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Role of Biopesticides in Crop Protection: Present Status and Future Prospects

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Abstract

The sharp increase in the use of chemical pesticides in India in recent years has resulted in severe implications in the development of insecticidal resistance in key pest species, pesticide residues in food chain, degradation in the quality of eco-system and human health. Microbials such as viruses, bacteria, fungi, protozoa, nematodes and plant products are the major biopesticides that were studied mostly to develop alternatives to chemicals. In India, biopesticide science is not a new tool and is as old as human civilization back to prehistoric days. Though biopesticides cover only about 1% of the total plant protection products globally, their number and the growth rate have been showing an increasing trend in the past two decades.

In recent years, ICRISAT in collaboration with National Agricultural Research and Extension Systems (NARES) in India have made significant progress in the identification, production and field evaluation of biopesticides. Understanding of ecology has increased to identify the potential problems to work on, the approach, when and where they have maximum impact. The virulence of various bioagents such as nuclear polyhedrosis virus (NPV), bacteria and plant products was tested under controlled conditions and the selected ones were evaluated under hot spots. Strategic research related to DNA of different HaNPV strains from India indicated their similarities with the presence of four major polypeptides with molecular weight ranging from 30.66-42.32 kilo Daltons.

There was significant progress in developing feasible production technologies, efficient storage to enhance the shelf life and filed applications. In this process ICRISAT trained several NARES scientists and farmers on bio-pesticide production and established 96 village level NPV production units in India and Nepal to encourage their use. On-farm studies in biopesticide front indicated 20-40% increased yields in pigeonpea and chickpea. Bio-intensive cotton IPM crops realized 1-30% and vegetable farmers obtained 72% increased yields through better management of pests and augmenting natural enemies.

The overall goal of biopesticide research is to see that the products are made available at farm level at affordable cost, and that they overcome the existing bottlenecks so as to become potential tools in the armory of plant protection. To ensure this, there is every need to strengthen the communication between researchers, industry and farmers. The biopesticide science is still young and evolving, hence in-depth research is needed in many areas such as production, formulation, delivery and commercialization of these products. On the other hand, more research is needed in integrating biocontrol agents into production systems, such as in sequencing biocontrol with other options and in developing these into forecast models for better timing of effective options.

More studies are also needed to determine the environmental effects on the fate of bioagents, new technologies such as micro encapsulation of bioproducts are of high priority in enhancing their potential. The present trends in research include the increased use of biorational screening processes to identify potential agents, evaluation under laboratory and filed conditions, emphasis on integrating these with other control methods in an overall system approach. Even though the organic products are considered less toxic it is important to be careful when using any pesticide and considerable precautions need to be taken while production, processing and utilization. Thus, this manuscript discussed various aspects of biopesticides covering the status, constraints, prospects, integration and the future strategies for their effective utilization to the benefit of human kind.

Keywords: Biopesticides, status, crops, protection

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Introduction

The agriculture research though made considerable progress in addressing food security, adopted policies to grow more and more food to support the growing populations in Asian countries ignoring the issues of health and environment which lead to disastrous situation. The use of chemical pesticides in Asian agriculture has seen a sharp increase in recent years particularly in India (Anon, 2005). The present day plant protection was mainly oriented towards chemical control and in the past five decades the use of chemical pesticides steadily increased from 2.2 g/ha of active ingredient (a.i) in 1950 to the current level of 650 g/ha (which is a 300 fold increase) (David, 1995). Though chemicals gained lots of importance and proved their positive effects in targeting the food security but their continuous and injudicious use in India and other Asian countries has resulted in several implications such as development of insecticidal resistance in key pest species (Armes *et al.*, 1997, Kranthi *et al.*, 1997) pesticide residues in food chain (Handa, 1995), degradation in the quality of eco-system and human health with eroded profits (Pratap, 2003).

There are many reports of presence of pesticide residues in the environment, food as well as in human beings. It is, therefore, an utmost urgency to identify alternatives to chemical pesticides in plant protection without sacrificing the productivity and profitability of agriculture. Among various non-chemical options (host pant resistance, cultural, biological and integrated pest management), biopesticides which are target specific, eco-friendly and biodegradable as potential alternatives to chemical pesticides in addressing various pest management issues.

The biopesticides fall into two major categories:

a) **Microbial** pesticides contain microorganisms (bacteria, fungus, virus, protozoan and nematodes) or their derivatives with deleterious effects on insect pests.

b) **Botanical** pesticides are naturally occurring plant substances that are used for managing the pests.

The efforts of various agencies to popularize integrated pest management (IPM), and the use of biopesticides have had little impact in spite of strong support from various angles. Thus, it is important to study the problem of pests and the pesticide induced problems together in systems approach.

Though eco-friendly approaches are known to farmers from pre-historic period, their use has never attained significant level to meet the requirement. Hence, it is important to discuss further the question of their importance and reasons for low up- take. Thus, this paper discusses the present status and future thrust of biopesticides and factors responsible for their effective propagation are as follows:

- Focus on sustainable ways for effective utilization of biopesticides
- Intensify the monitoring of pesticide residues in various agricultural products and niches for the presence of toxic chemicals.
- Need for creating awareness among producers and consumers about the health and environmental issues in agriculture and the ways of healthy life
- Promotion of the use of biopesticides by all the stake holders

Present status in biopesticides

There are several biopesticides that are commercially available to farmers. According to the recent information, there were approximately 175 registered biopesticide active ingredients and 700 products globally. In India, so far only 12 biopesticides were registered of which five were bacteria (four *Bacillus* species and one *Pseudomonas fluorescens*) three fungal (two *Trichoderma* species and one *Beauveria* species) two viruses (*Helicoverpa* and *Spodoptera*) and two plant products (Neem and *Cymbopogan*). Among various bio-products, *Bacillus thuringiensis* (Bt), *Trichoderma viride*, *Metarrhizium*, *Beauveria bassiana*, Nuclear polyhedrosis virus (NPV) and neem are popularly used in plant protection (US. Environmental Protection Agency, 2007). The importance of some commonly used biopesticides is as follows:

***Bacillus thuringiensis* (Bt).** *Bacillus thuringiensis* is the most commonly used biopesticide globally. It is primarily a pathogen of most damaging lepidopterous pests such as American bollworm in cotton, caster semilooper, tobacco caterpillar, diamond back moth, paddy stem borer etc. When ingested by larvae, Bt releases toxins which damage the mid gut of the pest, eventually causing the death. These are also popular in mosquito management in health programs.

***Trichoderma viride*.** It is a fungal bioagent effective against soil borne diseases such as root rot, collar rot, stem rot and wilts. It is particularly relevant for dry-land crops such as groundnut, blackgram, greengram and chickpea, which are susceptible to these diseases. Considering the ongoing importance of these diseases in several crops its production and usage has been enhanced in recent years in India.

Metarrhizium anisopliae. It is a biological insecticide for use against a wide range of insects including soil insects, caterpillars, sucking pests, and locusts. The entomopathogenic fungus, *Metarrhizium anisopliae* var. *anisopliae* is known to attack over 200 species of insects covering seven orders. The occurrence of the virulent *M. anisopliae* var. *anisopliae* has been reported from *Heliothis armigera* on tomato crop and leaf miner, *Aproaerema modicella* from groundnut.

Beauveria bassiana. It is an entomopathogenic fungus used in pest management. It exists saprophytically in the soil and often causes widespread epizootics wiping out insect pest populations on crops (Leathers *et al.*,1993). Entomopathogenic fungi infect insects in an aggressive manner by penetration through the cuticle. They secrete enzymes such as proteases and hydrolases that facilitate breaching of the insect cuticle (Padmavathi *et al.*, 2003).

Baculoviruses. These are target specific viruses which can infect and destroy a number of important plant pests. They are particularly effective against the lepidoptern pests of cotton, rice and vegetables. A new option for integrated pest management (IPM) through the use of a naturally occurring disease, caused by nuclear polyhedrosis virus (NPV) has gained importance in recent years. This has become popular and farmers have started using it as biopesticide on several crops. This insect pathogen is very specific and has no deleterious effect on non-target organisms. There is high demand for commercially available *Helicoverpa* and *Spodoptera* NPVs from local as well as international markets.

Botanicals. Increasing environmental pollution and health hazards associated with the use of synthetic chemical insecticides has resulted in renewed interest in the development and use of botanical pesticides for insect pest management (Crazywacz *et al.*, 2005). Botanical insecticides are either naturally occurring plant materials or products derived from such plant materials. Crude botanical insecticides have been used for several centuries and were known in tribal or traditional cultures around the world (Richard, 2000). Botanical insecticides are the most cost effective and environmentally safe inputs in integrated pest management.

Neem. derived from the neem tree (*Azadirachta indica*), and contains several chemicals, including '*Azadirachtin*', which affects the reproductive and digestive process of a number of important pests. Research carried out in India and abroad has led to the development of effective formulations of neem, which are being commercially produced.

Nematodes. The *Mermithid* nematodes, in general, are known to infect a wide range of insects in 15 different orders (Nickle, 1972). Ramakrishna and Kumar (1976) reported the association of species of *Mermis*, *Agamermis*, *Hexamermis* and *Geomermis* with 40 insect species in India, mostly infecting lepidopterns. The nematode parasitism was seen only between June-December with peak activity during July-September, stimulated by the arrival of the pre-monsoon showers in June. Nematodes in general, were more active on light soils than on heavy soils, frequently had a patchy distribution and varied in population.

Advantages of biopesticides

- Reduced pesticide risks
- Harmless to non-target organisms
- Often are effective in very small quantities and decompose quickly, thereby minimize the risk of pollution
- When used as component of IPM programs, biopesticides can greatly decrease the use of conventional pesticides with out sacrificing the yields.
- Very specific in action
- Suppress rather than eliminate a pest population
- Limited field persistence
- Are safer to humans and the environment
- Present no residue problems

Recent developments in biopesticides research

Bacterial pathogens

Bacillus thuringiensis. It is the most commonly used bacterium to control *Helicoverpa*. Developing a Bt strain involves isolating the toxin(s), followed by an evaluation of its efficacy in killing the pest. By accessing the micro-organisms from natural sources such as compost and dead larvae from unsprayed locations at ICRISAT, Patancheru led to the identification of several strains of *Bacillus* and other bacteria with ability to kill *Helicoverpa*.

BCB19 is an aerobic spore-forming bacterium that is easy to maintain under laboratory conditions. It survives under high temperatures, and therefore remains viable on leaf surfaces long after it has been sprayed. The method of multiplying BCB19 has been standardized; it can be scaled up for use on a commercial scale. A characterization study suggests that it is safe to humans. It has the potential to be developed into a commercially viable biopesticide by small enterprises.

Recent initiatives from Directorate of Oilseeds Research and Institute of Public Enterprise, Osmania University transferred the technology in promoting biotechnological tools relevant for the management of castor semilooper to resource poor farmers of Mahaboobnagar and Nalgonda districts of Andhra Pradesh. This has facilitated to establish village wide micro-enterprise for producing Bt locally to encourage the use of eco-friendly plant protection options. The products produced from the micro-enterprise proved their effectiveness with 80-90% semilooper larval mortality with in 2-3 days after application. The village micro-enterprise producing Bt proved (ha^{-1} Rs.75) cost effectiveness compared to commercial Bt products (Rs.325-800) (Vimala Devi and Rao, 2005).

Fungal pathogens

Research has focused on the relatively easily produced asexual spores (conidia) of the hyphomycele genera *Metarrhizium, Beauveria, Nomuraea, Trichoderma, Verticillium* and *Paecilomyces*. These fungi often have a wide host range although there is considerable genetic diversity within species and some clades show a high degree of specificity (Driver *et al.*, 2000). Mycoinsecticides are usually formulated products with live conidia as the active ingredient. The conidia germinate on contact with the cuticle of the insect, produce a penetrating germ tube and establish a systemic infection which kills the host in 7-21 days depending on çonditions, especially temperature, humidity and dose. Unlike other potential biocontrol agents, fungi do not have to be ingested to infect their hosts but invade directly through the cuticle, and so can potentially be used for control of all insects including sucking insects (Richard, 2000).

***Trichoderma* spp.** This biofungicide was recommended for seed treatment, soil application and soil drench for the control of seed and soil borne diseases. Recent farm surveys indicated that substantial reduction of plant mortality in cotton and chilli crops when used as seed treatment and soil application. Seed treatment and soil application of *T. viride* along with FYM effectively controlled various root diseases in different crops. *Trichoderma* formulation was effective against pre-and post-emergent damping-off, root rot and wilt in cotton and chilli and seedling rots in sugarcane (Bharati *et al.*, 2002). Considering the ongoing importance of these diseases in several crops its production and usage has been enhanced in recent years in India.

***Metarrhizium anisopliae* var. *anisopliae*.** The occurrence of the virulent entomopathogenic fungus *M. anisopliae* var. *anisopliae* has been reported from *H. armigera* on tomato crop. The fact that toxic effects of the heamolymph of infected individuals are linked to the production of toxins *viz.*, Destruxins A and B by the pathogen in living insects. The combined effect of toxin (in culture filtrate) and conidial infection will play a major role in increasing the effectiveness of *M. anisopliae* var. *anisopliae* as the biocontrol agent in controlling the gram pod borer. *M. anisopliae* var. *anisopliae* has been found to be pathogenic to larval instars, pre-pupae and pupae of *H. armigera* when applied as conidial suspension containing $1.8x10^9$conidia/ml inflected 80-100% mortality. The combined effect of toxin and conidial infection in latter instars has been discussed by Gopalakrishnan and Narayanan (1988).

A potential biocontrol agent, entomopathogenic fungus *M. anisopliae* has been identified on groundnut leaf miner, which has shown encouraging results on *Helicoverpa* under laboratory conditions. The mass multiplication and field-testing techniques for this biocontrol agent has been established. This technology at present is under validation in on-farm trials for the management of ground leaf miner.

***Beauveria bassiana*.** It is an insect pathogenic fungus used as a biopesticide in crop pest management. Twenty-nine isolates of *B. bassiana* isolated from different insects from diverse geographical areas across the globe. A large number of *B. bassiana* isolates showed a very wide pH tolerance and optimum range. A slightly acidic to a very alkaline medium permitted optimal growth of many of the *B. bassiana*. All *B. bassiana* isolates with dusty type colony morphology showed tolerance to a wide (4-14) range of pH and all the chalky isolates showed optimum growth over a wide (5-13) range of pH. Each isolate showed a specific growth pattern reflected in its gross colonial morphology. The conidial morphology of the isolates has remained unchanged over the period of six years in which they have maintained in labs (Padmavathi *et al.*, 2003).

The effectiveness of oil-based conidial formulations of *M. anisopliae*, *B. bassiana* and *Nomuraea rileyi* were evaluated against *Helicoverpa armigera* (Hubner) infestation on pigeonpea under field conditions. Fifteen isolates of *N. rileyi* were isolated from the infected *S. litura* larvae found in sugar beet field around Pune. In the bioassay, three isolates, showed >80% mortality of which one isolate was selected for further studies (Nahar *et al.*, 2004).

Viral pathogens

The recovery of the virus needed to be quantitatively optimized to enhance its efficiency and economy as a microbial biopesticide. An endeavor has been made in this regard to quantify the viral recovery at different post inoculation (PI) days to obtain the maximum poly inclusion bodies (PIBs) and to regulate the malodor through several techniques. Maximum larval mortality was found to be 88% on 7th day of PI followed by 50% on 6th day of PI. The NPV yield was maximum, 0.70 LE/larva at 7th day followed by 0.64 LE/larva at 6th day of PI. The ideal period of viral harvest can be suggested to be 6th day of PI when the mortality percent and NPV yield were in accord for optimal viral recovery to avoid the constraint of malodor associated with the *H. armigera* NPV production.

Determination of standardization of production. For mass multiplication of HaNPV, fourth instar larvae were inoculated with 10^8 POBs/ml and reared in the laboratory. There was 76% mortality with field-collected larvae where as laboratory reared ones recorded 73% mortality. The highest cadaver weight (283mg), highest POBs/larva (5.9×10^9) and the highest POB yield/g body wt. (2.54×10^7) were recorded from the field collected larvae where as laboratory reared ones recorded cadaver weight of 270.12 mg, POBs/larva of 5.02×10^9, POB yield/g body wt. of 1.94×10^7. Observations on the bacterial contamination levels indicated the highest number of colony forming units per ml (2.33×10^6 CFU/ml) for the sample multiplied on field-collected larvae. Whereas HaNPV multiplied on laboratory reared larvae recorded 2.06×10^6 CFU/ml.

Chemicals used, as preservatives for NPV were effective in minimizing the bad odor problem in storage and reduced the bacterial contamination level. NPV samples treated with acetone, ethyl alcohol and phenyl gave 73%, 70% and 63% mortality, respectively at the end of one year of storage and phenyl was found effective in suppressing the bacterial growth, which was followed by ethyl acetate. All the chemicals used were cost effective with an extra cost involvement of Rs.3-12.5 ha^{-1} only. NPV sample stored under refrigerated condition was found more virulent, with 98% mortality after a period of ten months. Whereas the samples stored in earthen pot, amber colored bottle and glass bottle at room temperature recorded 88%, 70% and 68% mortality, respectively. Development of bacterial contamination was 3.47 times more in samples stored under room temperature compared to refrigerated condition.

HaNPV production and utilization. During 2005-2006, the emphasis was on establishing biopesticide units and imparting training on HaNPV production to farmers, extension officers for their effective utilization. In this process, 76 HaNPV production units in India and 20 in Nepal have been established after detailed training to two farmers and one extension staff from each location. Through these interactions (on site training, and village wide interactions), this influenced the farmers in judicious use of pesticides in plant protection and the importance of protective clothing which was well adopted in all the villages. Farmers in these villages have adopted the concept of integrated pest management and initiated the bio-pesticide production and used the produce on different crops.

Development of efficient diagnostic tool to detect the quality of virus products. Many viral products produced in developing countries are failing to meet acceptable standards and the use of poor quality products will erode the farmers' confidence on biopesticides like NPV. In an attempt to develop an efficient diagnostic tool to detect the quality of virus products, the polyclonal antibodies were developed against polyhedra of nucleopolyhedroviruses infecting *H. armigera*, *S. litura* and *Amsacta albistriga*, and to standardize the ELISA protocol for the diagnosis and quality control of the NPVs of these species.

The results showed that the antibodies have good reactivity with polyhedron and did not show any cross-reaction with healthy insect proteins. In addition to this the antibodies are showing different degrees of cross-reactivity with purified polyhedrins of these three viruses. The detection limits of the antisera are about 20 ng of pure polyhedron in case of HaNPV and SlNPV, where as it is 10-8ng in case of AalNPV. (Sridhar Kumar *et al.*, 2007).

Results from the investigations carried on the efficacy of various IPM options in chickpea crop revealed neem as an effective ovipposition deterrent of *H. armigera*. *Helicoverpa* Nuclear polyhedrosis virus (HaNPV) proved effective in reducing larval population and was on par with plots treated with endosunfan (1.25, 1.33 larvae/plant, respectively) (Tables 1 and 2). Among the various IPM components (neem, HaNPV, bird perches and need based chemical application), plots treated with HaNPV did not show any significant effect on natural enemies (267.1/trap) present on the chickpea crop and was on par with control plots (302.4/trap) (Visalakshmi *et al.*, 2005).

Botanical pesticides. The earliest mention of poisonous plant is found in the Rig Veda, the classic book of Hinduism, composed in India during the second millennium BC (Chopra *et al.*, 1949). Secoy and Smith (1983) have listed around 700 plants species reportedly used in different parts of the world for pest control. Among the botanicals, neem has been studied extensively and found

Table 1. Mean effect of the treatments on the grain yield of chickpea during post-rainy 1998-2000 seasons

Treatment	Pod damage (%)	Grain yield (kg/ha)	% increase over control
Neem 0.006% (AZA 3%)	12.0 (20.2)[b]	1129.9[b]	41.6
HaNPV 250 LE/ha	12.6 (20.7)[b]	1140.4[b]	42.9
Bird perches One/plot	14.5 (22.3)[c]	977.0[c]	22.5
Endosulfan 0.07%	11.2 (19.6)[ab]	1223.0[a]	53.3
IPM	10.4 (18.8)[a]	1264.4[a]	58.5
Control	19.8 (26.4)[d]	797.9[d]	-
SEd.	0.550	34.26	-
CD	1.180	72.02	-

that it could manage over 120 different insect species that attack crops and stored products. Apart from neem, turmeric, garlic, vitex, glyricidia, castor, ginger, agave, custard apple, datura, calotropis, ipomoea and coriander are the other botanicals widely used to manage and repel the pests.

Eleven indigenous plant materials (*Cleistanthus collinus, Calotropis gigantean, Pongamia glabra, Artemisia dubia, Sphaeranthus indicus, Cassia occidentalis, Chloroxylon swietensia, Vitex negundo, Madhuca indica, Strychnos nuxvomica, S. pototirum*) known for insecticidal properties collected from Andhra Pradesh and Chattisgarh were evaluated against *S. litura* larvae. The water extract of these products against second/fourth instar larvae clearly indicated the superiority of *C. collinus*, *C. gigantia* (leaf extract) and *P. glabra* (seed extract) in suppressing the larval growth and development of *Spodoptera*. Since these botanical products significantly influenced the larval growth, need further studies in order to make use of them in future IPM programs.

Biological agents. Parasitic nematodes. The Mermithid nematodes, in general, are known to infect a wide range of insects in 15 different orders (Nickle, 1972). Ramakrishna and Kumar (1976) reported the association of species of *Mermis*, *Agamermis*, *Hexamermis* and *Geomermis* with 40 insect species in India. Nematodes were common on Lepidoptera than on other insects. Though the bio-pesticide science making rapid strides their production and utilization is not up to the expectations and farmers were unable to take the advantage of the technologies for effective management. Our experience for this low uptake found the following reasons.

Reasons for low uptake

- Biopesticide science is knowledge intensive, needs more time to understand the effectiveness.
- Intensive pest monitoring, which is a pre-requisite for decision making at farm level is a specialized job hence farmers considered it as impractical.
- Some farmers felt that they did not have time to keep a close watch on their fields to monitor pests and their natural enemies to calculate economic thresholds.
- Farmers have several miss concepts about biopesticides such as they are less effective, costly, difficult to produce, not compatible with other options.
- In general, the extension programs have very little knowledge and experience of biopesticides.
- In the absence of active promotion of biopesticides the demand for these products has not developed, for this reason that most private shops and dealers do not stock and sell biopesticides.

Table 2. Cost-benefit ratio of IPM components in chickpea during post-rainy 1998-2000 seasons

Treatment	Grain yield (kg/ha)		Gross income (Rs)	Cost of insecticide application (Rs)	Net income (Rs)	Cost-benefit ratio (C:B)
	Gross yield	Additional yield over control				
Neem	1129.9	332.0	14,544.0	2023.5	12,520.5	1:2.05
HaNPV 250 LE/ha	1140.5	342.6	14,697.0	2322.5	12,374.5	1:1.84
Bird perches One/plot	977.0	179.1	12,510.0	350.0	12,160.0	1:6.40
Endosulfan 0.07%	1223.1	425.2	15,717.5	1,942.0	13,775.0	1:2.74
IPM	1264.4	466.5	16,048.0	1935.0	13,907.5	1:3.01
Control	797.9	-	10,114.0	-	10,114.0	-

Cost of each spray/ha: Neem = Rs 405; HaNPV = Rs 465; Bird perches = Rs 350; Endosulfan = Rs 388; Cost of chickpea = Rs 12.5/kg

Evaluation of BIPM in Adarsha watershed, Kothapalli village - A case study

Under integrated watershed management program, Bio-Intensive Pest Management (BIPM) technologies were initiated during 2000 with Adarsha watershed in Kothapalli village to alleviate the plant protection problems in major crops like cotton, pigeonpea, chickpea and vegetables.

During 2000-01, pigeonpea BIPM farmers applied one spray each of neem fruit extract and HaNPV followed by manual shaking (3-5 times) and have not applied any chemicals. Non-IPM farmers sprayed chemicals 3-4 times. During 2001-02 season, BIPM farmers used one spray each of neem and HNPV followed by manual shaking (2-4 times), while non-IPM farmers used 2-3 rounds of chemical sprays. In chickpea, during post rainy season 2000-01, the BIPM plots received 1-3 sprays of HaNPV while the non-IPM farmers did not apply any plant protection measures to their crops. During 2001-02, BIPM farmers applied one spray of neem fruit extract and two sprays of HaNPV, while non-IPM farmers used two sprays of chemicals.

The cotton BIPM was initiated during 2003-04 and continued for the next two seasons i.e., up to 2006. The bio-intensive pest management protocol was evaluated by 17 farmers during 2003-04, followed by nine farmers during 2004-05 and five farmers during the year 2005-06. Each contact farmer was asked to divide a given field in to two halves, one each for BIPM and farmer practice (FP/Non-IPM). The BIPM protocol involved five items, and small changes in agronomy. The first two are extracts of two botanicals, neem (*Azadirachta indica*) and *Gliricidia sepium* (a leguminous tree), prepared using vermicomposting, a biological method. The third is a research product of ICRISAT –the bacterium *Bacillus subtilis* strain BCB19/, the fungus *M. anisopliae*. The last two components were items that farmers have traditionally used. These are a) cow-urine solution, and b) a curd recipe, that involves mixing specific quantities of curd, jaggery (concentrated sugarcane juice) and bread yeast – all mixed in water and sprayed. The cow urine is believed to serve as a repellant and the second as an attractant to friendly insects such as wasps. The curd recipe was applied only once at about 50% flowering stage. In addition, a mixture of three different bacterial strains (a) *P. fluorescens* - that promotes plant growth, makes insoluble-P soluble and suppresses soil-borne fungi, (b) *Azotobacter vinelandii* strain HT54 is nitrogen fixing bacterium (c) *Bacillus lichenriformis* with ability to promote plant growth were applied to the soil at sowing.

The adoption of BIPM in the village led to 50% reduction in pesticide use by 2005 (normally this village spends about Rs. 2 million in the purchase of chemical pesticides). The BIPM farmers harvested up to 20-40% increased yields in pigeonpea and chickpea crops (Figs 1 and 2) while cotton BIPM farmers realized 1-30% (Table 3) and vegetable farmers obtained 2-322% increased yields through better management of pests (Table 4). Besides yield increase, BIPM program also resulted in terms of cash savings in plant protection, and stability of production.

The beneficial effects on health and environment should be considered as additional bonus. Farm surveys indicated the non-availability of good quality IPM components such as seeds of high-yielding tolerant varieties, biopesticides, (insect pathogens such as nuclear polyhedrosis virus (NPV), bacteria and fungi), and pheromones, as primary constraint for rapid spread of IPM technologies. To overcome this constraint, farmers were encouraged to collect neem fruits from their back yards for extraction of insecticide and also a village-based production of biopesticides (NPV, compost wash) was established after imparting thorough training to few farmers in the production, which yielded satisfactory results for adoption of bio-intensive IPM.

Table 3. Cotton yields in BIPM and FP plots during three seasons in Adarsha Watershed, Kothapalli, R R District, Andhra Pradesh, India 2003-06

Season (No. of farmers)	Mean yield (t ha^{-1})		
	BIPM	FP	SE+
2003/04 (17)	2.43	1.87	0.080
2004/05 (9)	0.74	0.68	0.058
2005/06 (6)	1.74	1.38	0.096

Table 4. Tomato yields in BIPM and FP treatments in six farmers fields in Adarsha Watershed, Kothapalli, R R District, Andhra Pradesh, India during 2005

Name of farmer	Yield (t ha^{-1})		Yield increase over control	Cost of plant protection (Rs ha^{-1})	
	BIPM	FP		BIPM	Non-IPM
T. Pochaiah	5.53	1.31	322	2870	2929
B. N. Reddy	7.93	5.34	49	2154	2344
Md. Yousuf	3.21	2.35	37	1848	2344
T. Kishtayya	2.12	1.85	15	3144	2929
K. L. Narayana	2.42	2.22	9	1764	2344
K. Permaiah	1.68	1.65	2	561	2929
Mean	3.82	2.45	55.9	2057	2637
SE ±	0.488				

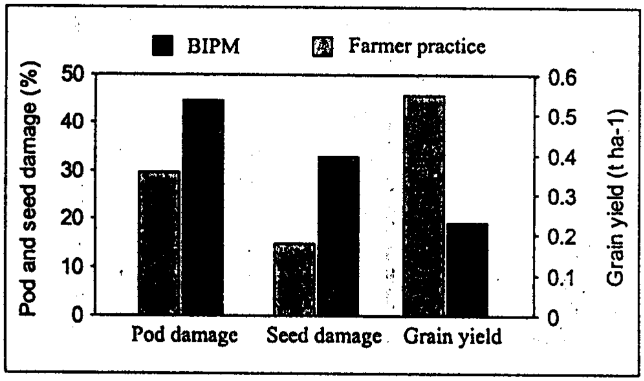

Figure 1. Pod damage, seed damage and grain yield in pigeonpea BIPM and farmer practice plots in Adarsha Watershed, Kothapalli rainy season 2001-02

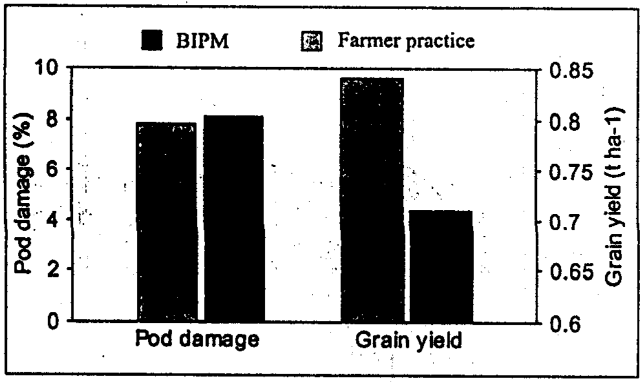

Figure 2. Pod damage, and grain yield in chickpea BIPM and farmer practice plots in post rainy season 2001-02

Conclusions

- Over the past 25 years, the approach to biopesticide research has evolved towards being more ecologically holistic and more oriented towards both production systems and industry's concerns.
- Although biopesticides still represent a very small portion of plant protection at present, their role was considered significant.
- Biopesticides provide environmentally friendly alternatives to chemical insecticides but they face a number of constraints in their development, manufacture and utilization.
- Lack of effective multidisciplinary research, poor public sector industry linkage and little understanding of quality of the product are of prime concern.
- Lack of education and awareness of biopesticides among farmers, extension and policy makers.
- Lack of effective regulations to promote biopesticide can lead to poor product quality, poor performance and loss of user confidence.
- Biopesticides that can perform effectively in extreme environments have immense potential.

Way forward

Technical inputs and training to producers can improve product quality and sales. If the goal of biopesticide research is to place the production in the growers' hands, there is a need for more communication between users, researchers and industry in the early stages of their development. A public/private sector approach to the development, manufacture and sale of environmentally friendly alternatives to chemical pesticides for developing countries is the need of the hour. This evolution is likely to continue as this science is still young hence further research is needed in many areas.

- Research in production, formulation, and delivery could greatly assist in commercialization of these agents.
- More research is needed in integrating bioagents into production systems, such as in rotating these with chemical pesticides and developing these into forecast models to choose whether to apply a chemical pesticide or bioagent.
- To promote these eco-safe approaches, encourage and empower developing countries to develop their capacities in biopesticide manufacture and use.
- Encourage public funded programmes, commercial investors and pesticide companies in the small enterprise sector to take up bioenterprise.
- Develop strict regulatory mechanisms to maintain the quality and availability of the biopesticides at affordable cost in the developing countries.

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