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Biopesticides: Ecofriendly and biorational alternatives to vegetable production and environmental sustainability

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Abstract

Insect pests, nematodes and plant diseases of vegetables are generally controlled by frequent applications of chemical pesticides with an objective to increase crop productivity and obtain greater profit in conventional farming. With consumers' awareness and perception, vegetables without residue of chemicals are being preferred in local and export markets. For this purpose, plant-derived crude products or formulated pesticides can be eco-friendly, effective and economical for an average producer. Several pressures have accelerated the search for more environmentally and toxicologically safe and more selective and efficacious pesticides. Biopesticides, including microbial pesticides, entomopathogenic nematodes, baculoviruses, plant derived pesticides, and insect pheromones are receiving increased exposure in scientific annals as alternatives to chemical pesticides and also as key components of integrated pest management (IPM) systems. The reality, however, is that biopesticides currently represent only a small fraction (1.3%) of the world pesticide market. However, the growth rate for biopesticides over the next 10 years has been forecast at 10–15% per annum in contrast to 2% for chemical pesticides. It is imperative to make aware the farming community regarding the use of biopesticides to reduce the environmental pollution.

1. Introduction

One of the major strengths of Indian agriculture is the potential for growing a wide range of vegetables, spices and plantation crops. In fact, India is one of the leading horticultural nations of the world. In the last one decade, export potential of horticultural crops has significantly increased attracting even multinationals to venture into olericulture, processing and value added products. In both the internal and export markets, consumers expect residue free products. However, insect, mite, nematode pests and a host of diseases collectively form a major constraint in quality production of horticultural products. Due to greater susceptibility towards insects, it becomes hard to achieve the maximum yield potential. Insect pests are responsible for reducing about 40% yield in vegetables (Singh *et al* 2000). In order to control these pests and diseases, farmers resort to indiscriminate use of chemical pesticides, which are often harmful.

Application of chemical pesticides during flowering lead to destruction of natural enemies, pollinators and honey bees, human/cattle poisonings; biomagnification and accumulation in non-target niches, deleterious effects on wildlife; development of resistant; secondary pest outbreak, pesticide residues and soil and water pollution. Indiscriminate use of pesticides has led to resurgence of sucking pests like leaf hoppers, white flies and mites. Besides, a few pests like fruit borer, *Helicoverpa armigera* on tomato, diamondback moth, *Plutella xylostella* on cabbage and cauliflower, are difficult to control even with repeated pesticide applications. Spraying the canopy of horticultural crops can result in large scale environmental pollution, mortality of bees, and other pollinators and birds besides animal and human health problems. High levels of pesticide residues (Awasthi, 1998) have been detected in cabbage, cauliflower, tomato, capsicum, leafy greens, okra & brinjal (Table 1).

Biopesticides

In view of the harmful effects of chemical pest control, several alternatives have been explored to limit the activities of insect pests. Biopesticides includes botanicals and microbials. Neem leaves had been kept by people in India in their beds, books, grain bins, cupboards and closets since thousands of years to keep away the troublesome insects. In a broader sense, biopesticides include pesticides of biological origin. There is no unanimity in the definitions of biopesticides, which vary from a very narrow to a very wide scope. For example, some workers interpreted biopesticides as simply the plant derived substances. Similarly, others defined biopesticides as preparations or formulations manufactured to be used in the control or eradication of pests, weeds or disease organisms in which the active ingredient or principle is based on a living microorganism or is derived from one without significant purification or modification. These narrow definitions stand in contrast to the wider one which includes all organic substances having a protective effect on plants, whether found in nature or chemically synthesized.

Table 1: Pesticide contamination level in vegetables

Vegetable	Sample with residue (%)
Potato	45.6
Tomato	51.5
Brinjal	51.7
Chilli	74.0
Cabbage	48.1
Cauliflower	61.0
Okra	58.0
Beans	78.1
Onion	33.3
Gourds	92.3
Leafy vegetables	96.4

Source: Awasthi (1988)

The term biopesticides refers to encompass many aspects of pest control such as microbial, entomophagous nematodes, plant derived pesticides, secondary metabolites from microorganisms, pheromones and genes used to transform crops to express resistance to pests. More recently, the encouragement of natural enemies (parasitoids, predators, microbes etc.) and the use of transgenic crop varieties, pheromones, growth regulators and plant derived materials via pest management, has been considered to constitute the biopesticides umbrealla (Koul *et al* 2003).At present world biopesticide market accounts for little over 1% (US $ 350 million) of total pesticide market and it is expected that in the next decade growth rate of these biopesticides will reach to 10-15% per annum as against 2% for chemical pesticides.

Botanical pesticides

In their simplest form, botanical pesticides may be crude preparations of plant part to ground to produce a dust or powder that may be used full strength or diluted in carrier such as clay, talc or diatomaceous earth. Only slightly more sophisticated are water extracts or organic solvent extracts of insecticidal components of plants. The most processed forms of botanical pesticides are purified insecticidal compounds that are isolated from plant materials by a series of extraction and distillations.

The most important thing that goes in favour of botanicals is their wide spectrum against target pests. This implies that with the use of a single botanical insecticide, we can control many pests. For example pyrethrum can be used against aphids, leafhoppers, spider mites, cabbage worms, bugs, Mexican bean beetles, flies, similarly rotenone can be used against loopers, Colorado potato beetle, Mexican bean beetle, Japanese beetle, aphids, fleas, mites, cabbage worm. Over the years, more than 6000 species of plants have been screened and more than 2500 plant species belonging to 235 families were found to posses biological activity against various categories of pests. Although very few reports have been documented from India for the use of botanical pesticides but there is still much scope for these pesticides to be included in IPM practices These botanical pesticides which are used worldwide for controlling the insect pests (Table 2).

Table 2: World Scenario of Botanical pesticides in pest management

Insecticides	Use against
Pyrethrum	Aphids, Leafhoppers, Spider mites, cabbage worms, bugs, Mexican bean beetles, flies
Rotenone	Loopers, Colorado potato beetle, Mexican bean beetle, Japanese beetle, Aphids, Mites, Cabbage worm
Ryania	Aphids, Corn ear worm, Oriental fruit moth, Onion thrips
Sabadilla	Armyworm, stink bug, Cucumber beetle, Leafhoppers, Cabbage loopers, Blister beetle
Neem (Azadirachtin)	Whitefly, Aphids, Leafhoppers, Rice leaf folder, Diamond back moth, Spotted bollworm, Stored grain pests

Neem

Derived from the neem tree (*Azadirachta indica*), this contains several chemicals, including 'azadi' rachtin', which affects the reproductive and digestive process of a number of important pests. More than 140 compounds (chemically diverse and structurally complex) have been isolated from the leaves, bark and kernels of neem plant. Recent research carried out in India and abroad has led to development of effective formulations of neem, which are being commercially produced.

Varaprasad *et al* (2006) proved that oil cakes, neem and *Simarouba glauca* @ 2.5 and 5 ml/kg soil, affect plant growth parameters and the root-knot nematode. *Meloidogyne javanica* build-up were studied under pot culture experinments in tomato and brinjal.Soil application of castor and neem cake was found superior to other treatments in tomato and brinjal respectively. Leaf blight diseases of onion caused by *Alternaria palandii* has become the main disease in Inidia. A few formulations were evaluated out of which Palmarosa oil were found effective for controlling disease (Karthikeyan *et al* 2006).

Microbial Pesticides

i) *Bacillus thuringiensis (Bt). Bacillus thuringiensis* is the most commonly used biopesticide globally. It is primarily a pathogen of lepidopterous pests which are some of the most damaging insects. When ingested by pest larvae, *Bt* releases toxins called delta endotoxin, which damage the mid gut of the pest, eventually killing it. The delta endotoxins (cry proteins) work in only alkaline medium, thus do not harm human beings who have acidic medium in the midgut. Bt based pesticides are being marketed by three companies in India. The total sale in 1999 was about 70 tons.

ii) *Nucleopolyhedrosis viruses:* These are target specific viruses which can infect and destroy a number of important plant pests. They are particularly effective against the lepidopterous pests of vegetables. Their large-scale production poses certain difficulties, so their use has been limited to small areas. They are not available commercially in India, but are being produced on a small scale by various IPM centres and state agricultural departments.

iii) Trichogramma. Trichogramma are minute wasps which are exclusively egg-parasites. After hatching, the *Trichogramma* larvae feed on and destroy the host egg. *Trichogramma* is particularly effective against lepidopteran pests like. They are used against vegetable and fruit pests. *Trichogramma* is the most popular bio-control agent in India, mainly because it kills the pest in the egg stage, ensuring that the parasite is destroyed before any damage is done to the crop.

The efficacy of two fungicides via carbendazim 0.05%, mancozeb 0.25%, the botanicals i.e. neem seed and leaf extract each at 5% concentration and tobacco decoction at 2% concentration was evaluated by Patil *et al* (2001) for the management of early blight of tomato caused by *Alternaria solani.*

Table 5. Landmarks in the history of biopesticides

Year	Landmark
1690	Tobacco extract – plant spray in Europe
1858	Pyrethrum – insect control in the USA
1888-89	Control of cottony cushion scale on citrus by vedalia beetle
1939	Bt – first used as a microbial insecticide
1948	"Doom" – based on *B. popilliae* and *B. lentimorbus* registered in the USA
1975	"Elcar" (*Helicoverpa* NPV) – registered in the USA
1980	First International Conference on Neem at Rottach – Egern, Germany
1987	First transgenic plant developed – tobacco containing Bt endotoxin gene

(Dhaliwal and Arora 1998)

Table 6. Bt. Based biopesticides marketed in India

Bt. Variety	Trade name	Target pest
B.t. kurstaki	Halt	Diamond back moth (DBM)
	Biolep	American bollworm (ABW) Pink Bollworm (PBW)
	Bioasp	ABW, PBW
	Delfin WG	ABW, PBW, DBM, *Spodoptera litura*
B.t. galleriae	Spicturin	ABW, DBM, *S. litura*

(Anonymous, 1994)

The lowest per cent disease incidence was observed in the treatment of carbendazim (13.93) and mancozeb (15.46). Similarly, the highest yield of tomato fruits was recorded in the treatment of carbendazim (200.86 q ha^{-1}) followed by mancozeb (179.10 q ha^{-1}) when sprayed five times at an interval of 15 days starting from the initiation of the disease. The plant products namely neem seed extract 5%, neem leaf extract 5% and tobacco decoction 2% also provide effective in reducing the disease incidence and obtaining the fruit yield to the tune of 168.56, 156.43 and 147.66 q ha^{-1}, respectively. In a field trial comprising six plant extracts along with two conventional insecticides undertaken by Kulat *et al* (1997) revealed that aqueous leaf extracts of *Nicotiana tabacum* Linn (2%) *Ipomea carnea* Jacq (5%) and seed extract of *Azadirachta indica A. juss* and *Pongamia glabra* Vent (5%) exhibited comparable effectiveness with that of conventional synthetic insecticides, endosulfan (0.06%) and monocrotophos (0.05%).A field experiment conducted by Rosaiah (2001) to evaluate the efficacy of different plant products on yield of Ridge gourd indicated that neem seed kernel extract at 5% concentration recorded highest yield 32.71 q ha^{-1}.Field experiments conducted by Rosaiah (2001) to evaluate the performance of various botanicals against pest complex of Okra showed that mineral oil 0.5% followed by NSKE 5% and 10%, Neemazal 0.5% were effective in reducing Jassid population. Efficacy of a new neem oil based formulation (containing 300 ppm Azadirachtin) was studied against aphids, Jassids, white fly and shoot and fruit borer (Gahukar and Balpande 1997). Two concentrations 4 ml and 8 ml/l water of this formulation were compared with Rakshak (4 ml/l water) and endosulfan (1.5 ml/l water). Three sprayings at 15 days interval showed superiority of the new formulation because the number of aphids and Jassids, and levels of leaf infestation of whitefly and shoot and fruit infestation of fruit borer were significantly lower than in plots treated with Rakshak or Endosulfan.

Bacillus thuringiensis **as biopesticide**

Bt is the most extensively used biocontrol agent in vegetables. It has been widely applied against *Plutella xylostella, Earias vitella* and *Helicoverpa armigera*. To evaluate the efficacy of different formulations of *Bacillus thuringiensis* var. *kurstaki* against the fruit borer of botanical insecticides viz. Neemax @ 1 kg/ha and Multineem @ 2.5 l/ha and bioinsecticides, Biotox (Bt) @ 1 kg/ha alternted with malathion @ 0.5 kg a.i./ha in different combinations were sprayed. Lowest fruit borer incidence was observed (8.6%) when Biotox was applied to the crop two times alternated with one malathion application followed by the treatment where malathion was applied twice alternated with one application of Biotox (10.6%) (Mishra and Mishra 2002).The aphid population remained very low 50.7 no's/top 3 leaves in treatment where Biotox, Neemax and Multineem were applied once in succession and was at par (52.2) with treatment where Multineem was applied in between two malathion applications. Application of multineem and neemax alternated with ma good as 3 applications of malathion except in Biotox where yield was low due to high aphid population.In tomato to control *Helicoverpa armigera* tree spraying of *B.t.* formulations viz. Delfin, Halt, Biolep and Spicturin were given at 15 days interval (Praveen *et al* 2001). The results indicated that Delfin and Halt @ 1.0 kg/ha was highly effective in reducing per cent fruit damage and increased the fruit yield, respectively.Evaluation of different *Bacillus thuringiensis* (*Bt*) formulations in comparison with neem and chemical insecticides against brinjal shoot and fruit borer *Leucinodes orbonalis* indicated that five sprays of Dipel 8L @ 0.2% at 10 days interval resulted in minimum shoot (9.56%) as well as fruit (11.78) infestation and maximum yield of marketable fruits 196.96 q ha^{-1} and proved to be the most effective treatment (Puranik *et al* 2002). The combination of commercial formulation of *Bacillus thuringiensis* (Dipel) and lower concentration of insecticide endosulfan, fenvalerate, multineem, carbaryl, acephate and Dipel alone were tested against okra shoot and fruit borer (Tomar 1998). The Dipel and endosulfan and Dipel and fenvalerate were found very effective in reducing per cent shoot and fruit infestation. The maximum yield of healthy fruits was obtained in Dipel and Fenvalerate combination. Solo and joint efficacy of some biopesticides viz. azadirachtin, *Bacillus thuringiensis* and avermectin against diamond back month *Plutella xylostella* revealed that the joint action of all biopesticides were significantly superior to control and usual recommended dose of synthetic pesticides; malathion (0.05%). Highest suppression of 88.85% and 90.54% larval population was achieved from combined spraying of *Bt* (0.05%) and avermetcin (0.05%) after 3 and 14 days of spraying respectively followed by Joint spraying of *B.t.* (0.05%) + azadirachtin – 1500 ppm (0.15%) recorded 87.43% and 84.85% after 3 and 14 days of spraying, respectively (Chatterjee and Senapati 2000). Overall efficacy of joint action of the above pesticides as well as solo application of *B.t.* and avermectin were more effective.

Nucleopolyhedrosis virus *vs.* biopesticide

Host specificity of this virus has limited its use to *H. armigera, Spodoptera litura* and *P. xylostella*. Lack of commercial production has suppressed its popularity and is used in limited areas. An experiment was conducted to study the effectiveness of nuclear polyhedrosis virus alone and in combination with endosulfan in the integrated control of fruit borer *Helicoverpa armigera* on tomato (Pokharkan *et al* 2002). Pooled mean of both the years indicated that the total yield obtained from all the treatment plots except HaNPV 125 LE/ha was significantly better than the control. Moreover endosulfan 0.07% proved to be the best and was at par with treatments i.e. endosulfan 0.07% followed by HaNPV 250 LE/ha, HaNPV 700 LE/ha, HaNPV 500 LE/ha and HaNPV 250

LE/ha + endosulfan 0.035%. In case of marketable yield HaNPV 700 LE/ha and endosulfan 0.07% followed by HaNPV 250 LE/ha were at par with the best endosulfan (0.07%) treatment. So first spray of endosulfan 0.07% followed by 2 sprays of HaNPV 250 LE/ha or 3 sprays of HaNPV @ 500-700 LE/ha could substitute 3 sprays of endosulfan 0.07% alone.The efficacy of certain chemicals viz., Bulldock 25 SC, Rimon 10 EC, Profenophos 50 EC and bioagents like NPV were separately evaluated. The data revealed that Rimon 10 EC @ 50 g a.i./ha gave highest yield and it was at par with treatment of NPV + endosulfan @ 300/700 alternately.

Table 7: Effect of bio control agents on disease intensity

Crop	Disease/ pathogen	Bio control agent(s)	Decrease in intensity (%)		Reference
			Biological control	Chemical control	
French bean	Collar rot (*Rhizoctonia bataticola*)	**T. VIRIDE**	67.2	55.3	Dubey (2002)
Tomato	Collar rot (*Sclerotium rolfsii*)	*T. harzianum*	61.0	63.0	Dutta and Das (2002)
Ginger	Rhizome rot, Pythium sp., *Fusarium oxysporum*	*T. harzianum*	39-90	50-100	Rajan *et al* (2002)

Table 8: Effect of bio control agents on yield

Crop	Disease/ pathogen	Bio-control agent(s)	Decrease in intensity (%)		Reference
			Biological control	Chemical control	
French bean	Collar rot (*Rhizoctonia bataticola*)	**T. VIRIDE**	80.0	40-75	Dubey (2002)
Tomato	Foot rot and Slow decline (*Phytophthora* and *Nematodes*)	*T. harzianum/ T. virens*	21-33	32-41	Anandaraj and Eapen (2003)
Ginger	Collar rot (*Sclerotium rolfsii*)	*T. harzianum*	70.0	30-60	Mani (2000)

Biocontrol agents

Manoranjitham *et al* (1999) reported significant increase in the seed germination and seedling vigour of chilies treated with *T. viride* by seed treatment. Kharakrang *et al* (2002) observed increased plant height and dry matter production of potato in the posts applied with *T. viride, T. harzianum, T. virens* and *P. fluorescens*. These biocontrol agents have been successfully used for control of nursery diseases (damping aff, collar rat, root rot, wilt) of various vegetable crops like tomato, chilies, onion, brinjal, cabbage, cauliflower and capsicum through seed treatment with talc formation of *Trichoderma* spp. (5 g/kg seed) and *P. fluorescens* (10 g/kg) and nursery bed application of *Tricholderma/P. fluorescens* enriched FYM.

Sharma and Sain (2002) have observed 68.2 and 57.3% control of *Fusarium* wilt of tomato treated with commercial formulations of *T. viride* and *P. fluorescence* with increased yields of 17.2 and 15.2 t/ha in the field trials respectively. Dubey (2002) observed a two fold decrease in the collar rot incidence and two fold increase in the yield of French bean when seeds were treated with *T. viride* (Table 7 and 8).

Conclusions

The environmental hazards posed by synthetic pesticides provide an impetus for investigations into some ecofriendly and biorational alternatives. At global level large quantities of the pesticides are being used by the farmers to control various insect pests prevailing in the region. Besides, insects have developed resistance to insecticides due to injudicious use. These problems have necessitated the search for alternative and effective biodegradable insecticides, which have greater selectivity. The re-evaluation and use of traditional botanical pest control agents (powder, water extracts, oil and wood ash), that local farmers have been using over the past decades though without much success, seem to provide a clue to local sourcing of pest control strategies. Botanical pesticides have proved moderately to highly effective against insect pests. These pesticides are comparatively safe to natural enemies and pollinators. The botanical pesticides are ideally suited for incorporation in IPM. Farmers need to be made aware of potential of botanical pesticides.

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