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Market Opportunities and Challenges for Agri-Biotech Products in India

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Abstract

Agricultural biotech is the emerging scientific area which is useful to breed more nutritious, high-yielding and less resource input-demanding crops. Agri biotech is the third largest contributor to Indian biotech industry during 2006-07 with a turnover of US$ 225 million, accounting for almost 11 per cent of the total biotech revenues. The agri-biotech industry has recorded Rs 8.65 billion of revenues in Indian domestic markets but the export revenues are abysmally small with Rs 0.49 billion in 2006-07. Recently, India has the fourth largest area (7.6 million hectares) under genetically modified (GM) crops. Almost entire area is occupied by Bt cotton. The market size of India's Bt cotton seeds is estimated to be over US$ 203 million. Besides, Bt cotton, more than 20 biotech crops are under development by both public and private sectors in the country. In addition to that bio-fertilizers, bio-fuels and bio-pesticides are contributing to the growth of Indian agri-biotech market. The Indian government is supporting the agri-biotech industry through a regulatory framework, policies and fiscal incentives. The presence of skilled human resource pool, favourable intellectual property rights (IPRs) climate, increasing investment from government and private sectors provide impetus to the growth of agri-biotech sector in India. However, since the introduction of Bt Cotton for commercial cultivation, several controversies and agitations have emerged. Risks and benefits associated with biotech crops should be duly disseminated to the farming community. The government should strengthen the regulatory system for GM crops to address the food safety problems, environmental effect and genetic drift should be monitored. Controversies like farmers suicides due to failure of Bt cotton, cattle and goat deaths on grazing Bt cotton fields, should be clarified through scientific research. Public and private sectors should fully utilize the market opportunities provided by the crop biotechnology sector to progress Indian agriculture towards productivity and quality to sustain production for future generations.

1. Introduction

The agricultural sector continues to play an important role in the Indian economy despite decline in its share in the total GDP to 17.8 per cent in 2007-08 (GoI, 2009). Agriculture engages more than 50 per cent of the total work force in India. The farming activity not only sustains their livelihood but also provides them a social milieu for their daily life. The 'green revolution', launched in 1960s, has mainly helped in increasing the yields of rice and wheat. The subsequent introduction of hybrids in the crops like corn, sorghum and other millets has increased their production over time. However, over the past one decade, area under food crops has declined and wheat and rice have attained yield plateau. Monocropping of rice and wheat in fertile areas has resulted in depletion of water table, soil erosion, micronutrients deficiency and increased use of plant protection chemicals to control pests and diseases. The excessive use of agro-chemicals in farming has led to increasing input-costs and significant damage to the environment and human health.

Despite achieving higher foodgrains production over time, India continues to import grain legumes and edible oils to meet its growing domestic demand . It is estimated that around 60 million Indian children (below

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the age of 5 years) suffer from malnutrition (World Bank, 2009). Achieving nutritional security at household level would require diversified agriculture through growing of fruits and vegetables, dairying and poultry production. The tools of plant biotechnology offer a greater scope for overcoming the challenges of malnutrition, productivity stagnation and crop diversification.

Plant biotechnology includes development of transgenic crops, structural and functional genomics and marker-assisted breeding. It is useful in achieving and breeding more nutritious, high-yielding and less resource-input demanding crops in a sustainable manner. Developments in genetic engineering in the early-1970s favour gene exchange and transfer of sequences from bacteria, viruses and eukaryotic systems to plants to develop transgenic crop varieties. The evolved biotech crops have potential to achieve food security, conserve biodiversity, reduce agriculturally-induced environmental problems and mitigate climate change (ISAAA, 2008).

With the above background, the present study has critically analysed the issues related to the development, dissemination and adoption of agricultural biotech crops in India. The paper is organised in nine sections. The second section presents views in favour and against GM crops. An overview of biotech industry has been presented in the third section. Fourth section has discussed structure of agri-biotech industry in India and the fifth section presents the spread of biotech crops. The status of agricultural biotechnology research is given in the sixth section. The seventh section has discussed trade in biotech products. Challenges and issues in promoting biotech crops have been presented in the eighth section and conclusion and policy implications have been made in the final section.

Since there are divergent views on the promotion of genetically modified (GM) crops in India, available past research studies have been grouped into two categories, viz. in favour of GM crops and against GM crops.

2(a). In Favour of GM Crops

Viswadia *et al*. (2006) have conducted a comparative study on the production and marketing of Bt cotton and hybrid cotton in Gujarat and have found that Bt cotton enjoys superior technology to hybrid cotton.The yield of Bt cotton was 29 per cent higher than of hybrid cotton. The average total cost of production and the bulk line cost were found to be lower for Bt cotton. ISAAA (2008) has reported that in India about 5 million small farmers in 2008 (up from 3.8 million farmers in 2007) have benefited from planting over 7.6 million hectares of Bt cotton by achieving yields higher by 31 per cent. Higher yields combined with reduced use of insecticide by 39 per cent had increased the profitability by 88 per cent, which was equivalent to US$ 250 per hectare. Meanwhile, Kurmanath (2009) has also found that the cotton farmers who adopted Bt cotton were able to cut cost of production, increase yields and raise net income. In fact, study has found that after the adoption of Bt cotton, the per quintal cost of production was reduced by by 31 per cent, yield was increased by 42 per cent and net income was improved by 83 per cent. Overall, farmers adopting the new Bt cotton technology obtained average farm business income of Rs 9,596 per acre.

2(b). Against GM Crops

Sahai and Farah (2007) have criticized that GEAC (Genetic Engineering Approval Committee) has approved the cultivation of Bt cotton without any proper field trails, and bio-safety and environmental assessment tests. The issues like gene drift and gene contamination, illegal trading of Bt cotton varieties and lack of transparency of GEAC in approving Bt cotton varieties for commercial cultivation are likely to impact the farmers adversely. Business line (2003) has illustrated that those farmers who cultivated Bt cotton varieties in Andhra Pradesh (north and south Telengana region) obtained five-to-seven times lesser income than local non-Bt varieties. It has also reported that there was a problem of cross pollination with nearby plants, increase in incidence of fungus, and secondary pests emergence. Jeremy (2003) has reported that biotech companies stand to make huge profits by introducing GM crops as farmers will depend on them for purchasing seeds every season and this will increasingly marginalise the world’s poorest farmers. Saraswati (2009) has reported that farm animals that were fed on GM cotton in Andhra Pradesh, have died and farmers had to forcefully purchase Bt Cotton, as the normal hybrids were not allowed to be sold in the markets.

3. Indian Biotech Industry — An Overview

In India, biotech industry mainly comprises five distinct segments, viz. biopharma, agribiotech, bioinformatics, bioindustrial and bioservices. As on 2006, there were about 325 biotech companies that contributed to the growth of the sector (Table 1). Among segments, ‘biopharma’ is the largest segment comprising about 130 companies involved in manufacturing of vaccines, therapeutics, diagnostics and animal health care. Bioservices is the second largest segment, which caters to clinical research, contract research, contract manufacturing and agri-biotech research involved in products like Bt cotton, biopesticides and bio-fertilizers. While bioinformatics deals with tools for genomics, proteomic databases, sequence analysis and database searches, the bioindustrial segment caters to the enzymes markets.

The size of Indian biotech market has doubled in recent years, reaching a value of US$ 2.08 billion in 2006-07, up from US$ 1.58 billion in 2005-06 (Table 1). During 2005-06, the industry grew by a remarkable 31 per cent, fuelled by the rise in domestic business, exports, mergers and acquisitions and new product innovations. Further, according to Kumar (2007) biotech industry has sustained growth of about 30 per cent during the past five years, indicating a rapidly maturing market. With splendid performance, the Indian biotech industry currently accounts for about 1.1 per cent of the global biotech market (IBEF, 2008). The total investment in the industry has also increased over time with US$ 360 million in 2006, of which agribiotech alone accounted for one-third of the total investments.

4. Structure of Agri-Biotech Industry in India

Agri-biotech includes the application of biotechnology to improve plant and animal production and to create new, high-value products. High population growth and increasing demand for food drives the need for disease-resistant, high-yielding crop varieties that biotech can offer. Biotech crops also help reduce the use of pesticides that pose hazards to the environment. India has made its entry into agri-biotech in March 2002 with the regulatory approval of Bt cotton by the Genetic Engineering Approval Committee (GEAC) of the Government of India for commercial cultivation. Since then several public and private sector organisations have forayed into research and development of biotech crops in India.

India’s agri-biotech industry comprises three broad categories of companies. The first category consists of larger integrated seed companies which develop their own transgenic crops. These companies included Monsanto India Ltd, Mahyco Monsanto Biotech (India), Syngenta India, Rasi Seeds, Ankur Seeds, Nuziveedu Seeds, Prabhat Agri, JK Seeds, Nath Seeds and Indo-American seeds. The second category comprises smaller companies which employ techniques such as tissue culture for their breeding programmes. These included Avani Seeds, Nav Gujarat Seeds and Nimbkar Seeds Pvt. Ltd. The third category covers highly specialized technology companies that provide services for specified research such as Contract Research Organisations (CROs) for American and European laboratories and industries.

The size of agricultural biotech segment has grown over time. Within the top 20 biotech companies, five agricultural biotech companies featured in the list in 2006-07 (Table 3). These companies included Rasi Seeds, Nuziveedu Seeds, Mahyco Monsanto Biotech, Mahyco and Ankur seeds. Among these, Rasi Seeds,

Table 1. Segments and size of biotech industry in India

Sl. No.	Segment	No. of companies	Size (in million US$) 2006-07	2005-06	Change, %
1	Biopharma	130 (40)	1453	1145	26.87
2	Bioservices	68 (21)	268	175	53.06
3	Agri-biotech	62 (19)	225	145	54.85
4	Bioinformatics	45 (14)	35	29	20.83
5	Bio-industrial	20 (6)	96	91	5.33
	Total	325 (100)	2078	1587	30.98

Note: Figures within the parentheses are percentages to total.
Source: Biospectrum (2007)

Table 3. Top 20 biotech companies in India

Sl. No.	Company	Biotech turnover* (million US $)		Change, %
		2006-07	2005-06	
1	Serum Institute of India Ltd.	231.40	171.07	35.27
2	Biocon	200.20	167.36	19.62
3	Panacea Biotec	145.90	106.47	37.04
4	Rasi Seeds	81.10	75.30	7.70
5	Nuziveedu Seeds	55.10	15.21	262.16
6	Novo Nordisk	54.00	42.57	26.86
7	Venkateshwara Hatcheries	46.40	-	-
8	Indian Immunologicals	38.40	24.85	54.50
9	Mahyco Monsanto Biotech	36.60	95.26	61.58
10	GlaxoSmithKline	29.20	22.87	27.66
11	Aventis Pharma	29.10	27.85	4.50
12	Shantha Biotechnics	28.00	20.01	39.90
13	Eli Lilly and company	27.30	20.72	31.76
14	Mahyco	26.90	28.62	6.00
15	Bharat serums	26.40	18.99	39.00
16	Novozymes South Asia	24.30	20.17	20.48
17	Intervet India	19.60	15.94	22.99
18	Bharat Biotech International	17.00	11.68	45.53
19	Ankur Seeds	16.90	-	-
20	Advanced Enzymes technology	16.90	13.66	23.75

Note: *The turnover figures are only for biotech products sales
Source: Biospectrum (2007)

Nuziveedu Seeds, and Mahyco generated over 72 per cent of the total revenue in 2006-07. Rasi seeds registered a record biotech sales of US$ 81.10 million in 2006-07. Nuziveedu Seeds, which entered the Bt cotton market in 2004-05, increased its turnover from US$ 15.21 million in 2005-06 to US$ 55.1 million in 2006-07. In fact, the rapid growth in turnover of agri biotech companies is driven by excellent performance of leading Bt cotton companies. The sale of Bt cotton seeds accounted for about 77 per cent of total sales of agri-biotech companies, followed by bio-pesticides and bio-fertilizers during 2005 (Kumar, 2007).

5. Spread of Biotech Crops

Area under biotech crops has increased from 114.3 million hectares (Mha) in 2007 to 125 Mha in 2008 in the world (Table 4). The major countries growing genetically modified (GM) crops are: USA (62.5 Mha), Argentina (21.0 Mha), Brazil (15.8 Mha), Canada (7.6 Mha), India (7.6 Mha) and China (3.8 Mha). India ranks fourth in terms of area under GM crops. Compared to other countries, Bt cotton occupies almost entire area in India; equivalent to about 82 per cent of the total area under cotton cultivation.

In India, market size of Bt cotton seeds was estimated to be of over US$ 203 million. In 2006, about 62 Bt cotton hybrids were approved for planting and by May 2007, a total of 111 Bt cotton hybrids were approved for commercial cultivation. Maharashtra, Andhra Pradesh, Gujarat, Madhya Pradesh, Karnataka and Tamil Nadu are the major states cultivating Bt cotton. The increased production of cotton as a result of introduction of Bt varieties, has changed the India’s position from net importer of cotton to net exporter in 2006. Cotton export increased from 0.9 million bales in 2005 to 4.7 million bales in 2006 (Kumar, 2007).

6. Status of Agricultural Biotechnology Research in India

To give fillip to biotechnology research, Government of India had set up the National

Table 4. Area under biotech crops by country: 2008

Rank	Country	Area (Mha)	Biotech crops
1	USA	62.5	Soybean maize, cotton, canola, squash, papaya, alfalfa, sugarbeet
2	Argentina	21.0	Soybean maize, cotton
3	Brazil	15.8	Soybean maize, cotton
4	India	7.6	Cotton
5	Canada	7.6	Canola, maize, soybean, sugarbeet
6	China	3.8	Cotton, tomato, poplar, petunia, papaya, sweet pepper
7	Paraguay	2.7	Soybean
8	South Africa	1.8	Maize, soybean, cotton
9	Uruguay	0.7	Soybean, maize
10	Bolivia	0.6	Soybean
11	Philippines	0.4	Maize
12	Australia	0.2	Cotton, canola, carnation
13	Mexico	0.1	Cotton, soybean
14	Spain	0.1	Maize
15	Chile	< 0.1	Maize, soybean, canola
16	Colombia	< 0.1	Cotton, carnation
17	Honduras	< 0.1	Maize
18	Burkina Faso	< 0.1	Cotton
19	Czech Republic	< 0.1	Maize
20	Romania	< 0.1	Maize
21	Portugal	< 0.1	Maize
22	Germany	< 0.1	Maize
23	Poland	< 0.1	Maize
24	Slovakia	< 0.1	Maize
25	Egypt	< 0.1	Maize

Source: Clive (2008)

Bio-technology Board in 1982, which during 1986 became a full-fledged department called Department of Biotechnology (DBT) under the Ministry of Science and Technology. For plant biotechnology research, DBT supported the establishment of Centres for Plant Molecular Biology (CPMB) in 1990. There are seven such centres set up at various universities/institutions across India. Most of the research on crop biotechnology presently underway in India is being supported by DBT, which has supported a large number of research projects in GM crops over the past two decades. However, to further strengthen research in the area of crop biotechnology, National Centre for Plant Genome Research (NCPGR) was established in 1998 at New Delhi. Within the segments of biotechnology, the DBT has increased its plan expenditure on crop biotechnology four-times, from Rs 19.16 crore in 8th plan (1992-97) to Rs 75 crore in 10th Plan (2002-2007). This increase shows that DBT is giving relatively high importance to crops research (Manju *et al.*, 2003).

6.1. Public Sector Research in Biotech Crops

To bring investigators with expertise in different facets of crop biotechnology together to address defined research goals, a large number of collaborative multi-institutional projects have been conducted in public and private sector institutes. Most of the R&D work in India has been, and is still conducted in the central government-funded public sector research institutes, universities and research centres. Agricultural universities receiving substantial financial and infrastructure support from respective state governments and Indian Council of Agricultural Research (ICAR) are also involved in conducting research in biotech crops. Public sector institutes are conducting research on more than 20 crops and four kinds of traits are being tackled, viz. resistance to attacks by insect pests, viral and fungal diseases (called 'biotic' stresses); tolerance of the 'abiotic' stresses of drought, waterlogging and salinity; delayed ripening, increase in shelf-life and improved storage properties, and increase in content of protein and micronutrients such as vitamins and minerals. Major transgenic crops that have been or are being developed in the public sector research domain have been given in Appendix Table 1.

6.2. Private Sector Research in Biotech Crops

The private sector began their efforts at introducing GM crops into India in 1995. Maharashtra Hybrid Seed Company (MAHYCO) was the first to obtain the approval of DBT to import Bt cotton seeds from the USA-based multinational corporation Monsanto for backcrossing into selected Indian cultivars and breeding hybrids resistant to biotic stresses. At present, more than 10 private companies are actively involved on GM crops research in India (Appendix Table 2). MAHYCO is leading in terms of development of number of transgenic lines, followed by Proagro PGS (India) Ltd.

Table 5. Indian biotech exports vs total domestic revenues: 2007-08

Sl. No.	Segments	Total export value (in billion Rs)	%	Total domestic value (in billion Rs)	%
1	Bio-pharma	37.05	75.00	23.07	64.00
2	Bio-services	10.37	21.00	0.36	1.00
3	Bio-agri	0.49	1.00	8.65	24.00
4	Bio-industrial	0.49	1.00	3.60	10.00
5	Bio-informatics	0.99	2.00	0.36	1.00
	Total	49.40	100.00	36.04	100.00

Source: Bio-spectrum (2007)

6.3. Other Areas of Agri-biotech Research

Besides application of biotechnology to development of promising crop varieties, there is a growing interest among public and private organisations to develop products like bio-diesel, bio-fertilizers and bio-pesticides.

Bio-diesel

India's bio-fuels market is still at its infancy with only about 66 million gallons of ethanol being utilized annually (IBEF, 2008). Though, the level of current production of bio-diesel is not commercially significant, the government has been actively promoting the use of ethanol. In November 2006, the Government of India declared it mandatory to blend five per cent of ethanol with petrol. Further, attempts have also been made to develop high-yielding varieties of jatropha seeds, promote jatropha nurseries, set up pilot plants for bio-diesel manufacturing, and test bio-diesel in public transport locomotives and buses. There are a number of Indian corporations that are venturing into bio-diesel production jointly with state governments to establish plantations on wastelands or develop contract farming with farmers. Meanwhile, companies like Southern Online Biotechnologies and Natural Bioenergy Ltd. have set up commercial production units for bio-diesel in collaboration with companies in USA and Europe, respectively.

Bio-pesticides and Bio-fertilizers

Biopesticides and biofertilizers are estimated to have a market value of almost US$ 19.5 million (IBEF, 2008). Leading players in this segment include Biotech International, Excel, and Multiplex. Phosphate-solubilising micro-organisms witnessed the highest growth among bio-fertilizers in India. Bio-fertilizer production is predominantly concentrated in the states of Maharashtra, Tamil Nadu, Madhya Pradesh, and Gujarat . Many universities and institutes like University of Hyderabad, National Research Centre for Plant Biotechnology, Indian Agricultural Research Institute, Tamil Nadu Agricultural University, Bhabha Atomic Research Centre and The Energy Research Institute have been pursuing research studies in bio-fertilizers.

7. Trade in Biotech Products

It can be observed from Table 5 that agri-biotech industry has recorded Rs 8.65 billion of revenues in the domestic markets, which is about 24 per cent of the revenues in the domestic market for the total biotech industry. However, the export revenues are abysmally low (Rs 0.49 billion) as compared to revenues (Rs 49.40 billion) generated by the total biotech industry in the export markets. However, exports from bio-pharma segment was the highest followed by bio-services .

8. Challenges and Issues in Promoting Biotech Crops

The presence of skilled human resource pool at lower costs offers huge scope for the growth of biotech industry in India. The government policy initiatives to develop infrastructural facilities like biotech parks, favourable intellectual property rights (IPRs) regime and encouraging patent culture (Damodaran, 2004) are attracting investments form private sector to develop crop biotechnology research in India.

The introduction of Bt cotton for commercial cultivation has generated several controversies and agitations. Risks and benefits of cultivating GM crops are not being disseminated adequately across the farming community. A wider public debate should be held to address various issues like ethics and safety to allay the common fears. In fact, crop biotechnology can be effectively employed to utilize waste or marginal lands to augment food production to meet the growing needs of population and at the same time preserving the natural resources by minimizing the use of agro-chemicals. However, experiments and testing procedures for GM crops should take into account the social and economic fabrics of rural economy. Agricultural biotechnology should provide a path way out of poverty.

9. Conclusions and Policy Implications

The agri-biotech industry is promoted by the Indian government through a regulatory framework and policies after India made its entry into agri-biotech in early-2002. The support from the Government of India and the Department of Biotechnology for funding research in crop biotechnology has increased and at the same time, private sector investment in agri-biotech industry has also increased over time. Though, biotechnology provides solutions to most problems related to sustainable production, the regulatory system should be followed strictly to address the food-safety issues. The performance of biotech crops in the field, environmental issues and genetic drift should be monitored and evaluated carefully. Controversies like farmers suicides due to the failure of Bt cotton, cattle and goat death on grazing Bt cotton fields, should be clarified through scientific research. The public and private sector should fully utilize the market opportunities provided by crop biotechnology sector to progress Indian agriculture towards achieving higher productivity and quality which is sustainable in future generations.

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Appendix Table 1. Major Indian Developments in Transgenic Research and Application in Public Sector

Institute	Plants/crops	Transgene(s) inserted	Aim of the project
AAU, Jorhat	Chickpea bean	Assam *alpha AI*	To generate plants resistant to bruchids
Bose Institute, Kolkata	Rice	*S-adenosylmethionine Decarboxylase*	To generate plants tolerant to stress
Central Institute for Cotton Research, Nagpur	Cotton	*Bt. cry* gene(s)	To generate plants resistant to lepidopteranpests
Central Potato Research Institute, Simla	Potato	*Bt. cry1A(b)*	To generate plants resistant to lepidopteranpests
Central Tobacco Research Institute, Rajahmundry	Tobacco	*Bt. cry1A(b)* and *cry1C*	To generate plants resistant to *Helicoverpaarmigera* and *Spodoteralitura*
Centre for Cellular and Molecular Biology,Hyderabad	Rice	*Bar*	To generate herbicide-tolerant plants
Central Rice Research Institute, Cuttack	Rice	*Bt cry1A(b)Xa21*	To develop plants resistant to lepidopteranpests, bacterial blight/ disease
Delhi University, South Campus, New Delhi	Mustard/ rapeseed	*bar*, *barnase*, *barstar*	To generate herbicide-tolerant plants,male-sterile and restorer lines for hybridseed production
	Rice	*Pyruvate decarboxylase* and*alcohol dehydrogenase*	To generate plants tolerant to flooding
	Tomato	*Ctx-B* and *Tcp* antigens of *Vibriocholerae*	Edible vaccine development
	Brinjal	Chitinase, glucanase and thaumatinencoding genes	To generate plants resistant to diseases
	Wheat	*bar*, *HVA1*, *PIN2*	Resistance against biotic and abioticstresses
	Rice Pusa basmati	*codA*, *cor47*	Resistance against biotic and abioticstresses
Directorate of Rice Research, Hyderabad	Rice	*Xa-21*, *cry1A(b)*	To generate plants resistant to lepidopteranpests and bacterial and fungaldiseases
Indian Agricultural Research Institute, New Delhi	Brinjal	*Bt. cry1A(b)*	To generate plants resistant to lepidopteran Pests
	Brinjal	Bt .cry1Aa and cry1Aabc	To control fruit and shoot borer
	Tomato	*Bt. cry1A(b)*	To generate plants resistant to lepidopteranpests
	Tomato	ACC synthase	To control fruit ripening
	Cauliflower	*Bt. cry1A(b)*	To generate plants resistant to *Plutella scylostella*
	Cabbage	*Bt. cry1A(b)*	To generate plants resistant to *P.scylostella*
	Rice	*Bt cry1A(b), chitinase*	To generate plants resistant to lepidopteranpests
	Mustard/ rapeseed	*Arabidopsis annexin* gene	To generate stress-tolerant plants

Contd.

Appendix Table 1. Major Indian Developments in Transgenic Research and Application in Public Sector — *Contd*

Institute	Plants/crops	Transgene(s) inserted	Aim of the project
	Mustard/ rapeseed	*Choline dehydrogenase*	To generate abiotic stress-tolerantplants
	Potato	ACC synthase	To control fruit ripening
	Banana	ACC synthase	To control fruit ripening
	Tobacco	Chitinase, glucanase and *RIP*	To generate plants resistant to fungalattack
	Brassica	Chitinase, glucanase and *RIP*	To generate plants resistant to fungalattack
	Pigeonpea	*Protease inhibitor* and *lectin* genes	To generate plants resistant to bollwormsand aphids
IARI sub-station, Shillong	Rice	*Bt. cry1A(b)*	To generate plants resistant to yellowstem borer
International Centre for Genetic Engineering andBiotechnology, New Delhi	Tobacco	*Bt. cryIIa5*	To generate plants resistant to *Spodoptera Litura*
	Rice	*Gm2*	To generate plants resistant to gallmidge
International Crop Research Institute for Semi-Arid Tropics, Hyderabad	Chickpea	*PGIP*	To generate plants resistant to fungalpathogens
	Groundnut	Chitinase gene from rice (Rchit)	
Indian Institute of Horticultural Research, Bangalore	Muskmelon	*Rabies glycoprotein* gene	To develop edible vaccines
	Tomato	*Leaf curl virus* sequence	To generate plants resistant to leafcurl virus
	Tomato	Chitinase and glucanase	To generate plants resistant to fungaldiseases
	Tomato	Coat protein gene of citrustriesteza virus	To generate transgenic citrus plantsresistant to citrus triesteza
Jawaharlal Nehru University,	Potato	*Ama-1**	To generate nutritionally enrichedplants
New Delhi	Tomato	*OXDC* *	To generate plants resistant to fungalinfection
Madurai Kamaraj University, Madurai	Blackgram	Coat protein and replicase genes of *Vigna mungo* yellow mosaicvirus	To develop viral-resistant plants
	Blackgram	*Dianthin* and *barnase* gene or*bar*	Development of insect resistant andherbicide-tolerant plants
	Rice	Chitinase, *b*-1, 3-*glucanase* and *osmotin* genes	To develop plants resistant to fungalinfection
	Coffee	Chitinase, *b*-1, 3-*glucanase* and *osmotin* genes	To develop plants resistant to fungalinfection
Narendra Dev University of Agriculture, Faizabad	Rice	*Cry1A(b) gene*	To generate plants resistant to lepidopteranpests, bacterial and fungaldiseases

Contd

Appendix Table 1. Major Indian Developments in Transgenic Research and Application in Public Sector —*Contd*

Institute	Plants/crops	Transgene(s) inserted	Aim of the project
National Botanical Research Institute, Lucknow	Cotton	*Cry1E* and *Cry1C* with terminalaltered at C-end	To develop transgenic resistant to *Spodopotera litura* and *Heliothisisarmigera*
Punjab Agricultural University, Ludhiana	Rice Pusa basmati	*Cry1Ab*, *Cry1Ac*	For resistance against yellow stemborer
Tata Energy Research Institute, New Delhi	Mustard	*Ssu-maize Psy* and *Ssu-tp CrtI*gene	To generate plants containing highlevels of *b*-carotene
Tamil Nadu Agricultural University, Coimbatore	Rice	*GNA* gene	To generate plants resistant to pestsgall midge
University of Agricultural Sciences, Bangalore	Muskmelon	*Rabies glycoprotein* gene	To develop edible vaccines
Directorate of Oilseeds Research	Castor	cry1Aa and cry1Ec	To control insects

Note: *Genes isolated in India. In most of the viral work, sequences for pest-derived resistance (PDR) have been isolated from the viral strains predominant in India.

Source: Department of Biotechnology (DBT), Government of India (2007)

Appendix Table 2. Transgenic Lines in Advanced Stage of Development for Field Trials in Private Sector

Institute	Plants/crops	Transgene(s) inserted	Aim of the project
Ankur Seeds Ltd, Nagpur	Cotton*	*Cry1A(c)*	To generate plants resistant to lepidopteran pests
Hybrid Rice	International, Gurgaon Rice	*Cry1A(b), cry9C* and *bar* genes	To develop plants resistant to lepidopteran pests and herbicide tolerance
Indo-American Hybrid Seeds, Bangalore	Tomato	*Alfalfa glucanase* and *Tomato leaf curlvirus* genes	To generate plants resistant to viral and fungal attacks
MAHYCO, Mumbai	Cotton*	*Cry1A(c)*	To generate plants resistant to lepidopteran pests
	Cotton*	*CP4 EPSPS*	To generate plants for resistance to herbicide glyphosate
	Cotton*	*CryX* gene	To generate plants resistant to lepidopteran pests
	Corn*	*Cry1A(b)*	To generate plants resistant to lepidopteran pests
	Pigeonpea	*GUS*	For transformation work
	Rice	*Cry1A*(c), *Xa21* and *GNA* genes	To generate plants resistant to lepidopteran pests, bacterial blight and sucking pests
	Mustard	*CP4 EPSPS*	To generate plants tolerant to herbicide
	Okra	*Cry1Ac*, *Cry2Ab*	To generate plants resistant to lepidopteran pests
MAHYCO Research Foundation, Hyderabad	Rice	*Bacterial blight resistance* conferring *Xa-21*gene	To generate plants resistant to bacterial blight
Proagro PGS (India) Ltd, Gurgaon	*Brassica*/ mustard	*Bar, barnase,barstar*	To develop superior hybrid cultivars
	Tomato*	*Cry1A(b)*	To generate plants resistant to lepidopteran pests
	Brinjal*	*Cry1A(b)*	To generate plants resistant to lepidopteran pests
	Cauliflower*	*Cry1H/cry 9C*	To generate plants resistant to lepidopteran pests
	Cauliflower*	*Bar, barnase, barstar*	To develop superior hybrid cultivars
	Cabbage*	*Cry1H/cry9C*	To generate plants resistant to lepidopteran pests
Syngenta India Ltd, Pune	Cotton*	*Vip-3* gene	To generate plants resistant to lepidopteran pests
	Maize*	*Cry1A(b)*	To generate plants resistant to lepidopteran pests
Sungro Seeds Ltd, Mumbai	Brinjal	*Cry1Ac*	To control fruit and shoot borer
	Cauliflower	*Cry1Ac*, *Cry1Ba* and *Cry1Ca*	To control insects
Mahyco, Mumbai	Brinjal	*Cry1Ac*	To control fruit and shoot borer
Nunhems India Pvt. Ltd.	Cauliflower	*Cry1Ac*, *Cry1Ba* and *Cry1Ca*	To control insects

Note: *Transgenics developed elsewhere are being backcrossed to inbred lines to develop commercially viable hybrids that can be grown in different agroclimatic regions of the country.
Source: Department of Biotechnology (2007), Government of India, New Delhi