plant origin, namely nicotine, pyrethrum, rotenone etc, which acted as nerve or respiratory poisons. But due to their poor availability and photolabile nature, which made them expensive, as they have to be used repeatedly, they could not make much impact.

2. Insecticidal control

In the real sense, the channel for the control of insect pests was opened in the second half of the nineteenth century (1865) when an inorganic human poison, paris green (copper aceto arsenite) was successfully sprayed against the Colorado potato beetle, *Leptinotarsa decemlineata,* which devastated the potato crop by feeding on potato haulm. Later in 1892, another inorganic compound, lead arsenate was used against gypsy moth, *Lymantria dispar* in apple orchards in USA. The use of most of the inorganic insecticides have been discontinued due to their residual persistence, being a stomach poison and high mammalian toxicity except for few like boric acid, which is still used in baits against household insects like cockroaches.

Another group of insecticides consisted of petroleum oils, also known as mineral oils, which, though recommended as insecticide as early as 1763, were not used after the nineteenth century, as they were phytotoxic when applied as such. The irst emulsion of kerosene was made around 1868 that successfully controlled San Jose scale, *Quadraspidiotus perniciosus*. Since then they have become increasingly important. These oils flood the spiracles of insects and cause death due to asphyxiation. They are quite effective against aphids, mites, scale insects, mealy bugs, whiteflies etc., when used as summer sprays during the growth period. The summer oils are highly refined and have unsulfonated residue (UR) value above 90% and are available as emulsifiable concentrate (EC). Heavy and less refined oils are used as dormant sprays against scale, mite and insect eggs on deciduous trees during dormant season. Their UR value is less than 90% and if applied during growth stage cause phytotoximia. The oils are also used as mosquito larvicides by spreading them on the surface of water, thus blocking the respiratory tubes of larvae coming to the surface of water for breathing. They are quite effective against animal parasites, namely ticks, mites and fleas. Ease in handling, and no problem of resistance are points in their favor and they are therefore are still being used as effective acaricides, when mites defy other control measures. Summer oil is the most widely used acaricide in USA. The main problem with oils is lack of stability in storage.

The advent of organic insecticides began with synthesis of DDT by Zeidler in 1874 and discovery of its insecticidal properties by Paul Muller in 1939, which earned him a Noble Prize. DDT was first used to control malaria and typhus by western allies during World War II. Later, more organochlorine compounds like HCH and other cyclodienes were synthesized. They mainly act as axonic nerve poisons. These are stable compounds with long residual effect, readily soluble in lipids, with low rate of excretion from the body of mammals, in which the level of toxicity is low. These insecticides dominated the scene up to the 1960s, and at the peak of DDT use (1962) it was registered for use on over 300 agricultural commodities. Many of them like endosulfan and lindane are still in use.

Although organophosphorous compounds (OPs) and carbamates came after organochlorines, they were actually developed during the same period as organochlorine compounds. German scientists experimented with synthesis of OP compounds to replace nicotine, as it was in short supply. Three of the compounds viz. TEPP, Parathion and Schradan attributed to Gerhard Schradar, were subsequently used on a worldwide scale. The median entry year for OP compounds was 1965. OPs are esters of phosphoric acid which inhibit the enzyme AchE, leading to continuous firing of neurons, causing convulsion, tremor and death. They are biodegradable insecticides, which do not persist in the environment but are toxic to man and other vertebrates. These compounds are widely used in agriculture for control of insect pests including sap suckers, tissue borers and soil insects due to their varying mode of reaching the insect. Examples include malathion, methyl demeton, dimethoate, dichlorvos, trichlorfon and chlorpyriphos.

Biologically active carbamates were in use as long ago as the seventeenth century in the Calabar region of southeast Nigeria where crushed Calabar bean, *Physostigma vaninosum* was used as a poison to establish the guilt of the prisoner. If the accused survived he was declared innocent and if he died he was declared guilty. The synthetic carbamates were introduced in 1956 when Union Carbide in USA launched carbaryl, though the median entry year for these compounds was 1969. The carbamates are esters of carbamic acid and inhibit the enzyme AchE reversibly. They have short residual activity and broad-spectrum effectivity as insecticides, miticides and molluscicides. They have better safety records for humans due to the reversible nature of the inhibition. The common examples are carbaryl, carbofuran, phorate, methomyl, pirimicarb, propoxur etc. Carbaryl is widely used in public health, veterinary medicine and agriculture to kill a variety of insect pests, and, because of its low mammalian toxicity, dust formulations have been used on mammals to kill fleas and lice. Propoxur has been used as a house spray against mosquitoes, fleas, flies, ticks and cockroaches etc.

The other group known as pyrethroids are synthetic analogues of pyrethrin. All the pyrethroids are lipophilic compounds almost insoluble in water, and they resemble organochlorine compounds. They have high contact activity and are particularly effective against lepidopteran larvae. Pyrethroids are effective at low doses and are quite safe to human beings due to their very low mammalian toxicity. They act as axonic nerve poisons. The median entry year for pyrethroids was 1979. The first successful commercial pyrethroid, allethrin was introduced in 1949; this constituted the first generation of pyrethroids. It is very effective against flies and mosquitoes and is ideal for use in coils and mats for repellency and control. The second generation of pyrethroids consisted of dimethrin, tetramethrin, resmethrin and bioresmethrin but they also could not be used in agriculture as they decomposed in sunlight. From the early 1970s the most light-stable compounds like permethrin, cypermethrin, deltamethrin and fenvalerate were produced, constituting the third generation of pyrethroids. These products achieved wide application in agriculture. The fourth generation (1975-83) included cypothrin, which has achieved commercial status in animal health for tick control, fluvalinate against phytophagous mites, cyfluthrin against cotton insects and cyhalothrin introduced as ectoparasiticide. Their efficacy is so good that a dose of only 10-40g a.i/ha is required. A major limitation of synthetic pyrethroids is non-effectiveness against soil pests; however tefluthrin is effective against soil insects but is not persistent.

From the discovery of the insecticidal properties of DDT, synthetic organic insecticides revolutionized the concept of pest control. It started as a '**panacea**' and ended as an '**elixir of death**' with the publication of Rachel Carlson's "Silent Spring" in 1962, in which she castigated the use of insecticides, mainly organochlorines. In the early 1970s these compounds were severely restricted or banned in USA with varying levels of curtailment in other parts of the world. In India, DDT is banned for agricultural use but is still used against pests of medical importance. The reasons for the shift away from organochlorines were mainly onset of resistance, biomagnification, and pest resurgence.

At a global level, insect pests of medical, veterinary and agricultural importance have developed resistance to all major classes of pesticides. When arranged by chemical groupings, 58% of species showed resistance to cyclodienes, 52% to DDT, 52% to OP and 17% to carbamates, 9.5% to pyrethroids and less than 10% to miscellaneous groups which reflect the use of each type but also the relative persistence of the chemical in the environment. The residues of DDT can be found in almost every human being throughout the globe even after its banning in most parts of the world, the simple reason being accumulation in the food chain.

Insecticides, particularly the contact ones, severely affect natural enemies as they are generally free ranging and come into more frequent contact with insecticides than pests which often shelter under foliage. This results in flare-ups or resurgence problem. This can be understood from the well known example of use of DDT against codling moth *Cydia pomonella* in the 1940s, which killed predators of the spider mite *Panonychus ulmi*, whereas, eggs of the mite survived and the spider mite, which was once a pest of minor importance, became a major pest in apple orchards. The use of synthetic pyrethroids on cotton against borers resulted in outbreak of whitefly population in Andhra Pradesh, Gujarat, and Tamil Nadu states of India. Cypermethrin used for the control of *Helicoverpa armigera* in Alabama, USA led to outbreak of *Aphis gossypii* in cotton. Pyrethroids, though safe from the viewpoint of vertebrate toxicity, can be highly hazardous to breeding habitats of waterfowl and beneficial insects including bees.

The main effect of insecticides is on human life. It has been estimated that 3 million people die of acute poisoning cases caused by pesticides worldwide every year, out of which 2 million accounts for suicide attempts and the rest are occupational hazards. An eye-opening industrial disaster known as the “Bhopal Gas Tragedy” in the leaves of history, occurred at the Union Carbide Plant in Bhopal (India) in 1984, where carbaryl, the most widely used and safest carbamate, was manufactured. A leakage of an intermediate, methyl isocyanate gas (MIC) vapors from the unit killed about 5000 people, caused disability in 50 000 people and in total it affected 200 000 people. The long term teratogenic, carcinogenic and mutagenic effects are still being observed in the surviving population.

Detrimental effects of synthetic insecticides on health, environment and organisms, and the problem of resistance discussed above, have necessitated the exploration of alternate strategies for insect-pest control. The other strategies are discussed hereunder.

3. Biological control

Biological control aims at suppression of insect pests of crops and other harmful organisms by using their natural enemies. The natural enemies can be parasites, predators or pathogens. Of the insect bioagents, 67% belong to Hymenoptera, 16% to Coleoptera, 16% to Diptera, Hemiptera and Neuroptera together, and 1% to Odonata and Strepsiptera.

Biological control involves introduction of natural enemies, their augmentation and conservation. Introduction involves importation of a natural enemy from one environment to another in the hope that they will become established and the control will become self perpetuating. This is often called classical biological control. If need be, inundative releases can also be made. The technique has been successful in controlling pest species by importation of a species from another continent. The first well-documented case of biological control is of a mynah bird, *Acridotheres tristis*, which was introduced from India to Mauritius to consume locusts, in 1762. In California the control of cottony cushion scale, *Icerya purchasi*, which had developed resistance to all insecticides available at the time, was achieved by importation of a predatory coccinellid, *Rodolia cardinalis*, from Australia in 1888. This controlled the pest within 15 months of introduction. The demonstrable success led to the adoption of this method in Florida, Hawaii, South Africa and other countries including India. Woolly apple aphid, *Eriosoma lanigerum* has been controlled in the western Himalayas by introduction of a parasite *Aphelinus mali* from USA, and subsequently from Canada and USA. Introduction has been tried against 292 insect pests and 70 weeds, with substantial rate of success (40% against insect-pests, and 31% against weeds).

Augmentation includes all activities designed to increase the number and effectiveness of exotic and/or existing natural enemies. This can be done by inoculative or inundative releases. The inoculative releases are made once a year to re-establish a species of natural enemy, which is periodically killed in the area by unfavorable environmental conditions, and control is expected from progeny or subsequent generations and not from release itself. Inundative releases are liberations of large numbers of bioagents, which are often cultured in laboratories e.g. *Trichogramma* spp. an egg parasitoid. Inundative release of *Trichogramma* spp. against bollworms in cotton is very effective. Release of egg masses of a microlepidopteran, *Epiricania (Epipyrops) melanoleuca*, at a rate of up 500 000/ha, or 4000-5000 viable cocoons/ha is quite effective for control of sugarcane pyrilla, *Pyrilla perpusilla.* Mass rearing and release of predatory coccinellid *Cryptolaemus montrouzieri* was found to be quite effective against guava mealy bug, guava scale etc., in India.

A recent approach in augmentation is use of the tritrophic paradigm. It has been demonstrated that olfactory cues emanating from host plants also influence parasite/predator action on pests. This obviously increased the rate of parasitization and hence achieved successful biocontrol. Volatiles emitting from scales of *Helicoverpa armigera* and *Corcyra cephalonica* have been identified as hexatricontane—chemicals which increased activity of *Trichogramma chilonis*. These could be applied on crops to attract natural enemies, to increase parasitism.

Conservation involves manipulation of resident natural enemies, native and exotic, to increase their regulating capabilities by providing favorable conditions. From ancient times Chinese have been practicing augmentive control, by collecting ants from wild colonies of the tree nesting ant *Oecophylla smaragdina*, and placing them on citrus trees for control of various leaf feeding insects. Also, bamboo runways from tree to tree have been provided for easy movements of ants, and this practice is still used in Myanmar and part of China. Generally a host-specific parasitoid/predator is preferable but to make biocontrol self-perpetuating other insects as prey become a necessity. For example gypsy moth outbreaks occur only in forests without ground vegetation, as this supports many caterpillars of other species. These are used by parasites of the gypsy moth when the gypsy moth is scarce. The concept of banker plants can be used, which is simply the use of non-host plants e.g. cereal plants in cotton. Aphid pests of cereal crops will attack the cereals and not cotton, so maintaining populations of aphid natural enemies which are common to both. Strip cutting is another method of conservation. Selective pesticides and their need-based use maintain untreated refuges and help in conservation. Nematodes are best suited for control of soil inhabiting insects. About 50 species of nematodes live as parasites of various insect species. Juvenile stages of *Stenrnema* spp. and *Heterorhabditis* sp. are harmful against insects. *S. carpocaspae* and *H. bacleuupthora* have shown promise against codling moth, *Cydia pomonella.*

Besides insects and nematodes, there are certain vertebrates like fish, tadpoles and frogs etc., which devour large numbers of mosquito larvae. Certain birds also eat caterpillars, so by making bird perches in the cropping area, larval mortality can be increased. Gambusia fish have been used against mosquito larvae.

Sometimes, however, introduction of vertebrate biocontrol agents have caused problems. A classical example is the introduction of mongoose, *Herpestes auropunctatus auropunctatus* from India into Jamaica in 1877 to destroy rats in sugarcane fields. The introduction was successful for some time, but increase in the number of mongoose became a worse scourge than rats, as this carnivore destroys reptiles, small birds and poultry. This indirectly gave rise to insect problems particularly the sugarcane beetle on which the lizards feed.

The main advantages of biological control are permanence, environmental and human safety and absence of any resistance problem. But lack of instantaneous kill, limitation in use of pesticides particularly in situations where biocontrol is exclusively used against a particular insect, and the consumers' need for blemish-free fruit, are limiting factors for biological control.

3.1. Microbial control

It is a part of biological control, which refers to use of microorganisms or their products (toxin) for control of insect pests, by man. The important groups of pathogens are protozoa, bacteria, fungi and viruses, of which fungi act by contact infection whereas the others need to be ingested to be effective.

3.1.1. Protozoa

These are unicellular organisms. The most abundant and widespread genera affecting mosquitoes are *Amblyospora* and *Parathelohania.* Other genera include *Nosema, Pleistophora and Stempellia***.** Corn borer, *O. nubilalis* can be easily suppressed with *N. pyraustae*. *N. locustae* has successfully been used against grasshoppers in rangeland in western USA. The protozoans are obligate parasites and their mass production is very expansive.

3.1.2. Fungi

Approximately 700 species of fungi are pathogenic to insects. The life cycle of fungus begins with spore germination, penetration of the host cuticle by means of enzymes that breaks down chitin and protein, and multiplication within the haemocoel, resulting into death. The insect is virtually filled with fungus and spores then erupt through the exterior of the insect.

The first record of entomogenous fungus is that of *Metarrhizium anisopliae* infecting the wheat cockchafer, *Anisoplia austriaca* in USSR as far back as 1879. The product B10-1020 developed by Bayer is based on *M anisopliae* for the control of coleopteran pests of several ornamental crops. Another important genus is *Beauveria*, mainly *B. bassiana* and a product based on it 'Beauvericin' or 'Bouverin', which is used for controlling codling moth, *C. pomonella*, and potato beetle, *L. decemlineata* . *Verticillium lecanii* has been found effective against aphids and whiteflies.

The main problem with fungi is that they need humidity for generation of the spores. Secondly, use of microbials become difficult where fungicides are to be applied on the crops. Uses of oil-based fungal pathogen formulations hold great promise as water-based formulations evaporate rapidly. It has been observed that *B. bassiana* is 30 times more effective by topical application when formulated in vegetable oil than in water as oil spreads over the cuticle, which is lipophillic and penetrates into the articular membranes carrying spores to vulnerable part of the cuticle. Water-based formulations, on the other hand, run off and spores are lost.

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Biographical Sketch

Divender Gupta completed his postgraduate training in Entomology, in 1989 from Dr.Y.S. Parmar University of Horticulture and Forestry, Nauni (Solan) Himachal Pradesh, India. This university is situated in the northern part of the country and is the first of its own kind in Asia, dealing exclusively with different aspects of Horticulture and Forestry. He joined the All India Agricultural Research Services (ARS), administered by Indian Council of Agricultural Research (ICAR), in 1989, and served for few months before returning to Nauni in 1990. He is presently working as an Entomologist in the Department of Entomology and Apiculture and is engaged in teaching (both at undergraduate and postgraduate level) and research, mainly on fruit and vegetable crops.