Biotechnological approaches in the management of plant pests, diseases and weeds for Sustainable Agriculture

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INTRODUCTION

Biotechnology with its promise to revolutionize agriculture around the world is assuming an increasingly greater role in India's agricultural research. The indiscriminate use of chemical pesticides has affected humans and their environment and insect pests remains to be one of the major limiting factors in sustaining the productivity of various crops. The concept of IPM for sustainable development has emerged with the increasing realization of the importance of sustainable agriculture. IPM with emphasis on biological pest suppression aims towards sustainability and is being promoted in all the cropping systems in the country. Biotechnology has opened an exciting frontier in agriculture. Agriculture is one of the most important sectors of the developing countries. Indian economy is basically agriculture oriented and country's economic development is largely dependent upon the development of agroculture. Agriculture represents 16.67% of India's GDP and almost 70% of the population in the country depends primarily on agriculture, which provides employment to about 60% of the work force. Agriculture production contributes nearly 40% of our national income and about 31% of the total export of the country.

In the last 50 years, the Indian agriculture has passed through several tough situations and, at the same time, made some significant progress. 'Green Revolution' and the subsequent advances made in agricultural sector has increased the total food grain production from 51 million metric tones (m MT) from a cultivated area of 97 million hectares (m ha) at an average of 522 kg/ha in the year 1950-51 to 209 m MT from 122 m ha at 715 kg/ha in 2005-06. Thus, in about 55 years, with an increase in area by only about 26%, India was able to achieve about 310% increase in food production at an average of 229% increase in yield per unit area (kg/ha). India now has achieved self-sufficiency in food and is emerging as a recognizable exporter of agricultural commodities. The Green, Blue, White and Yellow Revolutions are the example of remarkable accomplishments. However, our food security was somewhat shaken by the ever-increasing population which increased from 361 million in 1950 to more than 1,000 million (>1.0 billion) (about a three-fold increase) by 2007 and it is predicted to exceed 1.5 billion by 2050. Added to this and the vagaries of the monsoons, about 30% of our food production is lost to pests, diseases and weeds despite spending huge amounts on chemical pesticides for their control. Now, with the ever increasing human population the challenge before us is to double the food production in the next 30 years in the country on an environmentally sustainable basis.

Outbreak of Crop Pests Diseases and Weeds

Green revolution in India resulted in increased food production on one hand and innumerable problems of pests/diseases and weeds on the other hand. After the advent of intensive agriculture, there has been a vast change in the scenario of pests, diseases or weeds syndrome and the problems of biotic stresses in the field of plant protection and post harvest losses have also been aggravated. Very often minor pests, diseases or weeds become a major drawback due to monocropping under intensive condition. As such a large diversity of crops under varying agroclimatic conditions and ecologically unsound agricultural practices have led to the out break of a large number of insect and other pests. There are 200 major varieties of pests of economic importance in India. There are about 70,000 pest species (9000 insects and mites) worldwide that damage agricultural crops.

Damage by Insect Pests, Diseases and Weeds

In India the annual estimated damage (20-30%) caused by pests, diseases and weeds in various crops in the field and stored grains was of Rs. 60-70 billion in 1983 which at the present price estimates could easily exceed Rs.600 billion (US$ 15 Billion). Crop losses due to just one polyphagous pest i.e. *Heliothis armigera* which attacks a number of important crops is estimated to be over Rs.I0 billion per year in the country. Weeds like *Parthenium hysterophorus*, *Solanum elaeagnifolium* and *Eupatorium glandulosum* are very difficult to control due to their perennial nature and wider adaptability. Other weeds which can be identified based on the seriousness of yield loss and other allied problems include *Eichhornia crascipes*, *Salvinia spp.*, *Striga spp.*, *Orobanche spp.*, *Cyperus spp.*.

PESTICIDE USE

The pesticide usage has gone beyond 100,000 MT during the year 1997-98. In 2005 pesticides worth about Rs.2, 700 crores (Rs. 27 billion or US$ 675 million) were used in India. Among the total pesticides used in the country more than 60% of the pesticides are used in the agriculture sector. The use of pesticides is highest in Andhra Pradesh (20%), followed by Punjab (10%), Tamil Nadu (9%) and Karnataka and Gujarat (6%) each. Cotton, rice and vegetables use maximum quantity of pesticide in the country. Of the total annual pesticides usage 40% (earlier 55%) is used for cotton alone, though cotton is grown in only 5% of the cropped area. On the other hand, the pesticide share is only 6-7% in the case of millets, oil seeds and pulses though they have a cropped area share of 58%. Farmers are unable to use even minimum quantity of pesticide due to their high cost. The use of pesticide is also heavy in vegetables, fruits and plantation crops but very moderate in sugarcane. The rice crop also uses about 17-18% of the total quantity of pesticides used in the country. Among the chemical pesticides, insecticides are used to a large extent of about 60% in India followed by fungicides and bactericides (20%) herbicides (17%) and other chemicals (3%). While in western countries herbicide use is the highest. The world average for herbicide use is about (45%) followed by insecticides (36%), fungicides (17%) and other chemicals (2%) (Wahab, 2003, 2005)

Although average consumption of pesticides in India is far lower (300 gm/ha.) than its consumption in Europe and USA (3 kg/ha.) and Japan (12kg/ha.), the level of pesticide residues is very high in India. Though India shares only 12% of the total world usage of pesticides 1/3 of pesticide poisoning cases occur in India every year mainly due to lack of safety measures and also due to recalcitrant pesticides being more commonly used in this country. About 3 lakh Indian farmers lose their lives due to pesticide poisoning. The problem of pesticide residue is particularly serious in the case of cereals, pulses, vegetables, milk, and milk products. Pesticide residues in several crops (having export potential) like cotton, basmati rice, plantation crops like tea, coffee, rubber and spices and several fruits like mango, apple, citrus etc., have also affected export of these commodities in the last few years. While chemical pesticides have played an important role in increasing food production in India, their indiscriminate use has led to several environmental problems including development of resistance in insects to insecticides; resurgence of non-target pests, pesticide residues in food, fodder and feed; destruction of beneficial insects like honeybees, pollinators, parasites and predators. Persistent residues of DDT and HCH (BHC) have been detected in food grains, vegetables, fruits, milk, oil, butter, fish, meat, milk and milk products and even in breast milk. Infact, the use of chemical pesticides in agriculture has created negative impact on human health, wildlife and the environment as a whole.

Demand for Organically Cultivated Crops

There is a growing demand for organically cultivated fresh and processed fruits and vegetables. The current consumption of organically produced fruits and vegetables at the global level is valued at US$ 27 billion. India produced around 3,96,997 MT of certified organic products which includes all varieties of food products namely Basmati rice, pulses, honey, tea, spices, coffee, oil seeds, fruits, Processed food, cereals, Herbal medicines and their value added products. The production is not limited to the edible sector but also produces the organic cotton fiber, garments, cosmetics, functional food products, body care products, etc. India exported 86 items last year (2007-08) with the total volume of 37533 MT. The export realization was around 100.4 million US $ registering a 30% growth over the previous year. Organic products are mainly exported to EU, US, Australia, Canada, Japan, Switzerland, South Africa and Middle East. Cotton leads among the products exported (16,503 MT).The Agricultural Produces Export Development Agency (APEDA) of the Union Commerce Ministry had proposed to export organically produced fruits and vegetables and their products to a value of Rs. 1, 50,000 crores annually during the XI Five year period. This would require enormous efforts to produce and use bio-pesticides in the context of IPM. Similarly the pesticides in beverages like tea and coffee have also affected export of these commodities in the last few years. There is considerable export market for cotton fabrics and garments devoid of pesticide residues in Japan and Western countries, as even traces of chemicals could cause skin ailments in human beings. There is greater need to adopt an integrated approach to manage pests, diseases and weeds through environment friendly and economically viable procedures of plant protection.

Integrated Pest Management

The concept of Integrated Pest Management (IPM) for sustainable development has emerged with increasing realisation of the importance of sustainable agriculture. The farmers who were using chemical pesticides in the 60s and 70s are now looking for sensible and bio rational methods of IPM. In the practical IPM system six components which are usually advocated for integration are biological control, host plant resistance, cultural

Table 1. Estimated global market value of biopesticides by 2008, Market estimated by region ($ millions)

Type	Europe	NAFTA	Latin America	Africa	Asia	Oceania	Total
Macrobials	70	100	15	8	30	20	243
Microbials							
Bacteria	15	80	10	5	20	30	160
Virus	10	15	10	2	5	10	42
Fungi	25	45	20	3	15	20	128
Total	50	140	40	10	40	60	330
Biorationals							
Natural	30	70	25	10	40	15	180
Semiochemicals	40	80	20	10	30	20	200
Total	70	150	45	20	70	35	390
Grand TotalUS$ millions	190	390	100	38	140	115	973

Source: International Biocontrol Manufacturer's Association, 2004

control, mechanical and physical control, chemical control and regulatory control. IPM is an important principle on which sustainable crop protection is based. IPM involves the need based use of pesticides only when the pest reaches the economic threshold level, and this will promote the build up of many biocontrol agents in the crop eco-system. In this regard, the use of biopesticides and bio-agents has assumed significance as an important component of IPM due to their economic viability and eco-friendly nature.

Biological Control

Biotechnology has a great potential in biological control. Biocontrol methods, wherever tried judiciously on experimental scale have been proved superbly successful in an array of diverse situations. There are several successful cases of pest management through biological control, which represent an ideal form of management in both, short and long-term pest suppression. Biocontrol agents/biopesticides have been a boom to primitive agriculture and have been economically successful in modern progressive and intensive agriculture. It is being used harmoniously with pesticide application. Biopesticide/biocontrol agents are being used as an alternate strategy to chemical pesticides as they are target specific and environment friendly due to their higher selectivity and biodegradable nature. The importance of biological control in integrated pest management has been recognized in our country from early 1930s when certain exotic biocontrol agents such as Prickly Pear Cochineal insect and others were important.

Biopesticide/biocontrol agents are natural pest control agents which include: (i) Microbial pathogens like (a) baculoviruses (b) antagonistic bacteria (c) antagonistic fungi (d) entomopathogenic fungi (e) entomopathogenic nematodes (EPN) (ii) parasitoids; (iii) predators; (iv) botanical products and (v) pheromones, kairomones and other semiochemicals. They offer a number of advantages over synthetic chemicals like lack of polluting residues, high level of safety to non target organisms, lower development and registration costs and the reduced risk of pest resistance. Biocontrol agents viz. parasites, predators, insect pathogens, antagonistic organisms, weed killers etc. have other added advantages of being self-perpetuating and establishing for many years offering permanent control in the ecosystem.

BIOPESTICIDES-GLOBAL DEMAND/PROJECTION

Biopesticides are likely to have a greater impact on the insecticide sector. Some analysts believe that biopesticides will account for 15% of the total insecticide market by the year 2010. In 1995, various economic forecasting services estimated the world market for pesticides at approximately $29 billion. The biopesticide share of the market was estimated to be around $380 million i.e. 1.3% of the total market. Presently, biopesticides represent approximately 4.5% of the world insecticide sales. The growth rate for biopesticides over the next ten years has been forecast at 10-15% per annum in contrast to 2.5% for chemical pesticides.

The Indian biopesticide market is highly fragmented with numerous small-scale local producers, probably more than in any other country in the world, and yet it had occupied only 2.5% share of a total pesticide market worth Rs.2,700 crores (Rs.27 billion or US$ 675 million). Considering their environmental benefits, suitability for use in IPM

strategies and ability to satisfy increasing food safety standards, biopesticides have excellent opportunites to create their own niche and penetrate significantly into mainstream crop protection market. As regards, global scenario, more than 1,000 different products or technologies are available through more than 350 manufacturers in the world; the use of biopesticides represents only around 2% of the total plant protection inputs market of about US$ 588 million. However, the analysts feel that under the current scenario with marked regression in sales of chemical plant protection products due to various factors including significant increase in genetically modified crops with plant protection traits (i.e., insect resistance, disease resistance and herbicide tolerance), there is tremendous scope for biopesticides in integrated pest management of several crops, especially in developing countries. It was predicted that the global market value of biopesticides which was US$ 588 million in 2003 would increase to US$ 973 million in 2008 – a 65.5% increase (Table 1).

The estimation for Asia is still brighter. It was projected to increase from US$ 72 million in 2003 to US$ 140 by 2008 – an increase by 94.4% (Table 1). It is further predicted that such increasing trend would continue globally to record 150 to 300% increase in sales of biopesticides within the next 10 years. It reflects the huge opportunity available for biopesticides and they may replace some 20 to 30% of the chemical market.

AVAILABILITY OF BIOPESTICIDES IN INDIA

About 700 products of different microbials are currently available worldwide. In India about 16 commercial preparations of *Bacillus thuringiensis*, 38 fungal formulations based on *Trichoderma*, *Metarhizium*, *Beauveria* and about 45 baculovirus based formulations of *Helicoverpa* and *Spodoptera* are available. Microbials are expected to replace at least 20% of the chemical pesticides. Biotic agents are being supplied by about 128 units in the country (80 private companies). Besides, ICAR institutes (8), SAUs (10) and Central Integrated Pest Management centres (30) and 4 parasitoid producing laboratories are also supplying natural enemies (Wahab, 2003, 2004).

BIOPESTICIDES: INDIAN PERSPECTIVE

Biological control of pests and diseases has undergone a great deal of development in the last two decades in India. Both center and state Governments have been strong supporters of Integrated Pest Management (IPM) with main emphasis on biological control. In India, national and state governments have been strong supporters of IPM and biological solutions to pest control for many years. In 1977 the All- India Coordinated Research Project (AICRP) on Biological Control was initiated to conduct systematic studies on natural enemies of crop pests and to utilize both exotic and indigenous natural enemies. The AICRP functioning under Project Directorate of Biological Control, Bangalore with about 22 centres in different parts of the country has identified several important natural enemies for the control of major pests of economically important crops. Based on the technology developed so far, the Directorate of Plant Protection, Quarantine and Storage through their 30 Central IPM Centres in different states in the country has been culturing the biological control agents on large scale and supplying to the farmers for use on a limited scale. They are also providing training to extension workers and farmers about the biocontrol technologies. The first private insectary, Biocontrol Research Laboratory, was established at Bangalore in 1981. There are as many as 42 parasitoid breeding centres in the State Department of Agriculture, particularly in peninsular India. In 1989 Simbhaoli Sugar Mill at Simbhaoli Dt. (Ghaziabad, UP) also started *Trichogramma* production units for its own use. Many sugar factories in South India have now established laboratories of their own for mass production of the egg parasites. Currently biotic agents are being supplied by about 128 units in the country. These commercial concerns also supply inputs such as pheromone traps for lepidopteran monitoring and mating disruption, and plant products such as neem-based formulations. The companies supply end-users directly or through government agencies. In short, a vast array of biocontrol products is available in India, yet inadequate production is still identified as one of the major bottlenecks to IPM adoption.

During 1980's Department of Science and Technology, Department of Environment, GOI, UGC, CSIR, BARC, etc., have supported a large number of short-term ad-hoc projects on biological control. However, one lacuna in the application of biocontrol agents in the field was production of adequate quantity of the biocontrol agents in the context of the country being so vast. Based on the accomplishment made in the 1980's and taking cognizance of the need to extend the technology of biocontrol from laboratory to field, Department of Biotechnology (DBT) came forward to support a major project on biological control of pests and diseases in the country since 1989.

DBT's efforts towards the Development of Biopesticide Technologies

DBT has made concerted efforts towards the development of biopesticide technology in a systematic way during the last 18 years by launching various projects and programmes:

(A) NATIONAL BIOCONTROL NETWORK PROGRAMME

DBT had established a National Biocontrol R&D Network Programme in 1989 to study the control of pest diseases and weeds of economically important crops (oil seeds, pulses, rice, cotton, tobacco, sugarcane, vegetables, fruits, plantation crops viz. tea, coffee, ginger, black pepper and other spices) in the country. Almost 300 R&D projects have been implemented at various ICAR/CSIR National Institutes and SAUs throughout the country. This National Biocontrol R & D Network is a continued effort of the Department. Its main aim is to develop better biopesticide formulations as well as to develop cost effective, commercially viable mass production technologies of various biocontrol agents and biopesticides like microbial pesticides (baculoviruses, antagonistic fungi and bacteria, entomopathogenic fungi and nematodes), parasitoids and predators, pheromones and other semiochemicals and botanical pesticides, for use under IPM programmes and their large-scale frontline field demonstrations against key pests and diseases of economically important crops in varied agro-climatic zones. Biological control of weeds is also covered under this programme. A nationwide multicentric programme on *Parthenium* was launched on the integrated management of *Parthenium hyterophorus* (an obnoxious weed), which has ill effects on health and environment. 12 projects were implemented out of which 2 were related to human health, 4 on its utilization and value addition research, 5 are on the integrated management and 1 on remote sensing.

In view of the colossal losses being caused by post harvest storage pests, their importance in export and also on account of serious scarcity of information in the area, biological control of storage pest has been identified as one of the priority area during X plan and 13 projects were generated and implemented on the storage pests on crops like cereals, pulses, oil seeds, horticulture crops, plantation crops and spices etc. Under the programme generation for North-east region during XI plan, a network programme has been generated on the management of ginger pest & diseases through an Interactive Workshop on Management of Ginger Diseases and Pests in North East and Himalayan Region held at Gangtok. Six projects have been generated out of which, two projects are mainly on DNA fingerprinting and chemoprofiling of ginger in NE India and NW Himalayas. Rest four projects are on the various management strategies of pests and diseases of ginger. Considerable success has been achieved in terms of development of products/ formulations and cost-effective commercially viable mass production technologies of various biocontrol agents/biopesticides and their frontline efficacy demonstrations at large scale in varied agro-climatic zones covering crops of cotton, rice, chickpea, tobacco, groundnut, sunflower, sugarcane, sesamum, soybean, blackgram, greengram pigeonpea, lentil and other pulses; cauliflower, tomato, chilli and other vegetable spices; tea and coffee etc. The achievements are highlighted below:-

Mass Production Technologies Developed:

Standardized cost effective and commercially viable mass production technologies of 32 candidate biocontrol agents/biopesticides *viz.* a) Microbials- NPVs *of Helicoverpa armigera, Spodoptera litura, Hyblaea puera, Spilosoma obliqua and GVs of Chilo infuscatellus and Plutella xylostella, Trichoderma viride, T. harzianum, T.koningii, T. virens, Myrothecium verrucaria, Aspergillus niger, Bacillus subtilis, Pseudomonas fluorescense, Beauveria bassiana, Verticillium lecanii, Nomuraea rileyi, Debaromyces henseni* and *Pochonia chlamydosporia* b) Parasitoids and Predators – *Trichogramma chilonis, T. polae, T.japonicum* and *Chrysoperla carnea* c) Entomopa thogenic Nematodes (EPN) - *Steinernema carpocapsae, S. biocornutum, S. seemai spn,* and *Heterorhabditis indica.* d) Pheromones – Insects sex pheromone lures for *Chilo sacchariphagus indicus* and *Scirpophaga incertulas* have been established.

Bioefficacy Demonstration

Field efficacy of aforesaid biocontrol agents/biopesticides has been determined. They were tested at multilocation covering various crops viz., cotton, rice, chickpea, tobacco, groundnut, sunflower, sugarcane, sesamum, soyabean, blackgram, greengram, pigeonpea, lentil and other pulses, cauliflower, tomato, chilli and other vegetables, spices, tea, coffee etc. Substantial area of land (2,05,000 ha. approx) was covered in various agro-climatic zones of the country for managing pests and diseases of important crops. Significant achievements of the R & D projects in specific areas are given below:-

a) Microbial Biopesticides

- Mass production technology of the baculovirus HpNPV has been developed and technology is ready for transfer for the management of teak defoliator (*Hyblaea puera)* at KFRI, Peechi.
- At MPKV, Rahuri, two formulations of *Ha*NPV and *Sl*NPV have been developed against *H. armigera* and *S. litura*.
- In another study at MPKV, Rahuri various cell lines were used to grow entomopathogenic viruses as safe biopesticides. The established cell lines Sf-9, Sf-21 of

Spodoptera fugiperda, Sl-883 and Sl-992 of *S. litura* and Ha-197 of *Helicoverpa armigera* were successfully subcultured and passaged. Procedure and media for monlayer and spinner culture of Sf-9 cells with SlNPV (MPKV strain) and AcNPV was successfully carried out.

- The cost effective and easy methodology for producing PbGV against the larvae of *Pieris brassicae*, a pest of cruciferous crop has been developed at MU, Imphal.
- At IHBT, Palampur, diagnostic kits have been developed for the detection of Carnation Gladiolus Virus (CGV).
- The two promising strains of *Bacillus* and *P. fluorescens* were formulated in a methylcellulose : talc (1:4) formulation against *Xanthomonas oryzae* at University of Madras, Chennai. Two bioactive metabolite producing strains of *Bacillus* and *Pseudomonas* genera were screened and studied in detail. Both the strains showed plant growth promotion and disease control properties against fungus causing brown rot (*Fomes lamoensis*) in tea.
- At AMU, Aligarh, two biopesticides based on *Trichoderma harzianum* and *Verticillium chlamydosporium* have been developed for the management of mono and multi-pathogenic diseases of chickpea and pigeonpea caused by *Fusarium* and *Meloidogyne* species.
- At GBPUAT, Pantnagar, the isolate T35 amongst 45 isolates of *Trichoderma harzianum* and isolate P16 amongst 16 isolates of *Pseudomonas fluorescens* were found to be active against *Fusarium oxysporum* and growth promotory in tomato and chilli.
- At TNAU, Coimbatore it was found that combined application (talc based) of the native bacterial isolates of *Pseudomonas fluorescens* and *Bacillus* sp. to the betelvine rhizosphere is significantly effective in reducing the nematode and *Phytophthora* infestation in betelvine crop. Also fluorescent pseudomonds strains viz. TNAU-Pf1, TDK1, MDU2, PY15, TJE3 and K3 amongst hundred PGPR strains isolated from rhizosphere soil of rice plants collected from various parts of Tamil Nadu were very active against *Rhizoctonia solani, Pyricularia grisea* and *Xanthomonas oryzae*. At College of Horticulture, Thrissur bio-agents consortia consisting of combinations of *Trichoderma harzianum* & *Pseudomonas fluorescens* was developed for management of rhizome rot, bacterial wilt of ginger and chilli.
- **At NCL, Pune, t**he production of cuticle degrading and mycolytic enzyme complex (chitinase, chitin deacetylase, chitosanase, protease, lipase and â-1,3-glucanase) using *Myrothecium verrucaria* was optimized. This enzyme preparation was at par of chemical pesticide, endosulfan in controlling *Helicoverpa armigera* in pulses, and *Ceratovacuna lanigera* (woolly aphids) in sugarcane.
- At IISR, Calicut, endophytic bacteria isolated from black pepper were characterized and were found to suppress *R. similis* and *Phytophthora capsici*.
- Molecular mechanism of elicitor induced prospectives to combat Panama disease of Banana has been successfully studied at Sardar Patel University and a technology was developed for combating panama disease of Banana. Technology was transferred to farmers.
- At UAS, Bangalore, indigenous isolates of *Glomus fascicuatum* (Shimoga banana isolate) were found to be significantly effective in combination with neemcake and FYM in increasing the plant growth parameters and yield of tomato besides reducing root knot nematode population.
- At Mysore University, Entomopathogenic fungi *Beauveria bassiana* was field tested against Coffee berry borer and proved to be potential biocontrol agent.
- At Assam Agriculture University, Jorhat *Verticillium lecanii* was selected and field tested successfully against red spider mite in tea.
- At IARI, 162 seed dressings, 36 soil application formulations were developed from potential isolates of *Trichoderma viride* (IARI P-1=MTCC No.5369) *T. virens* (IARI P-3=MTCC No.5370) and *T. harzianum* (IARI P-4=MTCC No.5370) and their shelf life was monitored. *T. harzianum* based seed dressing formulations were found most effective against wilt and dry root rot, *T. virens* formulation against wet root rot was found most effective. Module for integrated management of these diseases was developed.
- Studies conducted by TERI, New Delhi at Aluchina village in Uttarkhanda state revealed that the use of consortium of Supi arbuscular mycorrhizal fungi (isolated from Supi soil) and consortium arbuscular mycorrhizal fungi (TERI culture) in combination with entomopathogenic nematode *(Heterorhabditis indica)* isolated from Supi soil suppress the root-knot nematode effectively in the field condition.
- A biocontrol technology for mango hoppers has been developed at IIHR, Bangalore. It was observed that entomopathogens *Metarhizium anisopliae* and *Verticillium lecanii* caused significant mortality of Mango hoppers *Idioscopus nitidulus* in field conditions.

b) Parasitoids and predators

- *Trichogramma sp*. and *Chrysoperla* species mass produced and field tested on cotton, tobacco, chickpea and sugarcane crops.
- At PDBC Bangalore, a genetically improved strain of egg parasitoid *Trichogramma chilonis* was developed with combined tolerance to three insecticides (Endosulfan 700ppm, Fenvalerate 20ppm, Monocrotophos 540ppm) and high temperature (38°C).
- At GBPUA&T, Pantnagar, also temperature and insecticides tolerant strains of *Trichogramma chilonis* and *Chrysoperla* have been developed.
- At UAS Bangalore, Various parameters for optimum mass production of *phytoseiid mite* predator for biologi -cal control of spider mites have been standardized.
- A biological control strategy involving the conservation and augmentation of the two major predators viz. *Dipha aphidivora* and *Microuns igorotus* has been developed for the management of the Sugarcane Woolly Aphid, *Ceratovacuna lanigera* at PDBC, Bangalore.

c) Entomopathogenic Nematodes (EPN)- Insecticidal nematodes

- At IIPR, Kanpur, bio-efficacy of promising populations of *Steinernema* and *Heterorhabditis* against *H. armigera* has been established. Two novel heat tolerant EPN viz. *Steinernema masoodi* and *S. seemae* have been identified and successful field trials were conducted to establish their efficacy. *S. seemae* has been found more potential in killing *H. armigera* larvae within two days.
- Indigenous entomopathogenic nematodes (EPN) are being used for the management of insect pests of rice at DRR, Hyderabad.
- Three EPN isolates *viz. Steinernema thermophilum*, *S. asiaticum* and *Rhabditis* (*Oscheius*) sp. have shown entomopathogenic ability to infect and multiply on *Corcyra cephalonica and Galleria mellonella*.
- At ICRI, Idukki, three isolates of EPN *viz.* ICRI-18 (*Heterorhabditis* sp.), ICRI-90 (*Steinernema* sp.) and ICRI-81 (*Heterorhabditis* sp.) have been identified for the management of cardamom root grub. Efficacy of three virulent strains were confirmed against root grub by laboratory bioassay. 100% grub reduction was observed in some of the field trials.
- Genetic improvement of *Heterorhabditis indica* and *Steinernema riobrave* for tolerance to environment and enhanced efficacy against *Helicoverpa armigera*, cotton bollworm, has been done at CICR, Nagpur.
- At DRR, Hyderbad, three indigenous entomopa thogenic nematodes, *Rhabditis (Oscheius) sp (DRR EPN 1), Steinernema thermophilum* (DRR EPN 2) *and Steinernema asiaticum* (DRR EPN 3) have been identified and their efficacy is being field tested.
- Detection and mapping distribution of EPNs in the country was done for the first time. 3 isolates each of *S. carpocapsae, S. biocornutum* and *Heterorhabditis indica* were isolated. Various formulations developed and field tested at PDBC, Bangalore.
- *In vivo* and *in vitro* cultivation techniques for *S. carpocapsae* developed at AAU was revalidated at RRL, Jammu. The technology was found feasible for small to medium scale.
- At AAI, Allahabad, successful field studies were conducted on *Steinernema carpocapsae* for the management of pests of Okra, brinjal, tomato against *E. vitelle, Leucinodes arbonalis* and *H. armigera.*

Botanical pesticides

- Under the development of biodegradable botanical pesticides, insecticidal activity of *Annona squamosa, Derris tephrosia, Acorus calamum, Melia azedarach, Walsuria tirfoliata, Dysoxylum ficiforma, D. balamaricum, Azadirachta indica* and *Vitex negundu* was established.
- At IBRC, Jalandhar, in the multi-component defense study of Neem allelochemicals, it has been established that Non-Azadirachtin type of limonoids have there own potential as insect control agents and there is specific synergistic interaction between the chronic toxins and antifeedant compounds like those from salannin group combined with gedunin type of compounds. However, Azadirachtin is not influenced by any other neem alellochemicals. Toosendanin has been isolated from *Melia dubia* species and found to be feeding deterrent for *Helicoverpa armigera* larvae.
- At AAU, Assam, on tea pest management, the root extract of *Linostoma decundrum* and leaf extract of *Clerodendron inerme w*as found to have both miticidal and insecticidal properties. It also showed ovicidal and antiovipositional properties against red spider mite (*Oligonychus coffeae)*.
- At IARI, New Delhi, fungicidal activity of crude extract of secondary metabolites (from broth and mycelia) of *Trichoderma virens* was found to be very active against *Sclerotium rolfsii, Rhizoctonia bataticola and Macrophomina phaseolina*.
- At SPIC Science Foundation, Chennai, a botanical fungicide was developed and its field efficacy was tested against leaf spot disease of Black gram, Green gram and Red gram. The formulation was evaluated for storage, stability and the data generated indicated its utility as commercial product.

- At SPIC Science Foundation, Tuticorin, studies on the photostability of Azadirachtin A, the most potent insect antifeedant compound in neem, revealed that 16 hrs of UV irradiation is required for degradation of 50% of Azadirachtin. The products of photolysis of Azadirachtin A showed decreased dipole movement. Stabilizing agent which decreases the rate of degradation of Azadirachtin A has been identified and stabilizer required for formulation has also been studied.
- Bioactive principles from certain indigenous plants viz. *Aegle marmelos* and *Phlogocanthus thyrsiflorus*, *Linostoma decundrum* and *Clerodendron inerme* have been developed and utilized in the management of tea pest at AAU, Jorhat.
- At VMSRF, Bangalore, entomogenous neural cytoskeletal proteins have been taken as targets for developing Bio-rational insecticides "*in silico* and *in vitro" from Neem limonoids.* Best available target for neem limonoids was identified to be Actin, a major cytoskeletal protein that is involved in many important cellular functions like cortical stiffness, transcription, protein biosynthesis, transport of vesicles etc. At this centre, protocols have been developed for *in vitro* regeneration and transformation of Lakshmi variety of tomato using leaf and embryonal explants for introduction of genes responsible for enhanced volatile release.

Pheromones and semiochemicals

- At IICT, Hyderabad, two synthetic pheromones viz. Z11-hexadecenal and Z9-hexadecenal were synthesized and studied against *Helicoverpa armigera*, *Earias vitella* and *Pectinophora gossypiella* and were found promising. Suitable dispensers from commercially available samples were identified for all the three aforementioned insect species.
- At IICT, Hyderabad, pheromones of Pomegranate fruit borer and fruit sucking moths of sweet orange were isolated, identified and synthesized. Field trials were found very successful in managing the fruit bores.
- IICT, Hyderabad in collaboration with MPKV, Dhule has demonstrated the feasibility of Pheromone Application Technology (PAT) for control of bollworms on cotton in the farmers' fields involving monitoring, mass trapping & mating disruption techniques. IICT developed and identified the locally available materials as the best suitable and affordable dispensers for all the three species of bollworms. Pheromone trap, dispenser with the pheromone components in required blend ratios for all the three species of bollworm complex along with the methodology of implementation is now available at IICT as a package.
- AHRE, Chennai has demonstrated pheromone Technology for the control of *Chilo infuscatellus* and *Chilo sacchariphagus indicus and s*ynthesised Z-11 hexadecen-1-ol and Z-13 Octadecenyl alcohol in laboratory scale.
- Methods for large-scale multiplication of *Caryedon serratus* in the laboratory and technique for large scale segregation of male & female *C.serratus have* been standardized successfully and the technique for collection of volatiles by air entrainment has also been successfully standardized both at IICT and GB Pant University.
- Sex pheromone based technology developed at IICT, Hyderabad in collaboration with MPKV, Rahuri confirmed the existence of strong female based sex pheromone communication system in pomegranate fruit pests *D.isocrates, E. materna* and *E. fullonia.* Four pheromone components from *E. materna* and three from *D.isocrates* have been identified and synthesized successfully in the lab and confirmed their bioactivity by GC-EAD technique.

Molecular studies on biocontrol agents

- Molecular characterization of 146 species of agriculturally important micro-organisms (*Bacillus, Trichoderma, Pseudomonas, Steinernema*) was undertaken at RRL, Jammu. DNA Finger printing was done by RAPD and PCR RFLP. Studies revealed both intra- specific and inter-specific polymorphism within the isolates. Sequence analysis of Internal Transcribed Spacer 1 (ITS) region of rDNA cluster, using ex-type strains and taxonomically established strains of *Trichoderma* as reference, clustered the *Trichoderma* isolates into following groups- *T. harzianum, T.inshamatum* complex, *T. asperellum* and *T. longibrachiatum* clusters. Co-relation between different genotypes and potential biocontrol activity has also been studied against phytopathogenic fungi.
- At Pondicherry University, molecular analysis of antifungal activities of antagonistic bacteria, *F. pseudomonads* isolated through screening of the rice rhizosphere was done. Two strains (Pf23 and PPS3) exhibited antagonism more efficiently than any standard strains of *F. pseudomonads* which were selected and studied. These could be used as an effective biocontrol agents as well as biofertilizers agents.
- At BHU, a PCR based quick diagnostic method has been developed using a strain specific DNA probe for *Macrophomina phaseolina*.
- In a multicentric project being implemented at ICGEB, and IARI, New Delhi, a 60 kDA native protein of *Xenorhabdus nemetophilus* was purified from cell

lysate and oral toxicity was checked on *Helicoverpa armigera* and *Spodoptera litura* neonates. The protein has shown potent oral toxicity on *H. armigera* with a LD_{50} value. However, it was not potent against *S. litura.*

- At TNAU, Coimbatore, a chimeric gene, *cry* 2Ax1 of *Bacillus thuringiensis* (Bt) was constructed by engineering C-terminal region of domain-III in Cry2Aa to improve toxicity of its protein against *Helicoverpa armigera*. The constructed chimeric *cry2Ax1* gene was expressed in transformant of acrystalliferous Bt strain. Analysis of Cry2Aa, Cry2Ab, Cry2Ac and chimeric Cry2Ax1 proteins for toxicity against larvae of *H. armigera* showed about 22-fold higher activity in the chimeric Cry2Ax1 protein (in terms of LC_{50}) than the Cry2Ab.
- At Pondicherry University, antagonistic Fluorescent pseudomonad isolates viz. W5, Pf6, Pf7, Pf10, Pf11 and Pf13, Pf24 were isolated. Strain W5 exhibited a broad-spectrum antifungal activity towards several phytopathogenic fungi that attack rice, groundnut, chilli, cotton, sugarcane, mango and banana. Bio-chemical and molecular characterization of novel *Fluorescent pseudomonad* strains and genetic analysis of antifungal metabolic production was done. Molecular analysis and transposon mutagenesis for other *Fluorescent pseudomonad* strains are in progress. At the same centre, a transgenic *Gluconacetobacter diaszotrophicus* containing Cry 1Ac toxin gene from *Bacillus thuringiensis kurstaki* has been generated by employing genetic engineering method. Interestingly the transgenic *G. diazotrophicus* though contained *Cry 1Ac* toxin gene did not impair the nitrogen fixing efficiency of the *G. diazotrophicus* as evidenced by normal nitrogenase activity both in wild type and transgenic *G. diazotrophicus*.
- At Lucknow University for cloning and characterization of a systemic antiviral resistance inducing protein gene test hosts *Cyamopsis tetragonoloba* and *Nicotiana tabacum* cv Xanthi-nc were raised in an insect free glass house and used as assay hosts for resistance against Sunnhemp Rosette Virus (SRV) and Tobacco Mosaic Virus (TMV) respectively. From leaves of *C. inerme*, CIP-29 was purified, cloned, sequenced and analyzed with respect to other antiviral protection. The maximum homology for the *CIP-29* gene was found with the antiviral protein from *Clerodendrum aculeatum*.
- Molecular characterization of potential biopesticides against *Sclerotium rolfsii* Sacc is done at ANGR University, Tirupati. The isolates of *S.rolfsii* revealed cultural, morphological and pathogenic variability. Among the bacterial antogonists GSE37, GRS15, GRS21 and GGS-6 were identified as *Pseudomonas fluorescens* based on *16 rDNA* sequence analysis, showed 98-100 % inhibition of *S. rolfsii.*
- The diversity of *Acinetobacter* species associated with rhizosphere of wheat has been studied by PCR-DGGE fingerprinting technique at Agricultural Research Institute, Pune in collaboration with University of Pune. Results revealed that majority of the strains were *A. calcoaceticus* whereas, other species detected were *A. baumannii, A. lwoffii* and *A. baylyi*. All the siderophore producing *Acinetobacter* strains restricted growth of *Fusarium oxysporum*, a causative agent for wilt of wheat, The studies on the alpha-amylases of the rice pest at NCL, Pune was done. The protocol for the purification of the inhibitors has been standardized and the samples were screened for crystal formulation.

Parthenium weed management

Parthenium hysterophorus is an obnoxious annual weed and a main source of nuisance and health hazard to mankind and animals. A multicentric programme on the integrated management of *Parthenium* weed was launched. Some of the achievements are:-

- At AIIMS, New Delhi, role of *Parthenium hysterophorus* in pathogenesis and exacerbations of atopic dermatitis has been established. Studies were conducted on the pathogenesis of *Parthenium* in Type I and IV hypersensitivity reactions and exacerbations of atopic dermatitis. The *Parthenium* pollen extract was prepared, filtered and diluted to obtain desired dilution of pollen antigen extract. Skin prick test was performed on the volar aspect of the forearm of serum donors suffering from atopic dermatitis patients out of ten showed positive response. For estimation of total IgE antibodies, total IgE level in serum samples and peripheral blood mononuclear cells was measured quantitatively. Almost 80% patients showed IgE levels above than the normal. Allergen specific IgE antibodies were also determined by ELISA.
- At RML Hospital, New Delhi,studies were undertaken to establish the incidences of *Parthenium* dermatitis in patients of photodermatoses. Preliminary results indicate that *Parthenium* as well as *Xanthium* plant act as a precipitating factor in 18% of photodermatoses patients. Out of 61 patients (23 male and 38 females) of various age groups, 31 cases of polymorphic light eruption (PMLE), 9 cases of chronic actinic dermatisis, 14 cases of photoallergic dermatitis, 4 cases of chronic actinic lichenoid dermatitis and 2 cases of photosensitive melanoses (PM) were reported. Females were found to be more vulnerable to *Parthenium* sensitivity. The role of UV light in exaggeration of

symptom and development of secondary photoder matoses has been studied.

- At FRI, Dehradun, studies on economic potential of *Parthenium* has been carried out for development of particleboard. *Parthenium* ligno-cellulosic material was converted into particles and blended with the phenol – formaldehyde adhesive. The *Parthenium* lignocell ulosic material was converted into fibre for the development of medium density fibre board.
- Control of *Parthenium* through eco-friendly approaches has been studied at NBRI, Lucknow. Effect of three tree species – *Jatropha curcas*, *Terminalia arjuna* and *Riccinus communis* on the growth of *Parthenium* was studied and *R. communis* was found to suppress the growth of *Parthenium* maximally. Leaf and bark extracted fraction of *T. arjuna* was tested on *P. hysterophorus* and found to be effective at different stages.
- At RDU, Jabalpur, various mycoherbicides are being developed for the control of *Parthenium*. *Colletotricum gleosporioides, C. dematium, Alternaria alternate, Fusarium oxysporum* and *F. solani*, has shown significant weed control at seedling stage particularly in seed function and germination. These mycoherbicidal agents have been successfully mass produced through solid substrate fermentation employing maize cob grit and when applied to the seedling of the target caused more than 90% mortality.
- Large-scale demonstration on management of *Parthenium* through integrated approach has been done at NRCWS, Jabalpur. Few plant species were found competitive against *Parthenium*. *Cassia tora* was found to be the best plant as it replaces *Parthenium* infected site during rainy season. Introductory releases of bioagants, Mexican beetle, *Zygogramma bicolorata* at newer sites, confirm its establishment, which reflected its success in integrated management programme.
- At IIIM, Jammu investigations have been completed on *Parthenium* for their chemical and biotransformation studies to develop new potential bioactive molecules. The major Sesquiterpene lactones of *Parthenium hysterophorus* were screened for their bioactivity. The work resulted in the preparation of unique and focused libraries of more than eighty structurally modified molecules.
- Management of *Parthenium* through integrated approach was demonstrated on large scale at PDBC, Bangalore. General survey on the extent of infestation of *Parthenium* and its ill effects in different parts of the country was completed. Botanical Agents and Mexican Beetle suppressing *Parthenium* in different parts of the country has been identified.
- At NRCWS, Jabalpur large scale demonstration on management of *Parthenium* has been completed. *Zygogramma* was successfully mass reared and its performance was assessed as biocontrol agent of *Parthenium* in the different agro-climatic regions and noted that release of beetles revealed large scale defoliation of *Parthenium* and restoration of local vegetation.
- Studies conducted at UAS, Bangalore in collaboration with IISc, Bangalore on allelo-chemicals from bioagents for management of *Parthenium hysterophorus* revealed that calcium alginate pellets of dry leaf extract of *Hyptis sauveolens, Cassia uniflora* and *Lantana camara* reduces the germination and seedling growth of the *Parthenium*.
- At IARI, New Delhi, bio-intensive management of *Parthenium* in non-cultivable land was undertaken. A safe and effective protocol has been developed for *Parthenium* Management (PPPM-2008). It comprises of two biological control agents namely botanical-Jangali bathua (*Kochea indica*) and insect-Parthenium beetle (*Zygogramma bicolorata*). Field Study revealed that biocontrol used in the protocol are self-perpetuating in nature, ecologically safe and reduces weed considerably. A module for integrated *Parthenium* management for north India has been developed.

Storage pests and their ecofriendly management

- At CIMAP, Lucknow insect pests (3) of stored grains of wheat and rice have been successfully managed through natural products.
- At NMU, Jalgaon, a series of cyclotides produced by members of the *Rubiaceae* and *Violaceae* families were screened and evaluated primarily for the insecticide property of the compound with the marker insect *C. chinensis*, a post harvest pest of the storage grain legumes and *H. armigera*, a cotton pest.
- At PDBC, Bangalore FAT3 and FAT6 fat oils were screened based on their good stability of invert-emulsion formulation i.e. 95% upto 9 months and tested for their inhibitory effects on growth and sporulation of *T. harzianum.* Phytotoxicity tests with chickpea, tomato and groundnut proved that the invert emulsion formulation were non toxic to these crop plants. The seed treatment with standardized invert emulsion formulations at the rate of 10ml/ kg of seed resulted in good yield as well as reduction of groundnut root rot incidence.
- Management studies of pests in stored grains have been conducted at IIPR, Kanpur. Four new entomopathogenic nematodes (EPN) have been isolated belonging to *Oschieus* and *Acrobeliodes* sp. were able to kill *C. cephalonica* larvae within two days under

laboratory conditions. Pulse beetles, *Callosobruchus chinensis* and *C. maculatus* have been found highly susceptible to EPN, *Oschieus amsactae*. The experiment has also been done to assess the EPN survival in dessicated bruchuid cadver and was found promising.

(B) BIOCONTROL PILOT PLANT UNITS (BCCP) FOR COMMERCIAL PRODUCTION

Based on the technology developed through DBT Coordinated Programme, two Biocontrol Production units were set up TNAU, Coimbatore and TNAU, Madurai. The mandate was to produce sufficient quantity of biocontrol agents viz., NPV of *H. armigera* and *S. litura*, GV of *C. infuscatellus*, *Trichogramma* and *Trichoderma* for the management of key pests and diseases of regional crops covering 22,000 ha. per annum. The commercial viability of these two model units were established from first year onwards which enthused the progressive farmers and entrepreneurs. The amount realized by way of sale proceed during a period of four years was Rs. 18.00 lakhs. Some of the technologies were transferred to various industries.

(C) MISSION MODE PROGRAMME ON "DEVELOPMENT PRODUCTION AND DEMONSTRATION OF BIO-CONTROL AGENTS UNDER IPM"

Based on the success achieved in the National Biocontrol Programme and commercially viability of the two production units, a time bound goal oriented mission mode programme was launched by the Department during the year 1994-95 for large-scale adaptation or biopesticide technologies under IPM and for their adoption by farmers. The main aim of this programme was to demonstrate the bio-efficacy of the biopesticides produced through various technology packages generated by various R&D efforts and to revalidate and fine tune the technologies through large scale frontline demonstrations. One of the major objective was to work out the cost benefit ratio in IPM and in Non-IPM trials. The mission mode programme was implemented successfully and was completed in 1998. This programme was logically concluded in Sept-1999. All the targets for crop-wise and biopesticide-wise area coverage (55000 ha.) in the fields of cotton, groundnut, sunflower, soybean, chickpea, pigeonpea, lentil, spices, vegetables and tobacco etc. have been covered. Under this programme 20 production units and 2 repository centres were set up in 15 states representing various agro-climatic zones of the country. These repository centres were set up for collection, maintenance and supply of nucleus culture of biocontrol agents and host insects to the various production units and others under this programme. The economics of IPM was established by working out the cost benefits ratio in several crops in IPM and Non-IPM plots/trials. The benefits have been realized in terms of yield increase (20kg-500kg per ha), monetary benefits per ha. (Rs. 12.000/- to Rs.35, 000/-) and reduction in pesticide usage (50%). Through this programme the gap of availability of sufficient quantity of biocontrol agent's along with the quality control and their adoption and adaptation in farmer's field have been bridged significantly. The cost of crop protection was optimized and income/profits were maximized.

(D) INTEGRATED PEST MANAGEMENT (IPM) FOR SUSTAINABLE AGRICULTURE

A major R&D programme on "Biological control of crop pests and diseases under IPM as a component of INM programme" was launched during 1998-99 on the role of biological resources for INPM for increasing agricultural productivity in existing cropping systems. This programme was launched at 14 centres in 12 states. The main aim of this programme was to develop effective modules/package of practices, which are cost effective, sustainable and eco- friendly in different ecosystems and also to demonstrate the sustained preservation of ecosystem by conducting frontline demonstrations in identified clusters/ adopted villages by adopting IPM and INM techniques and also to develop suitable techniques for packaging storage and application of bio-agents to enhance their field efficacy and to promote involvement of NGOs towards the use of biocontrol agents.. This programme has been concluded and finally reviewed in May, 2003.

Several effective IPM modules which are cost effective, sustainable and eco-friendly in different ecosystems have been developed for various crops viz., rice, pigeonpea, chickpea, French beans, soybean, lentil, green pea, mustard, tomato, brinjal, capsicum, cauliflower, cabbage, chilli and coconut etc. The economic benefits have also been realised in IPM modules of various crops grown in various agroclimatic zones. The cost-benefit ratio of IPM-INM modules worked out at large scale trials showed significant tilt in favour of adopting the technology by farmers for different crops. An IPM module with various strategies has been developed for green (organic) cotton with a mean net profit of Rs. 8000/ha. in IPM field. The sustained preservation of ecosystem has been successfully demonstrated in the adopted villages in Andhra Pradesh. The net profit was raised from over Rs. ll,000/ha. in 1999-2000 to over Rs. 20,000/ha. in 2000-2001. Accordingly the CB ratio was also raised from 1:1.62 to 1:2.31. Based on the cost effective mass production technology of *Nomuraea rileyi* and its bioefficacy at small

scale, it has been tested at large scale during Kharif season covering about 25 villages. Field demonstration trials conducted by SKUAST, Jammu covering an area of 55.6 ha using *rhizobium/azotobacter* + biocontrol agents gave highest yield in crops like *bhindi*, cucurbits, chillies and gram; The average increase in yield in different crops in Srinagar varied from 2.0-18% and 15.0-54.5% in Jammu. Significant advantages were realised in IPM-INM techniques exploited for the management of tea pests in Assam and the techniques were adopted by the farmers. Intensive promotion programmes launched for adoption of IPM-INM technique, training programmes and various extension activities for farmers and extension functionaries were organised throughout the country under this programme. These programmes have resulted in the conservation of ecosystem and environmental protection by reducing the quantity and cost of chemical pesticides leading to sustainable agriculture. It is also expected that the various module/package of practices developed through this programme would be used by the farmers as routine practice.

Patents

Several patents have been filed for the mass production technologies and development of product formulations of various biocontrol agents viz, *Trichoderma viride, Trichoderma virens, Trichoderma harzianum, Pseudomonas* spp., *Nomuraea rileyi, Beauveria bassi ana, Verticillium lecanii* and *Myrothecium verrucaria* etc. A US patent (US Patent No.: US 6,593,127 dated 15/07/2003) has been granted for the liquid fermentation mass production technology of *Trichoderma viride*. The process of preparing two biopesticide formulations (*Beauveria bassiana*) against Coffee Berry Borer (CBB) has also been granted Indian and South African patents (Patent No.:2005/5006 dated 26/07/2006) and the technology is ready for transfer . The novel process of commercial production of three bioformulations viz. Biowiltex (*Trichoderma harzianum*), Bionem-x (*Pochonia chlamydoisporia*) and Biocomp-x (*Pseudo monas fluorescens*) has also been granted Indian and USA patents (US Patent No.: US 0292124 dated 28/12/2006). Another US patent (US Patent No.: US 7,365,194 B2 dated 29/04/2008) has been granted for Dimer of Phenazine-1-Carboxylic Acid, a compound from broad-spectrum antifungal Fluorescent Pseudomonads and the process of its preparation thereof. Patents have been filed for biopesticides development from bacterial symbiont for management of sucking pests of cotton and also for the development of diagnostic kit for the detection of *Bean Yellow Mosaic Virus* in commercial crops. Several other patents are also under process.

Intellectual property safeguards

Initiatives were also taken and projects were developed for intellectual property safeguards. Molecular marker identification and DNA finger prints initiated as new projects for generating authentic data base on the microbial diversity of agricultural importance in the country and projects are implemented at RRL, Jammu, TNAU Coimbatore; UAS, Dharwad and KFRI, Kerala. In addition project for the development of PCR-based genomic fingerprinting of *Macrophomina phaseolina* and strain specific DNA probe was implemented at BHU, Varanasi. Substantial progress has been made in the project on studies on genomic flux and molecular analysis of insecticides resistance in cotton bollworm *Helicoverpa armigera* at UAS, Dharwad and molecular characterization (DNA fingerprinting) of selected fungal and bacterial species of agricultural importance at RRL, Jammu.

Popularization of biopesticide technology: extension and training programmes

Popularization of biopesticide technology is one of the important components of the overall biocontrol programme in order to create general awareness among farmers for the large scale use of biocontrol agents under IPM and also to develop farmer oriented technology packages for large scale adaptation. It was done by organizing several extension activities and by imparting trainings.

- Wide publicity of the biocontrol technology under IPM was given through farmers' field school, *krishi melas*/ exhibition cum information-cell and consultancy/ biocontrol stalls, agro-clinics, agri fairs, regional workshops and through mass media which included newspaper, magazines/popular articles/radio talks and video films etc. Besides, the press meets and Farmers' *Goshthis* were also organized and the significance of biocontrol under IPM was highlighted.
- Various centres were identified for imparting training regularly on the production and management strategies of biocontrol agents to progressive farmers, small entrepreneurs, scientists from private and public sectors and unemployed youth.
- Awareness programmes were conducted about the problems associated with *Parthenium* infestation and its possible management. Participants were educated about the health hazard effects of *Parthenium* and briefed about the management strategy of this invasive weed from cropped and non cropped area. About 1200 participants including eminent scientists, teachers and students were benefited.

- About 80,000 farmers' benefited and over 1800 handouts in various regional languages were released and distributed among the farmers and other users.
- DBT has also brought out several (20) technical brochures from various R&D projects giving the details of technologies developed for wide circulation including the end users.

This awareness programme has evoked the interest of the policy makers, extension workers, small entrepreneurs and farmers throughout the country. Already some private individuals, entrepreneurs, progressive farmers, unemployed agriculture and science graduates have started producing biocontrol agents.

TECHNOLOGIES DEVELOPED AND THEIR STATUS OF TRANSFER:

Several mass production technologies of biocontrol agents/biopesticides have been developed, standardised and transferred. The fermentation based technologies of 3 biocontrol agents viz., *Trichoderma viride, T. virens, Bacillus spp.* and 3 biofertilisers viz, *Rhizobium spp, Azotobacter spp., and Azospirillium spp.*. have been transferred as integrated package for biopesticides and biofertilizers to 3 industries viz., M/s Prathishta Industries Ltd., Secundrabad, A.P. and M/s Javeri Agro-industries & Investment Co. Ltd.., Javeri Nursery Premises, Amrawati, M.S and M/s Haryana Biotech, Gurgaon, in May 2000. *Aspergillus Niger* (AN27) transferred to M/s Cadila Pharma. Mass production technology of HaNPV(Heliokill), SlNPV (Magic), SoNPV (Spilocide), Phule Trichocards (*Trichogramma chilonis*), Phule *Trichoderma* have been developed, formulated, branded and being produced and supplied to farmers in large quantities for demonstration. At NARDI, Hyderabad, mass production technology of *T. viride*, *Trichogramma* (egg parasitoid) and Australian ladybird beetle, *Cryptolaemus montrouzieri* was standardised. 5 Mt. of *T. viride* was produced and distributed to farmers in A.P. and Karnataka covering about 2500 acres. Production technology was transferred to Nagarjuna Fertilizers and Chemicals Limited (NFCL). NFCL had utilised the technology for the production of *T. viride* which was used in manufacturing value added enriched organic manure "Mahasakthi". NFCL had produced and marketed 5000 Mahasakthi in the last three years. NFCL had also applied for CIB registration of *Trichoderma*. At NARDI, 11,375 cards (a card contains 20,000 parasitoids) were produced and distributed to the farmers in AP (cotton & sugarcane) and Maharashtra (Grapes) free of cost. Adult lady bird beetles (10,000) were produced and supplied to Maharashtra State Grower's Association for the management of mealy bugs on grapes. NARDI is using this technology for large scale production to distribute to grape farmers on non-profit basis. At IISR, Calicut, solid state fermentation technology of *Trichoderma harzianum* has been developed and transferred to 10 private entrepreneurs in the state of Tamil Nadu, Karnataka and Andhra Pradesh. Toxicological data is being generated for registration purpose. Mass production technologies of HaNPV and SlNPV developed at UAS, Dharwad are ready for transfer. These two technologies have also been developed using local strains / resources at RARS, LAM, Guntur and have been transferred to five industries. At GBPUAT, Uttaranchal, mass production technologies of two high temperature tolerant strains of *Trichogramma poliae* and *T. japonicum* have been developed and negotiations are on for technology transfer.

At TNAU, Coimbatore, technologies of *Trichoderma viride* and *Pseudomonas fluorescens* have already been transferred to several industries. At this centre, another liquid formulation of GV of *Plutella xylostella* have been developed and also three entomopathogenic fungi viz. *B. bassiana*, *Paecilomyces fumosoroseus* and *Metarhizium anisopliae* found pathogenic to larvae of *P. xylostella*. Commercial viability is to be pursued. At KFRI, Kerala mass production technology of HaNPV against *Hyblaea Puera* (teak defoliator) has been developed for teak forest ecosystem. Techno-economic feasibility has been done. 7 formulations have also been developed and mode of application on teak trees has been standardised and perfected. Technology is ready as a full package for transfer. Generation of toxicological data is awaited. Mass production technology of *B. bassiana* have been developed and perfected. M/s Phyto Myco Research Pvt. Ltd. approached for technology transfer. Negotiations are on with other companies. Techno-economic feasibility studies have been completed in case of an entomopathogenic nematode *Steinernema carpocapsae*. Technology is being fine tuned for up-scaling and commercialisation. Various formulations of *S. biocornutum* (isolated for the first time) have been developed and field tested at PDBC, Bangalore. Technology is to be fine tuned for up-scaling. Techno-economic feasibility of a potential biopesticide *Myrothecium verrucaria* is also underway and attempts are being made for it's up-scaling and shelf life studies. The pheromone technology for the management of Inter Node Borer lure (*Chilo Sacchariphagus indicus*) of sugarcane through sex pheromone have been standardized and field tested with the dispensers developed indigenously. 7 companies have approached for the transfer of internode borer (INB lure for sugarcane). Management of rice yellow stem borer

(*Scirpophaga incertulas*) by mating disruption technique was done through the use of specific pheromones. Pheromones were synthesized and dispensers /lures were prepared at Indian Inst. of Chemical Technology (IICT), Hyderabad. Feasibility of the technique validated under field conditions in multilocation trials by Directorate of Rice Research (DRR), Hyderabad. An IPM module with various strategies has also been developed for green cotton at Tamil Nadu Agricultural University (TNAU), Madurai and is being practiced in the state of Tamil Nadu. At IHBT, an ELISA based diagnostic kit of bean yellow mosaic virus infecting *Gladiolus iris* and *crocus* has been developed. The technology is to be up-scaled and validated before commercialization.

Besides, there are other 5-6 new potential biopesticide technologies viz., (1) *Aspergillus niger*(An17) (fungal antagonist), (2) *Debaromyces hensenii* (yeast antagonist), (3) *B. bassiana* and *Verticillium lecanii* (entomopa thogenic fungi) and (4) *Nomuraea rileyi*, *Geotrichum* and (5) *Hyblaea puera* NPV (for teak management) and (6) Neem bitter formulation and neem insecticidal soap, (7) *Myrothecium verrucaria* (a high mycolytic and cuticle degrading enzymes producing fungus) are being revalidated and fine tuned for commercialisation. NPV of *Hyblaea puera* has been found a potential biocontrol agents for the management of teak defoliators (*H. puera* in the teak plantation in the forest ecosystem). Detection and mapping disruption of entomopathogenic (EPNs) was done in the country for the first time. Three isolates each of *S. carpocapsae, S. biocornutum* and *Heterorhabditis indica* were isolated. Various formulations have been developed and field-tested.

Efforts are also being made for revalidation, up scaling and fine tuning of the technology packages for some of the potential biopesticides viz., *Steinernema carpocapsae* (entomopathogenic nematode) and *Myrothecium verrucaria*(chitin attacking fungi). *S. carpocapsae* has been found to be a potential biocontrol agent against the important pests of vegetable crops through the R&D effort of a DBT funded project. . This nematode biopesticide technology developed at Allahabad Agriculture Institute at laboratory scale was got validated by a feasibility study at Indian Institute of Integrated Medicine (IIIM, earlier known as RRL), Jammu. Based on the feasibility/validation report a detailed scale-up study is underway before the technology is transferred to industry for commercialization.

Myrothecium verrucaria has emanated as a potential biocontrol agent against soil borne pathogens and insect pests containing chitin through a completed R&D project implemented at NCL, Pune. With a view to develop the product at a pilot scale and for the development and packaging of the technology, it was felt necessary to undertake the techno-economic feasibility and scale–up studies of *Myrothecium verrucaria* through another project. It has been decided to carry out studies on a) optimization of production of chitinase complex for field trials; b) toxicity testing and shelf life studies and c) to make formulations for soil and foliage application for field trials to control insects and fungal pests of some identified crops.

Gujarat Agricultural University (GAU), Anand, Gujarat has produced *Trichogramma chilonis* and *Chrysoperla cornea* based biopesticides which are ready for transfer as small-scale industry. SPIC Science Foudnation,, Chennai has developed INB Lure (sex pheromone) for *Chilo Saccariphagus indicus* and a botanical anti-fungal product, 7 companies have approached for technology transfer indeed. NIV, Pune has established 8 new indigenous cell lines from different tissues of four insects. 4 cell lines (Two from *S. litura* (NIV-SU-992, NIV-SU-893); One from *B. Mori* (NIV-BM-1296); One from *H. armigera* (NIV-HA-197) are going to be patented. *Beauvaria bassiana* based biopesticides technology has been developed in University of Mysore, Karnataka and M/S PhytoMyco Research Pvt. Ltd. has approached for technology transfer. IARI, New Delhi has developed various technologies, which are ready for transfer.A. solid formulation of *Trichoderma virens* for the control of nematodes and fungus, improvement in /or preparation of Azadirachtin concentrate from Neem seed kernel extract and additives for improved stability of Azadirachtin and mechanized system for mass production/rearing are established in IARI, New Delhi and ready for transfer. Techno-economic feasibility of powder (fly-ash) formulation of *T. harzianum, P. chlamydosporia, P. fluorescens* developed at AMU, Aligarh, has been established. Patent has been filed and technology is to be fine tuned for up scaling and commercialization. Botanical Anti-fungal from *Cymbopogon martinii* against phytopathogenic fungi) developed by AHRF, Chennai is ready for transfer. At GBPUAT, Pantnagar, technologies of mass production and formulation of *Trichoderma harzianum* (Pant Biocontrol Agent-1), *Pseudomonas fluorescens* (Pant Biocontrol Agent-2), *T. harzianum* PBAT-43 + *P. fluorescens* PBAP-27 (Pant Biocontrol Agent-3), *Trichoderma virens* (Pant Biocontrol Agent-4) have been developed and branded. Technologies of mass production of *Trichoderma, Pseudomonas* and their mixed formulation on cow dung and cost effective mass multiplication of *Trichoderma, Pseudomonas* and their mixed formulation on FYM and chicken manure have been developed. The technologies have been transferred to farmers of Uttarakhand and U.P.

Thus, substantial success has been achieved in the National Biocontrol R&D Network Programme and subsequently in the mission mode and other programmes in terms of i) development of standardized, cost effective and commercially viable mass production technologies of various biocontrol agents/biopesticides; ii) demonstrating the field efficacy of biocontrol agents/biopesticides under different ecosystems in various economically important crops covering 2,05,000 ha; iii)realizing the economic benefits in IPM trials by working out the cost benefit ratio in terms of a) monetary gain; b) yield increase; c) reduction in pesticide consumption; iv) creating a general awareness about the biocontrol base IPM technology among the farming community and the end users. Successful demonstration trials under mission mode and the IPM-INM programme have culminated as a recommendation by the State Department of Agriculture in various states.

REGISTRATION STATUS OF BIOPESTICIDES IN INDIA

In India, the Central Insecticide Board and Registration Committee (CIB & RC) is responsible for the registration of all pesticides including biopesticides. These are regulated under the insecticides Act, 1968. All the pesticides are required to be registered under the Insecticides Schedule Act, 1968 and Certificate of Registration is issued under Section 9(3) in case of botanicals (like neem) and 9(4) in case of biopesticides based on microorganisms or other living organisms. As mentioned few botanicals have been registered. Neem based products with 0.03%, 0.15% and 1% Azadirachtin content have been registered. The registration committee has also granted regular registration to *Bacillus thuringiensis* and provisional registration to a number of other biopesticides based on Bt and Bs with a view to commercialize formulations based on bacilli for control of various crop pests. Fungi *Ampelomyces quisqualis*, *Beauveria bassiana*, *Metarhizium anisopliae*, *Paecilomyces lilacinus*, *Trichoderma harzianum*, *Trichoderma viride*, *Verticillium chlamydosporium*,*and Verticillium lecanii* have also been registered. NPV of *Helicoverpa armigera* and *Spdoptera litura* have also been registered. An antagonistic fungus *Trichoderma viride* has been registered provisionally under Section 9 (3B) for groundnut seedling wilt. So far 15 biopesticides (Bacteria 3, fungi 8, virus 2 and botanicals 2) with various formulations have been registered in India.

Initiatives Taken By DBT to Facilitate the Registration and Commercialization of Biopesticides

DBT has taken initiatives to facilitate the registration and commercialisation of biopesticides. As per the notification dated March, 1999 of the Central Insecticide Board, Ministry of Agriculture, the biopesticides were put into the Insecticide Schedule Act 1968. As such, the generation of toxicological data became a prerequisite for the registration of the biopesticides. This has hampered commercialisation of biopesticides. With a view to facilitate commercialization and quick dissemination of newly developed eco-friendly technologies, DBT had organized an interactive workshop on "Eco-friendly technologies of Biopesticides and Biofertilizers on Crop Management" in April, 2000. Important issues related to the registration and commercialization of biopesticides were addressed. Various recommendations emanated through detailed deliberations were taken up for recommendation to the concerned ministries, especially issues pertaining to registration of biopesticides. At the initiative of the DBT, the Directorate of Plant Protection Quarantine and Storage, Dept of Agriculture, Ministry of Agriculture convened several meetings of the technical group of the registration Committee of the Central Insecticide Board (CIB). The existing data guidelines/data requirements for the registration of biocontrol agents/biopesticides were reviewed, simplified and streamlined as per the recommendation of DBT. The revised guidelines have been issued in November, 2000.

Since several technologies have been developed through the R&D effort of DBT but their commercialization is at stake for want of generation of toxicological data for registration purpose. With a view to the facilitate the commercialization of biopesticide technologies developed through the Department's R&D effort, the Department had taken a proactive step and supported the generation of toxicological data for the registration of biopesticides in a phased manner. In the first phase, nine potential biopesticides viz., *Trichoderma viride*, *T. virens*, *T. harzianum*, *Beauveria bassiana*, *Nomuraea rileyi*, NPV of *H. armigera*, NPV of *S. litura*, NPV of *H. puera* and *Myrothecium verrucaria* have been taken up for generation of toxicological data from two identified CSIR centres. Data generation has been completed for almost all the biopesticides. One biopesticide product of *Trichoderma viride* (developed through DBT support) has been registered as 1.15% wettable powder in Feb 2005. The product is launched as "Protect" (Biofungicide). *Myrothecium verrucaria* has also been developed as a potential biopesticides and through DBT's initiative and request it has been included in the schedule to the insecticide Act 1968 of the Gazette Notification no. GSR 224(E), of the Central Insecticide Board, MOA, GOI. Guidelines have also been formulated by the Deptt. for the generation of toxicological data of this fungus.

Launching of Website on Biopesticides

Initiatives have been taken for developing a comprehensive website on Biopesticide/ Biocontrol programme with a view to disseminate the information generated through the R & D projects as well as other information relevant to this area. Salient achievements from more than 124 completed projects have been covered in this website. The outcome of these projects is very valuable since these have impact on promoting production of biological resources. Through this comprehensive website on Biopesticides which has linkages and hyper linkages with other relevant websites, information generated through the R&D efforts of DBT as well as other related information in this area are communicated to a variety of users like citizen/public, S&T communities, biotech industries etc. The website on "Biocontrol Strategies for Eco-Friendly Pest Management in India" was developed and officially launched on 23rd June 2008. This website is being updated, upgraded and maintained by TERI through a DBT supported project. The URL of the developed website is www.dbtbiopesticides.nic.in..

REFERRAL LABORATORIES FOR QUALITY CONTROL OF BIOPESTICIDES

As quality control is a prerequisite for the ultimate success of biopesticides, standards and quality control of biocontrol agent/biopesticides have to be ensured on the basis of latest technology. The institutional mechanism for monitoring and adaptation of standards are being evolved and strengthened through the efforts of DBT. Realising the importance and maintaining 'quality control' of biopesticides, the need of referral laboratories for the certification of biopesticide products in the country has been felt and as such, DBT has decided to designate some referral laboratories in the country. Seven centres have been identified for this purpose. These centers are Assam Agricultural University (AAU), Jorhat; University of Agricultural Sciences (UAS), Dharwad; Mahatma Phule Krishi Vishwavidyalaya (MPKV), Pune; Regional Research Laboratory (RRL), Jammu; Indian Agricultural Research Institute (IARI), New Delhi, G.B. Pant University of Agriculture and Technology (GBPUAT), Pantnagar and Allahabad Agricultural Institute-Deemed University (AAIDU), Allahabad. These centres have developed sufficient core competence as well as infrastructure through DBT funding for handling the quality control and assurance parameters under existing regulatory guidelines. Further these centres got notified by the Ministry of Agriculture for which an extra Gazette notification was published. Referral labs have been given good publicity by these centers and samples from various industries and other production units are being received by them for ensuring the quality control and shelf life.

MARKET SURVEY OF BIOPESTICIDES

DBT is making a systematic approach for commer cialization of biopesticide technology developed through R&D effort. With a view to assess the gap between demand and supply in the country and in order to identify region-wise requirements of biopesticides based on agricultural practices, crops and their pest profile for better acceptance and utilization by farmers, an extensive market survey study was got done at the instance of DBT by Biotech Consortium India Ltd., Delhi. The authentic data generated through this study would help in attracting entrepreneurs for commercialization of the technologies and also in creating awareness among farmers for proper selection and usage of biopesticides and their purchase from a suitable dealer. In addition, this study will also help policy makers in taking decisions for further development of biopesticides in the country. This study has been completed.

11th Plan Priorities

- Strengthening and consolidation of the existing programmes ; revalidation and fine tuning of the technologies and their subsequent transfer to industries.
- Registration and commercialization of the potential biopesticides would be facilitated by further streamlining the guidelines and generation of toxicological data and ensuring the quality of the product with international standards.
- NABL accredited Referral laboratories Network in the country would be encouraged for the certification of the products in order to maintain the quality control.
- Compliance of GMP norms in all the biopesticide production units in co- operation with the regulatory agencies.
- Efficient strains (with superior traits) of biocontrol agents would be developed exploiting biotechnology and genetic engineering.
- In insect biotechnology, areas like neuroendocrine research, sex specific selection using chimeric genes, pheromones, kairomones, insect tissue culture would be supported.
- Biological control of crops having export potential viz. (Coffee, Tea, Cashewnut, Mango, Apple, Citrus, Grape, Tomato, Cabbage /Cauliflower, Okra, Pepper, Small and large Cardamom, Ginger, Basmati Rice and Cotton (Green/organic).

- Development of a national facility for Collection and Maintenance (in vitro and in situ) of entomopathogens (fungi, bacteria and nematodes) and their field performance
- Post-harvest protection of grains, vegetables and fruits using eco-friendly technologies
- Biological control of pests and diseases in forest ecosystem.
- Creation of centres of excellence in the area of Biopesticides for advanced research.
- Extension activities (Technology upgradation & demonstration through farmer's participatory programme and others) to be strengthened to make biological control more popular among the farmers.
- Public private partnership for developing programmes on mating disruption pheromones and kairomones; new botanicals and microbials.
- Entrepreneurial development would be encouraged to set up a large number of small and medium scale units throughout the country.
- A countrywide training programme would be organised at regular intervals for the biocontrol workers.
- Rigorous training of the trainers and international linkages would be encouraged.
- A Network Project for developing / establishing *Trichoderma spp.* and *Pseudomonas fluorescens* as powerful biocontrol soldiers for the management of plant diseases of national importance by identifying existing gaps in their research domains.
- Development of molecular technology such as appropriate toxin genes against sucking pests like hoppers, jassids and aphids which affect brassicas, pulses, vegetables, cotton and sugarcane.
- Development of novel toxin genes in addition to Bt.
- Identification and expression of genes responsible for the antifungal lead molecules from natural (plant and microbial) sources
- Development of dynamic pheromone dispensers for the control of pests of economically important crop.
- Human Resource Development in the area of Biological Pest Control needs to be strengthened.

National Strategy Document on Biopesticides

As a background, Hon'ble Minister (S & T & ES) chaired a brainstorming on "Reinvigorating Indian Agriculture through Science & Technology" on 28.07.2007 at New Delhi for focusing and strengthening those activities that could deliver visible and tenable results in the immediate future in the field of biopesticides. Biopesticides was identified as one of the important areas for which it was suggested that a "Strategy Document" may be prepared, analyzing the various issues relating to the development and usage of biopesticides and identification of the constraints being faced in their registration and commercialization. DBT's "Strategy Document on Biopesticides" is going to be a national document with recommendations for enhancing the productivity in agriculture. The document has been prepared by a committee of eminent scientists and industry representatives and contains executive summary, detailed report, market scenario and constraints/bottlenecks, policy issue and other strategies to promote biopesticides and finally the recommendations. The final Strategy document has been approved by Secretary and Hon'ble Minister**.** The recommendations sent to various ministries are as under:-

A. Ministry of Agriculture

i) The regulatory system for biopesticides is modeled on a chemical pesticides model which is not conducive for their commercialization. Therefore, it will be more applicable to take them out of the purview of the Insecticides Act, 1968 and enact a separate Biopesticides Act for their evaluation and registration.

ii) To make it mandatory for all biopesticides production units to obtain licenses for their production and sale. Licenses may be issued only after a technical audit of the facilities by a notified apex body. Severe penalties may be levied for spurious products.

iii) To set up an apex body at the national level to fix quality parameters for biopesticides.

iv) Quality Control Laboratories, with adequately trained staff, to be established in all major States.

v) The State Governments and Agricultural Universities to develop crop specific IPM packages involving biopesticides and include them in their official Package of Practices.

vi) A well-structured plan of action and budget to enhance awareness about biopesticides, for which radio, TV and media can play an important role.

vii) Let each Krishi Vigyan Kendra (KVK) of ICAR demonstrate the use and efficacy of biopesticides on a selected crop in a minimum of 5 acres for the benefit of farmers.

viii) Let each MLA and MP convert one village in his/her constituency as Green Village with the help of State Department of Agricultural, University, KVK and farmers. Thus they can champion the cause of IPM and biopesticides. Awards may be instituted to recognize the best leaders/farmers.

B. Ministry of Commerce & Industry

i) To exempt biopesticides from State and Central Sales Taxes, Excise Duty and VAT to make these more affordable to farmers.

ii) To streamline the process of product procurement and distribution under the prevailing government subsidy schemes to make it more transparent. Subsidies may also be extended directly to the production units, based on their production capacities and supply.

C. Ministry of Environment and Forests

i) The State Pollution Control Boards do not have separate provision for giving consent for starting production units for biopesticides and treat them on par with any other industry. The Central Pollution Control Board may, therefore, issue separate guidelines for permitting establishment of biopesticide production units that do not cause environmental pollution and also charge only a nominal annual fee for their operation.

In order to summarize the efforts of Department of Biotechnology, achievements made in the Biopesticide research can be highlighted as under:

a. Development of cost effective and commercially viable mass production technologies of various candidate biocontrol agents / biopesticides.
b. Demonstrating the field efficacy of biocontrol agents / biopesticides under different ecosystems in various economically important regional crops grown in various agroclimatic zones throughout the country covering about 2,05,000 ha.
c. Several production cum demonstration units were set up in various states for the mass production of biocontrol agents / biopesticides and their subsequent efficacy demonstration and multiplication in different agroecological regions.
d. Collection, maintenance and supply of Nucleus cultures of biocontrol agents and host insects to the various production units was done by setting up two repository centres at TNAU, Coimbatore and PDBC, Bangalore.
e. Several capable IPM modules were developed for various economically important crops which are cost effective, sustainable and eco-friendly in various ecosystems. In addition, sustained preservation of ecosystem was also demonstrated in adopted villages.
f. The cost effectiveness of biopesticide technology in IPM and non-IPM plots of various crops was established by working out the authenticated cost of production of biocontrol agents produced in different units at various states.
g. The department took initiative in streamlining the guidelines for generation of toxicological data for registration purpose. In order to promote and facilitate commercialisation of the biopesticides, department has played a catalytic role and taken suitable measures for the generation of toxicological data of potential biopesticides for the purpose of registration etc.
h. An extensive market survey is being done to assess the gap between demand and supply in the country as well as in order to identify regions wise requirements of biopesticides based on agricultural practices, crops and their pest pro0file for their better acceptance and utilisation by farmers. This study will also help the policy makers in taking decisions for further development of biopesticides in the country.
i. For maintaining the standards and quality control of biocontrol agent/biopesticides, the department has designated six centres as “Referral Laboratories” in the country. Four have been made operational. Requests from few other centres have also been received.
j. Intensive promotion programmes were launched for the popularization and adoption of IPM and IPNM techniques through trainings and extension activities for farmers and extension workers throughout the country.
k. Several patents have been granted for the mass production and product formulation of various biocontrol agents/biopesticides.
l. A national strategy document has been prepared analyzing various issues relating to the development and use of biopesticides and constraints being faced in their registration and commercialization in the country. This document is a useful roadmap document for future.
m. These programmes have resulted in conservation of ecosystem and environmental protection leading to sustainable agriculture and income generation. The awareness programmes have also evoked the interest of the policy makers, extension workers, small entrepreneurs and farmers throughout the country. Already some private individuals, entrepreneurs, progressive farmers, unemployed agriculture and science graduates have started producing biocontrol agents.

CONCLUSION

Biological control is playing a very important role in the modern agricultural concept of IPM. Biopesticides are likely to have a considerable impact on the conventional insecticides. It is estimated that biopesticides based product could account for 15 % of the total insecticides sector by the year 2015. The growth rate for biopesticides over the next ten years has been forecast at 10-15 % per annum in contrast

to 2.5% for chemical pesticides. Biopesticides is a farmers' participatory technology and IPM is a practical and knowledge intensive subject. With a view to promote sustainability of crop production, it is of paramount importance to develop and adopt low cost systems of IPM as about 75% of the farm holdings are small and marginal. Today, as IPM spreads, farmers are developing their own local solutions and look increasingly to researchers for technologies to test and incorporate. This demand is likely to increase as farmers' participatory IPM method spreads. Moreover, the successful adoption of biocontrol needs countrywide farmers' training at a high level. Although more than 1,000 different products or technologies are available through more than 350 manufacturers in the world, the consumption of biopesticides represents only around 2% of the total plant protection input market of about US$ 588 million. There is tremendous scope for biopesticides in integrated pest management of several crops, especially in developing countries. It was predicted that the global market value of biopesticides which was US$ 588 million in 2003 would increase to US$ 973 million in 2008 – a 65.5% increase. In Asia, it was projected to increase from US$ 72 million in 2003 to US$ 140 by 2008 – an increase by 94.4%. It is further predicted that such an increasing trend would continue globally to record 150 to 300% increase in sales of biopesticides within the next 10 years (Dent & Waage, 2000). Despite such increase, it would still represent only a fraction of the chemical pesticides market. Nevertheless, it reflects the huge opportunity available for biopesticides even if they were to replace some 20 to 30% of the chemical market. The Indian biopesticide market is highly fragmented with numerous low-cost local producers showing some interest. Altogether 150 companies are involved in the production and marketing of about 15 registered biopesticides products in India. Although it was found to be very difficult to get dependable production and sales figures for biopesticides, all the available evidences suggest that biopesticides have taken only 2.5% share of a total pesticide market worth Rs.2,700 crores (Rs.27 billion or US$ 675 million) (Ray and Alison, 2006). This is equivalent to about Rs.675 million or US$17 million.

Through the awareness and large scale demonstration trial studies of DBT, it is now clear that the desire for biopesticides by the rural community is growing and fermentation technology can play a vital role in delivering such bio-products. The production and availability of sufficient quantity of biocontrol agents is further expected to be undertaken as a result of setting up of more production units in various states by transferring the technologies developed through DBT efforts. The availability and use of biopesticides in India is still low, due to several limitations coupled with low adaptation by the farming community. However, through various DBT programmes the gap of availability of sufficient quantity of biocontrol agents along with the quality control and their adoption and adaptation in farmers' field have been bridged to a considerable extent.

DBT has played a very important role in facilitating commercialization of biocontrol agents/biopesticides by simplifying the guidelines required for registration of the biopesticides. Department has also taken a step towards generation of toxicological data for some identified microbials from identified centres so that their registration may be facilitated. In order to ensure, the quality control and assurance parameters of biopesticides/biocontrol agents, DBT has designated several referral laboratories throughout the country. The delivery of biocontrol technologies or the method of application of biocontrol is a very important aspect for the success of the biopesticide technology. Attempts towards multidisciplinary and delivery-focussed approach should be made which address technical, economic, education and farmer related perspectives. There is also a need for greater attention to be given towards product formulation. Greater emphasis needs to be placed on developing formulations specific to the needs of the "active ingredient" of entomopathogens for greater success in the field with biological agents.

The successful adoption of biocontrol needs a high level countrywide farmer training. In particular farmers need to learn about augmentative biocontrol agents as living entities, their basic food and habitat requirements, and how to cater for these needs by providing alternative food sources/hosts. Explaining the importance of intercrops is seen as an essential component of IPM training, particularly in cotton and vegetables, to make the technique more sustainable. Unless knowledge and understanding is effectively conveyed to farmers, released agents may die on or soon after release, or migrate from the system.

It is expected that there will be considerable savings in the quantity and cost of chemical pesticides, which would be replaced by the biopesticides. Besides societal benefits by way of promoting better health among the people following reduction in the use of chemical pesticides and residue problems in food, feed, fodder, etc, there will be other advantages like environmental protection and conservation of ecosystem leading to sustainable agriculture and employment generation in the rural areas, particularly for women. There is also scope for setting up of large number of small units to cater to the needs of rural areas, which will ultimately use the local resources for IPM. Biopesticides is the "Thrust Technology" field. It is high time to raise the profile of biopesticides among the biotechnology community and to undertake more activities in this area by companies and research groups with fermentation facilities

and skills. Entrepreneurs and investors need to be informed about the opportunities that exist for establishing commercial companies to manufacture market and sell biopesticides. Part of this process requires that people are aware of the ongoing R&D in biopesticides and how this will lead to commercial opportunities. In this context, the interaction between the research laboratories, industry designs and consultancy organizations is required to achieve the goal of competitive and efficient biopesticides industry in the country.

Indian Government has taken considerable initiatives for the promotion of research and development of microbial biopesticides. There is a considerable amount of apparent activity, probably more than in any other country in the world, yet there is no evidence of any significant business breakthrough. Some of the probable reasons that might have hampered the progress of biopesticides, include the cumbersome and costly registration formalities; lack of adequate interest on the part of big manufacturers owing to limited market and profit margins; insufficient awareness on the part of consumers about the benefits of biopesticides; and also lack of consistent and convincing results to prove their efficacy to win the confidence of farmers. These issues need to be addressed if biopesti cides are to make a big dent in plant protection. For this Government is promoting Public Private Partnership programmes. Recognizing the importance of the role of private sector, Government has identified Public private partnership as the focus under the vision 2020 programme. For promoting biotech industries, it has been decided to invest upto 30% of DBT's budget in Public private partnership schemes. This is to promote innovation, pre proof of concept research, accelerated technology and product development in biotechnologies related to agriculture and other areas.

The recommendations of the national Strategy Document on Policy issues, quality control, technology promotion and marketing research and incentives etc. have already been taken up with concerned ministries like Ministry of Agriculture, Ministry of Commerce and Industry and Ministry of Environment and Forest. It is expected that positive impact will be created both on biopesticides manufacturers and end-users by making consistent and continuous effort on structured plans and programmes in the specific area of biopesticides research and development in the country.

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