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BIOTECHNOLOGY AND SUSTAINABLE AGRICULTURE: LESSONS FROM INDIA

by

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RÉSUMÉ

L'Inde est parvenue à l'autosuffisance alimentaire en adoptant des méthodes de culture à forte utilisation de produits chimiques. Ceux-ci ont gravement détérioré l'environnement. Limiter le recours aux engrais chimiques implique des technologies nouvelles moins dommageables, capables néanmoins de maintenir ou d'augmenter les niveaux actuels de productivité. Cette étude examine le développement et la diffusion des biotechnologies en Inde en se référant à la fois aux produits issus des méthodes biologiques conventionnelles et à ceux utilisant les techniques de pointe de la biologie moléculaire.

Jusqu'à maintenant, l'utilisation des fertilisants et des pesticides biologiques qui permettent de réduire l'emploi des engrais chimiques est marginale à cause du cercle vicieux que posent les problèmes de l'offre et de la demande. D'une manière générale, les fertilisants et les pesticides biologiques ne sont fabriqués qu'en petite quantité et avec des technologies peu efficaces. L'absence de qualité et la médiocrité des résultats n'incitent donc pas les fermiers à acheter et à accepter ces produits, attitude qui a des répercussions négatives sur les investissements dans la recherche et dans les moyens de production.

La recherche sur les végétaux transgéniques et sur les pesticides biologiques à partir du *Bacillus thuringiensis* est encore récente et il est difficile de prédire quel sera son impact potentiel. Cependant, il est certain que si l'on n'augmente pas de façon sensible les investissements dans ce secteur de recherche, la multiplication des brevets sur les végétaux pourrait bloquer l'accès au matériel génétique et aux techniques et limiter, par conséquent, le champ de la recherche dans les institutions publiques.

SUMMARY

India's self-sufficiency in food production has been achieved by the adoption of chemicals-intensive farming methods which have contributed to serious deterioration of the environment. New evironmentally-friendly technologies, which maintain (or increase) current levels of productivity, are needed if the use of chemical inputs is to be reduced. This study examines the development and diffusion of biotechnologies in India, with respect to both products derived from conventional biological methods and those using the more advanced techniques of molecular biology.

Thus far, the contribution of available biofertilisers and biopesticides to reduced use of agro-chemicals is marginal, due to the vicious circle created by problems of supply as well as demand. By and large, biofertilisers and biopesticides are being produced on a small scale, using inefficient technologies. Inconsistent quality and poor performance thus combine to limit demand and their acceptance by farmers which, in turn, has a discouraging effect on investment in research and production facilities.

As research on transgenic plants and on *Bacillus thuringiensis*-based biopesticides is at an early stage, it is difficult to predict their potential impact. However, it is argued that unless investment in research in these areas is dramatically increased, the strengthening of patents could impede access to genetic material and techniques and, consequently, limit the scope of research in public institutions.

PREFACE

This paper is part of a research project entitled Biotechnology and Sustainable Agriculture, which has been undertaken in the context of the Development Centre's 1993-1995 research programme on Sustainable Development: Environment, Resource Use, Technology and Trade. This project analyses developments in agricultural biotechnology research, development and diffusion in order to determine whether biotechnology is likely to contribute to a more sustainable model of agricultural production in developing countries. This alternative model would be less dependent on the use of agro-chemicals and based more on biological pest and disease control and local genetic resources.

The research comprises a number of different components. These include a conceptual study of agricultural biotechnology in the context of a national innovation system and an analysis of publicly-funded international initiatives to stimulate the introduction of biotechnology in developing country agriculture. In addition, six country studies have been conducted: India and Thailand in Asia; Colombia and Mexico in Latin America; and Kenya and Zimbabwe in Africa. Country studies, which have identified both successes and failures in biotechnology initiatives, have sought to determine incentives and constraints in the successive phases of research, technology development and diffusion of biotechnologies for plant protection and production.

This case study of India focuses on biofertilisers and biopesticides which have been developed by public research institutes and are already being produced and distributed to farmers. It also reviews developments in more advanced biotechnology research on transgenic plants and *Bacillus thuringiensis*-based biopesticides. The study illustrates forcefully the difficulties which can arise in the process of "translating" successful research into a quality product and in the successful transfer of that technology to the farmers for whom the research is ostensibly intended. It also highlights the limited success thus far achieved with biofertilisers and biopesticides and their marginal contribution to reduced use of chemical inputs.

India has strong public plant-breeding capability and an expanding seeds industry and, hence, sound infrastructure for the development of transgenic plants and new varieties obtained through new biotechnology methods. It remains to be seen, however, whether effective demand for these technologies will be stronger than for earlier biotechnology products.

Jean Bonvin
President, OECD Development Centre
December 1994

ABBREVIATIONS

The following abbreviations are used in the study:

B.t	Bacillus thuringiensis
BCIL	Biotech Consortium India Ltd.
BGA	Blue Green Algae
DBT	Department of Biotechnology
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
ICGEB	International Centre for Genetic Engineering and Biotechnology
JNU	Jawahar Lal Nehru University
NPV	Nuclear Polyhedrosis Virus
PAU	Punjab Agricultural University
TNAU	Tamil Nadu Agricultural University
USDA	United States Department of Agriculture

Current rupee/dollar conversion rates have been used for each year.

I. INTRODUCTION

Indian agriculture has seen major technological changes during the last three decades. The adoption of these chemical intensive farming techniques has provided India with much needed self sufficiency in food production. However, it has also contributed to a serious deterioration of the environment. The increased use of chemical fertilisers and pesticides, in particular, has been a cause of considerable damage.

Unless environmentally friendly technologies, which can maintain (or increase) the current levels of agriculture productivity, are developed, a decline in the use of chemical inputs can not be expected. The recent advances in biotechnology, which include the development of pest- and disease-resistant varieties, biopesticides and biofertilisers, can provide a powerful package of environmentally friendly technologies. This paper is aimed at an examination of the development and diffusion of these technologies in India. The extent of environmental damage caused by current agricultural practices and the status of biotechnology research in India are described briefly in the following paragraphs. The rest of the paper is divided into five chapters. The following four chapters deal with crop improvement, biopesticides, biofertilisers and intellectual property rights. The final chapter contains conclusions and their policy implications based on the findings of the study.

Agricultural Practices and Environmental Damage

The last 30 years have seen major technological advances in Indian agriculture. The introduction of high yielding varieties in the 1960s, along with chemical fertilisers and pesticides, has led to a large increase in agricultural productivity and food production. The yield per hectare of all food grains, for example, increased from 710 Kg. per hectare in 1960-61 to 1 382 Kg. per hectare in 1991-92. Similarly, the production of food grains increased from 82.0 million tons in 1960-61 to 168.4 million tons in 1991-92.[1] As a result of these advances, India has become self-sufficient in food grains.[2]

The spread of new agricultural technology has been particularly rapid in the case of wheat and rice. The area covered by high yielding varieties of rice, for example, increased from 2.20 million acres in 1966-67 to 6.62 million acres in 1968-69.[3] Similarly, the area covered by high yield varieties of wheat increased from 1.34 million acres in 1966-67 to 11.84 million acres in 1968-69. The total area covered by high yielding varieties of all crops increased from 4.66 million acres to 22.97 million acres during the same period.

While the successful adoption of new agricultural technology has provided India with much needed self sufficiency in food production, it has also contributed to a serious deterioration of the environment. As the high yielding varieties are highly responsive to chemical fertilisers, the consumption of fertiliser has seen a large increase since the 1960s, from 0.23 million tons in 1960-61 to 12.15 million tons in 1992-93. The consumption of nitrogenous fertilisers is particularly large; 7.43 million tons of these were consumed in 1992-93.[4]

Research has shown that excessive use of chemical fertilisers (especially nitrogenous fertilisers) is already causing serious damage to groundwater in some parts of India. The damage is particularly serious in parts of Punjab, where the adoption of new agricultural technology has been most extensive, and the intensity of fertiliser application is especially high. For example, a study of ground water in Punjab showed that about 10 per cent of the water samples contained more nitrate-nitrogen than the upper safety limit prescribed by the WHO.[5]

The application of chemical pesticides has also seen a similar increase. The total consumption of chemical pesticides increased from 4 000 metric tons in 1960-61 to about 100 000 metric tons in 1992-93.[6] Although the intensity of pesticide use in India is still less than in most developed and some of the developing countries, its indiscriminate use is already a cause of serious concern.[7,8] About 90 000 metric tons of the pesticides were used in India in 1990-91, of which 80 per cent were used in agriculture.[9] A very large proportion of pesticides used in India, about 75 per cent, are insecticides.[10] Compared to this, herbicides and fungicides account for about 12 per cent and 8 per cent of pesticide consumption. The intensity of pesticide consumption is particularly high in the case of cotton and rice. While these crops account for 5 per cent and 24 per cent of the cropped area respectively, they account for 55 per cent and 18 per cent of the total pesticide consumption.[11] Furthermore, BHC and DDT, which are especially damaging to health and environment, account for a large proportion of pesticide used in India; about 40 per cent of the pesticide used in India in 1989-90 consisted of these two pesticides.

The damage to health and environment caused by excessive and indiscriminate use of pesticides in India is now well documented. Research carried out since the 1980s shows that a large quantity of vegetables, fruits, cereals, oilseeds and cotton are highly contaminated with pesticide residue.[12] See Table 1.1.

Table 1.1 **Pesticide Residue**

Crop/Product	Number of Samples		
	Analyzed	Contaminated	per cent
Cauliflower	25	12	50
Grapes	30	17	57
Rice	61	42	69
Wheat	393	116	30
Groundnut	77	42	54
Cotton	36	28	78
Milk	43	35	81
Butter	105	105	100

Source: BCIL, "Technology Status Study on Biopesticides", Biotech Consortium Indian Limited, New Delhi, 1992, pp. 40.

The environmental damage caused by the excessive use of chemical inputs in agriculture has attracted increasing attention in recent years. Consequently, the government has taken a number of preventive steps. These include greater emphasis on diffusion of information related to the damage caused by the excessive use of chemical fertilisers and pesticides, and financial and technical support for the production of biopesticides. An integrated pest management (IPM) programme aimed at the reduction of the use of chemical pesticides was also set up in the 1980s. The effect of these efforts, however, has been only marginal, and the incidence of high application of these inputs has not come down. In fact, in the case of some crops, such as cotton, the consumption of pesticides has seen a sharp increase in recent years. On average, cotton farmers are reported to apply 17 rounds of chemical pesticides.

As the performance of high yielding varieties is highly dependent on the use of chemical fertilisers and pesticides, the possibility of a decline in the use of these inputs is small. In fact, considering the fact that government policy is aimed at promoting this technology to new areas, and that India continues to lose up to 30 per cent of its agricultural production due to pests, the consumption of both chemical fertilisers and pesticides is likely to increase.[13]

Biotechnology Research in India

The importance of biotechnologies was formally recognised in 1982 when a National Biotechnology Board was set up within the Department of Science and Technology. The Board was expanded into a fully fledged Department of Biotechnology in 1986. At present almost all the research in biotechnology is supported and co-ordinated by the Department and is carried out in government research laboratories and universities. The role of industry (both private and public) in research is very small. According to unofficial estimates 90 per cent of the research in biotechnology is government funded.[14]

Total government expenditure on biotechnology R & D amounted to Rs. 588.95 million ($18.99) in 1992-93. The relative importance of expenditures on biotechnology as a share of total R & D has seen a small but steady increase in the early 1990s (see Table 1.2).

Table 1.2. **Government Expenditure on Biotechnology Research and Development**
(millions of Rupees)

Year	Biotechnology R&D Expenditure (A)	Total Government R&D Expenditure (B)	A as percentage of B
1986-87	105.96	19792.1	0.54
1987-88	243.75	23588.8	1.03
1988-89	317.06	26755.9	1.18
1989-90	390.25	29339.2	1.33
1990-91	413.67	30582.7	1.35
1991-92	510.89	34672.9	1.47
1992-93	588.95	38910.9	1.51

Sources: India Government of, "Research and Development Statistics 1990-91", Department of Science and Technology, New Delhi, Various Years.

According to the Department of Biotechnology, there are about 50 laboratories in India which are capable of doing R&D in biotechnology.[15] These include six Centres for Plant Molecular Biology. These centres focus on research on plant tissue culture, plant genetic engineering (transformation and regeneration systems), RFLP-QTL mapping, cytoplasmic male sterility (CMS) and transgenic crop plants. Also, the Department supports a number of recombinant DNA research projects. In addition to these, a number of laboratories are reported to be working on biopesticides and biofertilisers.

While the Ministry of Science and Technology (of which the Department of Biotechnology is a part) puts strong emphasis on biotechnology research aimed at agricultural problems, the actual support given to this research is small.[16] For example, of the 13 task forces set up by the Department of Biotechnology during 1991-92, only three are related to agriculture. These are *a)* plant molecular and agriculture biotechnology; *b)* biological pest control and *c)* fuel, fodder, biomass, horticulture, plantation crops and sericulture.

Again, out of a total expenditure of Rs. 230 million ($9.39 million) on biotechnology research, the expenditure on agriculture related problems was only Rs. 61.5 million ($2.5 million) or 27 per cent. See Table 1.3.

Table 1.3. **Research Expenditure of DBT on Plant Biotechnology 1991-92. Rs. million**
(Millions of Rupees)

Objective	R&D Expenditure
Basic Research	15.5
Plant Molecular and Agriculture Biology	24.0
Fuel, Fodder, Biomass, Green Cover	15.0
Biological Control of Pest Diseases and Weeds	7.0
Total Agricultural Biotechnology R&D	61.5
Total Biotechnology R&D	230.0
Percentage	26.7

Source: India Government of, "Proposals of the Department of Biotechnology, Eighth Plan (1992-97) and Annual Plan (1992-93)", Department of Biotechnology, Government of India, New Delhi, 1992.

The research on agricultural biotechnology is largely aimed at an increase in productivity by the use of biofertilisers, biopesticides and the development of plants with resistance to biotic and abiotic stresses. In terms of crops, the research efforts are concentrated on rice, rape mustard and chickpea.

Summary

Indian agriculture has undergone a major technological transformation during the last 30 years. A successful adoption of "green revolution" technology, which is characterised by the use of high yielding varieties, chemical fertilisers and pesticides, has led to a large increase in yield and has enabled India to become self-sufficient in food grains.

The successful increase in agricultural productivity, however, accompanied by the large increase in use of chemical fertilisers and chemical pesticides, is causing serious damage to environment and health. Concerned by the danger, the Indian government has introduced a number of steps to rationalise the use of chemical inputs in agriculture. However, the success of agricultural technologies associated with "green revolution" relies heavily upon the use of these inputs. Unless environmentally friendly technologies which can maintain, or increase, the agricultural productivity associated with green revolution technologies are developed, a decline in the use of chemical inputs can not be expected. The recent advances in biotechnology, which include the development of pest- and disease-resistant varieties, biopesticides and biofertilisers, provide a powerful package of environmentally friendly technologies.

In India, research in agricultural biotechnology has begun comparatively recently. Most of this research is co-ordinated and funded by the Department of Biotechnology, which was set up in 1986. A number of research institutes are now engaged in the use of biotechnology in crop improvement, with particular emphasis on rice, chickpea and mustard. Research on the development of biofertilisers and biopesticides is also being carried out.

II. CROP IMPROVEMENT

Conventional Breeding and Seed Production in India-Achievements and Limitations

Organised seed production in India began in the early years of the 20th century. One of the first to set up these facilities was a private firm - Sutton Seeds - which started commercial seed production and marketing in 1912. The government also set up a few seed production facilities during this period. Expansion in the following years, however, was slow and sporadic.

It was only after independence that breeding and seed production activities were systematically expanded on government initiative. The first major initiative was taken in 1956, when the All India Coordinated Maize Project was set up jointly by the Indian Council of Agricultural Research (ICAR) and the Rockefeller Foundation. This was followed by a similar project for sorghum and pearl millet, which was set up by the ICAR in 1960.

The seed production sector received a further boost in the 1960s when a National Seed Corporation and a large seed production facility covering 16 000 hectares were set up. The crop improvement programmes also became more ambitious in the 1960s, as high yielding varieties of wheat and paddy and hybrids of maize, sorghum and pearl millet were introduced.

Plant breeding and seed development is almost exclusively undertaken by the public sector. These activities are coordinated and funded by the Indian Council of Agricultural Research (ICAR), which has a large number of agricultural universities, research institutes and stations. Crop improvement research is supported by the Council in two ways. Firstly, it funds and supervises a number of "All India Coordinated Crop Improvement Projects" for important crops and, secondly, it supports a large number of individual research projects for different crops in different locations. In order to prevent research at sub-optimal level, the efforts are concentrated in a few centres. Furthermore, these projects are multi-disciplinary and receive inputs from various agricultural sciences such as agronomy, entomology and pathology.

The new material developed by the universities and institutes is tested for a minimum of three years for yield and other traits. The material goes through three stages of screening called initial evaluation trials, preliminary varietal trials and uniform variety trials. The varieties selected after the uniform variety trials are further evaluated at a workshop, which recommends the most promising varieties for release.

The material selected for release is given to the national Seed Corporation (set up in 1963) for the production of foundation and certified seeds. The other agencies engaged in the multiplication and distribution of seeds include the State Farmer Corporation of India, State Seed Corporations and the state agricultural universities. 93 new varieties of seeds were released in 1993-94.[17]

The plant breeding and seed development work by the public sector agencies is concentrated on the improvement of cereals and pulses. Private firms, on the other hand, are mainly involved with vegetables, cotton and millet. See Table 2.1.

Table 2.1. **Crop Varieties Introduced by Private Firms**

Crops	Number of Varieties
Vegetables	55
Millet	39
Cotton	13
Fodder	4
Oil Seeds	9
Pulses	2
Total	122

Source: Singh Gurdev, S.R. Asokan and V.N.Asopa, "Seed Industry in India - A Management perspective", Indian Institute of Management, Ahmedabad, 1990.

In recent years the involvement of private firms — both Indian and foreign — in plant breeding has increased. Until a few years ago, the activities of these firms were restricted by government policy. In particular, the large Indian firms and those with majority foreign equity were not allowed to enter the seed business. Also, private firms were not allowed to import germplasm for breeding purpose as its import was regulated by the National Bureau of Plant Genetic Resources.

The policy has become more liberal since the late 1980s, and large Indian firms and foreign firms are now permitted to undertake breeding and seed production activities with little restriction. Furthermore, joint ventures with foreign firms and the import of technology and material for breeding purposes are now permitted.

As a result of changes in policy, the role of private firms in general and of foreign firms in particular has increased in the last few years. (See Table 2.2 for a list of foreign collaborations signed in recent years). In 1990, 29 out of about 100 seed producers were large private firms. Compared to this, the number of public sector firms was only 15. In terms of value, however, the government continues to play a very large role; the public sector accounted for 70 per cent of the turnover (Rs. 3 000 million — $166.6 million) of the Indian seed industry in 1990.[18]

The import of seeds and planting material has also seen a sharp increase in the 1990s. For example, the quantity of seeds imported increased from about 14 metric tons in 1988-89 to 83 metric tons during 1989-90. Imports reached a peak in 1991-92, when about 428 metric tons were imported. (See Table 2.3). Most seed imports were undertaken by firms jointly set up by Indian and foreign firms during the post-liberalisation period for the development and distribution of seeds based on imported material.

Table 2.2. **Foreign Collaborations in the Seed Sector**

Indian Firms	Foreign Firms	Product
1. Bejo Sheetal Seeds	Bezo Zadan BV Pvt. Ltd. (F)	Hybrid seeds
2. Bharat Pulverising Mills.	Nova Seeds USA (F)	Oilseeds, pulses, Vegetables.
3. Bilt Treetech	Plantex Australia (T)	Propagation of Trees, Shrubs, Flowers.
4. Bisco Seeds Tech. Pvt. Ltd.	Agripro. Biosciences USA (T)	Hybrid seeds
5. Cargill Seeds	Cargill USA	Hybrid Seeds
6. FCL Agrotech	Contro Coop. Yugoslavia	Hybrid seeds
7. Harrison Malyalam FRG (T)	Agri Saatan vegetables.	Hybrid seeds, HYV
	Semynio Statzucht FRG (T)	Hybrid, HYV Vegetables
	Green Tek, Holland (T)	Plant Tissue-culture
8. ITC Agrotech Ltd.	Continental Grains Australia(T)	Hybrid Seeds
9. Maharashtra Seeds Co.	Seedtec Hybrid USA (T)	Sunflower
10. Maharashtra Seeds.	Hybridl Asgrow Seeds Co.USA (T)	Hybrid vegetable seeds
	Zeneca U.K	Hybrid Seeds
11. Nath Seeds Pvt. Ltd.	Dobi Gon and Co. USA (T)	Hybrid Sunflower
	K.Z. Gebroaders Sluis Holland (F)	Hybrid vegetable seeds
12. Omega Agseed (India) Pvt. Ltd	Agseeds Pvt.Ltd. Australia (F)	Improved seeds
13. Phi Biogen Pvt. Ltd.	Pioneer Overseas Corporation (F)	Hybrid seeds
14. Pioneer Overseas Corpn.	Pioneer Overseas Corpn (USA)Subsidiary	Hybrid Seeds
15. Raunaq International	Centro Coop and University of Agriculture,Novisat,Yugoslavia	Hybrid seeds
16. Sandoz	i) Zaadunio BVP Holland (T)	HYV seeds
	ii)Northrup King Co. USA Plantlets.	HYV Seeds and
17. SPIC	Pioneer Overseas Corpn, USA (F)	Hybrid Seeds
18. Welcome Seed	NRI Cases, UK (F)	Vegetables seeds
19. Wimco Ltd., Bombay	Hilleshog AB Sweden (F)	Seeds and seedlings for forestry.

(F) = technical collaborations with foreign equity of the foreign collaborator.
(T) = technical collaboration.

Source: Economic Times, New Delhi, July 1994

Table 2.3. **Import of Seeds and Planting Material**

Year	Seeds (MTs)	Planting Material (Numbers)
1988-89	14.15	427 106
1989-90	82.81	772 969
1990-91	83.50	465 957
1991-92	428.39	3344 536
1992-93	148.10	2574 399
1993-94	62.00	3756 000

Source: India, Government of, "Annual Report 1993-94", Department of Agriculture and Cooperation, New Delhi, 1994.

The import of planting material has also seen a large increase during this period. Planting material imported increased from about 0.43 million plantlets in 1988-89 to 3.7 million during the first six months of 1993-94. Easy access to planting material has enabled a number of Indian firms (in collaboration with foreign firms) to multiply planting material for exports. This has also provided a strong boost to floriculture export.[19]

While India's breeding programme covers a wide variety of crops, its main emphasis has been on wheat, rice, oilseeds and cotton. The breeding efforts to improve these crops are described briefly in the following paragraphs.

Rice

Systematic breeding efforts to improve the characteristics of rice began in the 1950s. The first major programme, in which a number of Asian countries participated, was aimed at crossing a wide range of indica rice with japonica varieties. The programme did not result in significant benefits, and only a few early maturing non-seasonal varieties were developed.

Breeding efforts were more successful in the late 1960s when increased attention was paid to plant type, leading to the development of high-yielding varieties. (For figures showing increase in yield per acre, see Table 2.4). Since then, a number of varieties with high yield and suitability for low lying areas have been developed.

Table 2.4. **Area, Production and Yield of Rice in India**

Year	Area (Million hectares)	Production (Million tons)	Yield (kg/ha)
1965-66	34.47	30.39	862
1970-71	37.59	42.23	1 123
1975-76	39.47	48.74	1 235
1976-77	38.51	41.92	1 088
1977-78	40.01	52.67	1 308
1978-79	40.48	53.77	1 328
1979-80	39.41	42.33	1 074
1980-81	40.15	53.63	1 336
1981-82	40.71	53.25	1 308
1982-83	38.26	47.12	1 231
1983-84	41.24	60.10	1 457
1984-85	41.16	58.34	1 417
1985-86	41.1	63.8	1 552
1988-89	41.7	70.5	1 689
1989-90	42.2	73.6	1 745
1990-91	42.7	74.3	1 740
1991-92	42.7	74.7	1 751
1992-93	41.6	72.6	1 744

Note: Figures for 1992-93 are provisional.

Sources:
1. ICAR, " *50 years of Agricultural Research and Education*", Indian Council of Agricultural Research, 1979, New Delhi, pp. 26
2. India, Government of, "*Economic Survey*", Ministry of Finance, New Delhi, Various years.

Breeding efforts have been less successful in developing pest- and disease-resistant varieties. In fact, with the introduction of intensive cultivation practices and reduced genetic variability, the genetic vulnerability of rice to diseases has increased. Furthermore, some of the pests, such as rice gall midge and brown plant hopper, which were minor pests earlier, have become major pests in recent years. The yield loss caused by pests is often more than 30 per cent.[20] Also, many of these pests have acquired resistance to commonly used pesticides. Consequently, as vulnerability to diseases and pests remains a serious problem, the main emphasis of the breeding programmes has now shifted to stabilising the yield by increasing resistance to pest and disease.[21]

Wheat

Limited research on wheat in India started in 1905 at the IARI (called the Imperial Agricultural Research Institute at that time.) It concentrated on the survey of indigenous varieties, although some breeding work was also undertaken. The efforts were expanded considerably in 1961 when the ICAR set up a large research programme involving a number of research institutes. Later, in 1965, the programme was converted to All India Coordinated Wheat Improvement Project (AICWP).[22]

Research during the 1960s and 1970s was mostly concerned with yield increase. This was particularly so during the 1960s when a variety of semi-dwarf breeding material was made available by the International Maize and Wheat Improvement Centre (CIMMYT) in Mexico. Two of these varieties were found to be particularly suitable and were released.[23]

Further work involving cross breeding of the semi-dwarf varieties with local material followed in later years. This led to the development of varieties with improved grain characteristics and higher disease resistance, several of which were introduced in the 1970s.[24] (For figures showing the increase in the area under high yielding wheat varieties, and increase in yield per hectare, see Tables 2.5 and 2.6.)

As the figures in Table 2.6 show, the yield per hectare has seen a large increase since the 1960s, much of which is attributed to the success of breeding efforts. On the other hand, breeding efforts have been less successful in developing varieties with long term disease resistance. As great damage is regularly caused by these diseases, the need to impart disease resistance has become increasingly important.

Rust, loose smut and Karnal bunt are the most common diseases of wheat. Of these, rust is the most serious. In view of its importance, resistance to rust is an essential component of all wheat breeding programmes and, in fact, all varieties of wheat released since the 1960s are tolerant of rust. However, the problem has continued, as these varieties lose their tolerance after a few generations. In order to contain the damage, breeders continuously have to produce new varieties with rust resistance.[25]

Karnal bunt, the second most serious disease affecting wheat, was first reported during 1969-70, when most wheat varieties were affected. The disease, which is seed borne, appears sporadically; it often assumes epidemic proportion and causes large losses.[26]

Table 2.5. **Area Under High-Yielding Wheat Varieties in India**

Year	Percentage of Total Area Under Wheat Cultivation
1966-67	4.2
1970-71	35.5
1975-76	65.8
1980-81	72.3
1983-84	76.0

Source: Tandon J.P., and M.V.Rao, "Organisation of Wheat Research in India and its Impact", Twenty Years of Coordinated Wheat Research -1961-86", IARI, New Delhi, 1987.

Table 2.6. **Production and Productivity of Wheat**

Year	Area (Million hectares)	Productivity (Million tons)	Yield (Kg/ha)
1949-50	9.76	6.39	655
1950-51	9.75	6.46	663
1960-61	12.93	11.00	851
1965-66	12.57	10.40	827
1970-71	18.24	23.83	1 307
1975-76	20.45	28.84	1 410
1980-81	22.28	36.31	1 630
1985-86	23.07	46.89	2 032
1987-88	23.1	46.2	2 002
1988-89	24.1	54.1	2 244
1989-90	23.5	49.8	2 121
1990-91	24.2	55.1	2 281
1991-92	23.3	55.7	2 394
1992-93	24.4	56.8	2 323

Note: Figures for 1992-93 are provisional.
Source: 1. "*Technology for Increasing Wheat Production in India*", Wheat Project Directorate, IARI, New Delhi, not dated.
2. India, Government of, "*Economic Survey*", Ministry of Finance, New Delhi, Various years.

Systematic efforts to breed varieties resistant to Karnal bunt began comparatively late. The research was handicapped by the fact that it was not possible to screen for Karnal bunt resistance under natural conditions, as the infection was highly dependent on a favourable combination of low temperature and high humidity. It was only in the late 1970s, when the Punjab Agricultural University developed an artificial inoculation technique, which could be used for screening purposes, that systematic breeding work for bunt resistance could be commenced.[27] However, even now only limited success in the breeding of Karnal bunt-resistant varieties has been achieved.[28]

The third important disease, loose smut, is also a seed-borne disease; infection takes place at the time of the grain formation. Although some resistant varieties have been developed, this disease continues to be a major problem.

Oil seeds

Rape seed mustard (oil-seed rape) is the most important oil seed in India, accounting for 24 per cent of the total output. Although most mustard varieties grown in India until the late 1960s were poor in yield and were highly susceptible to disease, very little breeding work was undertaken. Systemic breeding work began only in the late 1960s when the All India Coordinated Research Project on Oil seeds (AICRPO) was set up in 1967. However, in spite of the efforts undertaken under this and other programmes, very few varieties of mustard with tolerance to common pests and diseases have been developed.[29]

Cotton

Cotton has two important pests; jassid and bollworm. The problem of jassid is not very serious as most varieties in use have some degree of tolerance to the pest. The indigenous varieties, most of which are jassid tolerant, are still popular and account for 30 per cent of the area under cotton cultivation. The high yielding varieties and hybrids are also tolerant to jassid.[30]

It has, however, not been possible to develop varieties which are tolerant to bollworm. As a result bollworm continues to be a very serious problem and is, in fact, responsible for a large proportion of the pesticide used in India. Furthermore, as bollworms have developed resistance to commonly used pesticides, its incidence has increased to epidemic levels in recent years. The difficulty with breeding for bollworm resistance is that wild varieties with resistance are not available. This considerably limits the options available to breeders.

It is clear from the above discussion that while the conventional breeders have been highly successful in developing high yielding varieties, their success in developing resistant varieties has been limited. The unavailability of wild varieties with resistance to ballworm is largely responsible for this failure.

The Role of Biotechnology in Crop Improvement

Recent developments in plant biotechnology have greatly increased the possibility of crop improvement.[31] These techniques allow the manipulation of genetic material to impart desirable traits with greater accuracy in a much shorter time than is possible with conventional breeding methods.[32]

The most commonly used techniques used for the manipulation of genetic material for crop improvement are:

— tissue culture
— recombinant DNA

Tissue culture allows mass reproduction of genetically identical copies — "clones" — of plant material. It eliminates the uncertainty caused by genetic variability, which is common in traditional cross-breeding. The technique is extremely important in the production of disease free plant material, as it can be used for mass propagation of disease-free plants in a very short time.

Recombinant DNA techniques, which enable direct manipulation of genetic material (most commonly through transfer of "foreign" genetic material to a plant cell), are potentially some of the most enabling plant biotechnologies.[33] The "foreign" genetic material can be transferred in a number of ways. The simplest, and the oldest, method is through protoplast fusion, or somatic hybridisation. This involves enzymatic removal of the cell walls releasing protoplasts which are then fused by either chemical treatment or electrical pulse. The fused protoplast is then cultured and regenerated into whole plants, hopefully with new genetic combinations. Although in many ways similar to classical plant breeding (the entire genomes of two plants are combined in both), protoplast fusion has an advantage in situations where sexual incompatibility prevents crossing of plants.

In the other methods of gene transfer, which are more direct and selective, a single gene (or a group of genes) is transferred to the target cell. The earliest of these methods relies on agrobacteria and certain other pathogens which infect plants.[34] The genes to be transferred are inserted into the DNA of agrobacterium, which infects the target cell and carries the genes into target nuclei.

Although very effective for a number of plants, agrobacterium have certain limitations. Most importantly, cereals are not infected by agrobacteria, and therefore, these can not be used as vectors for transformation in cereals. The recent developments in which target cells are bombarded with highly charged, DNA-coated particles with the help of a particle gun have changed this situation. The use of the "gun" has made the transformation of a number of important cereals a possibility. The regeneration, however, continues to be a problem in cereals.[35]

The first success in developing an intact transgenic plant (soybean) using particle bombardment was achieved in 1988.[36] Since then the technique has been used for the development of transgenic plants of rice, wheat and barley.[37]

A large number of transgenic plants are undergoing tests in developed countries. Herbicide tolerance and pest/virus resistance are the most common objectives of these exercises. For example, 76 per cent (371 out of 487) of the transgenic plants undergoing trials in 1993 in Canada were with herbicide tolerance (see Table 2.7). Similarly, an analysis of data on 425 permits issued by the USDA in the United States between 1987 and 1993 indicates that 34 per cent of these permits were for the testing of transgenic plants with herbicide tolerance. Insect and virus resistance are the second and third most common objectives of transgenic development. See Table 2.8.

Furthermore, *Bacillus thuringiensis* toxin genes were most often used to impart insect resistance.[38]

Table 2.7. **Transgenics Tests (Canada)**

Subject	number	per cent
Herbicide tolerance	371	76
Male sterility	42	9
Insect resistance	22	5
Nutritional and Compositional changes	20	5
Modified oil	19	5
Total	487	100

Source: Ag Biotech News and Information, 1993, 5, 11, 374N

Table 2.8. **Transgenics Permits (USA)**

Subject	No.	per cent
Herbicide tolerance	145	34
Insect resistance	96	23
Virus resistance	89	21
Product quality	51	13
Disease resistance	17	4
Genetic control	4	1
Others	23	4

Source: AgBiotech News and Information 1993 Vol.5 No.7, pp.235N

Table 2.9. **Transgenics Permits (USA), by Crop**

Organisms	No.	per cent
Maize	73	17
Tomato	72	17
Potato	58	14
Soybean	58	14
Cotton	39	9
Tobacco	38	9
Melon	17	4
Squash	14	3
Rapeseed	12	3
Lucerne	11	3
Clavibacter	6	1

Source: AgBiotech News and Information 1993 Vol.5 No.7, pp.236N

In terms of crops, maize, tomato, potato, soybean, cotton and tobacco are the most common candidates for the development of transgenics. See Table 2.9.

A very large proportion of research on transgenic plants is being carried out by private firms in developed countries. The concentration of research efforts is shown by the fact that in 1993, 83 per cent of the USDA permits (345 out of 487) were issued to private companies. Monsanto, the most active of these firms, was given 25 per cent of the permits. (See Table 2.10). The concentration of research efforts in a small number of private firms implies that the cost of acquiring these technologies and their products may be very high. This could prevent developing countries from benefiting from these developments.[39] Furthermore, much of the research in developed countries is focused on problems which are of limited relevance to developing countries, such as herbicide tolerance. In the circumstances, developing countries will need to build local technological capabilities to exploit the potential of biotechnology fully. In particular, they will need to undertake research aimed at developing disease/pest resistant varieties suitable for local agro-climatic conditions.

Table 2.10. **Transgenics Permits (USA), by Company**

Company	No.
Monsanto	108
Calgene	50
Pioneer	32
Upjohn	27
Frito-Lay	16
DNAP	10
CIBA-Geigy	9
Du Pont	8
Northrup King	8
DeKalb	7
Crop Genetics	6
Holdens	6
Cargill	6

Source: AgBiotech News and Information 1993 Vol.5 No.7, pp.236N

Biotechnology, Crop Improvement and Disease/Pest Tolerance in India

In India, crop improvement efforts using biotechnology are mainly concerned with the development of tolerance to biotic and abiotic stresses, though some work on rice and mustard hybrids is also being done. Most of this work is supported by the Department of Biotechnology and the Indian Council of Agricultural Research. According to the latest data on biotechnology research, 27 biotechnology studies aimed at the development of crops with resistance to diseases/pests were in progress in 1992-93. Of these 14 were supported by the DBT and 10 by the ICAR. Almost one third (8) of these studies were concerned with rice. The other crops with a concentration of research efforts were chickpea (4), brassica and cotton (3). (For a distribution of research studies by crop, see Table 2.11).

Table 2.11. **Projects Aimed at Development of Resistance (by Crop)**

Crop	DBT	ICAR	Agency Others	Total
Rice	3	3	2	8
Brassica	3	-	-	3
Tomato	-	1	-	1
Potato	-	1	-	1
Cotton	-	2	-	2
Chickpea	3	-	1	4
Others	5	3	-	8
Total	14	10	3	27

Source: Compiled from : "Research profile of Biotechnology Activities in India", Department of Biotechnology, 1993

The last five years have seen a considerable increase in the technological capabilities of Indian researchers. Significant advances, both in terms of expertise and equipment, have taken place during this period. Leading research institutes are increasingly using advanced techniques such as RFLP and RAPD. Similarly, equipment such as PCR and electron guns are available with many institutes. Leading research centres have the capability to clone and transfer genes and regenerate plants. Many of these centres are using these skills and techniques for the development of resistant varieties. According to some of the researchers interviewed for the study, the technological gap (in terms of techniques and equipment) is between six months to one year.

It is also possible to identify some of the major weaknesses in the capabilities. For instances, some of the devices commonly used by researchers in developed countries are not available in India. These include the automatic DNA sequencer and advanced computer software. Other important equipment which is not available in India includes UV cross linkers (which are used for binding DNA to membranes). The lack of these facilities often results in considerable delay in completing experiments.

The efforts to use biotechnology for the development of disease/pest resistant varieties are described in the following paragraphs.

Rice

Following are the major research programmes on rice, aimed at the development of disease/pest resistance, being undertaken now or completed recently.

Transfer of genes responsible for resistance to bacterial blight and sheath blight

Using RFLP and RAPD techniques, research aimed at the tagging and transfer of blight resistant genes from wild to cultivated species is being carried out. The studies are supported by the DBT and are being done at the MS University and the National Chemical Laboratory. Though rice blast is the most widespread and damaging disease of rice, breeding for blast tolerance has been difficult. Even when such varieties are developed, they lose their resistance within a few generations. The research in India is at a very early stage and significant results are not expected for a few years.

Resistance to gall midge

Of the rice pests, gall midge is one of the most damaging, responsible for 20 per cent of the rice yield lost in India. This research is aimed at the cloning of genes responsible for resistance to gall midges in rice and is being carried out at the International Centre for Genetic Engineering and Biotechnology (ICGEB). The researchers have mapped the gene responsible for the resistance in some wild varieties and have found that the resistance is caused by a single dominant gene. Markers developed at Cornell University have been used for the gene mapping. The Rockefeller Foundation provided support for obtaining these markers from Cornell University.[40]

The researchers plan to use a YAC (yeast artificial chromosome) library maintained by a Japanese research institute for identifying the fragment of DNA with the resistant gene. After isolation, the gene will be transferred to high-yielding susceptible varieties.

Transgenic rice

A limited amount of research is being undertaken to develop transgenic rice. The work is at a very early stage and it will be many years before transgenic rice will be available. The transgenic rice is being developed with two objectives in mind: *i)* insect resistance through *B.t* toxin gene; and *ii)* herbicide tolerance.

Transgenic rice with B.t toxin genes

Research for the development of transgenics with the *B.t* toxin gene is being done at the ICGEB. In order to improve the effectiveness of *B.t* toxin on lepidopteran pests found in India, the researchers are screening *B.t* strains found in Indian soils for toxicity. About one hundred strains have been isolated and are being tested them. They also plan to modify the *B.t* gene in order to increase the target range of B.t toxin and to minimise the possibility of resistance to the toxin.[41]

Researchers at the IARI, who are currently engaged in the development of transgenic rice with fungicide tolerance are also planning to start work on the development of transgenic rice with *B.t* gene (see below). Their research, however, will be less ambitious in scope, as they plan to use the *B.t* toxin gene available with the Rockefeller Foundation. Another institute (Bose) has done work on cloning and expressing *B.t* toxin gene in rice, but the expression is reported to be very weak.

Transgenic rice with herbicide resistance

Although the use of herbicides is not common in India, some research aimed at the development of rice with herbicide tolerance is being undertaken at the IARI and the ICGEB. [42]

The research at the IARI is being undertaken with support from the Rockefeller Foundation and is concentrated on basmati rice (see below). Recently the scientists have succeeded in transferring reporter genes to callous, from which plants have been regenerated. In the next stage, the gene responsible for herbicide resistance will be transferred into callous. Both the reporter and herbicide resistance genes have been given by the Rockefeller Foundation.[43]

The researchers at the ICGEB are also working on the development of transgenic rice with herbicide resistance. The herbicide in question is Glyphosate, which is produced in India by a local firm. Glyphosate acts by preventing the function of ESPP synthase gene, which produces aromatic amino acids required by plants. When a plant is starved of these acids, it dies. The ICGEB researchers are planning to introduce an ESPP synthase gene, which is not affected by the herbicide, into the crop plants. ESPP synthase genes with herbicide resistance have already been cloned through mutation, and preparations are being made for transfer to rice. Work on regeneration will follow.[44]

Rice hybrids

A large increase in rice yield is not possible with traditional breeding methods, and efforts are now underway to use biotechnology for the development of hybrids. In addition to improved yield, the hybrids are expected to have greater disease/pest resistance. A number of research institutes and international agencies such as the Rockefeller Foundation and the IRRI are involved in the work.

Based on male sterile lines given by the International Rice Research Institute (IRRI), which obtained them from China, six hybrids have already been developed in India. After being field tested for 2 seasons, these are now being test marketed. Also, the Punjab Agricultural University has independently used the Chinese lines to develop their own male sterile line.[45]

Efforts are also underway for the preparation of pure mitochondria, which can be used in the development of hybrids. Most of the research is being funded and coordinated by the DBT and is being carried out at a research foundation set up by a large private producer of agrochemical inputs. Researchers at the foundation (SPIC Science Foundation) have already carried out the molecular mapping of rice mitochondrial DNA.

Research is also being undertaken to develop hybrids of basmati rice. This is a special group of rice varieties which have superfine grain, a pleasant aroma and superior cooking qualities. These varieties, however, have some important disadvantages; they are tall, weak strawed and thus poor-yielding. Also, they are highly susceptible to most pests and diseases of rice.

The traditional breeders' efforts to impart resistance to basmati varieties have not been successful. Research using molecular biology is now being used to develop basmati hybrids with resistance and high-yield. Most of this research, which began three years ago, is being funded by the Rockefeller Foundation and is being undertaken at the IARI.[46] The researchers have already developed some haploids from anther culture and these will be used for the development of true lines, which can be used for the development of hybrids.

Attempts are also being made to develop wide hybrids using protoplast fusion. One government research centre has succeeded in plant regeneration from suspension-derived protoplasts of four indica varieties.

Brassica

Diseases are the major cause of damage to brassica. They risk three fungus infections; white rust, alternaria blight and powdery mildew. Of these the first two are the most important and can cause up to 50 per cent of crop loss.[47]

Brassica lines which are resistant to white rust are available in the wild, and conventional breeders have used these to produce resistant varieties. Consequently, most brassica varieties used in India are resistant to white rust. In the case of alternaria blight, on the other hand, only a few wild lines with resistance are known, and it has not been possible to cross these with cultivated lines. So, the conventional breeders have not able to develop blight resistant varieties. Protoplast fusion has now been used by the researchers at the IARI to combine the characteristics of wild (resistant) and cultivar varieties. The resulting plants are being back crossed and it is hoped that after 6-7 back crossings, plants with resistance to alternaria blight will be ready for use in breeding programmes. The work is expected to be completed in about two years.[48]

In another programme at the University of Delhi, research on wide hybridisation and use of pollen as a system for screening disease resistance in brassica is being undertaken. Research on the creation of RFLP markers and a linkage map of brassica and genome specific DNA sequences is also being carried out at different institutes and is likely to boost success in the development of disease/pest resistant varieties.

We have not come across any programme to develop insect-resistant mustard varieties. Insect-resistant oil-seed rape (canola) is, however, likely to become available in India soon through a joint venture between a private seed company, Proagro Seed Company Ltd and PGS International of Belgium. One of the proposed activities of the joint venture is to use PGS's insect resistant technology to produce selected varieties with *B.t* toxin genes for the Asian markets.[49]

Chickpea

A number of research institutes are engaged in research on chickpea. Most of it is aimed at the development of transgenic chickpea with *B.t* toxin genes. However, as in the case of other crops, the work is at a very early stage and it will be many years before transgenics will be available.

One of the institutes (the IARI) has carried out successful gene transfer experiments on chickpea with marker genes, but is yet to clone *B.t* toxin gene. Researchers at the institute are screening a wide variety of *B.t* strains, which have been collected from Indian soils, for toxicity. Once suitable strains are selected, work on genetic transfer will begin.[50]

The main problem in the development of chickpea transgenics is in regeneration. The success of this, and other similar projects, depends on progress in regeneration techniques. The IARI has tried to regenerate chick pea after introducing marker genes but has not been successful. Only one research institute (Bose) has claimed success in regenerating chickpea with a marker gene.

Limited research aimed at developing chickpea varieties with resistance to blight and wilt are also being undertaken. The most successful of these efforts has been made by the researchers at the Haryana Agricultural University, who have developed chickpea cell lines which are resistant to chickpea blight and wilt. However, they are having difficulty in regenerating plant from these lines.

Wheat

While pests are not a serious problems, wheat suffers very heavy damage from fungus infections. As mentioned earlier, conventional breeding methods have achieved only limited success in developing wheat varieties with long-term resistance to rust, loose smut and Karnal bunt. While the potential for using biotechnology in wheat improvement is large, technical difficulties in the gene transfer and regeneration have delayed progress. The recent advances in delivery systems and regeneration techniques are likely to escalate the pace of development.[51]

Very little research on wheat biotechnology is being done in India. Limited work on RFLP mapping for resistance to rust, loose smut and Karnal bunt has begun only recently. Some efforts aimed at achieving wide hybridisation are also underway.

The situation may change soon, as a large research project involving four institutes is now being considered.[52] This project, if initiated, will be the first move in India to use biotechnology in a systematic way to develop wheat varieties with durable resistance to various fungus infections. The decision on the funding of the project, however, is yet to be taken.

Cotton

Cotton is highly susceptible to bollworm and is responsible for a very large proportion of pesticide applied in India. The possibility of developing transgenic cotton with *B.t* toxin gene has evoked considerable interest in India. The first move in this direction was made two years ago when a proposal by Monsanto to transfer its transgenic technology was seriously considered by the government. According to estimates made by Monsanto, the use of transgenic cotton with *B.t* toxin gene can lead to a 30 per cent reduction in pesticide application in India. [53] The proposal was rejected, as the cost (Rs. 240 million — $7.74 million) was considered to be too high.[54]

Although it was decided to encourage efforts by local scientists to develop transgenic cotton with *B.t* toxin gene indigenously, little progress has been made. The situation is expected to change during the next five years, as an ambitious project involving seven institutes has been initiated by the DBT. The project will be completed in four years, at the end of which transgenic cotton with *B.t* toxin genes is expected to be available for field trials. The estimated cost of the project is Rs. 45 million ($1.66 million). [55]

Diagnostics

In addition to the work on the development of disease/pest resistant varieties, research on the development of diagnostic tools is also being undertaken. In particular, efforts are being made to develop monoclonal antibodies to various plant pathogens, which can enable large-scale diagnosis of viral diseases.

The National Botanical Research Institute, for example, has developed immunodiagnostic techniques such as enzyme-linked immunosorbent assay (ELISA), Ouchterlony's double diffusion test, dot immunobinding assay, and immunosorbent electron microscopy for the trapping and decoration of particles. These techniques allow the identification, differentiation and mass detection of viruses.[56] The institute is also working on the elimination of viruses with tissue culture and chemo-therapy.

Summary

Plant breeding and seed production activities have undergone a large expansion in India during the last three decades. Research aimed at crop improvement is almost exclusively concentrated within government agencies. Private industry, on the other hand, has a sizeable and increasing presence in the seed production sector.

Plant breeding programmes have concentrated on important cereals, pulses, oilseeds and cotton. Since the 1960s, when systematic breeding programmes were first initiated, the emphasis has been two-fold: yield increase and tolerance to disease and pests. The programmes have been highly successful in the development of high-yielding varieties. The development of varieties with resistance to pests and diseases, on the other hand, has been only partially successful. As a result, most crops continue to suffer widespread, regular damage from pests and diseases. Furthermore, many varieties have lost their tolerance and have become increasingly prone to pest/disease attack.

The limitations of conventional breeding techniques are largely responsible for the slow progress in this regard. The unavailability of wild varieties with resistance (which can be used in breeding programmes), the difficulties in cross breeding certain varieties and the long time taken, are some of reasons for the failure to develop resistant varieties.

Recent advances in plant biotechnology, which allow greater and more precise manipulation of genetic material, have increased the possibility of crop improvement enormously. An important application of these techniques is in the development of disease/pest resistant plant varieties, a number of which are already undergoing field trials.

Most of the research on plant biotechnology is being carried out by private firms in developed countries. The concentration of research efforts in a handful of private firms is likely to limit the developing countries' access to technology. These countries will, therefore, need to build local technological capabilities to exploit fully the potential of plant biotechnology. In particular, they will need to undertake research aimed at developing disease/pest resistant varieties suitable for local agro-climatic conditions.

The use of biotechnology in crop improvement is comparatively new in India. Most of it is concentrated on rice, chickpea and mustard. Research on cotton and wheat has been started recently. Although a number of research centres have acquired the capability to use the latest techniques, the size of research effort is comparatively small. Also, unlike in the past, where special breeding programmes aimed at improving various crops were set up, and co-ordinated, by the Indian Council of Agricultural Research, the biotechnological research is less systematic. Also, the size of these efforts in terms of resources devoted and researchers involved is comparatively small.

In the case of rice, research on the development of varieties with disease/pest (bacterial blight and gall midge) resistance and herbicide tolerance is being undertaken. In each of these cases the work is at an early stage. Although the genes responsible for resistance have been identified, work on the transfer of these genes to cultivar rice varieties is yet to begin. Further delay and uncertainty is expected due to the difficulties of regeneration in indica rice.

Research on brassica is concentrated on the development of tolerance to alternaria blight, which is its most serious disease. Plants with resistance have already been produced and are being back crossed. These plants are expected to be available for large scale breeding in about two years. No research on the development of pest resistance (which is also a major problem) is being undertaken.

Work on the development of transgenics with *B.t* toxin genes has also begun. Two crops are the main focus of this research: chickpea and cotton. The work on chickpea is, comparatively, on a small scale. The researchers are screening a wide variety of *B.t* strains for toxicity. Work on the cloning of *B.t* toxin genes will begin only after suitable strains have been identified. Furthermore, although experimental gene transfer using marker genes has been successful, serious difficulties in the regeneration of chickpeas are envisaged. Transgenic chickpea plants in large numbers are not expected to be available before ten years.

An ambitious programme to develop transgenic cotton with *B.t* toxin genes has been started by the DBT recently. The programme, which involves seven institutes, is one of the largest crop specific research efforts by the DBT. The following institutes are involved in the research programme: National Botanical Research Institute (NRBI); National Chemical Laboratry (NCL); Bhabha Atomic Research Centre (BARC); Bose Institute; Indian Agricultural Research Institute (IARI); Central Institute for Cotton Research (CICR); Tamil Nadu Agricultural University (TNAU). Considering the comparatively large funding and official support, it is likely that *B.t* resistant cotton will be the first transgenic to be developed in India. The official view is that this will be available by the end of the 20th Century.

III. BIOPESTICIDES

Introduction

The high intensity of chemical pesticide application has become a serious cause of concern in recent years. Although the use of pesticides is comparatively small in India, the damage caused by them to the environment and health is already evident. (see chapter I). Furthermore, the current trends suggest that the use of chemical pesticides is likely to continue to increase in the near future. In the circumstances, there is a growing need to promote the use of alternative methods of crop protection. It is particularly important that efforts are made to substitute chemical pesticides with biopesticides, which are environmentally friendly.

Biopesticides are living organisms which can destroy agricultural pests. The two most important advantages of biopesticides are that *a)* they are target specific and do not destroy beneficial organisms and *b)* do not leave harmful residues. Some of the important biopesticides include:

1. *Trichogramma* (egg parasitoid) for control of Lepidopteran pests such as sugar cane inter-node borer;

2. Fungi (*Trichoderma* and *Gliocladium*) for control of root rot and wilt disease in pulse crops;

3. Baculovirues. These include:

   a) Nuclear polyhedrosis virus (NPV) of *Heliothis armigera* for cotton, oil seeds, pulses, vegetables and millets.
   b) NPV of tobacco caterpillar (*Spodoptera litura*) for tobacco and cotton.
   c) Granulosis virus (GV) for sugar cane inter-node borer

4. *Bacillus thuringiensis*

5. Neem

Although the importance of biological control of pests has been known for many years, it is only during the last decades that organised efforts to popularise the use of biopesticides has begun in India. Their use is being encouraged by the Indian government as part of an integrated pest management programme (IPM). The Ministry of Agriculture and the Department of Biotechnology are largely responsible for supporting the production and application of biopesticides. The agencies engaged in these activities include the Directorate of Plant Protection and Quarantine (DPPQ), Directorate of Biological Centre and the National Centre of Integrated Pest Management (NCIPM).[57] In addition to promotional activities, these agencies are responsible for the surveillance and forecasting of pest problems in different parts of the country. These agencies also produce biopesticides, but the facilities in most of these centres are basic, and the quantity of biopesticides produced is very small. Many of these agencies suffer from resource constraints and their overall contribution to the popularisation of biopesticides is small.

The Department of Biotechnology (DBT) has recently set up a comparatively ambitious project to promote the use of biopesticides. The main emphasis of the project is to demonstrate the technical viability of various biopesticide production technologies developed in India. The project will also concentrate on training farmers, NGOs and extension workers in the production and use of biopesticides. The objectives of the programme include:

a) the setting up of biocontrol production units in different states.

b) the setting up of Repository Centres for the collection, maintenance and supply of nucleus cultures of biocontrol agents and host insects to production units.

The programme will run for 5 years, during which 50 demonstration units in different agro-climatic regions will be set up.[58] The cost of setting up the 50 units is estimated to be about Rs. 106 million ($3.39 million).

In spite of these programmes, at present the use of biopesticides in India is limited. Serious problems concerning the availability and acceptance of these products have restricted their use to government-sponsored promotion programmes, and sales to individual farmers are small. Furthermore, the situation is unlikely to change in the near future; the demand is expected to grow very slowly. According to most plausible estimates, biopesticides can be expected to take only 3 per cent of the pesticide market in India by 2000 A.D.

As the performance of the currently available biopesticides is poor and inconsistent, they are not considered by farmers to be economically attractive alternatives to chemicals. Biopesticides have to break into a market which is completely dominated by chemical insecticide companies. The information available to farmers, both from public and private channels, is still largely confined to the use of chemical insecticides. In the face of the aggressive marketing practices adopted by the chemical firms, and general unawareness of farmers about biopesticides, the demand for the latter will continue to be small.

The experience of developed countries shows that, when faced with competition from the existing chemical pesticides, the adoption of these agents has been slow and limited. For example, in spite of their obvious advantage as environment friendly products, microbial insecticides account for less than 1 per cent of the total yearly insecticide sales in the United States. The poor acceptance of these products is also shown by the fact that more companies have given up the production of biopesticides in the last 20 years than are producing today.[59]

When compared with chemical pesticides, the present day biopesticides suffer from certain limitations. These are related to:

Mode of Action

The mode of action of microbial biopesticides creates difficulties. Most chemical insecticides introduced since World War II are nerve poisons and can enter the insect in a number of ways. Also, most of them affect all stages of insect development. As a result, chemical insecticides are effective even when the spray coverage is not thorough. On the other hand, all microbial insecticides (excepts fungi), enter the insect primarily by ingestion. Also, in most cases only one stage (usually larva/nymph) of the pest is susceptible. Therefore, in order to be effective, biopesticides must be placed exactly where the susceptible target stage of the pest will consume it

Effective Life

The other important difference is in the effective residual life on the plant surface. Most chemical insecticides have an effective life ranging between several days and 4 weeks. The effective life of most microbial pesticides, on the other hand, is much smaller; commercial preparations of *Heliothis* NPV, for example, are reported to have a half life of only 12 hours.[60]

These, and other, advantages (as perceived by the farmers) put the chemicals in a preferred position. In most cases farmers are interested in using biopesticides only when the use of chemical pesticides is not feasible (as with the use of *Trichogramma* on sugar cane) or when the pest has developed resistance to chemicals (as in the case of *Heliothis*). In other instances, farmers are reluctant to try biopesticides. In fact, a recent study based on an international survey of researchers shows that there is little likelihood of biopesticides making a major breakthrough in the near future. According to experts, unless the effectiveness of biopesticides improves drastically, the growth in their popularity is likely to be only gradual.[61]

Biopesticide Research

Research on biopesticides is funded mainly by the DBT. Out of 14 studies concerning biopesticides listed in the DBT directory of research, seven were supported by the Department. (see Table 3.1)

Table 3.1. **Research Projects on Biopesticides According to Funding Agency**

Biopesticides	DBT	ICAR	Others	Total
Parasites/predators	2	1	-	3
Fungi	2	-	3	5
Baculoviruses	2	-	2	4
Bacillus thuringiensis	1	-	1	2
Total	7	1	6	14

Note: The funding agencies are public research organisations.
Source: Compiled from "Research profile of Biotechnology Activities in India", Publications and Information Directorate, New Delhi, 1993

Research activities on various biopesticides are described in the following paragraphs.

Trichogramma

Trichogramma belongs to a group of minute wasps, which parasitise eggs of more than 200 insects species, many of which are common pests of important crops such as sugar cane and cotton. The use of *Trichogramma* is particularly beneficial as they destroy pests before they have a chance to do any damage to crops.

Trichogramma is one of the most popular biocontrol agents and is widely used against Lepidopteran insects in a number of countries. For example, in the former Soviet Union more than 10 biological factories were reported to produce about 50 billion *Trichogramma* and other parasites per season. Similarly, more than 50 commercial insectaries are reported to be producing *Trichogramma* and other parasites in the United States and Canada. A number of communes in China are also known to produce *Trichogramma* on a large scale.[62]

Although the rearing and application of *Trichogramma* in India began more than 50 years ago, the early trials were not very successful, and the performance of the parasites was found to be less than satisfactory in most parts of the country.[63] These early failures, which are now believed to be largely a result of faulty experimentation techniques and wrong dosage and release timings, led to a severe decline in research on *Trichogramma*.

With the increased interest in the use of biocontrol agents, research on *Trichogramma* has been revived in recent years. It has been shown that if appropriate strains of the parasite are chosen and released at the right time in correct dosages, *Trichogramma* can be highly effective in many agro-climates.[64]

The mass production of *Trichogramma* is seriously constrained by the difficulty in rearing *Corcyra* moths, whose eggs are used as host. The technology for large scale production of *Corcyra* is not available in India and most rearing facilities are very small. Recent developments in the United States, Russia and China have led to the development of synthetic diet, which can be used in place of *Corcyra* eggs. This technology has allowed the setting up of *Trichogramma* production on a scale which was not possible in the past. However, this technology has not been developed in India.

The difficulties of rearing *Corcyra* on a large scale are compounded by the difficulty in storing the eggs of *Corcyra* and *Trichogramma*. As the demand for *Trichogramma* is seasonal (it is highest in summer), the volume and economics of production would improve if the *Corcyra* eggs could be stored to be used for parasitisation in the summer. Research has failed to increase the life of eggs for more than 15 days, without affecting their suitability for parasitisation.[65]

Parasitised *Trichogramma* eggs have a comparatively short shelf life. They can be stored at low temperature (at about 5 degrees centigrade) for about 3 weeks only. This also acts as a serious restraint on large volume production.

The demand for *Trichogramma* is also limited by a number of factors. Some of these are:

1. sensitivity to chemical pesticides, which limits its use to fields where no chemicals are used.

2. inability to survive harsh environmental conditions. This causes high seasonal mortality during adverse conditions, necessitating repeated releases every season.

3. the need to coincide the release with the egg-laying period of the pest.

As a result of these difficulties, the production and use of *Trichogramma* (and other parasites) in India is still very limited. There are fewer than ten commercial insectaries, most of which are very small. The largest of these, Biocontrol Research Laboratories (BCRL), was set up in 1981 and produces about 2 million parasites per day.

Trichogramma is also being produced in small numbers by some sugar co-operatives and government agricultural departments.

The research on *Trichogramma* has two main focuses: *a)* development of technology for the mass production (rearing) of *Trichogramma* eggs and *b)* study of the effectiveness of various strains of *Trichogramma* in different agro-climatic conditions;

Most efforts to improve production technology are aimed at *a)* the improvement of production efficiency; *b)* reduction in the possibility of contamination; *c)* limited degree of mechanisation and *d)* reduction in health hazards. As a result of work done during the last three years, some improvements in the production technology have been made. These include the mechanisation of certain processes which either pose serious health hazards to workers and/or are considered excessively labour intensive. The two most important examples of these developments are:

a) Moth scale separator for *Corcyra*;
b) Moth collection device for *Corcyra*.

These simple devices have increased the safety and productivity of *Trichogramma* production processes. In the conventional process, *Corcyra* moths are collected manually, exposing the workers to serious discomfort and health risk due to the presence of *Corcyra* scales in a closed atmosphere. The labour productivity of this process is also very low. In the past, these limitations have prevented large scale production of *Corcyra* moths (and, therefore, *Trichogramma*). The use of these devices is likely to make the production of *Trichogramma* a more attractive proposition than in the past.

The production of *Trichogramma* (and other parasites) can be undertaken at two levels: *i)* small scale, decentralised production facilities using labour-intensive technology. *ii)* large scale, centralised production facilities using a high degree of mechanisation and automation. The technology currently available in India is suitable for small to medium sized production. Discussions to import technology from Russia for the setting up of large scale production have also been held.

No research is being undertaken on the genetic improvement of *Trichogramma* and (other parasites) to expand their shelf life, and chances of survival in hostile agro-climatic conditions. Research using conventional breeding techniques to produce *Trichogramma* with temperature and humidity tolerance was started in the early 1970s. The results, however, were not promising and research was abandoned.

Trichoderma

The use of *Trichoderma*, which is a fungus, to control plant pests has been common for a number of years. *Trichoderma* is effective against root pathogens and is used for seed treatment. First used in 1930, it is one of the oldest and most widely used fungi-based pesticides in the world.

Trichoderma (and other fungi-based biopesticides) is particularly effective as it does not have to be ingested by pests but acts through physical contact. It is particularly effective in the case of groundnut, sunflower, sesamum, blackgram, green gram and chickpea crops, which are particularly susceptible to root rot. It can also be used for greenhouse crops and commercial nurseries, where environmental factors can be controlled.[66]

The large-scale production of *Trichoderma* is carried out in fermentors, and the quality and quantity of yield depends largely on the operative conditions (aeration, pH, temperature), media constituent and the rate of biomass production. Aeration and agitation to maintain the required oxygen tension in the medium are particularly critical for the achievement of optimum yield. At present, the average time needed for the production of an optimum quantity of *Trichoderma* is between 6 and 7 days. This is considered to be too long, and efforts are being made to reduce it.[67]

The shelf life and effectiveness of *Trichoderma* (and other fungal and microbial agents) depends largely on appropriate formulation. In fact, product formulation is one of the most complex R&D problems and is considered to be one of the most secret assets of the production technology.[68]

The effectiveness of *Trichoderma* (and other fungal pesticides used for seed treatment) can be improved by:

- the use of genetically superior strains;
- the development of seed treatment techniques which will provide a conducive environment for the growth of biopesticides and will minimise competition from soil born micro-flora.

In India, research and production of *Trichoderma* is of relatively recent origin and is largely limited to the Tamil Nadu Agricultural University (TNAU), which has set up a pilot plant for this purpose. The only other research — testing of *Trichoderma* on cardamom — is being done by the Cardamom Board.

TNAU produced and sold 830 kilograms of *Trichoderma* between November 1991 and November 1993, which was sufficient to treat enough seeds for more than 3 500 hectares. Compared to the total requirement, this is a very small amount. According to estimates prepared by TNAU, India's annual requirement for *Trichoderma* is about 6 000 tones.

The technology developed by the TNAU researchers is suitable for only small scale production. They use a small fermentor, which can produce batches of only 100 Kgs. Further research to update this technology to large scale production is necessary before commercial production facilities can be set up.

TNAU research, however, has successfully shown the effectiveness of *Trichoderma* in controlling root rot. The results of some of their experiments are shown in Table 3.2.

Table 3.2. **Effectiveness of *Trichoderma***

Crop	Root Rot per cent		Yield (Kg/ha)	
	Trichoderma	Control	*Trichoderma*	Control
Ground nut	3.7	16.5	2500	1900
Sesame	4.3	15.5	983	841
Sun flower	18.1	37.1	940	740
Urud Beans	3.0	10.2	910	775
Mung Beans	7.3	17.1	800	688
Chick peas	2.5	14.4	400	350

Source: Information provided by the Tamil Nadu Agricultural University.

TNAU's current research activities include the identification of more suitable strains of *Trichoderma* to suit different soils. The strains already identified work well on neutral and acidic soils but not on alkaline soils. Research is being carried out to isolate strains which can work on soils with pH of more than 8.

Research is also being carried out to improve the strains by genetic manipulation. Two of their scientists have received training in the United States and the work had already started by 1994, but it would be some time before new strains would be available.

Baculoviruses

Baculoviruses are target specific viruses which can infect and destroy a number of important plant pests. A number of these viruses have been registered in the United States, Europe and the former USSR. At least seven baculoviruses are registered in the United States and Canada, four in Europe and eight in the former USSR. They have also been developed in China. The most commonly used baculoviruses are the NPV of *Heliothis* and *Spodoptera*.

For a list of important baculoviruse products, see Table 3.3.

Table 3.3. **Baculoviruses Registered For Commercial Application**

Virus	Trade Name	To be used Against	Registrant	Year
NPV	ELCAR	Bollworm (*Heliothis*) and Tobacco bud worm (*H.virescens*) on cotton.	Sandoz	1973
NPV	BIOCONTROL	Douahals fir *(Oraya pseudot-suqata)* trussock moth	USDA Forest Service	1973
NPV	GYPCHECK	Gypsy moth (*Lymantriadispar*) on forest, shade and ornamental trees.	USDA Forest Service	1976
NPV	NEOCHECK	Pine saw fly *(Neodiprion certifer)*	USAD Forest Service	1978
CPV	MATSUKEMIN	*Dendrolimus spectabilis*	- -	

Source: Reproduced from Rabindra, R.J. and S.Jayaraj, "Genetic Improvement and Development of Baculoviruses as Microbial Pesticides.", in C.Sen and S.Dutta (eds.), Biotechnology in Crop Protection.

For commercial production of baculoviruses host larvae are inoculated with the virus under optimum conditions which promote the growth of the virus. Once the infected larvae dies, the viruses are separated through differential centrifugation.

As the process requires a very large number of larvae, the mass production of baculoviruses has faced serious problems. The maintaining of these larvae on a large scale poses serious technical problems due to the possibility of contamination. The difficulty in maintaining optimum conditions on a large scale and the cost of automation have limited the popularity of baculoviruses in the past.

The acceptance of baculoviruses has also suffered from competition from chemical and other biopesticides (mainly *B.t*). In fact, even large multinationals have faced serious difficulties in setting up commercial production facilities. An example is the case of "*Elcar*", a NPV of *Heliothis* introduced in the United Stated by Sandoz. The production facilities, set up in 1974, had a production target of 50 000 larvae/day. Even though, in order to reduce production costs and achieve high and consistent quality, the production process was partially automated, the level of contamination was found to be very high (40 per cent). After initial success (160,000 acres of cotton were covered during 1976 - 1977) the production was found to be commercially unattractive, and the facility was closed down.[69]

The situation has not changed a great deal since then and, although a number of firms have registered various baculoviruses, their production continues to be beset by production and marketing problems.

Recent increased concern for the environment has, however, led to a renewal in research interest in baculoviruses, and new approaches to production and application are being tried. The most promising of these is the possibility of using insect cell lines for the mass production of baculoviruses, without the use of host larvae.

Considerable success in this direction has already been made, although, at present, the cost of production is too high to be economical. Efforts to increase the production efficiency of cell lines is expected to bring down the costs and to make these products competitive with other biopesticides such as *B.t.* In one of these developments, Boyce Thompson Institute, USA is reported to have developed insect cell cultures which are up to 25 times more efficient for the production of insect viruses than the current standard lines of baculoviruses.[70]

In another important development, the scientists at the USDA Agricultural Research Services have identified an insect virus which is highly effective against a wide range of Lepidopteran pests. The broad target range of the virus is expected to improve the economy of application of baculoviruses.

Sandoz has signed an exclusive license with the USDA Agricultural Research Services to develop the virus further. Research is now being carried out to produce this virus through cell lines. For this purpose, Sandoz will take the help of Biosys of the United States, which will provide its patented liquid fermentation process and formulation technology. The commercial production, however, is not expected before 1998. Other major pesticides firms, such as Dupont and American Cynamide are also working on these lines.[71]

New application methods are also being studied. USDA, for example, have used new application techniques on 100 sq. miles of cotton fields. The techniques involved the spray of weeds and not cotton, as scientists have found that larvae develop on weeds during spring and then attack cotton plants in the season. The experiments were reported to be very successful; the number of pests was reported to be reduced by 88 per cent-95 per cent.[72]

Baculoviruses have attracted attention in India also, and a number of agricultural universities, research institutes and government agricultural departments are engaged in research/production. The scope and size of this work, however, is extremely limited. In most cases the research work is confined to testing the effectiveness of NPV and other baculoviruses on local crops. The production volumes are also very small.

The progress in the development of production technology for baculoviruses has been very slow. Barring the efforts of the TNAU, which has standardised technology for commercial production of NPV and granulosis virus (GV), no systemic work has been done. TNAU research is based on two pilot plants (set up jointly with the Biotech Consortium India Ltd.), in which about 0.38 million LE of NPV of *Heliothis* was produced between November 1991 and November 1993. In addition to this, 0.17 million LE of NPV of *Spodeptera* and 11,150 LE of Chilo GV were produced during the same period.

In order to improve the efficiency of baculoviruse production technology, TNAU has developed the following equipment:

i) Artificial diet production plant;
ii) Multi cellular rearing trays;
iii) Egg separator.

The use of multicellular trays has been particularly effective. TNAU is reported to have achieved a cell occupancy rate ranging from 75-80 per cent, which is comparable with the levels achieved by Sandoz in the United States. However, the yield of virus per larvae achieved by TNAU is low; it is reported to be one third the yield obtained by some of the United States researchers in the 1960s.[73]

The current research at TNAU is aimed at

1. Low-cost sterilisation and sanitation systems to minimise contamination.

2. Productivity improvement. It is hoped that the current level of virus recovery will be doubled, which will bring down the production cost to about 1/3 of its present level.

3. Improved formulation. TNAU has made an arrangement with the National Chemical Laboratories (NCL) to collaborate in the development of formulations. They have also entered into an arrangement with NRI of the U.K. for this purpose.

4. Screening of baculoviruses from different geographical locations in India for the selection of the most virulent strains.[74]

Although TNAU has introduced a number of improvements, the process continues to be basically labour-intensive and is still not suitable for large-scale production. The university has recently entered into a collaboration with the British NRI in order to obtain technology with a high degree of automation. This technology, which is reported to be suitable for setting up large scale production facilities, will also reduce the risk of contamination and will produce NPV of high and consistent quality.[75]

Research on the possibility of using cell lines for the production of NPV is being considered only now. A number of research centres have plans to initiate preliminary studies in the near future.

Research aimed at improving the effectiveness of NPV is also being planned. The acceptance of NPV suffers due to the slow pace of its action. It is known that this is caused by a gene (ET gene). Researchers at the Indian Agricultural Research Institute (IARI) are planning to start work on the removal of this gene from NPV to increase the pace of action. The project is being funded by the DBT and is to start very soon. The immediate goal of the project is to identify and clone the gene. The Institute has received an EGT probe from a British university.[76]

Bacillus thuringiensis

With a world market of about $140 million a year, *Bacillus thuringiensis* is the world's largest selling biopesticide. In fact, 80-90 per cent of biopesticides produced in the world are *Bt* based.[77] It is primarily a pathogen of Lepidopteran pests. When ingested by pest larvae, it releases toxins (commonly known as *B.t* toxin) which damage the mid gut, eventually killing the pest.

First produced in the United States in 1957, *B.t* was registered as a biopesticide in 1961. Today, there are more than 400 registered formulations of *B.t*, which are approved for use against insect pests.[78] The current *B.t* market is estimated to be more than $100 million and is expected to increase to $300 million in 1999.[79] The market is dominated by large multinationals. Three of these: Abbot Laboratories (50 per cent), Sandoz (25 per cent) and Novo Dorsik (25 per cent) accounted for 95 per cent of the world's *B.t* production in 1991. The other major producers include Mycogen, Dupont, Ecogen and Monsanto.[80]

Current research on *B.t* is aimed at improving the strains to increase the target range to non Lepidopteran insects and non-insect pests. Researchers at the University of Maryland, for example, are developing genetically improved strains of *B.t* which will attack more than one order of insects. Using a technique called conjugal transfer, they have crossed a Lepidoptera active strain with a Cleoptera active strain to produce a hybrid which kills both beetle and moth larvae.[81]

In another effort, Mycogen has screened *B.t* strains from more than 50 countries, has already found strains which are effective against nematodes and is developing a biopesticide based on it.

New techniques for devising more effective *B.t* formulation and application are also being developed. Mycogen, for example, replaced its M-One biopesticide based on *B.t.* against Colorado potato beetle with an improved version called *M-One plus.* It incorporates the *MCap* delivery system, which involves genetically engineering a *B.t.* toxin gene into a *pseudomonas* bacterium which is then killed to provide an encapsulated biopesticide.[82]

The use of *B.t* in India was delayed as there were fears about its possible damaging effect on silk worm.[83] It is only in the last few years that government permission to use *B.t* has been given. Estimates of the total market are not available, but a large demand, especially in cotton cultivation areas is said to exist. A number of firms — Sandoz, Lupin, Rallis and the Gujrat State Fertilisers Corporation (GSFC) — are importing *B.t* to sell in the Indian market. The GSFC has entered into an arrangement with Ecogen, according to which it will be the exclusive distributor of Ecogen's bio-rational agricultural products in India and neighbouring areas. It will first introduce *Cutlass* for vegetable crops and then *Condor* for cotton. Both are based on *B.t.* Later, *NoMate PBW Spiral*, a pheromone based insect attractant to control pink bollworm on cotton, will also be introduced.[84]

The early 1990s have also seen the beginning of research on various aspects of *B.t* toxin. Researchers at Anna University have developed fermentation technology for the production of *B.t.* An agreement for the transfer of this technology has been made with a private company (Tuticorin Alkali Chemicals and Fertilisers Ltd.), which belongs to a large producer of agro-chemical inputs. The production is planned to begin some time during 1994.

Researchers at the IARI are working on the possibility of using *E.coli* with *B.t* toxin gene for mass production of the toxin. They have transferred *B.t* gene to *E.coli* and report a high production of *B.t* toxin. While in a *B.t* cell only 0.5 per cent of the cell protein is toxin, in the case of *E.coli* with *B.t* gene, 20 per cent of the cell protein is found to be toxin.[85]

Research aimed at reducing the possibility of accidental damage from *B.t* toxin to silk worms is also being carried out. Researchers at the IARI are working on the transfer of *B.t* gene to non pathogenic bacteria (such as *Pseudomonas*) which are found naturally on plants. Unlike *B.t*, these bacteria do not form spores and can not be transported by wind to neighbouring fields where silk worms are cultivated.[86]

Neem

Interest in the use of neem as a biopesticide has also increased in recent years. Neem contains several chemicals, including "*Azadirachtin*", which affects the reproductive and digestive process of a number of important pests. Neem also acts as a repellent and anti feedant, and its oil is effective against leaf folders (rice), *Heliothis* (chickpea) and aphids and bollworms (cotton). In addition to being environmentally safe, neem is effective against a wide range of pests. In fact, 200 species of insects are known to be controlled by neem.[87]

As neem is non toxic to birds and mammals and is non-carcinogenic, its demand is likely to increase sharply all over the world. Large international biotechnology firms are already engaged in research and commercial production of neem-based pesticides. W.R.Grace, for example, has developed a neem-based pesticide called *Margosan-O*, which contains 0.3 per cent *Azadirachtin*. It is licensed by the US authorities for use in greenhouses, nurseries and forestries.[88] Another firm, Agri Dyna Technologies Inc. has filed registration application for neem-based pesticides for 4 European and 14 Latin American Markets. These pesticides cover both food and non food crops. They will be sold as *Azatin* and *Turplex*.[89]

The commercial production of neem-based pesticides is being undertaken in India also; ten Indian firms are already registered with the Central Insecticide Board for the production of neem-based pesticides and 37 neem-based pesticides are already being manufactured. Research on improving the effectiveness of neem has, however, begun only recently. Some private firms (such as SPIC) and government-funded research laboratories (such as the NCL) are now engaged in isolating the active ingredient of neem. Despite the fact that the neem tree is indigenous to India, the size and scope of these research activities is very small.

Summary

The effect of indiscriminate and excessive use of chemical pesticides on the environment is a cause of serious concern. The use of biopesticides provides a safe and environment-friendly alternative for crop protection. Recent years have seen a considerable increase in the interest in biopesticides.

Although the intensity of pesticide application in India is less than that in developed countries, their ill effects on health and environment are already visible. This has led the government to set up policies and institutions to promote the substitution of chemicals with biopesticides. However, in spite of these steps, the production and use of biopesticides in India is still extremely small. Most of the production is undertaken in laboratory sized facilities by research centres and government agricultural departments. By and large, the production technology used in these facilities is inappropriate for large scale production. Limited success in up-scaling the production technologies of some of the biopesticides has been achieved. These, however, have not been transferred to industry.

The demand for biopesticides is seriously constrained by their mode of action. In particular, their target specificity and slow pace of action put them at a disadvantage vis-à-vis chemical pesticides. Further research to improve the effectiveness and broaden the range of action are necessary before biopesticides can find wider acceptance among farmers. Limited research aimed at some of these objectives is being carried out in India. However, the research is at an elementary stage and its results will not be available for many years.

IV. BIOFERTILISERS

Introduction

The potential of certain micro-organisms to improve the availability of nutrient to crop plants has long been known. In view of the rise in the cost of chemical fertilisers and their adverse effect on the environment, these organisms (collectively called biofertilisers) have become increasingly important. They are considered to be particularly important in tropical countries like India, whose soils are deficient in organic matter and essential plant nutrients, due to high temperature and intense microbial activity.[90]

Most biofertilisers are nitrogen-fixing in nature; they fix atmospheric nitrogen to ammonia by a complex metabolic process. Broadly speaking, these are of two types: symbiotic and free living. The former, which require symbiotic association with plants, are represented by *Rhizobium*. The latter, which can fix nitrogen independently, include Azatobacter, Azospirillium, blue green algae (BGA) and *Azolla*.[91]

Rhizobium is the most researched and well known biofertiliser, and its role in nitrogen fixation in legumes is well established. It infects the lateral roots of these crops to form nodules, where nitrogen fixation is carried out. Although *Rhizobium* forms symbiotic association with legume crops naturally, in many cases its numbers are too small to fix sufficient nitrogen. Furthermore, not all strains of *Rhizobium* are efficient fixers of nitrogen. For example, In a survey of 87 groundnut rhizobial strains isolated from different parts of India, only five were found to be effective.[92] Artificial inoculation of soil with suitable *Rhizobium* strains to augment their nitrogen-fixing capability can contribute to crop yield in such situations. It is reported that, in favourable conditions, *Rhizobium* can fix 40-60 kilograms of nitrogen/hectare, and that 200 grams of *Rhizobium* is enough to meet one third of nitrogen crop requirements.[93]

Azotobacter and *Azospirillum*, which are commonly found in the rhizosphere of cereals, grasses and vegetables, are also bacteria. In addition to fixing nitrogen, they are known to produce growth-promoting substances and antibiotics. As in the case of *Rhizobium*, they can either be applied as seed inoculants, or the roots can be dipped in a suspension before planting.[94] Reports suggest that in favourable conditions their use can reduce the nitrogen requirement by 25 to 50 per cent.[95]

The other important, free-living, nitrogen-fixing agents are blue green algae (BGA) and *Azolla*. While, as the name suggests, BGA is an algae, *Azolla* is a water fern. Both prefer standing water for growth and are suitable for use as a source of nitrogen for rice. Of the two, BGA has attracted greater attention in India. In fact, Indian researchers were amongst the first in world to notice and study its nitrogen fixing properties.[96] The early interest in BGA, however, was not followed up by systematic research. It was only in the 1970s, that efforts were initiated to examine the potential of using BGA as a biofertiliser on a large scale. The initiative was taken by the Department of Science and Technology, which supported an All India Coordinated

Programme on algae during 1976-84. The programme is reported to have shown that in favourable conditions, the use of BGA can reduce the nitrogen consumption by 20-30 kg/hectare without affecting rice yield.[97] Similar increase in production has been reported in the case of *Azolla*.[98]

In addition to the nitrogen fixing micro-organisms, there are biofertilisers which can improve the availability and uptake of other nutrients. Two of these are considered to be most important. The first group consists of certain fungi mycelium which form a symbiotic relationship with plant roots. The symbiotic relationship, called vesicular-arbuscular *Mycorrhiza* (*VAM*), is considered to be associated with increased plant growth and enhanced accumulation of plant nutrients such as phosphate, zinc and copper.[99]

The second group of non-nitrogen-fixing biofertilisers are phosphate solubilising microorganisms. These micro-organisms, which include bacteria, fungi and yeast, excrete organic acids which solubilise rock phosphate and tricalcium phosphate by decreasing the size of particles to near amorphous forms.[100] Indian soils are characterised by poor to medium phosphorus availability; only about 25-30 per cent of the phosphorus applied to the soils is available for the crops. The presence of these microorganisms is reported to increase the availability of phosphorus considerably.[101]

Role of Government

Much of the production of biofertilisers is directly or indirectly supported by the government. Firstly, the Ministry of Agriculture of the central government has a national project on the development and use of biofertilisers, which was set up in 1983. A number of zonal production facilities have been set up under the National project, which produce biofertilisers suitable for various regions. Secondly, most of the state agricultural departments and state agricultural universities produce biofertilisers. Thirdly, a number of public sector firms and cooperatives have been encouraged by the government to set up production facilities. Fourthly, the government provides substantial subsidies to cover the cost of plant and equipment required by private industry for setting up production facilities.[102] Fifth, the state governments purchase a large proportion of the yield for distribution to farmers, thus providing the producers a guaranteed market.

In addition to its support to production, the government is also closely involved with programmes to popularise the use of biofertilisers. The National Centre of Biofertilisers, the state departments of agriculture and some of the agricultural universities are engaged in these programmes.

Production

More than 60 units are engaged in the production of biofertilisers; the total output in 1992-93 was 2 211.8 tons.[103] Most of the producers are small and only a handful of them produce more than 100 tons of biofertilisers per year. These include the production facilities set up under the National Biofertiliser Project, which produced about 350 tons of biofertilisers in 1992-93. In addition to these and various state agricultural departments, some industries in the public and private sectors and cooperatives are also engaged in the production.

The two largest producers are NAFED and Gujrat State Fertilisers Corporation (GSFC). NAFED, a government sponsored co-operative, was one of the first agencies to undertake large scale manufacturing of biopesticides in India. This began in the early 1970s when facilities for the production of 150 tons of *Rhizobium* for soybean, ground nut and pulses were set up. NAFED was also the first Indian producer to use fermentation technology and, at present, uses a 2000 litre fermentor.[104]

GSFC, the other large producer, is a public sector fertiliser firm, which began the production of biofertilisers in 1984. It produced a total of 266 tons of biofertilisers during 1992-93. This included 55 tons of azatobacter, 56 tons of *Azospirillum*, 58 tons of *Rhizobium* and 95 tons of phosphate solublising microorganisms.[105]

The other major producers are Madras Fertilisers (a public sector fertiliser firm), Zuari Agro-chemicals (a private sector agro-chemical firm), SPIC (private sector petrochemicals firm), Stanes and Co. (a private sector firm).

Rhizobium is the most commonly produced biofertiliser in India. About 1 000 tons of *Rhizobium* is being produced currently. A very large proportion of this is produced by government departments and public-sector firms. The private-sector firms account for only 16 per cent of *Rhizobium* production. Government agencies dominate the production of other biopesticides also.[106]

Demand Constraints

In spite of the government's policy of encouraging their use, the demand for biofertilisers continues to be very small. Even the comparatively small amount of biofertiliser produced can not be sold on commercial basis and, in most cases, is procured by the government for free distribution among farmers. Efforts to sell them on a commercial basis have, by and large, failed and, according to one of the producers, the production cannot be continued without substantial government support.[107]

The situation is unlikely to improve in the near future. According to official projections, the production of various biofertilisers at the end of this decade will be sufficient to meet less than 2 per cent of the perceived requirement. (See Table 4.1).

Table 4.1. **Projection for the production of Biofertilisers in the Year 2000 A.D.**

Biofertiliser	Production (tons)	Percentage of Potential Demand
Azospirillum	7 230	0.8
Rhizobium	14 460	1.7
Azotobacter	7 230	0.8
PSM	7 230	0.8
BGA	3 015	1.1

Source: Motsara M.R., "National Project On Bio-fertlisers-Status Position-VIIIth Plan Proposal", National Conference on Biofertilisers and Organic Farming, Organised by the Ministry of Agriculture, Madras, 1993 pp. 14-20

The acceptance of biofertilisers among farmers is very low. This, in turn is due to *a)* the poor and uneven quality of biofertilisers produced and *b)* the relatively small and uncertain contribution to crop yield.

Quality

The problem of quality has been serious since the 1980s, when the production of biofertilisers on a large scale was first started. Tests conducted in recent years show that the situation has not seen much change since then. For example, according to tests (which are based on the number of inoculi found in one gram) carried out by the ICRISAT on *Rhizobium*, a majority of the samples failed to pass.[108] Similarly, in tests carried out by the National Biofertiliser Project, more than one third of the samples were found to be of unacceptable quality. (See Table 4.2).

Table 4.2. **Quality of Biofertiliser Samples Tested Under National Biofertiliser Project**

Number of Samples Tested	Number of Samples Found Below Standard	per cent of Samples Below Standard
430	160	38

Source: Motsara M.R., "National Project on Biofertiliser- Status Position-VIII Plan Proposals", Paper presented in National Conference on Bio-Fertilisers and Organic Farming", Organised by the Ministry of Agriculture, Madras, 1993.pp 14-20

Unlike chemical fertilisers, the quality of biofertilisers is not regulated by the government. Also, except in the case of *Rhizobium*, there are no official quality standards for biofertilisers. Even in the case of *Rhizobium* the standards are not followed.

A number of factors contribute to the poor quality. The quality of strains and carriers, production processes and methods of packaging, storing and transport are largely responsible for this. In the case of bacterial biofertilisers (*Rhizobium*, *Azospirillum* and *Azotobacter*) carriers, which are known to be particularly important for increasing the shelf life, have been the focus of much recent debate and research.

Research has shown that peat, which has a high moisture-retaining ability, is the most suitable carrier for *Rhizobium*. Its use is particularly common in some of the developed countries such as Australia and the United States, where it is commonly available. In India, the availability of peat is limited and a number of alternative carriers have been tried, unsterilised lignite being the most common.[109] Although producers claim that the lignite impurities are within the limit, the performance of these and other materials used as carriers has been found to be less than satisfactory, as their moisture-retaining ability is inadequate, and they are prone to contamination. Consequently, the shelf life of biofertilisers using these materials as carriers is short. While many producers claim that their products have a shelf life of more than six months, in most cases it is found to be less than three months. For carriers used by various *Rhizobium* producers, see Table 4.3.

Table 4.3. **Carriers Used By Various Rhizobium Producers.**

Organisation	Carrier
TNAU	Peat
Madras Fertiliser	Lignite
GSFC	Lignite
NAFED	Lignite
Biofertiliser Centres	Charcoal

Source: Firm interviews

The situation is worse in the case of BGA as most of it is produced in open tanks, which are easily contaminated. Also, soil and straw, which are commonly used as the carriers, are also highly prone to contamination. The contamination not only reduces its effectiveness, but also sometimes damages the crop.

Performance

Most of the field trials highlight the fact that the contribution of biofertilisers to crop yield varies greatly, and that the farmers are justified in being sceptical of their contribution. The results of some these trials are listed in the following paragraphs.

— *Rhizobium*: An increase of only 3 to 12 per cent in yield has been achieved in chickpea.[110] Similar results, showing poor and inconsistent effects on crop yield have been reported by other researchers.[111]

— *Azospirillum*: An increase in yield was achieved in only 6 out of 9 tests on pearl millet. The change in yield varied between -10 to 17 per cent. In case of sorghum, an increase in yield was achieved in only 4 out of 9 tests.[112] In case of rice, the application of *Azospirillum* was found to make an important difference in only 48 out of 108 trials.[113]

— *Mycorrhiza*: Only in 50 per cent of the cases was a significant improvement in yield achieved. The plant response to *VAM* varied with soil type, soil fertility and *VAM* cultures.[114]

— *Azotobacter*: significant response to inoculation was observed in 342 out of 411 trials in wheat.[115]

Phosphate-solublising micro organisms: Out of 37 field trails conducted, only 10 showed significant increase in yield in the case of rice, wheat, chickpea, pigeonpea, soybean and groundnut.[116]

The crop response to biofertilisers depends on a number of factors. The most important of these are:

1. Number of living cells in the inoculum;
2. Suitability of the strain to soil and crop;
3. Competitiveness of the inoculant against microorganism already present in the soil;
4. Tolerance of inoculants to abiotic (salinity, pH, moisture and heat shock) stresses;
5. Application techniques.

Research Activities

Systematic research on biofertilisers began only in late 1980s. The two important objectives of research, most of which have been concentrated on *Rhizobium* and BGA, are: *a)* optimisation of the production process to improve the quality and the quantity of the yield and *b)* strain selection and improvement.

Improvement of Production Process

Rhizobium

Until the beginning in the 1980s *Rhizobium* (and other bacteria based biofertilisers) were produced in flasks. As a result, the quantity and quality of yield was extremely poor. The first major effort towards improving the production process was undertaken jointly by the Ministry of Agriculture and the FAO in the late 1980s. The programme involved the transfer of production and formulation technology and protocols developed by NIFTAL (an international research institute specialising in nitrogen fixation) to India and the training of Indian technical personnel. Some modification of protocols to suit Indian strains and agro-climatic conditions was also undertaken.

The other major research efforts — concentrating on *Rhizobium* and blue green algae — were initiated by the Department of Biotechnology in the early 1990s. This research has more or less the same goals as the Ministry of Agriculture initiative, namely optimisation of the process for the production of *Rhizobium* of suitable strains. According to DBT, a process for large scale production has been optimised. Some of the large producers (Madras Fertilisers, GSFC and NAFED) are also undertaking research aimed at the optimisation of large scale fermentor based production technology. NAFED, for example, is currently using a 2000 litre fermentor.

While the efforts to improve production technology have been successful to some extent, the shelf life of the products continue to be short and varying. This is because the efforts to develop suitable carriers which have desirable moisture retaining and other qualities, and are not prone to contamination, have not been very successful. Experiments with synthetic materials were planned, but it would be some time before results will be available.[117]

Blue Green Algae

Progress in the improvement of BGA production technology has been even less marked. As mentioned earlier, until recently BGA was being produced in open tanks. As these tanks are extremely prone to contamination, the quality of production was very poor. The problem of contamination was made worse by the use of soil and straw, as carriers.

Current research efforts are focused on the production of BGA in plastic bags and containers, which are used as simple bio-reactors. As a result of these efforts, which are funded and co-ordinated by the DBT, trials to produce BGA in liquid cultures using breathing bags are being undertaken. The technology, which is reported to have been optimised, is yet to be used for large scale production.

Studies have also been initiated recently to produce near pure forms of BGA in open ponds without soil. It is planned to mix pure BGA with suitable carriers (Soft stone, kaolin and clay are being considered) for transportation, storage and application.[118]

Strain Improvement

The effectiveness of microorganisms as biofertilisers depends very largely on the selection of strains which are suitable for a particular crop, soil and other factors. This is particularly true in the case of *Rhizobium* which is highly specific in its action. Collection of strains from Indian soils and their screening for survival and nitrogen fixing abilities is being carried out by a number of agriculture universities and research institutes. The Department of Biotechnology has supported the setting up of a germplasm bank at the Indian Agricultural Research Institute (IARI) for maintaining a variety of *Rhizobium* strains. The bank has about 200 strains of *Rhizobium* specific for chickpea, arhar, soybean, french bean and groundnut. It also has about 2 000 soil samples, which are used for studying the effectiveness of *Rhizobium* strains.[119]

Except for a handful of large producers such as NAFED and GSFC, who have their own strain collection, most producers depend on universities and research institutes for strains. NAFED has established a large culture bank which consists of suitable strains of Rhizobium, *Azotobacter*, azospirllum, *Pseudomonas*, *Aspergillus*, *VAM* and phosphate-solublising micro-organisms. Some of the institutes which provide these strains are IARI, ICRISAT, BNFRC (Bangkok) and NIFTAL (Hawaii). GSFC are working on isolating strains which can survive high-temperature and drought conditions. This will increase the life and effectiveness of the strain both on shelf and in soil.

Strains of *Rhizobium* are being screened with the help of genetic techniques. Protein finger printing techniques to study rhizobial variants are also being developed. Also, methods of strain identification using intrinsic antibiotic resistance have also been developed, and are being standardised.

Studies on the development and testing of mutants of microbial biofertilisers are also being undertaken. For example, a number of mutants of *Rhizobium* are being studied for a) the variation in symbiotic effectivity, b) the ability to grow at low pH and c) the competitiveness with native *Rhizobium.*[120]

More ambitious research involving genetic manipulation of micro-organisms to improve their effectiveness as biofertilisers (by improving survivability and competitiveness) has also begun. For example, researchers at the IARI have isolated genes responsible for stress-tolerance (for heat shock, high temp, low moisture) from alfa *Rhizobium* and have cloned these to chickpea *Rhizobium*. This was done during 1990-93. The strains with stress tolerance genes have already been tested in the laboratory and are now undergoing national trials. The new strain is expected to have a longer shelf life as it is likely to withstand stress during transportation and storage better.[121]

Researchers at the Tamil Nadu Agriculture University are also engaged in genetic manipulation of bacterial biofertilisers. They have transferred genes responsible for abiotic stresses in *Rhizobium* and *Azospirillum*. They are now exploring the possibility of transferring genes responsible for the production of indole acetic acid, which is a plant growth hormone, to bacterial biofertilisers.

In another study, researchers at IARI are hoping to increase the effectiveness of *Rhizobium* inoculi by introducing genes which can increase their competitiveness vis-à-vis *Rhizobium* already present in soil. They have isolated certain *Rhizobium* strains which are resistant to toxins (produced by competing *Rhizobium*) but are poor fixers of nitrogen. The genes responsible for toxin resistance from these strains will be transferred to those which are high nitrogen fixers. The research is in its preliminary stages and is currently focused on isolation of genes responsible for toxin resistance. The gene transfer is expected to take about one year.

Compared to *Rhizobium*, the research efforts aimed at improving the strains of other fertilisers are much smaller. A National Facility for Blue-Green Algae, which holds 550 strains of BGA has been set up with the support of the DBT. The facility acts as a source of strains to researchers throughout the country.

Some work on the selection and improvement of BGA strains suitable for various soil conditions is also being done. For example, the DBT has recently funded research on isolating strains of BGA suitable to local conditions. Attempts are also being made to introduce genetic markers in BGA to be used for quality control.[122]

Research to combine the beneficial properties of more than one microbial fertiliser through genetic manipulations is also underway. The IARI researchers, for example, are working on isolating the genes responsible for the production of phosphate solublizing acids in bacteria. They plan to transfer these to nitrogen-fixing *Azotobacter* and *Azospirillum*, so as to combine nitrogen fixation with increased availability of phosphorous. They have finished the screening of bacteria and will soon start working on the isolation of genes responsible for the trait. The completion of work will take at least 3 years. Once isolated, these genes can also be transferred to bacteria for use as bio-reactors which can produce phosphate fertilisers from rock phosphates on an industrial scale, without using energy and causing pollution.[123]

Summary

Biofertilisers are micro-organisms which can improve the availability of nutrients to plants. They are an important component of sustainable agriculture, as they can reduce the use of chemical fertilisers. *Rhizobium*, blue green algae, *Azospirillum* and *Azotobacter* are some of the important nitrogen-fixing biofertilisers. Others, such as *Pseudomonas* and VA-*Mycorrhiza* are phosphate-mobilising biofertilisers.

The Indian government has taken a number of steps to promote the use of biofertilisers. These include technical support and financial incentives to encourage the production and use of biopesticides. However, in spite of these steps, the acceptance of biofertilisers among farmers continues to be very low. Consequently, almost all the biofertiliser produced in India is procured by the agricultural departments for free or heavily subsidised distribution.

The demand for biofertilisers suffers from three factors: poor and uneven quality, short shelf life and small contribution to crop yield. Research aimed at the optimisation of production process and improvement of quality is being undertaken at a number of centres. The progress in this direction, however, has been small. Work to increase the survival and effectiveness of biofertilisers through genetic manipulation of strains has begun very recently. A significant improvement in the performance and increase in acceptance of biofertilisers is possible only if these efforts are successful. Otherwise, the contribution of biofertilisers to sustainable agricultural development will continue to be small.

V. INTELLECTUAL PROPERTY RIGHTS

The impact of Intellectual property rights (IPR) on India's agriculture in general and biotechnology in particular has attracted wide attention.[124] At the time of writing India did not recognise intellectual property rights in the field of agriculture, and the Indian Patent laws exclude plants and animals from such protection. The situation, however, is likely to change, as India has accepted the Dunkel proposals related to intellectual property rights. According to Article 27 of Section 5 of Dunkel Draft, the GATT signatories are required to include the protection to micro-organisms and microbiological processes in their patent system. Furthermore, plant varieties are to be protected through either patents or a *sui generis* system. It is generally understood that in order to be accepted as effective, the *sui generis* system would need to be modelled on the International Plant Breeders' Rights devised by the International Convention for the Protection of New Plant Varieties (UPOV) 1978.

The 1978 version of UPOV provides two important exemptions. These are breeders' exemption and farmers' exemption. The breeders' exemption allows breeders to develop new varieties based on protected varieties, without requiring permission or licence from PBR holders. The farmers' exemption allows farmers to use the last year's crop for sowing during the next year. It also allowed farmers to exchange with and sell this material to other farmers.

The UPOV was revised in 1991 to strengthen the protection given to the breeders. Among other changes, the 1991 version reduced the scope of both breeders' exemption and farmers' exemption. Accordingly, breeders cannot use the protected material for breeding purposes without the permission of the PBR-holder. The scope of the farmers' exemption was also restricted and they may not use their own production for sowing purpose without paying some compensation to the PBR holder.

The Indian government has drafted a Plant Variety Protection Act in 1993, which was being considered for approval as a *sui generis* system to meet the GATT requirement. The proposed Act attracted criticism, as in some important aspects it provides a greater degree of protection to PBR holders than available in the UPOV 1978.[125] The main features of the proposed Act are:

1. The Act covers the whole plant kingdom. The UPOV 1978, on the other hand, covered only 24 plant species.

2. The Act provides protection for 15 years for all plant varieties (including hybrids) except in the case of trees and vines. In the case of the latter, the protection will be for 18 years.

3. The farmers will be permitted to use their crop for next year's sowing. They will also be permitted to exchange their seeds with other farmers. However, they will not be permitted to sell seeds to other farmers.

4. The Act provides protection not only to protected varieties but also to varieties essentially derived from a protected variety or varieties whose production requires repeated use of the protected variety.

It is likely that India will adopt a *sui generis* system based on the proposed Act. Once adopted, the system will put restrictions on the use of protected material for breeding purposes and will also prohibit farmers from production of seeds of protected varieties for commercial purposes. Will this affect the development and diffusion of new varieties?

In the past, Indian breeding efforts have greatly benefited from inputs — both in terms of technology and material — from outside the country. However, in most cases, these inputs have been received from non-profit making international agencies. For example, the International Rice Research Institute (IRRI) and the Rockefeller Foundation have made significant contributions to India's rice-breeding programme. Similarly, India's wheat-breeding efforts have greatly benefited from the transfer of breeding material from CIMMYT in Mexico.

The transfer of breeding material from these institutions to India has been possible as it is not protected. As long as these agencies continue a policy of not protecting their material and technology through patents and other means, Indian researchers would continue to have access to it. In the circumstances, India's conventional breeding activities for major food crops will not be seriously affected by its adoption of a *sui generis* system.

The effect of the restriction on the sale of seeds protected under the Act, however, is likely to affect the rapid diffusion of new varieties seriously. According to some estimates, about 60 per cent of the seed requirements of Indian farmers are met by inter-farmer trade.[126] Clearly, the restrictions on the sale of protected seeds by farmers will limit the diffusion of these varieties.

In addition to the adoption of a *sui generis* system aimed at plant protection, India is also required to modify its patent system to include protection to micro-organisms and microbiological processes. The modifications relating to various aspects of the patent system are required to be carried out within a period ranging between 5 and 10 years. Although no official move is known to have been made in this direction, it is likely that the modified patent system will cover genetic materials. The effect of such a system on the future of agricultural biotechnology research in India is likely to be serious.

A number of processes and products in the field of crop improvement, biopesticides and biofertilisers are already covered by patents in developed countries, and many more patents are in the pipeline.[127] Once the Indian patent system is modified, it will become possible for patent holders in developed countries to extend the scope of these patents to India. This is likely to create important impediments in the way of Indian research in the field of agricultural biotechnology.

Many of the research programmes initiated in India in recent years could be seriously affected by patent restrictions. For example, one of the most ambitious projects initiated by the Department of Biotechnology relates to the development of transgenic cotton with *B.t* toxin genes. The transformation process of cotton (as many other important crop plants) is already protected by a number of patents held by leading biotechnology firms such as Monsanto, PGS and Agracetus. Clearly, once India modifies its patent laws, it is likely that the scope of these patents will be expanded by these firms to cover India.[128] In that eventuality, the future of Indian research is less than certain.

India had a grace period in 1994 of five to ten years for making the necessary modifications to its patent laws. In order to reduce the impact of foreign patents on local research efforts, India will need to use this period to make a determined effort to achieve some of its technological goals in these areas (such as transgenic cotton and rice, and production of baculoviruses through cell lines). Unfortunately, the urgency of the situation is yet to be appreciated in India, and there is no significant increase in the resources devoted to agricultural biotechnology research.

V. CONCLUSIONS AND POLICY ISSUES

The "new" agricultural technology, comprised of a package of high-yielding varieties, irrigation and chemical inputs, had diffused to wide areas of India during the three decades to the mid 1990s. With an increase in the area covered by the new technology, the consumption of agro-chemicals (fertilisers and pesticides) also increased steadily during this period. Although the intensity of their use is comparatively small in India, their ill effects on environment and health are already evident. For example, tests have shown that the incidence of pesticide residue in food products is very high. Similarly, in areas with a large consumption of nitrogenous fertilisers, the ground water contains dangerously high levels of nitrates.

The situation poses a serious dilemma for the policy makers. On the one hand, faced with an increasing population, India needs to increase its agricultural production continuously. As a large part of Indian agriculture is still based on traditional farming practices, there is a strong temptation to spread the use of chemical-intensive agricultural technology and practices to new areas. On the other hand, if the spread of this technology to new areas continues, the environmental consequences would obviously be serious. As the need to increase food production is considered to be paramount, the tendency to ignore the environmental dangers will continue. Therefore, unless "cleaner" and environment-friendly technologies, which can equal or increase the agricultural productivity associated with "green revolution" technologies are available, the use of environmentally damaging practices and inputs will continue to increase.

Recent advances in agricultural biotechnology have increased the options available to policy makers and farmers considerably. Many of these developments have the potential of increasing agricultural productivity, without a corresponding increase in the consumption of agro-chemicals. If successfully developed and widely diffused, these technologies can greatly contribute to environmentally friendly and sustainable agricultural development.

The developing countries' ability to benefit from the opportunities provided by biotechnologies will depend on a number of factors. Their ability to acquire these technologies (through import or indigenous development) will obviously be one of the most important of these. Presently, much of the biotechnology research is being carried out by a handful of private firms in developed countries. Supported by the strengthening of industrial property rights, these firms exercise close control on many of the existing and emerging biotechnologies with commercial application. It is feared that the concentration of agricultural biotechnologies in a handful of firms with world-wide commercial interests is likely to have an extremely negative impact on developing countries' chances of acquiring these technologies.[129] Even when available, the cost of technology acquisition may prove to be too high for most developing countries. Furthermore, as most agricultural technologies are highly crop and agro-climatic specific, the imported technologies may need to be adapted to local conditions. In the circumstances, local R&D capabilities to generate/adapt biotechnologies will greatly increase the developing countries' ability to benefit from these technologies. It is in this context that India's capability to develop and utilise agricultural biotechnologies with environmental implications has been studied.

Research in biotechnology is of relatively recent origin in India. The Department of Biotechnology, which funds most of this research, dates from the 1980s. As very little technological capability in biotechnology existed before this period, the focus was on capability building. It is only during the 1990s, that specific, problem oriented R&D efforts have been initiated.

Biotechnology research with a potential to reduce the use of agro-chemical inputs can be treated in two categories. The first category deals with efforts to improve, standardise and diffuse technologies and products which are already available. Most of the research in the fields of biofertilisers and biopesticides, such as strain selection, production optimisation and field testing, fall within this category. As a result of these activities, a number of biopesticides and biofertilisers are now available.

The second category of research is more basic. Using plant molecular biology techniques, most of it is aimed at crop improvement through genetic manipulation. Research aimed at the development of transgenic rice and chickpea, and cotton with *B.t* toxin genes are some of the important examples. The research aimed at *B.t* toxin genes to *E.coli* for the mass production of toxin, and the plans to develop techniques for the production of NPV from cell lines also belong to this category.

At present, the contribution of various biotechnology products to a reduction in the consumption of agro-chemicals is only marginal. The production of biopesticides and biofertilisers is small, and their use is almost exclusively through extension services. Biofertilisers have failed to find acceptance among farmers due to poor and uneven performance. Although a number of centres are engaged in the improvement of production and application technologies, these efforts lack innovation. Most of the work is repetitive and very little progress in removing the major shortcomings of the product and production techniques has been made. Furthermore, in most places the research is being carried out at sub-optimal level and suffers from a shortage of resources. In fact, the approach has been to set up an ever-increasing number of production-cum-demonstration units, without solving critical problems (such as short shelf life). Not surprisingly, this approach has failed. In fact, attempts to popularise the use of sub-standard biofertilisers in the past have created very serious obstacles in the way of their acceptance in the future.

In the case of biopesticides, the unavailability of efficient technologies for large scale production has been a serious bottleneck. Again, although a number of centres claim to be working on this problems, their actual work is no more than routine production and field testing of various bio-control agents. Although the joint efforts of TNAU and BCIL have made progress in the standardisation of production technologies for important biopesticides, these have yet to be commercialised. Furthermore, as in the case of biofertilisers, the acceptance of biopesticides among farmers is low. Slow pace of action and target specificity of these agents are cited as the most important causes for this. By and large, the use of biopesticides is limited to situations where chemical pesticides can not be used. These include instances where the pests have developed resistance to chemical pesticides (such as in the case of cotton bollworm) or where application of pesticides is not practical (as in the case of sugar cane fields).

It is clear that the growth of the biopesticide and biofertiliser industries is caught in vicious circle. By and large, they are being produced on a small scale using inefficient technologies. The poor quality and performance of these products limit their demand, which in turn has a discouraging effect on investment in research and production facilities. In the circumstances, governmental intervention to break this circle by providing investment incentives for technology development and the setting up of production facilities using efficient technology, may be necessary. The financial resources required for this support can be raised by imposing a levy on the sale of chemical pesticides and fertilisers.[130]

The second category of research is at a very early stage. It is only recently that leading research centres have developed the capability to start research aimed at the development of varieties with disease/pest resistance. The size of these efforts, both in terms of researchers and financial resources, is still very small. This is particularly so when compared with the size of various crop improvement programmes based on conventional techniques. Furthermore, compared to conventional crop breeding efforts, the research in biotechnology lacks a focus. Conventional breeding research has been closely co-ordinated by the ICAR since the 1960s. Most of these programmes are crop-based and involve a number of scientists representing a variety of institutions. This problem oriented approach with a clear focus is largely responsible for the success of these programmes. On the other hand, perhaps due to the lack of sufficient manpower and financial resources, this pattern has not emerged in the case of crop improvement efforts based on biotechnology. It is hoped that with the increase in trained manpower, the Department of Biotechnology and the ICAR will be able to set up better co-ordinated and focused research programmes.

As the research is at a very early stage, it is hard to assess its potential contribution. In most cases the activities are at the level of gene mapping and cloning, though some regeneration experiments with marker genes are also being carried out. Even according to the most optimistic estimates, it will be at least five years before plants with desired traits can be produced and used in breeding programmes. Only in the case of brassica, whose blight resistant plants are being back-crossed, are early results expected.

A very large proportion (more than 70 per cent) of pesticide application in India is accounted for by cotton and rice crops. Unless disease- and pest-resistant varieties of these two crops are available, a significant decline in pesticide consumption is unlikely. In the case of rice, limited research on the transfer of genes responsible for resistance to blight and gall midge is being undertaken. This is, however, at a very early stage, and considering the difficulties likely to be encountered in regeneration in rice, early progress is not expected. In the case of cotton, while there has been a lot of interest in the development of transgenics with *B.t* toxin, it is only during the last few months that a concerted move has been made in this direction. With the setting up of a large, DBT supported programme, it is hoped that cotton transgenics will be available for field trials after four to five years. As the field trials and large scale breeding can take up to five years, resistant varieties of both rice and cotton cannot be expected to be available before the 21st century.

As India has a well organised crop breeding programme, the use of transgenic plants for breeding purposes is not likely to pose problems. Many of the research institutes engaged in biotechnology research (such as the IARI) have their own breeding programmes. Others, such as the ICGEB, have collaborated with institutes where plants can be field tested and used in breeding. Also, the ICAR has a well established system and organisation for testing new varieties in various agro-climatic regions. The new varieties and trasnsgenics developed through biotechnology research will greatly benefit from the existing infrastructure and capabilities in conventional breeding.

The role of foreign agencies (private firms, development agencies, public institutions) in India's efforts in the field of agricultural biotechnology, is small. The role of private firms has been particularly small. Although recent years have seen a rise in the entry of foreign firms through joint ventures and technical collaborations, most of these are concentrating on the production of hybrid seeds with imported breeding material, and tissue culture. Except for one case, where a Belgium firm is planning to develop and market pest resistant rape mustard in a joint venture, no foreign firm is involved with the development/marketing of resistant varieties. Some Indian firms have also begun marketing imported *B.t* and have plans to set up production facilities with technical collaboration. The number of such proposed projects, however, is very small. For example, the number of firms involved with the import of *B.t* is only four.[131]

Except for rice, research on which has received considerable financial and technical support from the Rockefeller Foundation and the ICGEB, the international development agencies have also played a marginal role. On the other hand, universities in the developed countries (particularly in the United States), have been a very important source of training and exposure for Indian researchers. Many of these researchers have close (both formal and informal) working relationship with their counter parts in developed countries. In fact, almost all the researchers we interviewed for the study had spent considerable time in the facilities in developed countries. These visits are by far the most beneficial and cost-effective mode of technology transfer to India.[132] On numerous occasions these contacts have also been used for receiving genetic and other materials, which would not have been possible otherwise.

One of the most important effects (from India's point of view) of the increasing trend of patenting in the developed countries will be on the transfer of biotechnology related techniques and material from universities in developed countries to India. As the tendency to take patents gathers momentum in the public institutions and universities of developed countries, the exposure and access to genetic material and techniques that has benefited Indian researchers will diminish drastically.[133]

India's acceptance of the Dunkel proposals related to IPR is also likely to have a serious effect on research in the field of agricultural biotechnology. India is required to modify its patents laws to provide protection to products and to micro-organisms and microbiological processes within a period ranging between five and ten years. Once Indian laws are modified, international firms are likely to extend the scope of their patents to India. As these firms already have a number of patents pertaining to crops which are important to India, the implication of these patents for agricultural research in India can be serious.

In the circumstances, it is imperative that the Indian government and the research establishment appreciate the urgency of the situation and utilise the five to ten years of grace period to consolidate advances in the areas of particular relevance to Indian agriculture. This will require a massive increase in the resources devoted to agricultural biotechnology and concentration of efforts in fields where the chances of developing technology to the level of products are high.

At present, the resources devoted to agricultural biotechnology by India are comparatively small. According to our estimates, the Department of Biotechnology, which is the major funding agency in this field, spent about $6 million on supporting agricultural biotechnology research during 1992-93.[134] This amount is similar to what many of the leading agbiotech firms spend individually. For example, Calgene and DNA Plant Technology spent $9.3 million and $9.1 million respectively during 1992-93.[135] Large chemical and seed companies, such as Monsanto, Sandoz, Pioneer Hi-Bred and Dow Chemicals are known to spend even larger amounts of agricultural biotechnology research.

Considering the unusual situation where scope of research may become seriously restricted due to patent laws after ten years, a policy of gradual increase in the resources devoted to agricultural biotechnology is not suitable for India. Instead, a massive investment during the next decade will be required. This will not only enable India to have a number of technologies and products available for application, but will also strengthen its bargaining power to enter into cross-licensing arrangements for gaining access to proprietary technologies and products held by international firms.

NOTES

1. Government of India,1994:S-17, S-18.

2. Hanumantha Rao,1989:385.

3. Government of India,1969.

4. Government of India,1994:S-27.

5. Nitrogen fertilisers are converted by soil organism into nitrates, which are highly soluble in water and move down to groundwater. When water with an excess of nitrate is consumed by human beings, it is reduced to nitrite, which affects the blood's ability to transport oxygen. Singh et.al, 1987 and WHO,1963.

6. Parmar et.al,1993.

7. The consumption of pesticides per hectare in India in 1989-90 was 400 grams. The figures for Mexico, the United States and Japan were 750 grams, 3000 grams and 12,000 grams. BCIL,1992.

8. The application of pesticides is often found to be two to three times the recommended dosage and frequency. Khan et.al.,1991.

9. Government of India,1992 b.

10. BCIL,1992.

11. BCIL,1992.

12. For details of research results, BCIL,1992.

13. Government of India,1992b. The development of resistance has also led to a sharp increase in pesticide consumption in some cases. The first incident of insect resistance was reported in 1963 when Singhara beetle acquired resistance to DDT and BHC. The most serious case in recent years was in 1987-88 when cotton pests developed resistance to insecticides. The farmers had borrowed large sums to apply heavier and heavier doses of insecticides. The crop failed and the farmers could not repay their debts. Many of them committed suicide. See BCIL,1992.

14. Government of India,1992c.

15. Government of India,1994a.

16. Government of India,1992c.

17. Government of India, 1994c.

18. Singh et.al ,1990.

19. Export of flowers by India increased by 90 per cent between 1990-91 and 1992-93. The value of flowers exports in 1992-93 was Rs. 149 million ($4.81 million).

20. ICAR,1985.

21. Rice is affected by a number of diseases. The most important of these are: blight, rice blast, sheath blight, rice tungo virus and brown spot. Important pests include gall midges, stem borer, brown plant hopper, green leaf hopper and white back hopper. see: Singh and Balasubramanian,1979.

22. IARI,undated.

23. ICAR,1983.

24. For a history of wheat research in India, see: Tandon and Rao,1987.

25. Interview with Dr. Sethi, IARI.

26. Goel and Sinha,1992:18-21.

27. ICAR,1983.

28. Directorate of Wheat Research, 1991.

29. The common diseases of mustard are: white rust, Alternaria blight, aphid and downey mildew. For details, see: Rao and Ranga Rao,1988.

30. Interview with Dr. V.P.Singh, Genetics, IARI.

31. For a discussion of the role of biotechnology in crop improvement, see: Hansen et.al, 1986.

32. Conventional plant breeding techniques have been particularly ineffective in developing varieties with disease resistance.

33. This and the following paragraph are based on UNCTAD,1991.

34. For example, Agrobacteria cause crown gall disease in dicotyledonous plants.

35. Rhem and Reed,1989.

36. McCabe et.al,1988:923-926.

37. McElroy and Brettell,1994:62.

38. AgBiotech News and Information, , Vol.5 No.7, 1993:235N.

39. For example, the negotiations between Monsanto and the Indian government for the transfer of technology for transgenic cotton with *B.t* toxin gene broke down as India considered the price to be too high. In another instance,

Monsanto is believed to have asked the Bulgarian government $4 million for its fungicidal resistance gene.

40. Interview with Dr. Madan Mohan, ICGEB.

41. Interviw with Dr. Raj Bhatnagar, ICGEB.

42. The first successful transgenic plants with resistance to herbicide glyphosphate were developed in 1985. For details, see: Comai et al. 1985:741-744. For reports of herbicide resistant tomatoes, see: Fillatti et al., 1987:726-730, for Brassica, see: Thompson et al, 1987, 19-23 and for sorghum, see: Ag Biotech News and Information, vol 6, No.2, 1994:20N. Also, Calgene is planning to launch a herbicide resistant cotton by 1996. For details, see: Ag Biotech News and Information, vol.6, No.3, 1994:43.

43. The reporter, marker and herbicide genes made available by the Rockefeller Foundation are non-proprietary genes. As these were developed under the Rockefeller Rice Biotechnology Programme, they can not be patented and are available freely to all researchers involved in this programme.

44. Only a handful of groups including International Rice Research Institute (IRRI) and Purude University in the USA and Bose Institute in India have claimed success in re-generation of Indica rice.

45. The organisations which have developed hybrids include two universities (one hybrid each), one government research institute (one hybrid) and one private seed company (two hybrids).

46. Attempts were made in 1985 to use traditional breeding techniques made to cross Basmati with some disease resistant varieties. These efforts failed as the derived variety lost its aroma, which is essential for basmati rice.

47. Interview with Dr. Kirti, IARI.

48. The IARI researchers have already produced the world's first genetically engineered mustard variety with 17 per cent increase in yield. See: UNI Agriculture Service, 1994.

49. Ag Biotech News and Information, vol. 6,No. 3, 1994:42N.

50. Interview with IARI researchers.

51. Paul,1993:137-138.

52. The following research institutes are involved in the proposed project: Directorate of Wheat Research (nodal agency), Punjab Agricultural University and National Chemical laboratories.

53. For details of Monsanto technology for transgenic cotton with *B.t* toxin gene, see Farley,1991:65-70.

54. Government of India, 1992 b.

55. Interview with Dr. K.S.Chark, DBT.

56. Chandra et al.,1992:281-282.

57. India also has a World Bank funded IPM project. The main objective of the programme, which is being run by the National Centre For Integrated Pest Management, is to prepare data base and model for studying the extent of pest occurrence in major crops.

58. Government of India,undated.

59. Falcon,1985.

60. Falcon,1985.

61. Gotsch and Rieder,1990.

62. Manjunath,1992.

63. Subramanian,1937 and Manjunath,1992.

64. Misra and Pawar,1991.

65. Balasubramanian, Bishnoi and Pawar,1991.

66. Lewis and Papavizas,1991.

67. Lewis and Papavizas,1991.

68. Powell and Faul,1989.

69. Jayraj,1993.

70. *AgBiotech News and Information*, vol. 13, no. 4,, 1992:51N.

71. *AgBiotech News and Information*, vol. 14, no. 1,, 1993:3N.

72. *AgBiotech News and Information*, vol. 11, No. 2,1990:99.

73. Jayaraj,1993.

74. Information provided by TNAU.

75. Information provided by TNAU.

76. Interview with Dr. Ramakrishnan, IARI.

77. Sathyanarayan and Sharma,1993.

78. Sathyanarayan and Sharma,1993.

79. *AgBiotech News and Information*, vol. 11, no. 3,1990:201.

80. *AgBiotech News and Information*, vol. 12, no. 4,1991:348.

81. *AgBiotech News and Information*, vol. 13, no. 3,1992:35N.

82. *AgBiotech News and Information*, vol. 12, no. 2,1991:113.

83. Sathyanarayana U.G. and R.P. Sharma,1993.

84. Biotechnology News, Vol 14, NO.9,1994:9.

85. Interview with Dr. Khanuja, IARI.

86. Silk worms belong to Lepidoptara class of insects and are vulnerable to *B.t* toxin.

87. *AgBiotech News and Information*, vol. 13, no. 2,1992:21N.

88. *AgBiotech News and Information*, vol. 13, no. 2,1992:21N.

89. *AgBiotech News and Information*, vol. 5, n. 5,1993:205N.

90. A considerable amount of nutrients is lost in India due to aridity and deep percolation. Consequently, Indian lands are particularly poor in nitrogen and phosphorous. See: Singh and Bisoyi,1992.

91. Das,1991.

92. Kulkarni and Joshi,1988.

93. Discussion with Dr Besoy.

94. Singh and Bisoyi,1992.

95. Hegde and Divedi,1994.

96. Fixation of nitrogen by blue-green algae was first discovered in India in 1939. Verma and Bhattacharyya,1992. Also see: Singh,1961.

97. Venkataraman and Shanmugasundaram,1992.

98. Hegde and Dwivedi,1994.

99. Wani and Lee,1992.

100. Gaur,1990.

101. Tilak and Singh,1994,pp.15.

102. The cost of capital equipment for a factory to produce 75 tons of biofertilisers annually is about Rs. 1.3 million ($0.06 million). The Ministry of Agriculture gives a grant of this amount to encourage these units. A total of Rs. 240.40 million ($7.68 million) has been provided by the government in the form of subsidies and grants for the promotion of biofertiliser production. see: Motsara,1993.

103. Motsara,1993.

104. Adkar and Dwivedi,1994.

105. Kute and B.J. Patel,1994:23-24.

106. Verma and Bhattacharyya, 1992:137.

107. Patronobis,1994.

108. Thompson,1982:49-64.

109. Only some research institutes and universities, such as the Tamil Nadu Agricultural University, are using peat for experimentation purposes.

110. Government of India,1994a.

111. Wani and Lee, 1992.

112. Subba Rao,1986:23-30.

113. Hegde and Dwivedi,1994.

114. Wani and Lee,1992.

115. Hegde and Dwivedi,1994.

116. Hegde and Dwivedi, 1994.

117. GSFC carry out R&D on carrier efficiency and increase in shelf life. They are experimenting with acrylic polymers in place of lignite, which is used at present. See: Kute and Patel,1993.

118. Government of India,1994a.

119. Government of India,1993.

120. Tilak and Singh,1994.

121. Interview Dr. Khanuja, IARI.

122. Government of India,1992a.

123. Interview with Dr. Khanuja, IARI.

124. For debate on the impact of IPR on agriculture in general and plant breeding in particular, see the following: Ganeshan, 1994; Gill, 1993; Menon, 1993; Sahai 1994 .

125. Dhavan and Viswanathan,1994, p.10

126. Sahai, 1993.

127. Many of the leading biotechnology firms and institutes, such as Agracetus, Bactec-Huston Texas, Biosys, Boyce Thompson Institute, Calgene, Lubrizol Genetics Inc., Molecular genetics Inc., Monsanto and Sandoz, have patents which cover current and potential areas of research in India. These include patents for the transformation of cotton, brassica, maize and rice. Similarly, a number of more effective strains of baculoviruses and bacterial pesticides, and methods of their production are already covered by patents.

128. In fact, even though the present Indian patent laws do not cover living organisms, Agracetus has already been granted a very broad patent which covers genetic transformation of cotton. The patent gives Agracetus monopoly over any method of genetically transforming any variety of cotton in India. Realising the mistake, and its far reaching effects, the Indian Prime Minister has directed the government to revoke the patent. This, however, is proving to be a difficult and time consuming process as it can only be done through a lengthy legal process. Times of India, June 23, 1994.

129. UNCTAD, 1991:17

130. A similar levy is already being imposed on technology import payments to support indigenous R&D in various industries.

131. It must, however, be mentioned that a number of foreign firms are involved with tissue culture activities in India. A number of Indian firms have arrangements with these firms for the supply of protocol and plant material. In most instances, the activities include mass propagation of material for export as plants and flowers. The access to proven technology and the availability of markets (usually through buy-back arrangements with the collaborators) have contributed to the success of these ventures.

132. These visits are financed in a number of ways. By far the most common mode is for the concerned universities in developed countries to provide fellowships to Indian researchers. These are usually funded by government agencies, such as USAID in the USA or research foundations, such as the Rockefeller Foundation. In addition to this, visits to foreign universities and research institutes are supported by various international agencies, such as the various UN agencies and bilateral programmes.

133. Many of the universities in developed countries are encouraging their researchers to take patents. See: Weisbach Jerry A. and Henry T.Burke,1990, pp31-35. Again, some of the research foundations have began to transfer their proprietary technologies to private industry on the bases of exclusive licenses.

For example, Noble Foundation, which is a non-profit organisation, has transferred its patent rights for the strearoyl-ACP hydrolase gene to Calgene. The gene is responsible for controlling the level of saturated fat stearate in vegetable oils and can be used for the production of solid oils. See: *Ag Biotech News And Information, March 1994, 43N.* In another instance, the US Department of Agriculture has given an exclusive licence to Sandoz for the development and commercialisation of a new insect virus which is effective against a wide variety of pest lepidoptera. *See: Biocontrol News And Information, 93, Vol 14, No1, 3N.*

134. Separate figures for expenditure on agricultural biotechnology are available for 1991-92 only. Agricultural biotechnology accounted for one fourth of DBT's total research support during that year. Using this ratio, it is estimated that out of a total support of Rs. 761.35 million during 1992-93 ($24.56 million), the support to agricultural R&D amounted to Rs. 190.25 million ($6.12 million).

135. "Agbiotech Firms Increase R&D Spending 39.6 per cent", *Bio/Technology*, Vol 11, August 1993, p 87.

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