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BRIEF 38

The Development and Regulation of Bt Brinjal in India
(Eggplant/Aubergine)

by

Bhagirath Choudhary
Kadambini Gaur

No. 38-2009

Scientific Review:

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Cover Picture:
Bt brinjal hybrids MHB-9 Bt, MHB-11Bt, MHB-80Bt and MHBJ-99Bt in large-scale field trials at the Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu.

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Foreword

In the early 1990s, many critics of crop biotechnology were skeptical that genetically modified (GM) or transgenic crops, now more often referred to as biotech crops, could ever deliver improved products and make an impact at the farm level. Many critics referred to crop biotechnology as the science of promises, and more promises, but never to have the capability to deliver a product. The critics were even more skeptical that small resource-poor farmers in the developing countries of Asia, Latin America and Africa would ever be able, or want, to accept and adopt biotech crops - that was the speculation of the critics; however, the actual facts reveal that nothing could be further from the truth. In 2007, the twelfth year of commercialization of biotech crops, of the 23 countries growing 114 million hectares of biotech crops (equivalent to more than two-thirds of the total arable land of India) strikingly, 12 were developing countries, compared with only 11 industrial countries; and the trend in favor of developing countries is expected to continue in the second decade, as more and more developing countries from all three continents in the South embrace biotech crops. Importantly, of the 12 million farmers who benefited from biotech crops in 2007, remarkably 11 million of them, equivalent to 90%, were small resource-poor farmers in developing countries, 7.1 million in China, 3.8 million in India, over 100,000 in the Philippines and the balance in the other 7 developing countries.

It is evident, that the first decade of commercialization of biotech crops, 1996-2005, was clearly the decade of the Americas where over 90% of the global biotech hectarage was grown. However, ISAAA has projected that the second decade of commercialization of biotech crops, 2006 to 2015, will witness much stronger growth in Asia, with the two most populous countries in the world, China (1.3 billion) and India (1.1 billion), both exerting global leadership and utilizing biotech crops to ensure not only fibre security, but more critically, food security. Both India and China have already benefited enormously from the deployment of a biotech fibre crop, Bt cotton. India, the country with the largest hectarage of cotton in the world, estimated at 9.6 million hectares in 2007, benefited from an unprecedented 125 fold increase in Bt hybrid cotton hectarage in only six years, 2002 to 2007. A total of 3.8 million farmers in India increased their income from Bt cotton by approximately 1 billion dollars at the national level in 2007. This was an important contribution to the alleviation of their poverty and it is noteworthy that farmers represent the majority of the extremely poor in India. In addition to the substantial economic benefits from Bt cotton, there have been other multiple and substantial benefits including environmental benefits, through decreasing insecticide requirements by half, thereby resulting in significantly less exposure with positive health implications for farmers. Bt cotton has also resulted in a better quality of life for their families, who for the first time can afford better health care and education for their children.

Given the significant and multiple agronomic, economic, environmental and welfare benefits generated by Bt cotton, there is strong and growing political support for Bt cotton in India, and in turn for other biotech crops, particularly food crops. The remarkable success of Bt cotton in India has been recognized by leading politicians and policy makers who have become advocates of biotechnology because of the multiple benefits it offers. The increased political support for crop biotechnology in India parallels increased support by global society for biotech crops due to their capability to directly contribute to more affordable food prices, especially when prices of the basic staples, rice, wheat and corn (maize) have skyrocketed; precipitating food riots in many developing countries. The following recent public statements by leading Indian politicians illustrate the concern about food security, escalating food prices and the role of technology, including biotechnology to remedy the grave situation now exacerbated by a global financial crisis.

Smt. Pratibha Devisingh Patil, the President of India

"The success story of the First Green Revolution has run its course. We cannot afford to rest on our laurels. The fruits of the Green Revolution and the momentum generated by it, needs to be sustained. Efforts towards sustainable agriculture can be greatly augmented with the help of space technology and biotechnology advances".

Dr. Manmohan Singh, the Prime Minister of India

"We need to strike a balance between using the potential of biotechnology to meet the requirements of hungry people while addressing concerns about interfering with nature".

Mr. P. Chidambaram, the Minister of Finance

"Bt cotton has made India a cotton exporting country. We thought of ourselves as exporters of wheat and rice, but today we import wheat. No country as large as India can survive on imports for its food needs,"...."The production figures for rice and wheat are far below the world average and yield gaps vary dramatically across different states,"...."The success achieved in cotton must be used to make the country self sufficient in rice, wheat, pulse and oil seed production".

The statement by the Prime Minister Singh addresses the issue of acceptance of biotech food crops by society and implicitly the need to inform society of the science-based attributes of biotech food crops to facilitate a science-based, meaningful and transparent dialog about acceptance of biotech food crops. This is precisely the objective of this comprehensive ISAAA Brief on the development and regulation of biotech brinjal in India, which is likely to be the first biotech food crop to be approved and adopted in India in the near term. More specifically, this Brief is a comprehensive review of all aspects of the cultivation in India ofthe important vegetable brinjal, also known as eggplant or aubergine. Importantly, the Brief summarizes the development, status and content of the extensive regulatory dossier in India for biotech Bt brinjal, which confers resistance to the most important insect-pest of brinjal, the Fruit and Shoot Borer (FSB).

It is a pleasure to commend the senior author of this ISAAA Brief, Mr. Bhagirath Choudhary and his co-author Ms. Kadambini Gaur, based at the ISAAA office in New Delhi, India for proactively anticipating the knowledge needs of society about the development and status of Bt brinjal in

India, which has undergone a rigorous safety assessment by the regulatory authorities. In the spirit of sharing and caring, the Bt brinjal technology used for hybrids has been generously donated by its developer, M/s Maharashtra Hybrid Seeds Company (Mahyco) to public institutes in India, Bangladesh and the Philippines for use in open-pollinated varieties of brinjal in order to meet the specific needs of small resource-poor farmers in neighboring countries in the region where brinjal is an important crop. This is an excellent working example of a model philanthropic public/private sector partnership that has facilitated the generous donation of a biotechnology application by a private sector company for use by public sector institutes to meet the needs of small resource-poor farmers. The partnership has been managed by Cornell University under the USAID biotechnology project, ABSP II, in which ISAAA helps facilitate the technology transfer and adoption in the Philippines.

Thus, this ISAAA Brief will not only serve the needs of India but also the needs of Bangladesh and the Philippines. There are immense potential benefits to be gained from regional harmonization of regulatory procedures for neighboring developing countries which have common regulatory requirements but where there are insufficient resources within each national program to support costly regulation of biotech products. This is particularly true for smaller and poorer countries that cannot afford costly regulation, and are by default condemned to suffer further by being denied the technology and the benefits that it delivers to their larger neighboring countries in the region. It is my sincere hope that this ISAAA Brief, which is the result of an intensive review by the authors of all aspects related to the development and regulation of Bt brinjal in India, will also serve the common regulatory needs in Bangladesh and the Philippines and generally facilitate regional harmonization of biotech crops in Asia; it can also serve as a model to facilitate regional harmonization in Sub-Sahara Africa where the need for simplified, responsible and appropriate regulations is even greater than in Asia, and for smaller countries in the Andean region of Latin America.

The lack of simplified, responsible and harmonized regulations for biotech crops is undoubtedly the key barrier that denies developing countries timely access to the significant benefits that biotech crops offer - this opportunity cost at the time of a food crisis can have grave food security consequences. This Brief will hopefully contribute one element to an evolving harmonization process that will allow a biotech crop with the same specific transgene, which has been carefully evaluated to meet accepted standard regulatory protocols in one country in the region, not to be again subject to time-consuming and costly duplicative assessments in a neighboring country's approval process, so that benefits to all countries in the region wishing to benefit from biotech crops are not unduly delayed. I am pleased, that consistent with the ISAAA mandate of freely sharing knowledge on biotech crops with developing countries that this Brief is being offered by ISAAA at no cost to all eligible nationals from all developing countries in the three continents of the south.

Clive James
Founder and Chairman of ISAAA

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ABSP II	:	Agricultural Biotechnology Support Project II
ANGRAU	:	Acharya N. G. Ranga Agricultural University
AICVIP	:	All India Coordinated Vegetable Improvement Project
AICPVC	:	All India Coordinated Project on Vegetable Crops
AINPPR	:	All India Network Project on Pesticide Residues
AVRDC	:	Asian Vegetable Research and Development Centre (The World Vegetable Centre)
BARI	:	Bangladesh Agricultural Research Institute
BCIL	:	Biotech Consortium India Ltd.
BBS	:	Bangladesh Bureau of Statistics, Bangladesh
CAB	:	Cotton Advisory Board
CABI	:	CAB International
CBD	:	Convention on Biological Diversity
CCS HAU	:	CCS Haryana Agricultural University
CHES	:	Central Horticultural Experiment Station
CIE	:	Commonwealth Institute of Entomology, UK
CFIA	:	Canadian Food Inspection Agency, Canada
CIBRC	:	Central Insecticides Board and Registration Committee
CSAUAT	:	CS Azad University of Agriculture and Technology
CSL	:	Central Science Laboratory, UK
DBT	:	Department of Biotechnology
DLC	:	District Level Committee
ERMA	:	Environmental Risk Management Authority, New Zealand
FAO	:	Food and Agriculture Organization
GAU	:	Gujarat Agricultural University
GBPUA&T	:	Govind Ballabh Pant University of Agriculture and Technology
GEAC	:	Genetic Engineering Approval Committee
HARP	:	Horticulture and Agro-forestry Research Program
IARI	:	Indian Agricultural Research Institute
IBSC	:	Institutional Biosafety Committee
ICAR	:	Indian Council of Agricultural Research
ICMR	:	Indian Council of Medical Research
IGMORIS	:	Indian GMO Research Information System
IIHR	:	Indian Institute of Horticultural Research
IIVR	:	Indian Institute of Vegetable Research
ISAAA	:	International Service for the Acquisition of Agri-biotech Applications
JAU	:	Junagadh Agricultural University

JNKVV	:	Jawaharlal Nehru Krishi Vishwa Vidyalaya
KAU	:	Kerala Agricultural University
LSTs	:	Large-Scale Field Trials
MEC	:	Monitoring and Evaluation Committee
MLRTs	:	Multi-Location Research Trials
MoEF	:	Ministry of Environment and Forest
MoH&FW	:	Ministry of Health and Family Welfare
MPKV	:	Mahatma Phule Krishi Vidyapeeth
NABL	:	National Accreditation Board for Testing and Calibration Laboratories
NBPGR	:	National Bureau of Plant Genetic Resources
NCIPM	:	National Centre for Integrated Pest Management
NDUAT	:	Narendra Deva University of Agriculture and Technology
NHB	:	National Horticulture Board
NIN	:	National Institute of Nutrition
NRCPB	:	National Research Centre on Plant Biotechnology
OECD	:	Organization for Economic Cooperation and Development
OGTR	:	Office of the Gene Technology Regulator, Australia
OUAT	:	Orissa University of Agriculture and Technology
PAU	:	Punjab Agricultural University
PMFAI	:	Pesticides Manufacturers and Formulators Association of India
PRKVV	:	Punjab Rao Krishi Viswa Vidyalaya
RAU	:	Rajendra Agricultural University
RCGM	:	Review Committee on Genetic Manipulation
RDAC	:	Recombinant DNA Advisory Committee
SAUs	:	State Agricultural Universities
SBCC	:	State Biotechnology Coordination Committee
TNAU	:	Tamil Nadu Agricultural University
WHO	:	World Health Organization
WTO	:	World Trade Organization
UAS	:	University of Agricultural Sciences
USDA	:	United States Department of Agriculture
USAID	:	United States Agency for International Development
VPKAS	:	Vivekananda Parvatiya Krishi Anusandhan Sansthan

This Brief is a comprehensive review of all aspects of the cultivation in India of the important vegetable brinjal, also known as eggplant or aubergine. Importantly, the Brief also summarizes the development and regulatory status in India of biotech Bt brinjal hybrids which confer resistance to the most important insect-pest of brinjal, the fruit and shoot borer, hereafter referred to as FSB. Bt brinjal was approved in India for experimental seed production in 2008-2009 and is under consideration for commercial release in the near term. Bt brinjal hybrid (referred to as Bt brinjal in this Brief) is of particular interest for three reasons. Firstly, it is likely to be the first biotech food crop commercialized in India, following the unparalleled success of the commercialization of the fibre crop, Bt cotton. Secondly, Bt brinjal technology has been generously donated by its private sector developer, Mahyco, to public sector institutes in India, Bangladesh and the Philippines for incorporation in open-pollinated varieties of brinjal for the use of small resource-poor farmers. Thirdly, sharing of knowledge and experience of the regulation process for Bt brinjal in India could greatly simplify and lighten the regulatory burden in Bangladesh and the Philippines by eliminating duplication of the significant effort already expended by India, thereby contributing to the important goal of harmonizing regulations between countries.

Brinjal is a very important common man's vegetable in India. After potato, it ranks as the second highest consumed vegetable in India, along with tomato and onion. A total of 1.4 million small, marginal and resource-poor farmers grow brinjal on 550,000 hectares annually in all the eight vegetable growing zones throughout India. It is an important cash crop for poor farmers, who transplant it from nurseries at different times of the year to produce two or three crops, each of 150 to 180 days' duration. Farmers start harvesting fruits at about 60 days after planting and continue to harvest for 90 to 120 days, thereby providing a steady supply of food for the family; it also provides a stable income from market sales for most of the year. Brinjal was one of the first vegetable crops adopted by farmers as hybrids, which occupied more than 50% of the brinjal planted area of 550,000 hectares in 2007, the balance being planted with open-pollinated varieties. Brinjal is marketed in different sizes, shapes and colors to meet consumer preferences. Of the global production of 32 million tons (1ton=1,000kg) of brinjal produced on 2 million hectares worldwide annually, India produces 8 to 9 million tons, equivalent to one quarter of the global production, which makes India the second largest producer of brinjal in the world, after China. Brinjal is a hardy crop that yields well under stress conditions, including drought. Productivity has increased from 12.6 tons per hectare in 1987-88, to15.3 tons per hectare in 1991-92 to 16.5 tons per hectare in 2005-06. Although the centre of origin for brinjal is not known for certain, cultivated and related wild species of brinjal in India represent a broad range of genetic diversity which has likely migrated from India, and China, to other countries in South-East Asia, Africa, Europe and the Americas.

Brinjal is prone to attack by many insect-pests, and diseases; by far the most important of which is the fruit and shoot borer (FSB), for which resistance has not been identified and thus it causes significant losses of up to 60 to 70% in commercial plantings. Damage starts in the nursery, prior to transplanting, continues to harvest and is then carried-over to the next crop of brinjal. FSB damages brinjal in two ways. First, it infests young shoots which limits the ability of plants to produce healthy fruit bearing shoots, thereby reducing potential yield. Secondly, and more importantly, it bores into fruits making them unmarketable at harvest - it is this decrease in marketable yield, as opposed to total yield, that is the most important yield loss caused by FSB. Due to the fact that FSB larvae remain concealed within shoots and fruits, insecticide applications, although numerous, are ineffective. Farmers usually spray twice a week, applying 15 to 40 insecticide sprays, or more, in one season depending on infestation levels. The decision of farmers to spray is influenced more by subjective assessment of visual presence of FSB rather than guided by the more objective science-based methodology of economic threshold levels. This reliance on subjective assessment of visual presence leads to gross over-spraying with insecticides, higher insecticide residues, and unnecessary increase in the farmers' exposure to insecticides. For example, for the more productive hybrid brinjal plantings, 54 litres of formulated insecticide per hectare is sprayed, compared with a requirement of only 16 litres when economic thresholds are used to trigger spraying. Similarly, for the less productive open-pollinated varieties, 26.7 litres of insecticides per hectare are used, compared with only 4.9 litres per hectare as required by economic thresholds. On average, 4.6 kg of active ingredient of insecticide per hectare per season is applied on brinjal at a cost of Rs 12,000 per hectare; this is the highest quantity applied to any vegetable crop with the exception of chilli, which consumes 5.13 kg of active ingredient per hectare; okra consumes 3.71 kg of active ingredient per hectare. To illustrate the importance of FSB, of the 15 recommended insecticides for brinjal more than half, or eight are prescribed only for FSB. Typically, farmers indiscriminately apply a cocktail of insecticides on brinjal, including insecticides such as monocrotophos that are restricted or banned for use on vegetable crops. In a survey of pesticide residues in vegetable crops taken at the farm gate and markets from 1999 to 2003 confirmed that of the 3,043 samples, two-thirds were found to have pesticide residues, but these were within accepted tolerances, whereas 9% contained residues above the minimum recommended levels. The increasing amount of insecticide residues in vegetables and fruits has been a major concern to consumers who currently have no choice except to buy brinjals with high insecticide residues, but despite the application of many insecticides the brinjal fruits sold in the market are still of inferior quality, infested with larvae of FSB.

Bt brinjal has been under development by Mahyco in India for the last 8 years. It has undergone a rigorous science-based regulatory approval process in India and is currently at an advanced stage of consideration for deregulation by the Indian regulatory authorities which approved the experimental seed production of Bt brinjal hybrids by Mahyco in 2008-2009. Studies on food and feed safety, including toxicity and allergenicity tests, have been conducted on rats, rabbits, fish, chickens, goats and cows; these studies have confirmed that Bt brinjal is as safe as its non-Bt counterpart. Similarly, environmental impact assessments to study germination, pollen flow, invasiveness, aggressiveness and weediness, and effect on non-target organisms were completed, and it was confirmed that Bt brinjal behaves in a similar way to its non-Bt counterparts. Agronomic studies showed a significantly lower number of FSB larvae on Bt brinjal, 0-20 larvae, as compared to 3.5-80 larvae on the non-Bt counterpart. Multi-location research trials confirmed that insecticide requirement for Bt brinjal hybrids was on average 80% less than for the non-Bt counterpart for the control of FSB; this translated into a 42% reduction in total insecticides used for control of all insect-pests in Bt brinjal versus the control. As a result of the effective control of FSB, Bt brinjal's average marketable yield* increased by 100% over its non-Bt counterpart hybrids, 116% over popular conventional hybrids and 166% over popular open- pollinated varieties (OPVs) of brinjal. Thus, to-date the studies submitted to the regulatory authorities confirm that Bt brinjal offers the opportunity to simultaneously provide effective control of the most important pest of brinjal, FSB, decrease insecticides for this important insect-pest by 80%, and more than double the yield over conventional hybrids and open-pollinated varieties, thereby providing significant advantages for farmers and consumers alike. At the national level it can thus contribute to food safety and security and to sustainability.

****Marketable yield*** *refers to the net yield of non-infested undamaged brinjal fruits that a farmer can sell at a premium price. It is the decrease in marketable yield of fruit, as opposed to total yield of fruit that is the most important yield loss caused by fruit and shoot borer (FSB) of brinjal.*

Part-I
Biology, Production and Significance of Brinjal in India

1. Introduction

Improved seeds have been a key contributing factor to quantum increases in crop productivity and production in India during the last 50 years. Three significant developments in improved seeds and crop technologies have changed the face of Indian crop production and contributed to food security, and the alleviation of poverty and hunger.

The first major development was the Green Revolution in the 1960s and 1970s which resulted in unprecedented increases in food production from the high yielding self-pollinated varieties of semi-dwarf wheat and semi-dwarf rice, which literally saved millions from hunger in India. Dr. Norman Borlaug was awarded the Nobel Peace Prize in 1970 for developing the semi-dwarf wheat varieties, which were credited with saving one billion lives in Asia, the majority in India. Dr. Borlaug's counterpart in India was Dr. M.S. Swaminathan, the recipient of the first World Food Prize in 1987.

The second development was more modest and associated with the introduction of hybrid seeds, which replaced open-pollinated varieties (OPVs) in the 1980s and 1990s, primarily in selected vegetable crops, such as tomato, capsicum, brinjal, bottlegourd, okra, chilli and cabbage, and in field crops such as corn, sorghum, pearl millet and cotton. Whereas hybrid seeds need to be replaced by farmers every year, they offer an attractive incentive to both large and small farmers because of the significant yield gains from hybrid vigor, and moreover they provide an important technology platform for enhancing productivity in a sustainable manner in the longer term.

The third major development was in 2002, which featured the application of biotechnology to crops which led to the approval and commercialization of the first biotech crop in India featuring Bt gene in hybrid cotton, which confers resistance to the critically important lepidopteran insect-pest, cotton bollworm. The Bt cotton experience in India is a remarkable story, which has clearly demonstrated the enormous impact that can be achieved by adopting genetically modified crops, referred to consistently as biotech crops in this publication. In the short span of six years, 2002 to 2007, cotton yield and profitability almost doubled, and insecticides application was almost halved, transforming India from an importer to an exporter of cotton. Acknowledging that infestations of cotton bollworm do vary with season, location and climatic conditions, it is estimated that a typical small resource-poor farmer cultivating an average of 1.65 hectares of Bt cotton will benefit from a 39% reduction in insecticides, a 31% increase in yield, and an 88% increase in profitability, which is equivalent to a $250 gain per hectare. These gains in crop production are unprecedented; that is why 3.8 million small farmers in India in 2007 elected to plant 6.2 million hectares of Bt cotton, which represented 66% of the total national area under cotton of 9.55 million hectares - the largest area under cotton in any country in the world. In addition, significant environmental and socioeconomic benefits were enjoyed by Bt cotton farmers including, lower insecticide residues in the soil and aquifers, and significantly less exposure to insecticides, with notable health implications. Welfare benefits are also starting to emerge for women and children in Bt cotton households versus non-Bt cotton households; these include more pre-natal visits for pregnant women, more help with at-home births, more children enrolled in school and higher percentage of children vaccinated. These emerging welfare benefits are important at the cotton-farm family level in India and reflect a better quality of life associated with higher incomes of small resource-poor farmers. Thus, Bt cotton is already contributing to the alleviation of poverty of small resource-poor farmers, who represent the majority of the acutely poor in India, and who play a critical role in producing cotton and other commodities for India's burgeoning population.

Importantly, one common element in all of the three above major developments in improved seeds was the willingness, indeed, the eagerness, of small-resource-poor farmers to embrace change and adopt these new technologies in order to quickly overcome production constraints and to increase their income to sustain their livelihoods and escape poverty. Thus, Indian farmers have not only been receptive but also proactive in the adoption of all the new technologies, as and when they were made available to them, though the pace of introduction of new technologies has been slow in agriculture compared to any other sector because of onerous regulation requirements. These regulatory constraints have been exacerbated by procedural delays precipitated by activists who are well resourced and mobilized in national campaigns to unnecessarily delay the adoption of biotech crops which are subject to a very rigorous science-based regulation system. Despite the intensive actions of activists, Bt cotton has achieved unparalleled success in India simply due to the multiple and significant benefits it consistently delivers to farmers and it is reflected in the unprecedented 125 fold increase in Bt cotton hectarage between 2002 and 2007. The vote of confidence of farmers in Bt cotton is also reflected in the "litmus-test" trust which confirms that 9 out of 10 farmers who planted Bt cotton in 2005 also elected to plant Bt cotton in 2006 and the figure was even higher in 2006-2007. This is a very high level of repeat adoption for any crop technology by industry standards and reflects the level of trust in the technology by small resource-poor farmers who have elected to make the additional investment in Bt cotton because of the superior returns and benefits it offers over conventional hybrid cotton, and even more over open-pollinated varieties.

Not surprisingly, the remarkable success of Bt cotton in India and the support of farmers for the technology, has led to a widespread strong political support with recommendations to emulate the success of Bt cotton in other food crops. Mr. P. Chidambaram, the Minister of Finance of India, succinctly declared at the 'BangaloreBio' 2007, 7-9 June 2007, at Bengaluru, that "***it is important to apply biotechnology to agriculture. What has been done with Bt cotton must be done with food grains.***" Whilst India has already approved the initial field testing of Bt rice, with drought and saline tolerant rice under development, it is Bt brinjal hybrid *(eggplant* *or aubergine)*, which is the most advanced biotech food crop, for which approval for experimental seed production has already been granted for 2008-2009 and is under consideration for commercial approval in the near-term. Thus, Bt brinjal hybrid is of special significance because it is the most probable first biotech food crop to be approved for commercialization in India.

Given that biotech crops are not a technology in which society is well informed, this publication is designed as a primer for all interest groups who desire to: firstly, learn about the cultivation of brinjal in India and secondly, to learn about the status of regulatory approval and the attributes of Bt brinjal which provides an option for significantly decreasing the use of insecticides on this important vegetable crop which sometimes requires as many as 40 applications of insecticides to control the major pest, fruit and shoot borer (FSB). The subjects covered in this primer, in the chronological order they appear in the text are divided into four parts: the first part describes the biology, production and significance of brinjal as a vegetable crop in India; the second focuses on biotech crop development and its relevance to India; the third highlights the current efforts to develop Bt brinjal- the first biotech food crop in India and the fourth part explains the regulatory framework being applied to Bt brinjal. The various topics covered in these four parts are: the origin and genetic diversity of brinjal; biology of brinjal; characteristics of brinjal production and utilization as a vegetable used in diverse dishes in India and internationally; major challenges to increasing productivity of brinjal in India; the adoption and impact to-date, of biotech crops globally with special emphasis on the Bt cotton story in India; the development and regulatory approval status of Bt brinjal in India; regulation, biosafety and food safety assessment of Bt brinjal in India; environmental impact assessment of Bt brinjal in India; socio-economic implications of adopting Bt brinjal in India; future prospects for Bt brinjal and implications for other biotech food crops.

The knowledge and data base in this ISAAA Brief is offered freely whilst respecting the independence and rights of readers to make informed decisions based on the content of this primer and the diversity of views about the option to develop and commercialize Bt brinjal in India. This sharing of knowledge with global society is consistent with the mandate of ISAAA to share knowledge about biotech crops with all stakeholders, particularly those in developing countries with less access to knowledge. Thus, the objective is to provide information and knowledge to the scientific community and global society re biotech/GM crops to facilitate a more informed and transparent discussion re their potential role in contributing to global food, feed and fibre security and a more sustainable agriculture.

2. Origin and Genetic Diversity of Brinjal

2.1 Botanical classification

Brinjal belongs to the nightshade family Solanaceae and genus *Solanum,* which includes other popular vegetables such as potato, tomato, pepper and petunia. Its botanical classification or taxonomic status is illustrated in Figure 1. Brinjal is included under the genus *Solanum*- which is one of the largest genera having more than 1,500 described plant species (Chen, 1997). Brinjal is botanically known as *Solanum melongena* L. *(2n =24)* and can be categorized into cultivated and wild types. The cultivated types are fit for human consumption and are divided into three main varieties based on fruit shape. Round or egg-shaped cultivars are grouped under *S. melongena* var. *esculentum.* The long, slender types are included under *S. melongena* var. *serpentinum* and the dwarf brinjal plants are placed under *S. melongena* var. *depressum* (Choudhary, 1976). The wild and exotic relatives of brinjal are not used directly for human consumption. Cultivated varieties of brinjal can be easily distinguished from wild relatives on the basis of phenotypic and morphological characteristics such as lack of prickles on stem, leaves and calyx and the size and color of fruits (Kumar *et al.,* 1998).

Figure 1. Botanical classification of brinjal

Kingdom: Plantae - Plants
Sub-kingdom: Tracheobionta - Vascular plants
Super-division: Spermatophyta - Seed plants
Division: Magnoliophyta - Flowering plants
Class: Magnoliopsida - Dicotyledons
Sub-class: Asteridae
Order: Solanales
Family: Solanaceae - Potato family
Genus: *Solanum* L. - Nightshade
Species: S. *melongena* L. - Brinjal

Binomial nomenclature*: Solanum melongena* Linnaeus

(Source: USDA, 2008)

2.2 Centre of origin

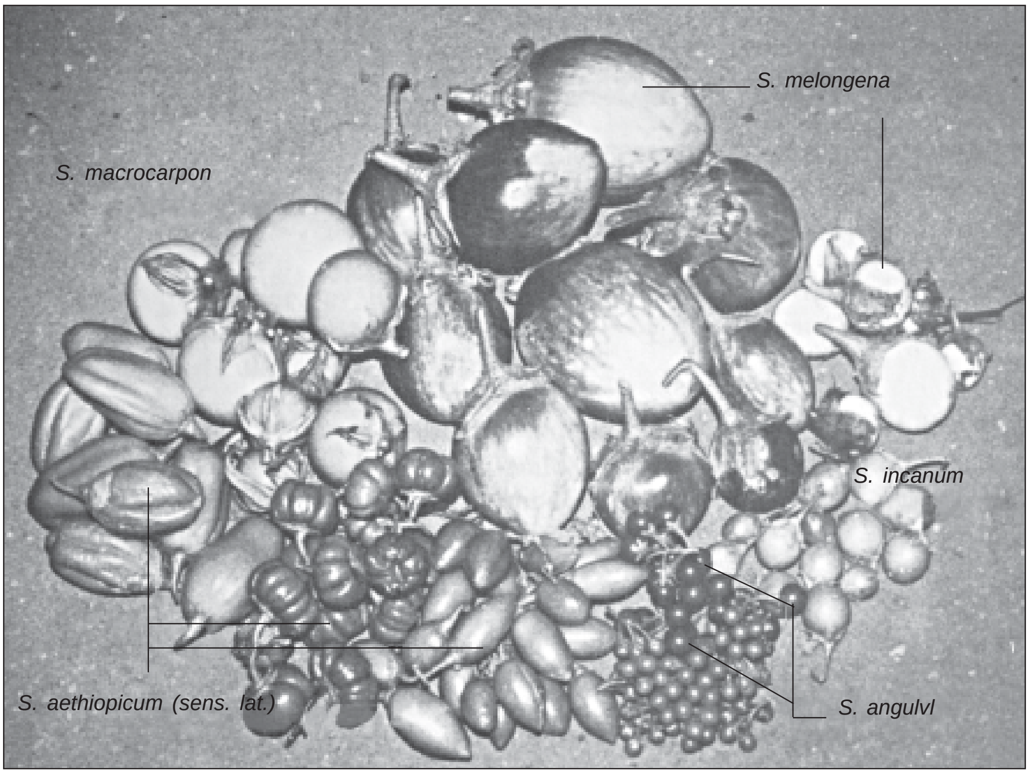
The genus S*olanum* to which major vegetable crops such as brinjal, potato and tomato belong is predominant in Central and South America, but the centre of origin of brinjal is uncertain. Brinjal is among a few cultivated plants which are believed to have the centre of origin in India. In *'Origin of cultivated plants'* published in 1886, De Candolle stated that *S. melongena* has been known in India since ancient times. On the basis of variability and distribution, Vavilov regarded India as the original home of brinjal. However, there is some uncertainty as to whether the centre of origin of brinjal is India or China. In either case, it is certain that it has spread from these countries to other countries in South-East Asia, Africa, Europe and America (GEAC Minutes of Second Expert Committee, 2007; Chen, 1997; Vavilov, 1951).

2.3 Genetic diversity

2.3.1 Different species, distribution and germplasm conservation

India possesses rich diversity and immense variability in cultivated and closely related wild species of brinjal. The genetic diversity of brinjal is manifest in its morphology (growth habit, plant vigor, hairiness, prickliness, fruit color, size and shape), physiology (time of flowering, water requirement and uptake) and biochemical features (bitterness of fruit). In addition to a large number of high-yielding cultivars, there are many landraces and wild species of brinjal including *S. incanum, S. insanum, S. indicum, S. sisymbrifolium, S. macrocarpon, S. mammosum, S. khasianum, S. aethiopicum, S. anomalum, S. integrifolium, S. torvum, S. xanthocarpum, S. nigrum*, *S. gilo* and *S. viarum* that have been reported. These species constitute a part of the genetic diversity of brinjal in India (Agarwal and Munshi, 2008). The major cultivated and wild species of brinjal are depicted in Figure 2.

Figure 2. Diversity of brinjal in India



(Source: Reproduced with the permission of Bioversity International (formerly IBPGR))

Brinjal is predominantly found in eastern, northern plains, southern and north-eastern India. Primitive types are found in the Eastern Ghats. Many landraces are found in the tribal belts of Maharashtra, Madhya Pradesh and other states including some drought-tolerant landraces in West Bengal (Rana *et al.*, 1994). The genetic differences among the landraces are potentially relevant to breeding programs as they offer great scope in creating variability through hybridization. In order to pool the genetic diversity of both cultivated varieties and wild species, a large number of cultivars have been collected, characterized and preserved in the gene banks of the National Bureau of Plant Genetic Resources (NBPGR) and in gene banks at different State Agricultural Universities (SAUs). NBPGR holds 3868 accessions belonging to 24 species of brinjal, as of 31 December 2007. The accessions are preserved at -18°C and include 3,531 accessions of cultivated varieties and 337 of related wild species. Some of these varieties have exhibited natural resistance to bacterial wilt and also have certain unique features such as plant spread, number of branches, fruit weight and fruit yield per plant (Gangopadhyay, 2008; Rajam *et al.*, 2008; Kumar, 2008).

A growing germplasm collection is also being maintained at several institutes including the Indian Institute of Vegetable Research (IIVR), Indian Institute of Horticultural Research (IIHR), Govind Ballabh Pant University of Agriculture and Technology (GBPUAT), Punjab Agricultural University (PAU), Tamil Nadu Agricultural University (TNAU), Orissa University of Agriculture and Technology (OUAT), Horticulture and Agro-forestry Research Program (HARP) and at other SAUs. These centres maintain landraces, advanced lines and released varieties. The inventory of germplasm stored in gene banks allows scientists to identify and closely analyze genetic diversity based on morphological, physiological, cytological and biochemical characteristics of cultivars with the help of DNA based marker techniques and other advanced biotechnological tools. Therefore, conservation and documentation of genetic identity of germplasm collection fulfils various curatorial and utilization needs, such as safeguarding original types in germplasm repositories, determining varietal distinctiveness, and pedigree, and development of high yielding varieties and hybrids for registration and commercial cultivation (Tiwari, 2007).

Over the years, a large number of traditionally grown cultivars have evolved in different agro-climatic zones of India. These cultivars possess valuable genes for resistance to biotic and abiotic stresses and adaptation to different environments. A large number of these cultivars have been utilized directly as varieties and also as donor parents after proper characterization and evaluation (NBPGR, 1993). A literature survey has revealed that continuous selections and hybrid vigor have played an important role in the evolution and development of improved cultivars bearing various desirable characteristics. Such cultivars bear large edible fruits and are adapted to a wide range of climatic conditions. Local preferences and rapid adaptability of newly developed cultivars have paved the way for development of different genotypes (NBPGR, 2007-08; Rai *et al.*, 1995). At present, a selected number of early, high quality, high-yielding and disease resistant varieties and hybrids are commercially cultivated and these account for almost the entire production of brinjal in India.

3. Biology of Brinjal

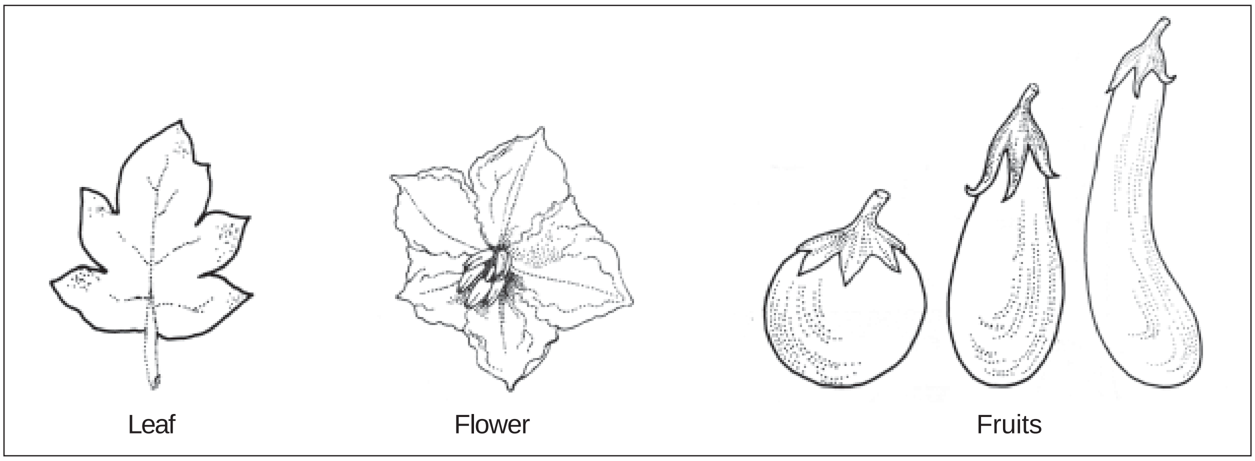
3.1 Morphology

Brinjal is a perennial herbaceous plant, grown commercially as an annual crop. It generally grows three to five feet tall. Although seedlings have tap roots, they change to fibrous root system on transplantation. The plant stands firm and compact above the ground and usually sets out a large number of branches on the main stem. The leaves are large, simple and lobed with the undersurface covered by dense wool-like hairs. The leaves generally possess spines at the midrib portions. The flowers are large, showy and purple. Inflorescence is mostly solitary but sometimes constitutes a cluster of 2-5 flowers depending on the variety or hybrid. Flower is complete, actinomorphic (characterized by radial symmetry), and bisexual (having both male and female parts). There are four types of flowers in brinjal:

i) long-styled with large ovary,
ii) medium-styled with medium size ovary,
iii) pseudo-short styled with rudimentary ovary and
iv) true-short styled with very rudimentary ovary (Krishnamurthi and Subramaniam, 1954).

Fruit setting occurs in long or medium styled flowers. The pseudo-short styled and true-short styled flowers do not set fruits. It is reported that cross-pollination is possible in long styled flowers. The calyx forms a cup-like structure at the base and has five united sepals, which are persistent and may be with or without spines depending on the cultivars. A set of five united petals remain curved inward to form a corolla. There are five stamens, which are inserted at the throat of the corolla and are free at a marginal distance from each other. Anthers are cone-shaped, free and pollen release is through apical dehiscence. The ovary is hypogynous (floral parts borne on receptacle beneath the ovary), bicarpellary (having two carpels), syncarpous (united carpels) with a basal placentation (ovules attached to the base of ovary) (Bose *et al.,* 2002).

Figure 3. Botanical description of brinjal



(Source: ISAAA, 2008; Leaf and Fruits are reproduced with permission of Bioversity International)

The fruit is pendent, fleshy berry and borne singly or in a cluster. The most common cultivars have a distinctive elongated broad oval shape, gently curving to a wider bottom. The fruit is attached close to the stem and is often hidden beneath leaves. The mature fruit usually has a glossy skin-with colors varying from green, white and purple to combinations of all three colors. The seeds are borne on a fleshy placenta which completely fills the locular cavity. The fruits contain numerous small, soft seeds, which are edible but bitter because of nicotinic alkaloids (Bose *et al.,* 2002).

3.2 Reproductive biology

3.2.1 Growth and development

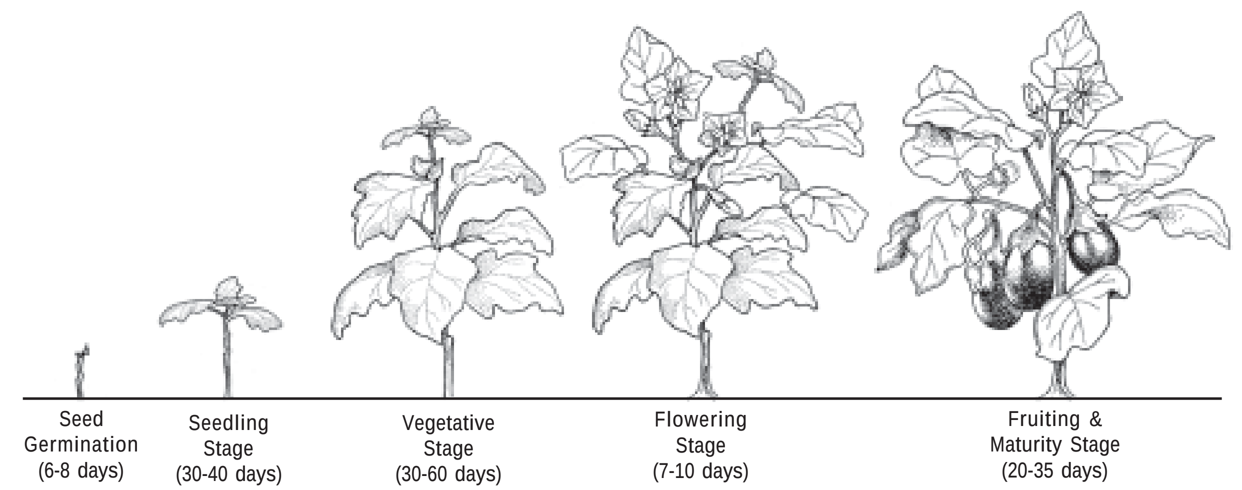
The growth and development of brinjal involves a series of stages from germination to maturity. The interval between different stages varies depending on the varieties/hybrids and climatic conditions. Farmers prefer to transplant brinjal, as opposed to direct seeding in the field. Transplanting provides the best means for growing uniform and healthy plants. Seeds are sown in nursery beds for 5 to 6 weeks before transplanting. Generally, 400-500 gm of varietal seeds or 150-200 gm of hybrid seeds are sufficient to generate seedlings for transplanting in one hectare (Singh, 2007). There are five developmental stages between seed germination and fruiting. Growth and flowering continue throughout the life of the plant. Crop duration varies from 150 to 180 days, which may extend to 250 days depending on the short, medium or long duration variety/hybrid. Generally the plant grows 3 to 5 feet tall with sizably broad leaves producing fleshy fruits that are of 5-10 cm in diameter in cultivated varieties (Kalloo and Bergh, 1993).

Table 1. Five growth stages of brinjal

No.	Growth stages	Duration (in days)
1	Seed germination (6-8 days)	6-8
2	Seedling stage (30-40 days)	35-50
3	Vegetative stage (30-60 days)	65-110
4	Flowering stage (7-10 days)	70-120
5	Fruiting and maturity (20-35 days)	90-155

(Source: Agarwal and Munshi, 2008)

Figure 4. Different developmental stages of brinjal



(Source: ISAAA, 2008)

Seed germination: Germination usually takes 6-8 days depending on different varieties/hybrids. It is affected by environmental factors including soil moisture, temperature and various other factors. Ideally a moisture content of about 60% and a temperature of 30-35°C are required for good germination.

Seedling stage: In favorable conditions, seedlings emerge in 30-40 days after sowing. Before transplanting, seedlings are hardened by slightly withholding water and exposing them to sunlight to decrease transplanting shock. They are then thoroughly watered for 12-14 hours before transplanting. Generally, the seedlings are ready to set in the field, 5-6 weeks after sowing.

Vegetative stage: Vegetative growth starts 30 days after sowing and finishes with flowering i.e., from 30-60 days after transplanting. Vegetative growth supports photosynthetic capacity of the plant that in turn supports flowering and fruiting.

Flowering stage: A main stem with a dozen leaves develops before the appearance of the first flower. Depending upon the sowing period and favorable agro-climatic conditions, flowering takes place from 45-90 days after sowing.

Fruiting and maturity: Fruit development takes place about two weeks after flowering. A single brinjal plant may bear 15-40 fruits per season, but the number can vary widely depending on the variety/hybrid.

3.2.2 Pollination and fertilization

Brinjal is usually a self-pollinated crop. However in some cases, cross-pollination has been reported from 20% to as high as 48% for long-styled flowers. Therefore, it is classified as an "often-cross pollinated crop". The extent of cross-pollination depends on the variety, location, and insect activities. Some of the known insect pollinators are bumblebees (*Bombus* sp.), wild bees

(*Exomalopsis* sp., *Xylocopa* sp., *Anthophora* sp.) and domestic bees (*Apis* sp.). The extent of pollination also influences the degree of out-crossing. Many researchers in India, Taiwan, China and other parts of the world have studied the extent of cross-pollination in brinjal (Chen, 1997). They observed that the degree of cross-pollination depends on the position of the stigma in relation to the stamens which varies with cultivars, and can also vary in different flowers of the same cultivar. In cultivated long-styled flowers, stigmas are found either above or at the same level as stamens, resulting in high percentage of fruit-setting; the contrary is the case for short-styled flowers. Opening of anthers is mostly by pores or slit at or near the apex. Repeated pollination with pollen from different plants also increases both fruit and seed setting. The anthesis and dehiscence are mainly influenced by daylight, temperature and humidity (Bose *et al.,* 2002).

4. Production and Utilization of Brinjal in India

4.1 Significance of brinjal in India and other countries

Brinjal or *baingan*, known as eggplant or aubergine in North America and Europe respectively, is a very important common man's vegetable in India. Brinjal features in the dishes of virtually every household in India, irrespective of food preferences, income levels or social status. As a part of the most basic or sophisticated Indian meal, brinjal is used in the preparation of a number of sumptuous dishes. Cooked and served in a variety of ways, this poor man's vegetable is a perfect complement for "hot" Indian dishes such as curries. The most prevalent brinjal dishes are *Baingan ka bhartha* in North India and *Sambar* in South India. Due to its versatility in use in Indian food, brinjal is often described as the '*King of vegetables'*. Thus, a large proportion of the population of rural and urban India prepares brinjal in different recipes for local dishes. Some of the most well-known brinjal dishes in India include *Begun bhaja* in Eastern India, Andhra Pradesh relishes *Gutti vankaya kura*, *Katharikai kozhambu* is popular in Tamil Nadu, *Upperi* in Kerala, *Vangi bath* in Karnataka, *Wangyacha bharit* in Maharashtra, *Sambharelu shak* in Gujarat while Bihar serves the popular *Baingan jhonga.* There are some folk songs in local languages centered around brinjal in different states of India such as *Bihu folk* songs in Asom, *Konkani songs* in Maharashtra, *Jaina* in Karnataka and *Guthi vankya kooroyi baava* in Andhra Pradesh.

Brinjal is used worldwide to complement main dishes in the form of soups, salads and other side dishes; it is also used in curries. Brinjal dishes are particularly popular in Italy and France in Europe, in the USA, in Egypt and Sudan in Africa, in China and in the Philippines, Thailand and Indonesia in South East Asia. Italian and French recipes of brinjal are the most popular in Europe and North America for preparation of soups, curries and other dishes. A selection of some of the important brinjal dishes in India and other countries are listed in Table 2. They include *Parmigiana di melanzane* from Italy*, Eggplant parmesan* from the USA*, Caviar d'aubergine* from France, *Yu Xiang Qiezi* from China, *Yum Ma-Kuea* from Thailand and *Tortang talong* from the Philippines.

Table 2. Popular brinjal dishes in India and other countries

India		International	
State	**Dish**	**Country**	**Dish**
Andhra Pradesh	*Gutti vankaya kura*	Bangladesh	*Baingan bharta*
Asom	*Baingan bhuja*	China	*Yu Xiang Qiezi*
Bihar	*Baingan jhonga*	Egypt	*Mesaqaa*
Gujarat	*Sambharelu shak*	France	*Caviar d'aubergine*
Haryana	*Baingan bharta*	Greece	*Melitzanosalata*
Karnataka	*Vangi bath*	Indonesia	*Terong balado*
Kerala	*Upperi*	Italy	*Parmigiana di melanzane*
Maharashtra	*Wangyacha bharit*	Malaysia	*Terung goreng bercili*
Orissa	*Baingan bharta*	Pakistan	*Baingan bharta*
Punjab	*Baingan bharta*	Philippines	*Talong*
Tamil Nadu	*Katharikai kozhambu*	Russian Federation	*Baklazhannaya Ikra*
Uttar Pradesh	*Baingan bharta*	Thailand	*Yum Ma-Kuea*
West Bengal	*Begun bhaja*	USA	*Eggplant parmesan*

(Source: Bawarchi.com, 2008; Biotech Information Centres, 2008; Indobase.com, 2008)

There are several names by which brinjal is known in India and in other countries and a few of them are listed in Table 3. Varying from light green to dark-purple in color, brinjal is available in different sizes and shapes throughout India. Long, medium and short sized brinjals are available in combination with different shapes which vary from round, pear, and finger to egg shape - that is why brinjal is also named *'eggplant'*. Selected varieties/hybrids of varying shapes and sizes of brinjal are cultivated in different vegetable growing zones of the country to meet local preferences. The All India Coordinated Project on Vegetable Crops (AICPVC) promotes R&D and breeding of improved varieties of vegetable crops including brinjal. Vegetable growing states in India are classified into eight different zones, mainly on the basis of agro-climatic conditions and these are listed below:

Zone-I : Jammu & Kashmir, Himachal Pradesh and Uttarakhand
Zone-II : West Bengal and Asom
Zone-III : North East States and Andaman and Nicobar Islands
Zone-IV : Punjab, Uttar Pradesh, Bihar and Jharkhand
Zone-V : Chhattisgarh, Orissa and Andhra Pradesh

Zone-VI : Rajasthan, Gujarat, Haryana and Delhi
Zone-VII : Madhya Pradesh and Maharashtra
Zone-VIII : Karnataka, Tamil Nadu and Kerala

Table 3. Names for brinjal in Indian languages and the languages of other selected countries

Botanical name : *Solanum melongena* Linnaeus			
Indian name		**International name**	
Bengali	*Begun*	Bangladesh	*Baingan*
English	*Brinjal*	China	*Qiezi*
Gujarathi	*Ringna*	Egypt	*Bedingan*
Hindi	*Baingan*	France	*Aubergine*
Kannada	*Badnekai (Badane)*	Germany	*Oberginen*
Kashmiri	*Waangum*	Greece	*Melitzana*
Malayalam	*Vazhuthinanga*	Italy	*Melanzana*
Marathi	*Vaangi (Vange)*	Malaysia	*Terung goreng bercili*
Marwari	*Reengana*	Indonesia	*Terong*
Punjabi	*Baingan*	Philippines	*Tortang talong*
Tamil	*Kathari*	Russian Federation	*Baklazan*
Telugu	*Gutti vankaya*	Thailand	*Ma Keua*
Urdu	*Beingan*	USA	*Eggplant*

(Source: Biotech Information Centres, 2008; Decoteau, 2000)

In India, a large number of brinjal varieties and hybrids are grown by small, marginal and resource-poor farmers throughout the year. It is planted on 550,000 hectares in different parts of the country and is a significant source of income of approximately 14 lakh or 1.4 million small and marginal farmers. On average, brinjal occupies 1 acre or 0.4 hectare. As a short duration seasonal vegetable, it is planted 2 or 3 times per year, thereby allowing several harvests and sales of fruits almost throughout the year, ensuring steady income to farmers.

Rich in nutrition, brinjal has a low calorific value and is a very healthy vegetable. It has very high water content and provides adequate calcium, phosphorous, potassium, fibre, folic acid, sodium and vitamins B and C. Its nutritional composition and values are detailed in Table 4.

Table 4. Nutritional composition of brinjal
(All values are per 100 gm of edible portion)

Nutrients	Value	Nutrients	Value
Moisture	92.7 %	Calcium	18.0 mg
Energy	24 Kcal	Magnesium	16.0 mg
Fibre	1.3 gm	Phosphorus	47.0 mg
Fat	0.3 gm	Iron	0.9 mg
Protein	1.4 gm	Sodium	3.0 mg
Carbohydrates	4.0 %	Copper	0.17 mg
Vitamin A	6.4 mg (124 I.U.)	Potassium	2.0 mg
Vitamin B	0.15 mg	Sulphur	44.0 mg
Vitamin C	12.0 mg	Chlorine	52.0 mg
Oxalic acid	18.0 mg	β-carotene	0.74 μg

(Source: Chadha and Kalloo, 1993; Chen, 1997)

It is believed that brinjal possesses certain medicinal properties that enrich the hemoglobin in the human body. In *ayurvedic* medicines it is used for curing diabetes, hypertension and obesity. Patients with liver complaints are recommended brinjal in their diet. It is also used for pickle-making and for processing in other dehydration industries. Apart from these varied applications, dried shoots are used as a fuel in rural areas (Chadha and Kalloo, 1993; Chen, 1997; Bose *et al.,* 2002; Kumar *et al.,* 1998).

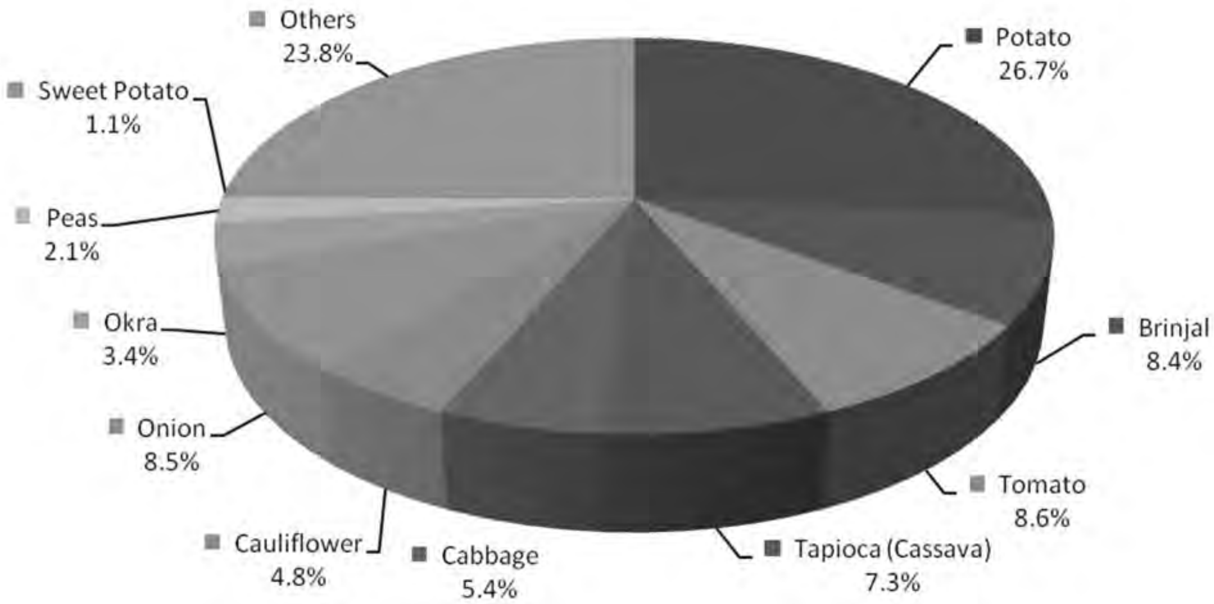
4.2 Economic importance in India and globally

Along with tomato and onion, brinjal is the second most important vegetable after potato in India. The market share for vegetables produced in India is as follows: 26.7% potato, 8.6% tomato, 8.5% onion, 8.4% brinjal, 7.3% tapioca (cassava), 5.4% cabbage, 4.8% cauliflower, 3.4% okra, and 23.8% others. Figure 5 shows the production share of vegetables in India in 2005-06.

It is estimated that per capita consumption of vegetables in India is only about 190 gm per day, which is far below the minimum dietary requirement of 280 gm per day per person (Rajya Sabha, 2006). Brinjal, being the most affordable vegetable, is consumed as a main meal, soup, salad, and curry, and is also served as a side dish virtually in every household in the country. It is relished in popular dishes such as *Baingan ka bhartha* in Northern India, *Begun bhaja* in West Bengal and forms the main ingredient of *Sambar* in South India.

Annually, India consumes around 8-9 million metric tons of brinjal, which is produced on 550,000 hectares in different parts of the country. India grows both high-yielding superior varieties and

Figure 5. Production share of vegetables in India, 2005 to 2006



(Source: Indian Horticulture Database, 2006)

hybrids of brinjal. Most of the superior varieties grown were developed by public sector institutions under the aegis of the Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs). The institutions/centres undertaking vegetable crop improvement programs in India are listed in Annex-1. In recent years, there has been increasing preference among Indian farmers for cultivation of hybrids in vegetable crops. This has resulted in intense R&D activities by the Indian as well as multinational seed companies (Sidhu, 1998). A list of important vegetable seed companies active in India is provided in Annex-2.

After China, India is the second largest producer of vegetables and brinjal in the world. India's share of global vegetable production is 9.2% compared to 36.6 % of China. India produces 26% of the total 32 million tons of world brinjal production (Table 5) whereas China leads with 56%. In terms of area, India cultivates 512,800 hectares (550,000 hectares as per NHB) of an estimated 2.04 million hectares worldwide. Other important countries that grow brinjal include Bangladesh, Indonesia, Egypt, Turkey, Iraq, the Philippines, Italy, Japan, Sudan, Thailand, Romania, Pakistan, Syria, Azerbaijan, Algeria, Greece, Kazakhstan, the United States, Venezuela and France. Table 5 shows India's standing in the world in terms of area, production and productivity of brinjal as of 2007.

Table 5. Worldwide area, production and productivity of brinjal, 2007

Country	Area (ha)	Production (tons)	Productivity (tons/ha)	% World production share
China	1,200,000	18,000,000	15.00	56.2
India	**512,800**	**8,450,200**	**16.47**	**26.4**
Bangladesh	57,747	3,39,795	5.80	1.1
Indonesia	53,000	3,90,000	7.35	1.2
Egypt	43,000	1,000,000	23.25	3.1
Turkey	30,000	7,91,190	26.37	2.5
Iraq	22,000	3,80,000	17.27	1.2
Philippines	21,000	1,98,000	9.42	0.6
Italy	12,059	2,71,358	22.50	0.8
Japan	12,000	3,75,000	31.25	1.2
Sudan	12,000	2,30,000	19.16	0.7
Thailand	12,000	68,000	4.00	0.2
Romania	11,500	1,56,000	13.56	0.5
Pakistan	9,000	89,000	9.88	0.3
Syria	7,300	1,56,000	21.37	0.5
Azerbaijan	7,000	28,000	4.00	0.1
Algeria	3,100	45,000	14.52	0.1
Greece	2,700	66,300	24.55	0.2
Kazakhstan	2,700	51,500	19.07	0.2
USA	2,200	75,000	34.09	0.2
Venezuela	1,000	10,200	10.20	0.1
France	425	17,500	41.17	0.1
Others	65,204	11,91,724	18.27	3.7
Total	**2,041,988**	**32,039,972**	**15.69**	**100**

(Source: FAO Agriculture Database, 2007; BBS, 2005)

4.3 Geographical distribution in India

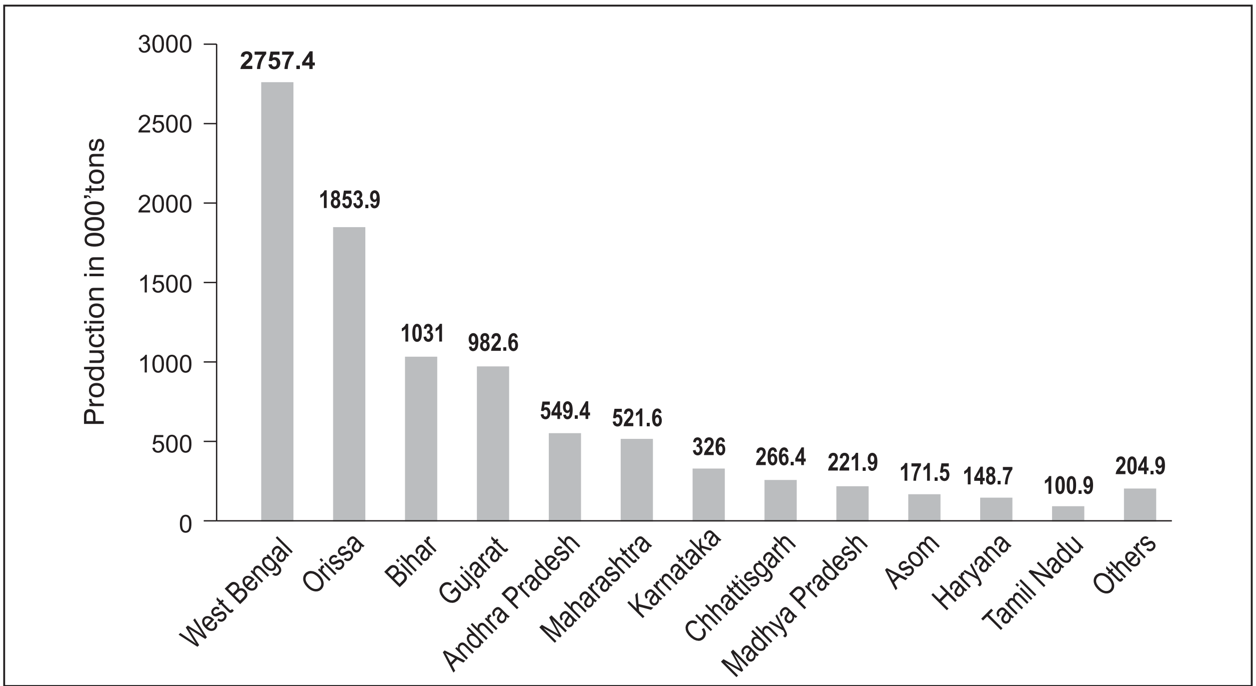
Brinjal is grown in almost all parts of India. The major brinjal producing states are West Bengal, Orissa, Gujarat, Bihar, Maharashtra, Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Karnataka, Asom, Haryana and Tamil Nadu. The national average productivity of brinjal is around 16.0 tons per hectare which varies substantially from 12.9 to 22.1 tons per hectare. The National Horticulture Board (NHB) reported the highest productivity of 22.1 tons per hectare in Karnataka, followed by 21.0 tons in Andhra Pradesh, 19.2 tons in Bihar, 18.0 tons in West Bengal, 15.7 tons in Gujarat, 15 tons in Maharashtra and the lowest was 12.9 tons per hectare in Haryana. The state-wise distribution of area, production and productivity of brinjal is listed in Table 6.

Table 6. Area, production and productivity of major brinjal growing states in India, 2005 to 2006

State	Area (in 000′ ha)	Production (in 000′ tons)	Productivity (tons/ha)	% Production share
West Bengal	**152.9**	**2757.4**	**18.0**	**30.2**
Orissa	127.9	1853.9	14.5	20.3
Gujarat	62.7	982.6	15.7	10.8
Bihar	53.7	1031.0	19.2	11.3
Maharashtra	32.0	521.6	15.0	5.7
Andhra Pradesh	26.2	549.4	21.0	6.0
Chhattisgarh	19.4	266.4	13.7	2.9
Madhya Pradesh	14.8	221.9	15.0	2.4
Karnataka	14.7	326.0	22.1	3.6
Asom	13.0	171.5	13.2	1.9
Haryana	11.5	148.7	12.9	1.6
Tamil Nadu	9.0	100.9	11.0	1.1
Others	15.2	204.9	12.5	2.2
Total	**553.3**	**9136.4**	**16.5**	**100.0**

(Source: Indian Horticulture Database, 2006)

Figure 6. Major brinjal producing states in India, 2005 to 2006



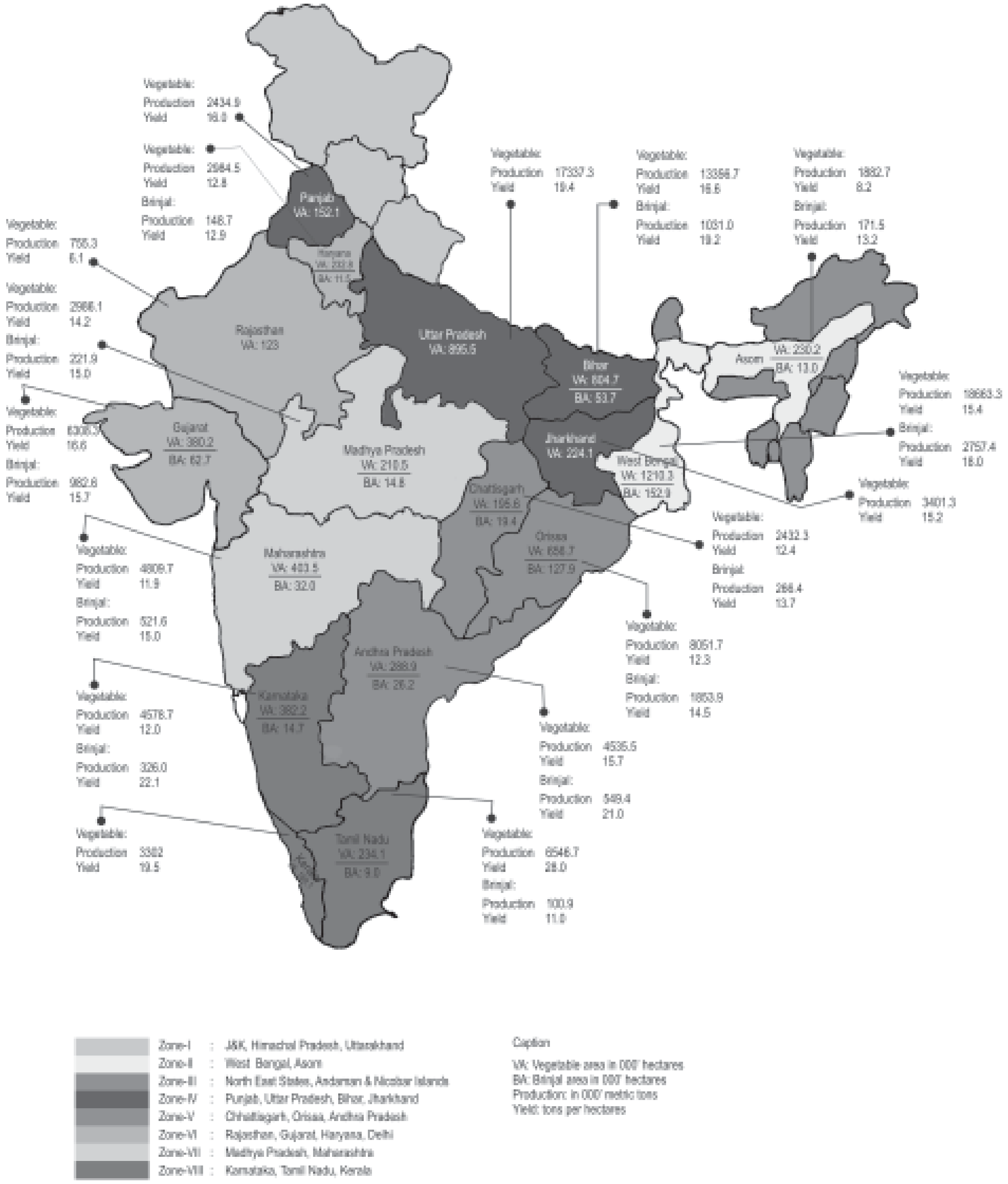
A number of different varieties/hybrids have been developed and made commercially available to farmers throughout the country to suit consumers' preferences in terms of color, size, shape and also yield. An area-wise distribution of vegetables and brinjal in various states of India in 2005-06 is given in Figure 7.

As illustrated in the vegetable and brinjal map of India, brinjal occupies a relatively significant proportion of the vegetable area in the respective states. Approximately 90 varieties and 30 hybrids have been released either as "notified cultivars" by the Ministry of Agriculture, Government of India, State Agricultural Universities, and State Agricultural Departments or as "truthfully labeled cultivars" by private sector over the last three decades. Additional 25 or so hybrids have been released by the private companies in various parts of the country. Amongst these, oblong-fruited and long-fruited varieties are the most widely grown. According to NHB, the major brinjal growing areas in various states are as follows:

- Andhra Pradesh - East and West Godavari, Krishna, Guntur, Nellore, Kurnool, Ananthapur, Srikakulam, Visakhapatnam.
- Karnataka - Belgaum, Dharwad, Bijapur, Hassan, Mysore
- West Bengal - Hooghly, 24-Paraganas, Burdwan
- Tamil Nadu - Salem, Dindigual, Coimbatore
- Rajasthan - Alwar, Jaipur, Kota, Tonk, Ajmer, Sriganganagar and
- Maharashtra, Orissa, Uttar Pradesh, Gujarat, Bihar, Haryana and Asom.

Brinjal hybrids have contributed to increased yield and quality, but they all lack resistance to fruit and shoot borer (FSB). A comprehensive list of varieties and hybrids developed by both public and private sector institutions and released at the national and state levels is detailed in Annex-3 and Annex-4.

Figure 7. Vegetable and brinjal map of India



(Source: Compiled by ISAAA, 2008)

4.4 Cultivation requirements

Brinjal is a versatile crop that adapts well to different agro-climatic environments. Climatic conditions are extremely important for optimal growth of brinjal and better quality fruits. It is a warm season crop and the optimum temperature for growth and fruit setting is 30-35°C. Drastic variation in climate conditions, especially low temperature during winter, can produce deformed fruits as it is susceptible to severe frost. Many of the round varieties set fruit at a slightly lower temperature than the long fruited varieties which are tolerant to frost.

Brinjal can be grown practically on all soils from light sandy to heavy clay. Light soils are good for an early crop while clay-loam and silt-loam are well suited for high yield. Generally, deep, fertile and well drained silt-loam and clay-loam soils are preferred for cultivation. Brinjal is moderately tolerant to acidic soil and soil pH of 5.5 to 6.0 is optimal for growth and development. Several varieties/hybrids are grown successfully under high pH with rich application of farmyard or green manure before transplanting (Bose *et al.*, 2002; Chen, 1997).

4.5 Cropping practices

Brinjal can be regarded as a perennial crop since it is grown throughout the year. It is sown in both the *kharif* (June-Sept) and the *rabi* (Nov-Feb) crop seasons and a third rainy season crop can also be raised by cultivation in March in India. The season and sowing time vary geographically as depicted in Figure 8.

Figure 8. Sowing time and seasons of brinjal in India

Zone	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
North	-Crop		Autumn Season Crop			Rainy Season Crop				Spring Summer-		
Central	Summer Season Crop				Rainy Season Crop				Winter Season Crop			
South & East	Round the Year											

(Source: Mahyco, 2008a; Singh, 2007)

All hybrid seeds are pre-treated for protection against soil borne diseases and to ensure improved seed vigor. Germination is 90% in hybrids and 70-80% in varieties not treated with fungicides. Given that vegetable production is a commercial activity, farmers prefer hybrid seeds to ensure maximum seed germination and higher yield. The successful production of hybrid seeds, planted by direct seeding or transplanting is dependent on adequate fertility and good soil and growing conditions. Long cultivars are transplanted with a spacing of 45 cm x 60 cm, and round and high yielding varieties with a spacing of 60 cm x 75 cm and 90 cm x 60 cm respectively.

Spacing depends on variety, season and fertility of soil. In addition to timely irrigation, balanced application of manures and fertilizers are important for successful crop production. Consistent with good farming practices, farmers are advised to rotate crops and not plant brinjal consecutively in the same plot because this increases the probability of fruit and shoot borer and other insect-pest infestations. Control of weeds either by traditional methods or by application of modern herbicides is essential for optimizing yield (Agarwal and Munshi, 2008; Bose *et al.*, 2002; Chen, 1997).

Brinjal is prone to attack by many insect-pests, and fungal, bacterial and viral diseases. The prevalence of insect-pests and diseases depends on many factors. Some of them that cause major damage and losses cannot be adequately controlled by pesticides or other means. The fruit and shoot borer (FSB) is the most limiting constraint to increased productivity of brinjal. A list of major insect-pests, mites and diseases affecting brinjal is detailed in Table 7.

Table 7. Major insect-pests, mites and diseases of brinjal

Principal insect-pests, in order of importance	**Minor pests**	**Principal diseases**	**Minor diseases**
Fruit and shoot borer (FSB) *Leucinodes orbonalis*	Cotton aphid *Aphis gossypii*	Damping off (fungal)	Fruit rot
Leaf eating beetle *Epilachana vigintioctopunctata*	Budworm *Pthorimoea blapsigona*	Phomopsis blight (fungal)	Collar rot
Jassid *Amrasca biguttula biguttula*	Lace wing *Gargaphia solani*	Leaf spots (fungal)	Ring rot
Red spider mite *Tetranychus neocaledonicus*	Termites *Trinervitermes biformis*	Alternaria leaf spot (fungal)	Corky rot
Leaf roller *Eublemma olivacea*	White fly *Bemicia tabaci*	Cercospora leaf spot (fungal)	Brinjal mosaic (viral)
Fruit borer *Helicoverpa armigera*	–	Verticillium wilt (fungal)	–
Stem borer *Euzophera perticella*	–	Bacterial wilt (bacterial)	–
Mealy bug *Centrococcus insolitus*	–	Little leaf (mycoplasma)	–

(Source: Bose *et al.*, 2002; Chauhan, 1981; Mahyco, 2008a; Kumar *et al.*, 1998)

Brinjal fruits are harvested once or twice a week after they have reached sufficient size for marketing. High quality fruits are healthy, disease free, glossy with desirable color and free of cuts and scars. Yields are commonly in the range of 12 to 22 tons per hectare which vary widely depending on varieties and hybrids. A properly managed brinjal plant yields a large number of marketable fruits weighing 300-400 gm each, depending on the variety. The elongated varieties may produce twice as many fruits, with individual fruits weighing 100-150 gm each (Gopalkrishnan, 2007; Mahyco, 2008a).

4.6 Production and productivity of brinjal

According to the National Horticulture Board (NHB), India produced 9.14 million tons of brinjal in 2005-06, compared to 4.6 million tons in 1991-92, and 2.6 million tons in 1987-88. A marked increase in brinjal productivity was noticed during 1990s. This increase in production has been attributed to the introduction of high yielding varieties and hybrids. The major driving force for the introduction, development, testing and deployment of superior varieties and hybrids was the establishment of the All India Coordinated Vegetable Improvement Project (AICVIP) by the Indian Council of Agricultural Research (ICAR) along with divisions of vegetable crops in various State Agricultural Universities (SAUs).

India has achieved substantial increase in productivity of brinjal over the last two decades. At the national level, productivity increased from 12.6 tons per hectare in 1987-88 to15.3 tons per hectare in 1993-94 and to a high of 16.5 tons per hectare in 2005-06 as detailed in Table 8. However, the productivity gains in India are lowest as compared to other brinjal growing countries of the world. France reported highest productivity of brinjal with 41.2 tons per hectare followed by 31.2 tons per hectare in Japan, 26.4 tons per hectare in Turkey, 23.2 tons per hectare in Egypt and 22.5 tons per hectare in Italy (FAO Agriculture Database, 2007). The area occupied by brinjal has more than doubled in the last 20 years (Table 8), increasing from 202,000 hectares in 1987 to 553,000 hectares in 2005. This increase in area along with increase in productivity has contributed to more than a 3-fold increase in production from 1987 (2.6 million tons) to 2005 (9.1 million tons). Figure 9 indicates the trend in growth of area corresponding to increase in production. In the future, most of the increased production is likely to be generated from productivity rather than increase in area.

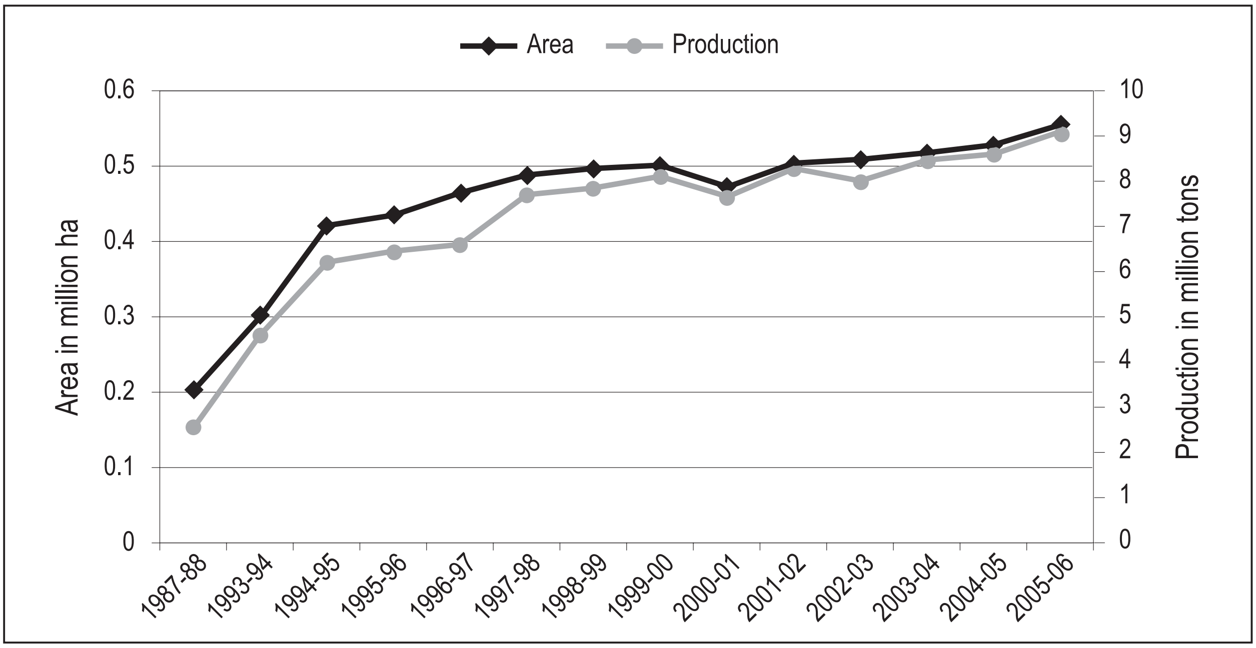
Table 8. Area, production and productivity of brinjal in India, 1987 to 2006

Year	Area (million ha)	Production (million tons)	Productivity (tons per ha)
1987-88	0.20	2.55	12.6
1993-94	0.30	4.61	15.3
1994-95	0.42	6.23	14.8
1995-96	0.43	6.44	14.8

Year	Area (million ha)	Production (million tons)	Productivity (tons per ha)
1996-97	0.46	6.58	14.2
1997-98	0.48	7.73	15.9
1998-99	0.49	7.88	15.9
1999-00	0.50	8.11	16.2
2000-01	0.47	7.65	16.2
2001-02	0.50	8.34	16.6
2002-03	0.50	8.00	15.8
2003-04	0.51	8.47	16.4
2004-05	0.52	8.60	16.3
2005-06	0.55	9.13	16.5

(Source: Indian Horticulture Database, 2006)

Figure 9. Growth in area and production of brinjal in India, 1987 to 2006



5. Major Challenges in Brinjal Production in India

The production of brinjal poses challenges at every step in the production-consumption value chain. On the one hand, it is difficult for researchers to develop superior cultivars that are resistant to major insects and diseases by conventional breeding methods. It is well established that farmers often lose a significant share of production due to insect-pests and that fruit and shoot borer (FSB) is the most destructive and unmanageable pest of brinjal which accounts for the majority of insecticide usage and yield losses. On the other hand, consumers have generally no choice but to buy insect-damaged and infested fruits or those with high pesticide residues. Farmers suffer because brinjal is highly susceptible to insect-pests and have no option except to apply insecticides which provide ineffective control of the principal pest, fruit and shoot borer (FSB).

One of the critical factors involved in the control of FSB is that farmers have to time the application of insecticides in such a way as to kill the larvae before they bore into shoots and fruits. If they are not controlled at this early stage, FSB larvae remain and feed within the shoots and fruits. Infested shoots retard vegetative growth and affect yield while damaged fruits are responsible for direct losses in marketable yield. It is estimated that FSB causes yield losses of 60-70% even after repeated insecticide sprays. Farmers also have to apply additional insecticides to control other pests including epilachna beetle (hadda), stem borer, red spider mite and jassids. Collectively these insect-pests cause substantial crop losses leading to heavy economic losses, and ultimately increased indebtedness. Application of frequent insecticide sprays results in a high pesticide exposure for farmers and sometimes this can be associated with recurring health problems (Kaur, 2008). In addition to the failure to control FSB resulting in heavy financial losses for farmers, broad spectrum insecticides can also impact non-target beneficial organisms and have negetive implications in relation to pesticide residues in fruits and in soil and ground water.

In view of the above unresolved crop protection challenges, which are not restricted to brinjal alone but also apply to several other crops, farmers are assigning high priority to seeking alternative options. Modern biotechnology is one approach that is considered very promising. New techniques such as marker-aided selection (MAS), *in vitro* regeneration, protoplast culture and fusion, androgenesis and transgenics could facilitate the development of superior hybrids and varieties resistant to biotic and abiotic stresses (Kumar *et al.,* 1998). The first generation of transgenic crops including biotech cotton, corn and soybean that are resistant to specific insect-pests and tolerant to herbicides have already been widely commercialized in several countries including India, where Bt cotton has been a great success. Biotech crops with other attributes such as tolerance to abiotic stresses such as drought, frost and salinity as well as enhanced shelf-life and nutritional contents are at various stages of development. In India, a large number of biotech fruits and vegetables are being developed by both public and private sector institutions. A comprehensive list of biotech fruits and vegetables which are at various stages of regulatory development, either at laboratory or in field trials stage is given in Table 9.

Table 9 : Status of laboratory and field trials of biotech/GM fruits and vegetables in India, 2008

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Research Trials	Large Scale Field Trials	Seed Production Stage	Commercial Release
Brinjal	*S. melongena L.*	IR	EE-I	Mahyco	✓	✓	✓	✓	✓	✓	
		IR	EE-1	Sungro Seeds	✓	✓	✓	✓			
		IR	EE-I	TNAU	✓	✓	✓	✓			
		IR	EE-I	UAS	✓	✓	✓	✓			
		IR	cry 1Fa 1 gene	Bejo Sheetal	✓	✓	✓	✓			
		IR	cry 1Fa 1 gene	Krishidhan Seeds	✓	✓	✓				
		IR	cry 1Fa 1 gene	Nath Seeds	✓	✓	✓				
		IR	cry 1Fa 1 gene	Vibha Agrotech	✓	✓	✓				
		IR	cry 1abc gene	NRCPB/ICAR	✓	✓	✓				
		DST	ots B-A gene	NRCPB/ICAR	✓	✓					
		IR	cry 1Ab gene	IIHR/ICAR	✓	✓					
		IR	cry 1Ac gene	IIVR/ICAR	✓	✓					
		IR	cry 1 ia5 gene	Nirmal Seeds	✓						
		IR	vip gene	Nirmal Seeds	✓						

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Research Trials	Large Scale Field Trials	Seed Production Stage	Commercial Release
Banana	*Musa spp.*	VR	Rep antisense	NRCB/IARI/ICAR	✓						
		VR	Cp gene	NRCB/IARI/ICAR	✓						
		DR	AP gene	IIHR/ICAR	✓						
		DR	Replicase gene	TNAU	✓						

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Research Trials	Large Scale Field Trials	Seed Production Stage	Commercial Release
Cabbage	*Brassica oleracea var. capitata*	IR	cry 1Ba & cry 1Ca gene	Nunhems	✓	✓	✓				
		IR	cry 1Ac gene	Mahyco	✓	✓	✓				
		IR	cry 1Ac gene	Sungro	✓	✓	✓				

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Research Trials	Large Scale Field Trials	Seed Production Stage	Commercial Release
Cassava	*Manihot esculenta*	VR	Rep antisense	CTCRI/ICAR	✓						
		DR	Replicase gene	TNAU	✓						

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Research Trials	Large Scale Field Trials	Seed Production Stage	Commercial Release
Cauliflower	*Brassica oleracea botrytis*	IR	cry 1Ac gene	Sungro	✓	✓	✓	✓			
		IR	cry 1Ba & cry 1Ca gene	Nunhems	✓	✓	✓				
		IR	cry 1Ac gene	Mahyco	✓	✓	✓				
		IR	cry 1Ac/vip gene	Bejo Sheetal	✓	✓					

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Research Trials	Large Scale Field Trials	Seed Production Stage	Commercial Release
Okra	*Abelmoschus esculentus L.*	IR	cry 1Ac gene	Mahyco	✓	✓	✓	✓			
		IR	cry 1Ac gene	Sungro Seeds	✓	✓	✓				
		IR	cry 1Ac gene	Bejo Sheetal	✓	✓					
		IR	CP-AV 1 gene	Arya Seeds	✓	✓					

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Trial Stage	Large Scale Field Trials	Seed Production Stage	Commercial Release
Onion	*Allium cepa L.*	DR	n/a	NRCOG/ICAR	✓						
		DR	n/a	IIHR/ICAR	✓						

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Research Trials	Large Scale Field Trials	Seed Production Stage	Commercial Release
Papaya	*Carica papaya L.*	PRSV	Coat protein	IIHR/ICAR	✓	✓					
		PRSV	Coat protein	TERI	✓	✓					
		PRSV	Coat protein	TNAU	✓						
		PRSV	Cp sense/Cp antisense	CISH/ICAR	✓						
		LCV	Rep antisense	CISH/ICAR	✓						

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Research Trials	Large Scale Field Trials	Seed Production Stage	Commercial Release
Potato	*Solanum tuberosum L.*	NE	Ama 1 gene	NIPGR/CPRI/ICAR	✓	✓	✓				
		LBR	RB gene	CPRI/ICAR	✓	✓	✓				
		LBR	cry 1Ab gene	CPRI/ICAR	✓	✓	✓				
		LCV	Cp sense gene	CPRI/ICAR	✓	✓					
		DST	Osmotin gene	NRCPB/CPRI/ICAR	✓	✓					

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Research Trials	Large Scale Field Trials	Seed Production Stage	Commercial Release
Tomato	*Solanum lycopersicum L.*	IR	cry 1Ac gene	Mahyco	✓	✓	✓				
		LCV	Rep antisense gene	NRCPB/ICAR	✓	✓	✓				
		DST	Osmotin gene	NRCPB/ICAR	✓	✓	✓				
		AP	ACS gene	NRCPB/ICAR	✓	✓	✓				
		AP	Expansin gene	NRCPB/ICAR	✓	✓					
		DST	DREB 1a gene	IIVR/NRCPB/ICAR	✓	✓					
		DST	DREB 1a gene	IIHR/NRCPB/ICAR	✓	✓					
		LCV	Truncated Rep gene	NRCPB/ICAR	✓	✓	✓				
		LCV	Truncated Rep gene	IIHR/ICAR	✓	✓					
		IR	cry 1Aa3 gene	NRCPB/IIHR/ICAR	✓	✓					
		AP	n/a	CFTRI/CSIR	✓						
		AP & NE	unedited NAD9 gene	Avesthagen	✓	✓					
		VR & FR	n/a	Indo-American Hybrid	✓						
		IR	cry 1Ac gene	Bejo Sheetal	✓	✓					

Crop	Botanical Name	Trait	Gene/Event	Developer	Laboratory Stage	Greenhouse Trial Stage	Confined Field Trial Stage	Multi-Location Research Trials	Large Scale Field Trials	Seed Production Stage	Commercial Release
Watermelon	*Citrullus lanatus*	VR	n/a	IIHR/ICAR	✓	✓					
		VR	N gene	UAS/IISc	✓						

LEGEND

AP : Agronomic Properties
BR : Bacterial Resistance
DR : Disease resistance
DST : Drought & Salt Tolerance
FR : Fungal Resistance
IR : Insect Resistance
LBR : Late Blight Resistance
LCV : Leaf Curl Virus
NE : Nutritional Enhancement
PRSV : Papaya Ring Spot Virus

ST : Submergence Tolerance
VR : Virus Resistance
CFTRI : Central Food Technological Research Institute
CISH : Central Institute of Subtropical Horticulture
CPRI : Central Potato Research Institute
CSIR : Council of Scientific & Industrial Research
CTCRI : Central Tuber Crops Research Institute
IARI : Indian Agricultural Research Institute
ICAR : Indian Council of Agricultural Research
IIHR : Indian Institute of Horticultural Research

IISc : Indian Institute of Science
IIVR : Indian Institute of Vegetable Research
NIPGR : National Institute for Plant Genome Research
NRCB : National Research Centre for Banana
NRCOG : National Research Centre for Onion and Garlic
NRCPB : National Research Centre on Plant Biotechnology
TERI : The Energy & Resources Institute
TNAU : Tamil Nadu Agricultural University
UAS : University of Agricultural Sciences

(Source : Compiled by ISAAA, 2008)

Part-II
Biotech Crops: A Paradigm Shift in Crop Development

6. Unfolding Biotech Development in Food Crops

6.1 Biotech crops: What are they?

Biotech crops are also known as genetically modified (GM) or genetically engineered (GE) crops. Phenotypically they look just like their traditional counterparts. Among biotech crops, Bt crops such as Bt cotton and Bt corn are already prevalent in many countries. Bt crops are incorporated with one or more modified Bt genes sourced originally from naturally occurring soil bacterium, *Bacillus thuringiensis* (Bt is its popular abbreviation). These crops have been developed worldwide to provide alternative methods to control specific insect-pests in agriculture. Rapid adoption of Bt crops in past twelve years, both in developed and developing countries, is a testimony that this technology works effectively to control target insect-pests in a broad array of agricultural mega-environments. Biotech crops benefit both the farmers and consumers. Farmers gain higher crop yields with less insecticides and consumers have access to crops grown with fewer insecticides, low pesticide residues and with healthier nutritional characteristics.

With the rapid progress in advanced biology, biotech crops have been developed with the help of genetic engineering tools to possess special characteristics (traits) that make them better. The most common traits deployed in biotech crops include insect resistance, herbicide tolerance, virus resistance and improved product quality. The "stacking" (use of more than one trait in a single crop) of these traits is an important feature that has been used increasingly to tackle multiple constraints in agriculture. It is expected that development of crops with tolerance to drought and salinity, improved nitrogen use efficiency, enhanced yield, quality and nutritional status coupled with existing traits will make food better and safer. At the national level, it will make agriculture more efficient and competitive to meet the challenges of hunger, poverty, malnutrition and food security in tomorrow's world (Global Knowledge Centre on Crop Biotechnology, 2008).

6.2 Biotech crops: Technology perspective

Over the years, gene exchange between two plants have been attempted to produce offspring that inherited desired traits. This was done by transferring pollens from male flower of one plant to the female flower of another. Such traditional cross-breeding methods have some limitations. Firstly, the gene exchange is only feasible between the same or very closely related species. Secondly, it usually takes a long time to achieve desired results and characteristics of interest may often not exist, or not be available at the required level in the species or in any related species. Also, there is little or no guarantee of obtaining specific gene combination from millions of crosses generated. Undesirable genes also get transferred along with desirable genes or while one desirable gene is gained, another may be lost because genes of both parents are mixed together and re-assorted more or less randomly in the offspring. Biotech crops offer viable options to counter these limitations.

In the twentieth century, the broad application of breeding techniques, exploitation of hybrid vigor and application of principles of genetics to crop improvement has contributed to a phenomenal increase in cereal crop yields. One of the most cited examples of success of plant breeding is the incorporation of dwarfing gene for improvement of semi-dwarf wheat and rice varieties. The adoption of dwarfing varieties ushered the famous 'Green Revolution' in India in the 1960s and 1970s. Around the same period, advances in cytogenetics greatly facilitated wide hybridization and chromosome-mediated gene transfers from wild species into cultivated crop plants. For example, chromosome engineering methodologies were applied to transfer disease and pest specific resistant genes of foreign origin into wheat varieties. Similarly, the *norin* gene (dwarfing gene) from wild rice species was successfully transferred to cultivated varieties of rice and wheat using cytogenetic tools and this heralded the advent of modern biotechnology era in agriculture. Thus, cytogenetic tools have been instrumental in genetic improvement of several crops (Jauhar, 2007; Global Knowledge Centre on Crop Biotechnology, 2008).

During the same era, conventional breeding techniques for the improvement of vegetable crops were also utilized. This resulted in the development of several improved varieties and hybrids with improved fruit size, weight, shape and resistance to diseases and pests. Table 10 details different techniques and their application for the development of improved varieties and hybrids in various crops.

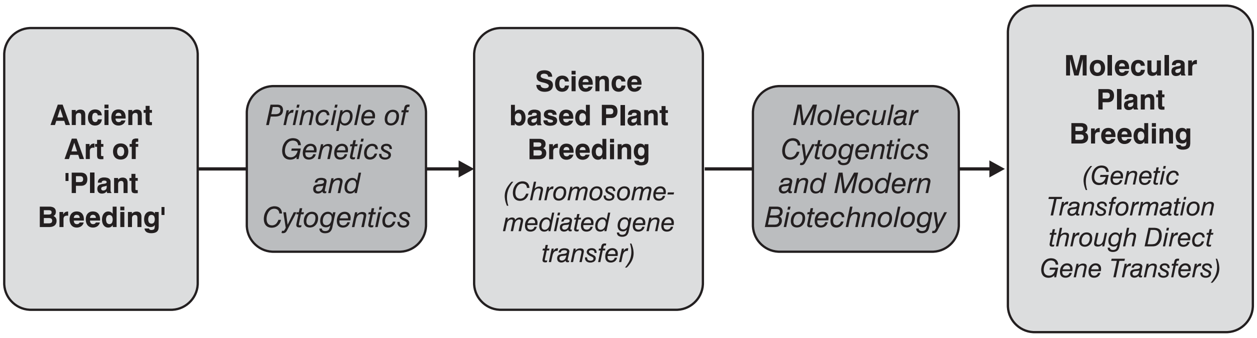
Table 10. Application of biotechnology in crop improvement

Technology	Application	Example
Meristem and bud culture	Micro-propagation for commercial purposes, genetic conservation and exchange of material	Banana, sugarcane, spices
Zygotic embryo culture	Inter-specific crosses	Cotton, jatropha
Anther and microspore culture	Haploid production	Line development, recovery of traits, creating homozygosity
Cell and tissue culture	*in vitro* selection, somaclonal variation, somatic embryogenesis and artificial seeds	Used in micro-propagation
Chromosome engineering	2n gametes for inter-specific crosses	Haploid development
Protoplast culture	Fusion for somatic hybridization	Carrot

Technology	Application	Example
Molecular markers	Aid to breeding programs	Rice
Monoclonal antibodies	Diagnosis of plant diseases	Diagnostic kits
Biotech/genetic engineering/transgenics	Gene transfer	Brinjal, brassica, cauliflower, cabbage, okra, potato, tomato

(Source: Mahyco, 2008a, 2008b; Liu, 1998)

Figure 10. Evolution of modern plant breeding



(Source: Jauhar, 2007)

The advent of recombinant DNA technology and gene transfer techniques through *agrobacterium* mediated and ballistic gene gun methods have added new dimensions to breeding efforts in the last couple of decades. The gene transfer technology is defined as any non-conventional tool aimed at mobilizing specific genetic information from one member of the plant kingdom or for that matter from any organism into another. It is also termed as transgenics or genetic engineering (GE) or genetic modification (GM) technology. This asexual technique of biotechnology helps engineer into plants new characters that are otherwise very difficult to introduce by conventional breeding. The molecular techniques, including recombinant DNA methods, involve introduction of well-characterized foreign DNA into recipient plant cells which express desired protein and permanently transform plant's genetic makeup. The application of genetic engineering varies widely from introduction of new genes with specific traits, to blocking certain gene functions (gene silencing) and splicing for desired protein expression etc. The genetic engineering technology can be used to develop plants resistant to biotic and abiotic stresses, to enhance nutritional content (bio-fortification), and also to develop plant-based-pharmaceuticals and biofuels. Due to its precision, predictability and versatility, genetic engineering technology has the potential to accelerate crop improvement and has already yielded encouraging results (Global Knowledge Centre on Crop Biotechnology, 2008; Jauhar, 2007).

6.3 Global status and impact of biotech/GM crops, 1996 to 2007

The first genetically modified organisms were developed in the laboratory in 1971, but it took about 25 years to come out with commercial products. The global foray into exploiting biotechnology in agricultural sector began in early 1990s with the commercialization of virus resistant tomato in China. This was followed by regulatory approval for commercial sale of delayed-ripening GM tomato in the USA in 1994. However, the real large-scale commercial plantings began in 1996 with the approval of insect resistant Bt cotton and Bt corn, and herbicide tolerant soybean in the USA and five other countries. The USA, China, Canada, Argentina, Australia and Mexico were the early leaders. Other GM crops such as herbicide tolerant canola, cotton and corn; disease resistant squash and virus resistant papaya; crops such as corn and cotton stacked with genes for both insect resistance and herbicide tolerance were subsequently developed and commercialized in several more industrial and developing countries.

The rate of adoption of biotech/GM crops in the world has been dramatic. The cultivated area under biotech crops was a mere 1.7 million hectares in 1996, the first year. Since then, it has registered a consistent double digit annual growth and reached 114.3 million hectares in 2007 - a staggering 67 fold increase in about 12 years. The number of countries growing biotech crops also increased from 6 in 1996 to 23 in 2007. The indications are that this trend will continue in the second decade of commercialization 2006 to 2015 (James, 2007). Biotech crops are the fastest adopted crop technology in the recent history of agriculture, outperforming the adoption of hybrid corn in the US in the 1930s and the elite high-yielding varieties of semi-dwarf wheat and rice during the Green Revolution. With increasing cost of cultivation and falling crop yields, it is not surprising that an increasing number of farmers are favoring biotech crops as they have realized that this technology offers effective protection against pests and weeds, resulting in substantial reduction in insecticide sprays, higher yield, increased profit and a myriad of other benefits. In 2007 alone, 12 million farmers in 12 developing countries and 11 industrial countries planted biotech crops. The countries that have approved biotech crops have provided their farmers with the opportunity to benefit from biotech crops; the farmers are to be commended for quickly recognizing the superiority of the technology and taking every action to expedite adoption despite much criticism from groups opposed to the technology. Table 11 gives a brief overview of adoption and growth of biotech/GM crops.

Table 11. Worldwide adoption and growth of biotech/GM crops, 1996 to 2007

Country	1996		2007	
	Crop	Total biotech crop area (million ha)	Crop	Total biotech crop area (million ha)
USA	Tomato, cotton, soybean, corn, canola potato, squash	1.5	Soybean, corn, cotton, canola, squash, papaya, potato, alfalfa	57.7
Argentina	Soybean	0.1	Soybean, corn, cotton	19.1
Brazil	–	–	Soybean, cotton	15.0
Canada	Canola, corn	0.1	Canola, corn, soybean	7.0
India	–	–	Cotton	6.2
China	Tobacco, tomato	Trace	Cotton, tomato, poplar, petunia, papaya, sweet pepper	3.8
Paraguay	–	–	Soybean	2.6
South Africa	–	–	Corn, soybean, cotton	1.8
Uruguay	–	–	Soybean, corn	0.5
Philippines	–	–	Corn	0.3
Australia	Cotton	<0.05	Cotton	0.1
Spain	–	–	Corn	0.1
Mexico	Cotton, tomato	<0.05	Cotton, soybean	0.1
Colombia	–	–	Cotton, carnation	<0.05
Chile		–	Corn, soybean, canola	<0.05
France	–	–	Corn	<0.05
Honduras	–	–	Corn	<0.05
Czech Republic	–	–	Corn	<0.05
Portugal	–	–	Corn	<0.05
Germany	–	–	Corn	<0.05
Slovakia	–	–	Corn	<0.05
Romania	–	–	Corn	<0.05
Poland	–	–	Corn	<0.05
TOTAL	**Soybean, corn, tobacco, cotton, canola, tomato and potato**	**1.7**	**Soybean, corn, cotton, canola, squash, papaya, alfalfa, carnation, tomato, poplar, petunia and sweet pepper**	**114.3**

(Source: James, 1997, 2007)

Biotech crop countries have deployed one or more of the following major traits in their biotech crops: i) insect resistance to control insect damage, ii) herbicide tolerance towards certain herbicides, and iii) virus resistance to control viral infections. These traits are used alone or in combination with others (i.e., stacked or gene pyramiding). The stacked approach is being increasingly preferred as it confers multiple benefits in a single crop such as combined resistance to insect-pests and herbicides. The benefits of stacked traits are particularly suitable for developing countries where small resource-poor farmers face many constraints such as insect infestation, ineffective weed management, frequent drought and increasing salinity problems.

Table 12 shows the global status of various biotech crops and traits in 2007. The herbicide tolerant soybean was the most dominant crop occupying 64% of 91 million hectares of global soybean area. Cotton with single/stacked traits occupied 43% of 35 million hectares while corn with single/stacked trait occupied 24% of 148 million hectares of global areas. The lead countries such as the USA have planted biotech soybean, corn and cotton in over 89%, 87% and 61% respectively of the total area of these crops in the country in 2007.

Table 12. Summary of global status of biotech/GM crops and traits in 2007

Crops	Trait	Approving country	Global area (million ha)	Biotech area as % of global area
Soybean	Herbicide tolerance	USA, Argentina, Brazil, Canada, Paraguay, South Africa, Uruguay, Mexico, Chile	91	64%
Cotton	Insect resistance, herbicide tolerance and stacked traits	USA, Argentina, Brazil, India Cotton, South Africa, Australia, Mexico, Colombia	35	43%
Corn	Insect resistance, herbicide tolerance and stacked traits	USA, Argentina, Canada, South Africa, Uruguay, Philippines, Spain, Chile, France, Honduras, Czeck Republic, Portugal, Germany, Slovakia, Romania, Poland	148	24%
Canola	Herbicide tolerance	USA, Canada, Chile	27	20%
Papaya	Virus resistance	USA, China	0.39	2%

(Source: James, 1997, 2007)

6.4 Research and development of biotech/GM vegetable crops

Among the vegetable crops, potato (*Solanum tuberosum*), which belongs to the same genus as brinjal (*Solanum melongena*), was one of the first biotech crops developed and commercialized in the USA. Other solanaceaeous vegetables like tomato, petunia and pepper were also developed and commercialized in China. As early as 1994, a series of vegetable products were developed using biotechnological tools. These included vine-ripened tomatoes with extended shelf-life (known as *Flavr Savr* tomato), tomatoes with superior quality and attractive deep red color, *and "Endless summer"* tomato and squash with novel virus resistance. Presently, a number of biotech fruits, vegetables and flowers are being either field tested or commercialized in different parts of the world. These are indicated in Table 13.

Table 13. Research and development of biotech/GM fruits and vegetables in the world, 2008

Fruit/vegetable	Botanical name	Trait	Country
Apple	*Malus domestica*	AP, PQ, IR, BR, FR	USA,Sweden, Germany
Banana	*Musa spp.*	VR, DR, FR	India, USA
Blueberry	*Vaccinium corymbosum*	HT	USA
Brinjal	*Solanum melongena*	IR, DST	India, Bangladesh, the Philippines, Italy
Broccoli	*Brassica oleracea var. italica*	IR, HT	New Zealand, Japan
Cabbage	*Brassica oleracea var. capitata*	IR	India, Australia, New Zealand
Cassava	*Manihot esculenta*	PQ, MG, VR	India, USA
Carrot	*Daucus carota*	NR, PQ, HT	USA, New Zealand
Citrange	*Citrus x poncirus*	PQ	Spain
Cauliflower	*Brassica oleracea botrytis*	IR, HT	India, Japan, Australia, New Zealand
Cucumber	*Cucumis sativus*	AP, VR, HT,PQ, IR	USA, Poland, Japan
Garlic	*Allium sativum*	AP, PQ	New Zealand
Grape	*Vitis spp.*	VR, BR, FR, HT, MG, PQ	USA
Grapefruit	*Citrus x paradisi*	IR, MG, VR, BR, PQ	USA

Grapevine	*Vitis vinifera*	BR, FR, MG, PQ	USA, Australia
Lemon	*Citrus limon*	FR	Italy
Lettuce	*Lactuca sativa*	VR ,HT, FR, PQ	USA, Japan
Okra	*Abelmoschus esculentus*	IR	India
Onion	*Allium cepa*	HT, FR, DR, AP	India, New Zealand, USA
Orange	*Citrus sinensis*	PQ	Spain
Papaya	*Carcia papaya*	VR, IR	Australia, Japan, India, USA, Canada, China
Pear	*Pyrus communis*	PQ, BR	USA, Sweden
Pineapple	*Ananas comosus*	PQ, NR, VR	Australia, USA
Pea	*Pisum sativum*	OO, HT, VR, PMP, DR	USA, Germany, United Kingdom (UK)
Potato	*Solanum tuberosum*	FR, VR, OO, PQ, IR, AP, BR, HT	India, Canada, New Zealand, USA, Germany, Spain, UK, Netherlands, Czech Republic, France, Poland, Ireland, Sweden, Finland, Japan
Strawberry	*Fragiara x ananassa*	AP, FR, HT, MG, VR, IR	USA, Italy, Japan
Squash	*Cucurbita spp.*	VR	USA, Canada
Sweet Potato	*Ipomoea batatas*	HT, VR	USA
Tomato	*Solanum lycopersicum*	PQ, FR, IR, VR, AP, BR, OO, HT, NR	India, Canada, USA, Italy, Japan, China
Watermelon	*Citrullus lanatus*	AP, OO, VR	USA

LEGEND: AP-Agronomic performance, BR-Bacterial resistance, DR-Disease resistance, DST-Drought and salinity tolerance, FR-Fungal resistance, IR-Insect resistance, HT-Herbicide tolerance, MG-Selectable marker, NR-Nematode resistance, OO-Cold/drought resistance, PMP-Plant manufacturing pharmaceuticals, PQ-Product quality, VR-Virus resistance

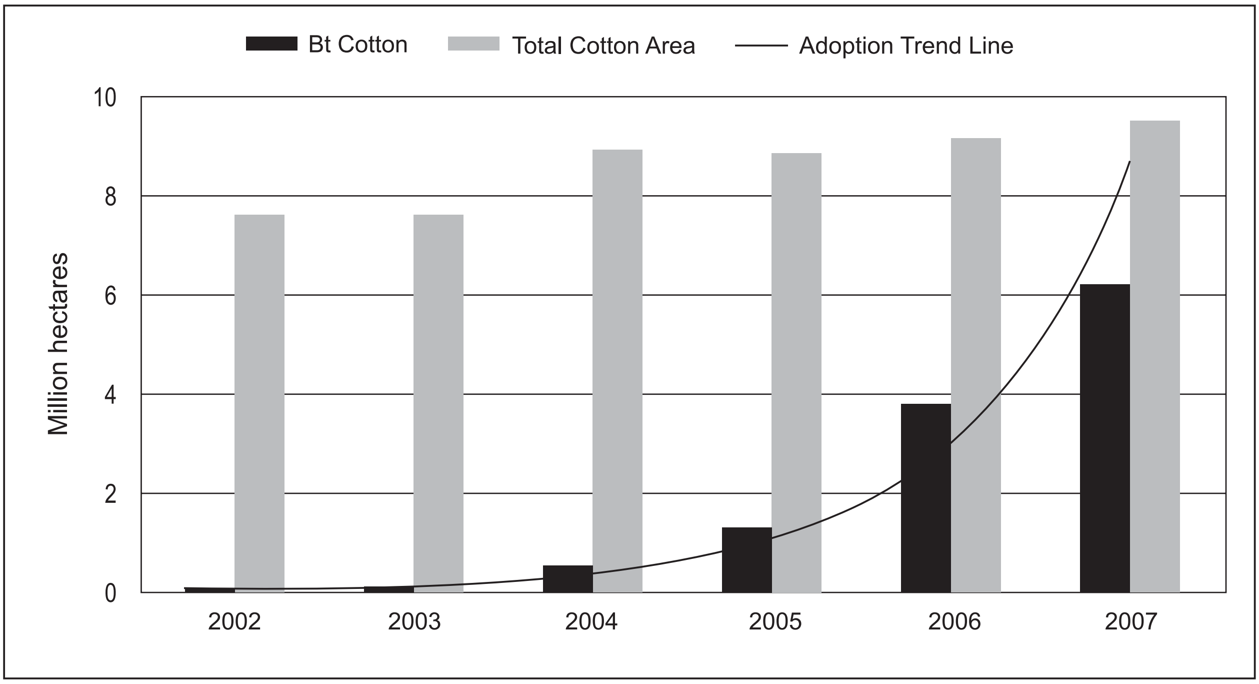
(Source: ERMA New Zealand; OGTR, Australia; CFIA, Canada; GEAC and IGMORIS 2008, India; US Regulatory Agencies Unified Biotechnology; ISB, USA; JRC, European Commission; FAO, 2008; Katie Hagen, 2006)

Among the deregulated fruits and flowers, papaya cultivars resistant to papaya ring spot virus (PRSV) and mauve-colored carnation flowers have created quite an impact (Gonsalves, 2004).

6.5 Success of the first insect-resistant biotech crop in India - Bt cotton

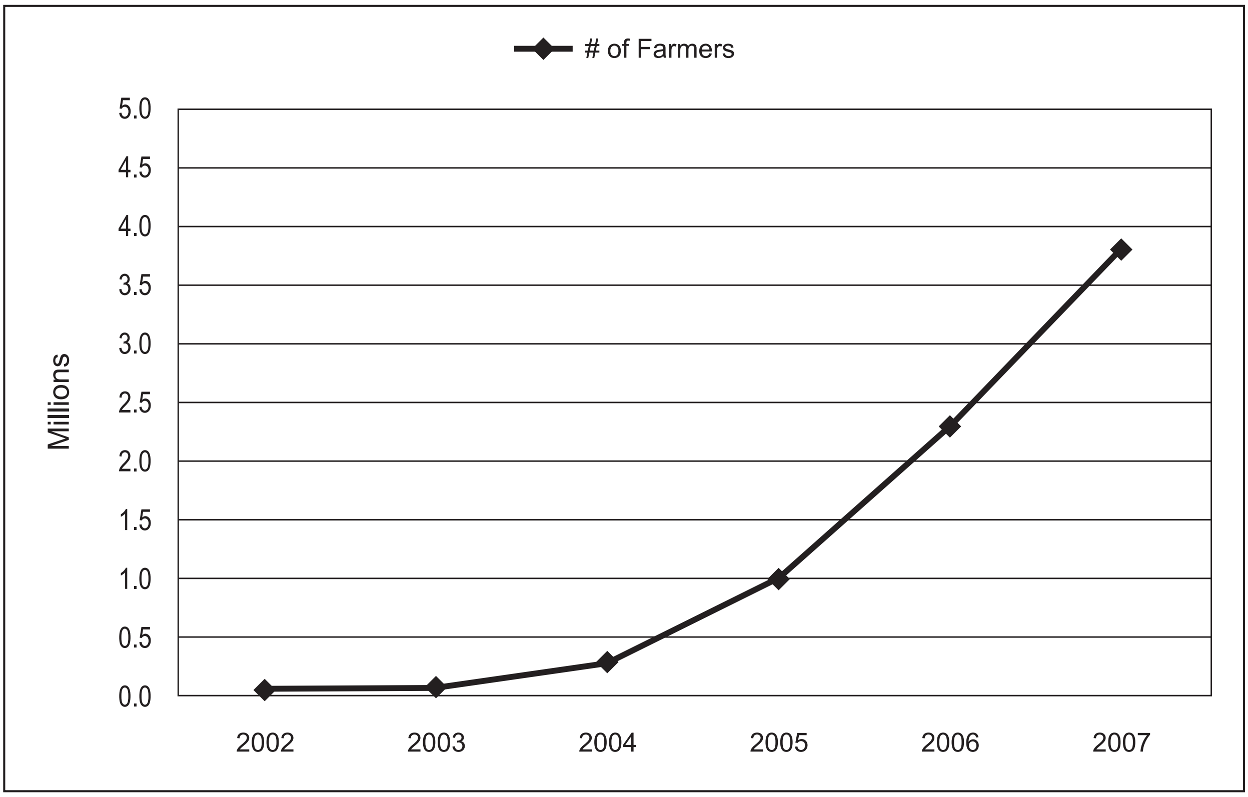
Bt cotton, approved in March 2002 is the first, and until now the only crop biotech product that has been granted regulatory approval for commercial cultivation in India; its success has been remarkable. The area occupied by Bt cotton hybrids in 2002, the first year, was 50,000 hectares. It increased significantly every single year and reached 6.2 million hectares in 2007 - an impressive 125 fold-increase in six years occupying 65% of the 9.55 million hectares under cotton in India in 2007. The annual growth of Bt cotton from 2002 to 2007 is depicted in Figure 11. Similarly, the number of farmers who planted Bt cotton also consistently increased from a few thousand in 2002 to 3.8 million in 2007, as shown in Figure 12. Coincidentally, whereas the number of Bt cotton hybrids approved in 2002 was only three developed by a single company, by 2007, 25 seed companies were engaged in the production of Bt cotton with 131 Bt cotton hybrids.

Figure 11. Adoption of Bt cotton in India, 2002 to 2007



(Source: ISAAA, 2008)

Figure 12. Adoption of Bt cotton by farmers in India, 2002 to 2007



(Source: ISAAA, 2008)

With the large-scale adoption of Bt cotton, which protects against damage by bollworms, the productivity of cotton has increased from 302 kg of lint per hectare in 2002 to 560 kg of lint per hectare in 2007; 50% or more of this increase is attributable to Bt cotton. The total national cotton production also leapfrogged from 13.6 million bales in 2002 to 31.5 million bales in 2007 as shown in Table 14. As a result, India emerged as the world's second largest cotton producer in 2006-07, edging past the USA which held the second rank till recently. China is the leading producer and consumer of cotton in the world. India also has been transformed from an importer of cotton to a major exporter, projected to export a record 8 million bales in 2008.

It is important to note that there has been a positive impact of Bt cotton on cottonseed oil production in India over the years. The Cotton Advisory Board (CAB) indicated that Bt cotton has been a major contributing factor for increasing cottonseed oil production by 22% or more than 1.1 million tons in 2007-08, from 0.9 million tons in 2006-07. The Solvent Extractors' Association of India (SEA) estimated that the recovery of cottonseed oil, particularly from Bt cotton hybrid seeds is higher, which has helped to increase the production of cottonseed oil. This may be attributed to availability and wide spread use of good quality cotton hybrids.

Interestingly, cottonseed oil is generally consumed as such or blended with other vegetable oils in India as a cheaper alternative to most other edible oils and is gaining popularity among consumers (SEA, 2007; Mayee, 2008).

Table 14. Area, production and productivity of cotton in India, 2002 to 2007

Year	Area (million ha)	Production (million bales)	Productivity (kg of lint/ha)
2002-03	7.67	13.6	302
2003-04	7.63	17.9	399
2004-05	8.92	24.3	463
2005-06	8.87	24.4	467
2006-07	9.14	28.0	520
2007-08	9.55	31.5	560
1 bale = 170 kg			

(Source: CAB, 2008)

The unprecedented adoption of Bt technology in cotton has once again proved that timely introduction of new technology can break productivity barriers and improve crop production in a sustainable manner. A large number of socio-economic studies conducted by the public sector institutions have confirmed the benefits of Bt cotton. Typically Bt cotton increases yield up to 31% due to effective control of bollworm and reduces insecticide sprays by 39% or more. The income of farmers growing Bt cotton increased by $250 (Rs 10,000) or more per hectare. The studies also revealed that 9 out of 10 Indian farmers replant Bt cotton year-after-year, thus confirming their trust in this new technology once they have experienced the benefits.

Traditionally, cotton required the maximum number of insecticide sprays of any field crop and its equivalent in vegetables, are brinjal and chilli. A clear understanding of the benefits of Bt technology has emerged with the success of Bt cotton for the control of cotton bollworms including *Helicoverpa armigera*. The same technology is now being deployed in brinjal to control the fruit and shoot borer (FSB), *Leucinodes orbonalis*, which is a very difficult pest to control with insecticides and other methods, especially because of its concealed feeding habit. Like cotton bollworms, FSB belongs to the insect order Lepidoptera. Given that Bt technology has a long history of safety, proven efficacy and benefits, Bt brinjal promises to be of great value to Indian farmers.

The unprecedented adoption and success of Bt cotton in India, has proven the views of the critics to be unfounded and opened the door for crop biotechnology in India. The experience and knowledge gained in technology application and regulation will be very valuable in dealing with future biotech products. Bt brinjal has already completed several stages of regulatory requirements and is now in the final stage of large-scale field trials. In all probability, Bt brinjal is likely to be the next biotech product to be approved in the near future by the Government of India for commercialization. It assumes greater importance as it is going to be the first vegetable biotech product to be approved in India. Bt technology in brinjal is a very effective tool for mitigating damage caused by the economically important fruit and shoot borer (FSB) and has the capability to deliver substantial benefits to small and resource poor, medium and large farmers in the same way as Bt cotton.

Part-III
Development of Bt Brinjal in India

7. Bt Brinjal - Development of the First Biotech Vegetable Crop in India

7.1 A brief overview

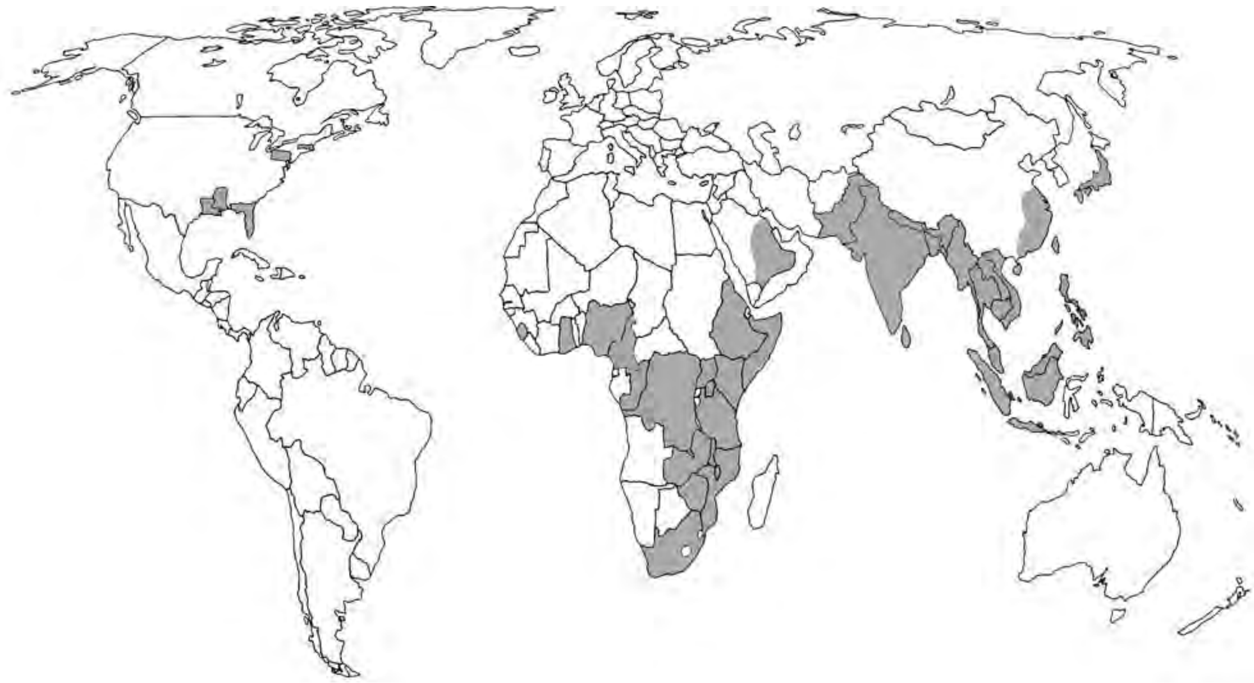
Bt brinjal is a state-of-the-art technology which is considered as one of the most safe, convenient and viable options to control the fruit and shoot borer (FSB), *Leucinodes orbonalis* (Lepitoptera, Pyralidae). The attempts made so far to control this pest by developing resistant cultivars through traditional plant breeding, indiscriminate use of insecticides and application of integrated pest management (IPM) have met with limited or almost no success. In this context, it is expected that timely deployment of Bt brinjal will help farmers to effectively control FSB while significantly reducing insecticide sprays. This will also enable farmers to improve yield by saving damage to marketable fruits and consumers to get healthier vegetables devoid of insect damage and pesticide residues.

7.2 Fruit and shoot borer (FSB): The target insect-pest

The fruit and shoot borer (FSB) known as *Leucinodes orbonalis*, is the most devastating and troublesome insect in brinjal crop. It is popularly known as *Praroh avum phal bedhak*. It belongs to insect order Lepidoptera and family Pyralidae. It is almost monophagous as it predominantly feeds on brinjal while few other closely related Solanaceaeous vegetable crops such as potato and tomato have been reported as its host. It is widely prevalent in all brinjal growing states and is active all through the year in India.

Globally, *Leucinodes orbonalis* is a tropical pest which is mainly found in South Asia, South-East Asia and African countries. The distribution of *Leucinodes orbonalis* clearly indicates that the pest causes significant damage to brinjal and is well established in major brinjal growing countries in Asia such as Bangladesh, China, India, Indonesia, Japan, Malaysia, Nepal, Pakistan, the Philippines, Sri Lanka, Taiwan and Vietnam; in Africa such as Ethiopia, Ghana, Kenya, Mozambique, Nigeria, South Africa, Tanzania, Uganda and Zimbabwe and the USA in North America. Figure 13 indicates the distribution of *Leucinodes orbonalis* in different countries. It is a revised global distribution map of *Leucinodes orbonalis* taking in account the latest information provided by AVRDC, CSL, CABI and USDA.

Figure 13. Distribution map of *Leucinodes orbonalis* Guen.



Asia : Bangladesh, Brunei Darussalam, Cambodia, China, Hong Kong, India, Indonesia, Japan, Laos, Malaysia, Myanmar, Nepal, Pakistan, the Philippines, Singapore, Sri Lanka, Taiwan, Thailand and Vietnam

Africa : Burundi, Cameroon, Democratic Republic of the Congo, Ethiopia, Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda, Sierra Leone, Somalia, South Africa, Tanzania, Uganda, Zaire, Zambia and Zimbabwe

North America : Florida, Louisiana, Massachusetts, Mississippi, Pennsylvania (USA)

Central America, South America, Europe, Oceania : Absent

(Source: CIE Map No. 364 (revised) from CABI; CSL, 2006; USDA and courtesy of AVRDC- The World Vegetable Centre)

7.2.1 How does FSB infestation start?

FSB infests and damages shoots and fruits throughout the life cycle of brinjal plant - from nursery stage till harvest. The small larvae bore into tender shoots and chew up the tissues, as a result the affected shoots get paralyzed and wither. This seriously affects the plant growth and flowering. When the plants enter reproductive phase, the larvae bore into fruits and feed on them. Fruits are their most preferred food. The damage renders the fruits inedible and unsuitable for market. Because it bores into shoots as well as fruits, the insect is called 'fruit and shoot borer'. As the larvae lead a concealed life, it is difficult to control through insecticide sprays. The pest is known to be mainly carried from one season to another through stalks as most of the farmers store dried stalks to be used as fuel. FSB moths emerging from stored stalks lay eggs on brinjal seedlings grown in the vicinity, thus starting fresh infestation (Talekar, 2002; Talekar *et al.,* 2003).

Figure 14. FSB infestation in shoot and fruit

(Source: Mahyco, 2008a; ABSP II, 2007)

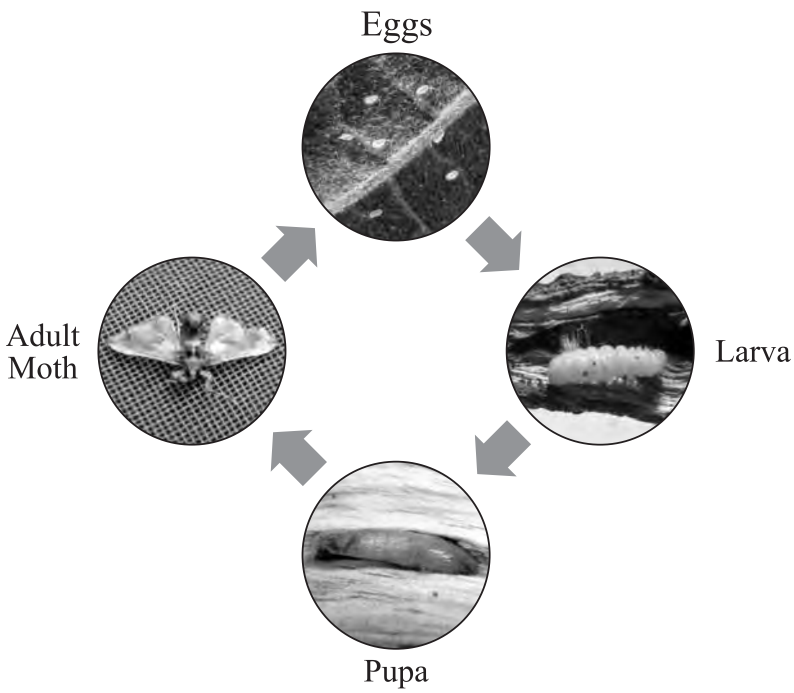
There are several sources of FSB infestation. Although, it is a specific pest of brinjal, the infestation of a newly planted crop comes through the following routes:

1) Adults migrating from the neighboring brinjal fields, which are the most important sources of infestation.
2) Adults emerging from pupae in the soil where brinjal was grown earlier lay eggs.
3) Brinjal seedlings used for transplanting may carry eggs or tiny larvae.
4) If old uprooted brinjal plants or their stalks are stored nearby, the pupae from underneath such debris can develop into adults and become a source of infestation (Talekar, 2002).

7.2.2 Life cycle of the fruit and shoot borer (FSB)

The fruit and shoot borer (FSB), like other lepidopteran insects, has four stages in its life cycle- egg, larval, pupal and adult. FSB lays eggs which mature into larvae and then pupae before developing into full grown adult moths. It generally takes 25-43 days to complete the life cycle. The adult moth lays eggs to produce new offspring. Figure 15 illustrates the different forms and life cycle of FSB.

Figure 15. Life cycle of fruit and shoot borer (FSB)



(Source: ISAAA, 2008; Eggs picture is reproduced with the permission of AVRDC - The World Vegetable Centre)

The moths lay tiny white eggs mainly on leaves, green stems, buds and calyx. Eggs hatch in 4-5 days and the tiny translucent larvae crawl a short distance before entering tender shoots or fruits where they feed and grow. Soon after boring into shoots or fruits, the larvae plug their entrance holes with excreta. After 15-20 days of feeding, larvae are full-grown, measuring 10-15 mm. As a result of larval feeding, extensive damage is caused to fruits and shoots. A full grown larva, prior to pupation, makes a small hole in the fruit or shoot. It may escape through it at night and pupate in soil underneath or may pupate within the plant itself. In the latter case, the hole serves as an exit point for the moth. A mature larva spins a sturdy cocoon around it before pupation and thus the pupa is very well protected. The pupa looks like dried plant debris and cannot be easily recognized. After a week, moths emerge from pupae. The moth is small and measures 20-22 mm. Wings are white with a pink and bluish tinge and have a few brown spots. Moths live for 6-10 days, feeding on plant exudates or dew drops. They hide under brinjal leaves during day and are not easily seen. During night, they come out in open and mate and are ready to lay eggs soon after (ABSP II; Talekar, 2002; Talekar et al., 2003).

7.2.3 Nature of symptoms, damage and control measures

The first symptom of FSB infestation is the appearance of wilted and drooping shoots. At the initial stage, when brinjal fruits have not yet developed, larvae bore into tender shoots, feed inside and then tunnel downwards and kill growing points. The affected shoots ultimately wither and die away. Later when plants start bearing fruits, most larvae prefer to feed on tender fruits. Larvae also feed on flowers, reducing fruit set and yield. The damaged flower buds drop without blossoming and fruits show visible circular exit holes. When larvae become mature, they exit fruit or shoot by making a hole and descend to soil for pupation. Once infestation begins, it can continue until the last harvest and carried on to subsequent season (Talekar, 2002; Talekar *et al.,* 2003).

Farmers resort to frequent insecticide sprays and biological control measures to combat the menace of FSB. The larvae need to be killed with available plant protection tools before they enter shoots or fruits. Once inside shoots or fruits, FSB becomes a hidden enemy that destroys both fruits and shoots and escapes insecticide sprays. The integrated pest management (IPM) strategies, which allow for minimal use of insecticides are exploited but not to a great extent. Traditionally, farmers use labor-intensive practices to control FSB including manual removal of wilted shoots and damaged fruits. Sex pheromone traps are also used to mass-trap male moths to reduce mating. However, these approaches and use of chemicals have not been able to provide satisfactory control of FSB. As a result, the farmers continue to undergo heavy losses and are frustrated. This is where Bt brinjal, with an in-built FSB protection system, in conjunction with good farming practices can help the farmers to protect the crop and get good yields (ABSP II; Handbook of Horticulture, 2007; NCIPM, 2006; Talekar, 2002; Talekar *et al.*, 2003).

7.3 Bt brinjal: How is it developed?

Bt brinjal is a biotech crop developed using Bt technology and transformation process similar to the one exploited in Bt cotton. Like Bt cotton, Bt brinjal carries an additional gene that provides in-built insect protection against fruit and shoot borer (FSB). The development of Bt brinjal involves introduction of *cry1Ac* gene expressing insecticidal protein to confer resistance against FSB. The *cry1Ac* gene is sourced from environment friendly and ubiquitous soil bacterium called *Bacillus thuringiensis* (Bt), which has been frequently used as a biological control measure in granular or powder form to control FSB and other insect-pests for many years.

The Maharashtra Hybrid Seeds Company (Mahyco) - a leading Indian seed company has developed a new DNA construct, which contains a gene sequence encoding insecticidal protein in all parts of brinjal plant throughout its life. The *cry1Ac* gene along with two other supporting genes namely *nptII* and *aad* genes are put together in such a way that they work in tandem to produce insecticidal protein that is toxic to the targeted insect, in this case the fruit and shoot borer (FSB). The *cry1Ac* gene is under the transcriptional control of the enhanced CaMV35S promoter (P-E35S), which works as an on/off switch and regulates when and where *cry1Ac* gene should express. This new strand of DNA is called the 'gene construct' and is illustrated in Figure 16.

Figure 16. New gene construct

The gene construct contains the following genes and a brief summary of each gene is given below:

i) ***cry1Ac* gene** - It is isolated from the common soil bacterium *Bacillus thuringiensis* sub-sp. *kurstaki* (*B.t.k*) strain HD73, and introduced into the plant after suitable modification. It encodes for an insecticidal protein Cry1Ac.

ii) ***nptII* gene** - It is a selectable marker which encodes enzyme neomycin phosphotransferase II (nptII) and is used to identify transformed cells that contains *cry1Ac* gene. It has no insecticidal properties. The *nptII* gene is derived from prokaryotic transposon Tn5.

iii) **CaMV 35S promoter** - *The cry1Ac* gene is expressed under the control of the Cauliflower Mosaic Virus 35S promoter.

iv) ***aad* gene** - It encodes for bacterial selectable marker enzyme 3"(9)-O- aminoglycoside adenyl transferase (AAD) and allows for selection of bacteria containing the pMON 10518 plasmid on media containing spectinomycin or streptomycin. The *aad* gene is under the control of a bacterial promoter and hence not expressed in Bt brinjal.

The plasmid vector pMON 10518 containing the *cry1Ac* gene expression cassette has been transferred to *Agrobacterium tumefaciens* strain LBA4404 using methods such as electroporation or triparental mating.

A vector containing *cry1Ac* gene, *nptII* gene, CaMV 35S promoter and *aad* gene was used to transform young cotyledons of brinjal plants by co-cultivation with *Agrobacterium* and cultured on kanamycin-containing medium using standard tissue culture techniques for plant regeneration. An improved method for *Agrobacterium*-mediated brinjal transformation has been developed and used at Mahyco. This is based on a method that was described earlier by Fari *et al.* (1995). The regenerated plants from the transformed cells were carried forward and analyzed in subsequent generations to identify lines in which transgene segregated in expected Mendelian fashion. Selected lines were also analyzed by southern blot and a single copy elite event was selected and named as event EE-1 (Elite Event-1)**.

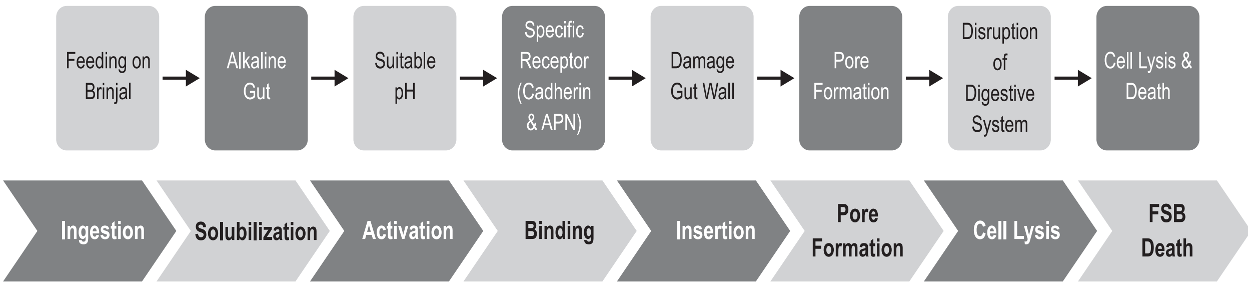
*****An event** refers to a unique DNA recombination event that took place in one plant cell, which was then used to generate entire transgenic plant. Every cell that successfully incorporates the gene of interest represents a unique "event." Every plant line derived from a transgenic event is considered as biotech crop. The event names correspond to the identifiers commonly used by regulatory authorities and international organizations, such as the Organization for Economic Cooperation and Development (OECD).*

Mahyco has also developed a PCR - based event identification system (ID) for this unique event EE-1 in order to track this event in green-house and field. The event EE-1 was then introduced into the regular breeding program where it was back-crossed with seven best performing brinjal hybrids namely MHB-4 Bt, MHB-9 Bt, MHB-10 Bt, MHB-11 Bt, MHB-39 Bt, MHB-80 Bt and MHBJ-99 Bt at Mahyco Research and Life Sciences Centre at Jalna, Maharashtra (Kumar 2008; Mahyco 2008b).

7.3.1 Bt brinjal: How does it control FSB?

Bt brinjal hybrids containing *cry1Ac* gene express Bt protein in all parts of the plant (i.e. constitutive expression) throughout its life cycle. To get activated and exhibit insecticidal property, Bt protein must be ingested by FSB. When FSB larvae feed on Bt brinjal plants, they ingest Bt protein along with plant tissue. In the insect gut, it is solubilized and activated by gut proteases generating a toxic fragment. The activated insecticidal protein then binds to two different receptors in a sequential manner. The first contact of the insecticidal protein is with the cadherin receptor, triggering the formation of oligomer structure. The oligomer then has increased affinity to a second receptor, amino-peptidaese-N (APN). The APN facilitates insertion of the oligomer into membrane causing ion pores. These events disrupt digestive processes such as loss of trans-membrane potential, cell lysis, leakage of the mid-gut contents and paralysis that in turn cause the death of fruit and shoot borer (American Academy of Microbiology, 2002; Manjunath, 2007; Soberon and Bravo, 2008). This exemplifies how Bt technology can work as a safe and viable strategy for insect-pest management in brinjal and other potential vegetable crops like cauliflower, cabbage, okra and chilli.

Figure 17. Mode of action of Bt in FSB



(Source: ISAAA, 2008; Manjunath, 2007; Soberon and Bravo, 2008)

7.3.2 Bt brinjal: Why is it better and safer?

It is important to note that Bt insecticides whether in the form of a spray or a Bt crop, do not function on contact as most chemical insecticides do, but rather act as mid-gut toxins. To be active and function as an insecticide, Bt proteins require certain specific conditions. These include:

i) Bt protein has to be ingested by the target insect. In the case of Bt brinjal, FSB larvae ingest Bt protein when the larvae feed on plant tissues.

ii) Bt protein requires an alkaline gut with a suitable pH (9.5 and above) for its activation.

iii) Presence of specific receptors particularly cadherin and APN, in the insect mid-gut epithelial cells is required for protein binding.

Fruit and shoot borer (FSB) larvae possess all these specific conditions and therefore succumb when they feed on Bt brinjal. Bt brinjal does not harm or pose any threat to higher order organisms and non-target organisms as they lack specific receptors and conditions for activation of Bt protein in their gut. So, Bt brinjal is safe for consumption by all non-lepidopteran insects, birds, fish, animals and human-beings. Owing to its in-built insect resistance and specificity, Bt technology is regarded as a superior technology for control of target pests, in this case FSB, either alone or as one of the important components of integrated pest management (IPM) (American Academy of Microbiology, 2002; Manjunath, 2007; Soberon and Bravo, 2008).

In 2006, the total agro-chemical market in India was worth Rs. 4038.6 crore (approximately US$900 million, based on Rs. 45 per dollar), of which insecticides accounted for 63%, followed by herbicides 19% and fungicides 18% (Indian Chemical Industry, 2007). It is estimated that around 13-14% of the total pesticides used in the country are applied on vegetable crops, of which insecticides account for two-thirds of the total pesticides used on vegetables. Also, it is evident from the research studies that farmers use insecticide sprays as the key control tactic for the management of insect-pests in vegetable crops, particularly for FSB in brinjal. The number of sprays on brinjal to control FSB varies widely from 15 to 40 or more in a single crop season depending on the level of infestation in different areas. It is reported that farmers usually spray twice a week, which translates to an average range of 20-30 times in a single crop season. The minimum range of pesticide use intensity is from 3.1 kg to 8.6 kg of active ingredient per hectare with an average of 4.6 kg active ingredient per hectare, which is the second largest, after chilli among all vegetable crops. An average farmer spends Rs. 12,000 ($270) per hectare on pesticide sprays. It is to be noted that farmers growing the open-pollinated varieties use 26.7 litres of pesticides per hectare as against the estimated economically optimal use of 4.9 litres per hectare. And those growing hybrids use 54.3 litres per hectare against the optimal level of 16.0 litres per hectare. Brinjal farmers resort to multiple insecticide sprays by just observing the presence of insect-pests in the fields rather than following the economic threshold level (ETL) based sprays. Inspite of such heavy application of insecticides, farmers suffer heavy yield losses as severe as 50-90% due to various insect-pests and diseases. It has been reported that FSB causes considerable damage to brinjal fruit in the range of 48 to 86% and significantly reduces yield by 50-60%. Other studies reported that FSB alone is responsible for losses upto 60-70% (Jeyanthi and Kombairaju, 2005; Lesser and Kolday, 2006; Mahyco 2008b; Mehto *et al.*, 1983; Patnaik, 2000).

The Central Insecticides Board and Registration Committee (CIBRC) of the Ministry of Agriculture has recommended 15 pesticides for control of pests, weeds and diseases in brinjal. However, farmers extensively apply only a few insecticides such as monocrotophos, endosulfan, megha (chlorpyriophos+cypermethrin) and a cocktail of other insecticides (chlorpyriphos, cypermethrin, monocrotophos and dimethoate) on brinjal (Sardana, 2005; Arora, 2008). Most of these pesticides are restricted and a few of them such as monocrotophos have been banned for use on vegetable crops. Out of the 15 recommended pesticides on brinjal alone, 8 pesticides are being used for controlling FSB infestation. It is evident that development of Bt brinjal is a very wise and only viable option to significantly cut-down the usage of pesticides for FSB control. The list of recommended pesticides in brinjal is given in Table 15.

Table 15. List of recommended pesticides for brinjal

Pesticide	Pest/Disease/Weed	MRL (mg/kg)
Cypermethrin (0.25% D.P.)	Fruit and shoot borer	0.2
Endosulfan (2%D.P.)	Fruit and shoot borer	2.0
Cypermethrin (10%EC)	Fruit and shoot borer	0.5
Chlorpyriphos (20%EC)	Fruit and shoot borer	0.2
Cypermethrin+Quinalphos (3%+20%EC)	Fruit and shoot borer	–
Lindane (6.5%WP)	Aphid, epilechna beetle, fruit fly, fruit and shoot borer, lacewing bug	3.0
Neem seed kernel based EC containing Azadirachtin	Fruit and shoot borer	–
Carbaryl (50%WP)	Fruit borer	5.0
Carbendazim (50%WP)	Leaf spot	0.5
Phorate (10%CG)	Aphid	n/a
Malathion (50%EC)	Mites	3.0
Carbofuran (3%CG)	Root knot nematode	0.1
Dimethoate (30%EC)	Jassid	2.0
Fenitrothion (50%EC)	Thrips	0.2
Gibberellic acid technical	Seed treatment	–

(Source: CIBRC, 2008; PMFAI, 2008; Sharma, 2007)

The increasing amount of pesticide residues in vegetables and fruits has been a major concern for the past several years. Farmers often apply a large number of sprays and use higher dosages of pesticides in their anxiety to control pests and save their crops from damage. This results in higher amounts of pesticide residues in the final produce and persistence of pesticides in the environment. Keeping in view the safety parameters, the Ministry of Health and Family Welfare under the Prevention of Food Adulteration Act (PFA), 1954 and Rules 1955 has fixed the Maximum

Residue Limits (MRLs) for each pesticide approved by CIBRC. ICAR has also set up the All India Network Project on Pesticide Residues (AINPPR) to monitor and ascertain the levels of pesticide residues in food crops, vegetables and fruits at a national level (AINPPR; Sharma, 2007). Table 16 shows the summary of AINPPR study that determined the prevalence of pesticide residues in different vegetables at farm gate and market yards from 1999 to 2003. Notably, out of a total 3,043 samples of different vegetables that were analyzed from 1999 to 2003, two-thirds were found to have residues, but these were within accepted tolerances, whereas 9% contained pesticide residues above their respective MRL values (Rajya Sabha, 2003; Lok Sabha, 2005).

Table 16. Extent of pesticide residues in vegetables above the Maximum Residue Level (MRL), 1999 to 2003

Year	No. of samples analyzed*	Samples above MRL (%)
1999	277	10 (3.6)
2000	712	81 (11)
2001	796	93 (11.7)
2002	592	54 (9)
2003	666	35 (5.3)
Total (1999-2003)	**3,043**	**273 (8.97)**

* Cabbage, cauliflower, brinjal, okra, potato, bean, gourds, tomato, chilli, spinach, carrot, cucumber and cowpea.

(Source: Rajya Sabha, 2003; Lok Sabha, 2005)

7.3.3 Bt brinjal: India pioneers first Bt brinjal in the world

It is a matter of national pride as India takes its first biotech food crop-Bt brinjal close to commercialization. Importantly, Bt brinjal is an indigenous product developed by India's leading seed and biotech company Mahyco in collaboration with public sector institutions. The world is closely watching the regulatory and other developments on Bt brinjal as it is likely to be released in the near future. The US is optimistic whereas the EU countries have expressed mixed reactions. However, there is a great hope and expectation in developing countries that face similar constraints in improving crop productivity, which is a key to alleviate hunger and poverty.

Many fellow-developing countries, especially in Asia and Africa, foresee India as a potential partner in creating biotech capacity, implementing biosafety regulations and sharing knowledge and state-of-the-art crop biotech applications. It is, therefore, pertinent that India uses its natural resource base and rich experience from Bt cotton, and now with Bt brinjal, to exert its leadership in networking with both public and private sector institutions in industrial countries. This will enable India to develop partnership and create new modes of cooperation and biotechnology transfer that can be shared with other biotech crop aspiring countries in Asia and Africa. The South-South collaboration in biotechnology is evident from the fact that developing countries see biotech as an important tool to improve agriculture, to provide job opportunities and increase income of poor farmers. More importantly, there is an increasing need to address various concerns, share knowledge and experiences from major biotech countries that are reaping benefits, and also to create awareness about safety and benefits of biotechnology among farmers, consumers and the public alike.

As a first step in that direction, India has already responded to the need of two Asian countries. Based on their request, Mahyco has transferred FSB resistant Bt brinjal technology to public sector institutions in Bangladesh and the Philippines. The transfer of this technology to the Institute of Plant Breeding of the University of Philippines, in the Philippines and Bangladesh Agricultural Research Institute (BARI) and East West Seeds Ltd., in Bangladesh materialized under the aegis of the Agricultural Biotechnology Support Project (ABSP II) of the Cornell University, which is supported by the United States Agency for International Development (USAID). Mahyco has generously donated Bt brinjal technology for the development of pro-poor varieties of brinjal to benefit fellow citizens of Bangladesh and the Philippines (GEAC 66 Meeting; ABSP II, 2007).

The fruit and shoot borer is a major constraint in brinjal production in Bangladesh and the Philippines. Brinjal occupies 57,747 hectares and 21,000 hectares in Bangladesh and the Philippines respectively - a relatively significant area under brinjal cultivation after China and India. In Bangladesh, there are 300,000 farmers planting brinjal on average 0.2 hectare while in the Philippines 30,000 farmers grow brinjal in an area of 0.7 hectare on average. The pest causes significant yield loss and reduction in the number of marketable fruits. Farmers often resort to intensive use of insecticides to control FSB without much success. Therefore, Bt brinjal is important for them as well. The local varieties have been used to back-cross event EE-1 and these varieties are being evaluated for their agronomic performance, safety and efficacy. These open-pollinated Bt brinjal varieties are at an advanced stage of regulatory approval in Bangladesh and the Philippines (ABSP II, 2008).

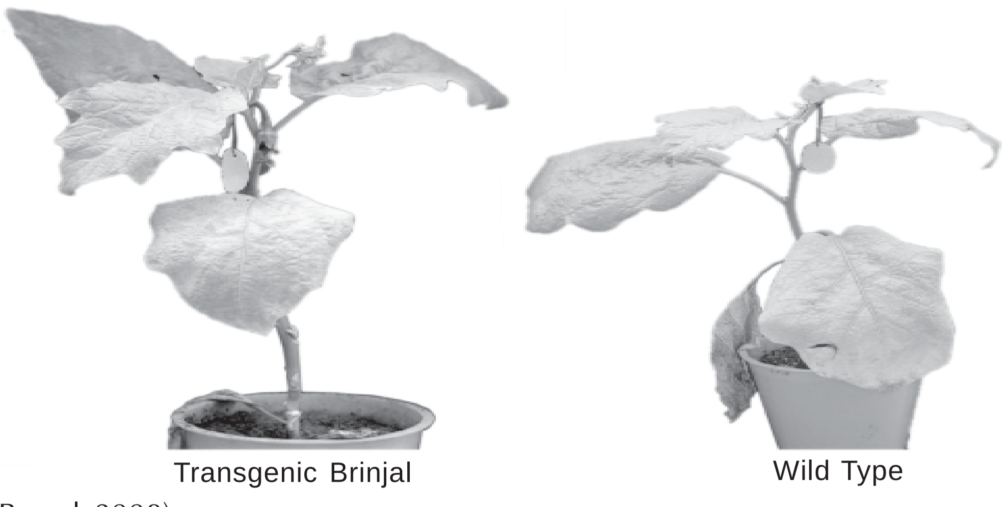
At the national level, Mahyco has generously donated Bt brinjal technology to public research institutions to benefit a large number of resource-poor vegetable farmers in India. The Tamil Nadu Agricultural University (TNAU), Coimbatore, and the University of Agricultural Sciences (UAS), Dharwad have successfully back-crossed event EE-1 into locally adapted open-pollinated brinjal varieties. Both these institutions are testing and evaluating different open-pollinated Bt brinjal varieties under the multi-location research trials (MLRTs) and these varieties are likely to be made available to farmers in the near future. These varieties expressing *cry1Ac* (event EE-1) are:

- Co2-Bt, MDU1-Bt, PLR1-Bt, and KKM1-Bt developed by TNAU, Coimbatore, Tamil Nadu, and
- Malapur Local, Manjari Gotha, Kudachi Local, Udupi Gulla, 112-GO and Rabakavi Local developed by UAS, Dharwad, Karnataka.

Remarkable success achieved with Bt cotton in India has led to a noticeable increase in investment for R&D of biotech crops by leading national research institutions of the Indian Council of Agricultural Research (ICAR) with increasing project based support from the Department of Biotechnology (DBT) and the Council of Scientific and Industrial Research (CSIR). Many small and medium private seed and biotech companies have invested heavily in expanding research base, developing state-of-the-art biotech laboratories and in establishing high quality and high quantity seed processing plants. Recently, there has been emphasis on public-private partnership, particularly in agriculture sector and many such collaborative projects have been successfully materialized. Another important milestone in the development is the transfer of Bt brinjal technology developed using *cry1Fa1* gene by the National Research Centre on Plant Biotechnology (NRCPB) to Bejo Sheetal Seeds Pvt. Ltd, Krishidhan Seeds Pvt. Ltd, Nath Seeds Pvt. Ltd, and Vibha Agro-tech Pvt. Ltd. These companies have made considerable progress and Bt brinjal hybrids expressing *cry1Fa1* gene are at the confined limited and multi-location research trial stages (Business Standard, 2005; Kumar, 2008).

The Indian Institute of Horticultural Research (IIHR), Bengaluru, is also developing Bt-brinjal using *cry1Ab* gene construct in two important brinjal varieties, *Arka keshav* (purple long) and *Manjarigota* (striped round). The selected lines of these varieties are being advanced for further evaluation under controlled network conditions as well as using *Leucinodes orbonalis* insect bioassays (IIHR, 2008). A new protocol to develop transgenic brinjal using chloroplast transformation technique has been developed by the National Research Centre on Plant Biotechnology (NRCPB). The *ots B-A* gene derived from *E. coli* was successfully expressed to confer drought and salt resistance to *'Pusa shyamala'* variety of brinjal. This method offers multiple advantages including no transgene flow via pollen transfer and gene silencing. Figure 18 shows transplastomic and wild type brinjal plants which were subjected to salt stress of 300mM NaCl and phenotypic response observed after 3 weeks of stress (Bansal, 2008).

Figure 18. Transplastomic brinjal with improved salt stress tolerance



(Source: Bansal, 2008)

Part-IV
Bt Brinjal - The Regulatory Framework in India

8. Bt Brinjal - Regulation, Biosafety and Food Safety Assessment

8.1 Regulatory framework

The research and product development in rDNA technology or biotechnology are strictly regulated in India. The regulatory framework is well established and functional for the past two decades. The Ministry of Environment and Forest (MoEF) notified the EPA Rules 'Manufacture/ Use/Import/Export and Storage of Hazardous Microorganisms, Genetically Engineered Organisms or Cells' way back in 1989 under the provisions of the Environment Protection Act (EPA), 1986. The EPA Rules 1989 clearly define the composition, function and roles of competent authorities. These are responsible for regulating various biosafety, food safety, agronomic evaluation and environmental concerns of biotech crops as shown in Table 17. The Ministry of Environment and Forest (MoEF) and the Department of Biotechnology (DBT) coordinate the implementation of various provisions of the Rules 1989 which are assigned to relevant ministries, state governments and public sector institutions. The competent authorities under the Rules 1989 have framed guidelines, protocols and procedures for evaluating biosafety, toxicity, allergenicity, field trials, food and feed safety, production processes, large-scale use of genetically modified organism (GMOs) and products thereof and their release into the environment (Indian Biosafety Rules and Regulations, 2008; IGMORIS, 2008).

MoEF and DBT closely follow and track the regulatory developments vide the WHO Biosafety manual, FAO Codex Alimentarious, WTO, OECD guidelines, Cartagena Protocol on Biosafety, and the Convention of Biological Diversity (CBD). Keeping in view the developments, the Department of Biotechnology has been updating guidelines from time to time. The first such guidelines 'Recombinant DNA Safety Guidelines' and 'Recombinant DNA Safety Guidelines and Regulations' were published in 1990 and subsequently revised in 1994. These guidelines provide information on regulatory procedure and its implementation, provisions of the Rules 1989, approval mechanisms, risk groups, handling and import of GMOs. In 1998, the Department of Biotechnology published a set of revised guidelines which included 'Revised Guidelines for Research in Transgenic Plants' and 'Guidelines for Toxicity and Allergenicity Evaluation of Transgenic Seeds, Plants and Plant Parts'. These guidelines provide instructions to the applicants on various levels of approval for conducting research on transgenic plants, category of experiments and testing procedures for toxicity and allergenicity. The Department of Biotechnology has also devised proformas for submission of applications to different competent authorities for specific approvals. Table 17 gives the details of competent authority, implementing ministry, guidelines and protocols and function of different committees for implementation of the EPA Rules 1989.

Table 17. Role and jurisdiction of competent authorities

Competent authority under the EPA Rules 1989 of the EPA Act 1986	Implementing ministry/agency and jurisdiction	Guideline/protocol	Function
Recombinant DNA Advisory Committee (RDAC)	DBT in consultation with all relevant ministries and stakeholders	–	Overall advisory role, to oversee global biotech development and recommend technologies/ processes for revision of safety regulations.
Genetic Engineering Approval Committee (GEAC)	Ministry of Environment and Forest (MoEF)	Revised Guidelines for Research in Transgenic Plants and Guidelines for Toxicity and Allergenicity Evaluation of Transgenic Seeds, Plants and Plant parts-1998 (revised in 1990, 1994 and 1998)	Responsible for approval of R&D, safety assessment, field trials and environmental release of GM crops and import/export of GM food.
Review Committee on Genetic Manipulation (RCGM)	Department of Biotechnology (DBT), Ministry of Science and Technology	Guidelines and Standard Operating Procedures (SOPs) for Confined Field Trials of Genetically Engineered Plants (2008)	Draft and bring out guidelines and protocols, issue import permit, review projects, guide and oversee biosafety and food safety regulations and environmental assessments.
		Protocols for Food and Feed Safety Assessment of GE crops (2008)	
	Indian Council of Medical Research (ICMR), Ministry of Health and Family Welfare (MoH&FW)	Guidelines for the Safety Assessment of Foods Derived from Genetically Engineered Plants (2008)	Evaluation of food safety concerns addressing risk assessment, risk management and communication and ensure safety of GM foods to human health.
Monitoring and Evaluation Committee (MEC)	Department of Biotechnology (DBT) in collaboration with Indian Council of Agricultural Research (ICAR)	Guidelines for the Monitoring of Confined Field Trials of Regulated, Genetically Engineered Plants, 2008	Monitoring of field trials, storage facility and documentation of records and check compliance with the terms and conditions of field trial permit.

Institutional Biosafety Committee (IBSC)	DBT and Institute undertaking rDNA research.	Handbook for IBSC members	A nodal point for interaction within the institution for implementation of the biosafety regulatory framework.
State Biotechnology Coordination Committee (SBCC)	State Government	–	Inspect, investigate, assess the damage if any and take punitive action in case of violation of statutory provisions at state level.
District Level Committee (DLC)	State Government	–	Monitor the safety regulations, inspect on-site control measures, assess damage if any and report to SBCC in case of non-compliance at district level.

(Source: Biosafety Information Kit, 2008)

A science-based-regulatory system for GM crops has been developed in India with the efforts of MoEF and DBT. The Indian regulatory system is considered by many national and international experts as one of the most robust regulatory systems in the world. Some of the salient features of the Indian regulatory system are the following:

i. Provision of revision and improvement of regulatory guidelines from time to time, keeping pace with the rapid biotechnological advances taking place in other parts of the world.
ii. Seven layers of regulatory committees to keep track of product development.
iii. ICAR as a parallel system to check and validate data submitted by the technology developers.
iv. Periodic revision of biosafety and food safety guidelines and also field trial protocols to ensure fool proof system.
v. Time-bound approval system to track progress and take corrective action, if any, and,
vi. Post-commercial monitoring system to review safety and evaluate performance.

In 2000, Mahyco started research and development work on Bt brinjal. Complying with the prevailing regulatory system, it obtained permits and submitted the results of various experiments to the competent authorities. A list of important steps in the development of Bt brinjal are highlighted in chronological order in Table 18. In addition, Figure 19 gives the detailed process for regulatory approval of Bt brinjal in India. It also indicates time taken in completing different studies including laboratory experiments, greenhouse and confined field trials, biosafety and food safety studies, multi-location and large-scale field trials for agronomic evaluation, and environmental impact assessment. The data generated from 2001 to 2008 has been made available on GEAC website for public information, scrutiny and comments. A full biosafety dossier of Bt brinjal is available at: http://www.envfor.nic.in/divisions/csurv/geac/bt_brinjal.html

Table 18. Chronology of Bt brinjal in India, 2000 to 2008***

2000	Transformation and greenhouse breeding for integration of *cry1Ac* gene into brinjal hybrids and seed purification.
2001-2002	Preliminary greenhouse evaluation to study growth, development and efficacy of Bt brinjal.
2002-2004	Confined field trials to study pollen flow, germination, aggressiveness and weediness; biochemical, toxicity and allergenicity studies and backcrossing into the regular breeding program.
2004-2005	Submission of data re the effect of Bt brinjal on soil microflora, collembola and earthworms; field evaluation of Bt brinjal for efficacy against fruit and shoot borer; pollen flow and comparative studies on the chemical composition of Bt brinjal to RCGM.
2004-2007	Multi-location research trials (MLRTs) to evaluate agronomic performance and environmental impact of Bt brinjal hybrids conducted by Mahyco and All India Coordinated Vegetable Improvement Program (AICVIP), ICAR.
2006-2007	Submission of biosafety, environmental safety, gene efficacy and agronomic performance data to GEAC.
2006	Posting of full dossier of biosafety, environmental safety, gene efficacy and agronomic performance data on GEAC website.
2007-2009	Large scale field trials (LSTs) to evaluate agronomic performance and environmental impact of Bt brinjal hybrids conducted by the Indian Institute of Vegetable Research (IIVR), ICAR.
2008-2009	Experimental seed production of 7 Bt brinjal hybrids by Mahyco.

*** Details of toxicity and allergenicity assessment and nutritional studies, environmental impact studies and agronomic evaluation studies are given in Tables 20, 21 and 24.

(Source: Compiled by ISAAA,2008)

Bt brinjal is the first GM food crop under evaluation for commercial release in India and also the first GM brinjal to be released globally. Knowing that, GEAC took a cautious approach and decided to set up an 'Expert Committee' on Bt brinjal and related issues in 68 meeting held on 1 June, 2006. GEAC issued a notification in this regard on 24 August, 2006.

The 'Expert Committee' comprised of 13 eminent members from different scientific disciplines such as biotechnology, genetics, entomology, nutrition, toxicology, plant breeding and social sciences. The terms of reference of the Committee were to review literature from studies conducted by various national and international institutions; to evaluate comments received from various stakeholders vis-à-vis biosafety data generated by the technology developer; to suggest additional studies to be conducted; to evaluate adequacy of the protocol proposed for large-scale field trials; to recommend additional safeguards and protocols for socio-economic studies and any other recommendation on the related aspects (GEAC Expert Committee; GEAC Reconstitution of Expert Committee; GEAC 68 Meeting).

The first meeting of the 'Expert Committee' on Bt brinjal was held on 25 September, 2006 which extensively deliberated on technology and safety aspects. The committee decided to summarize the issues raised by various stakeholders, response received from members and external experts and other relevant issues for consideration in the second meeting. Meanwhile, the GEAC directed Mahyco to comply with certain additional requirements for conducting large-scale field trials as recommended by the Supreme Court vide order dated 22 September 2006 and 8 May 2008 (the Supreme Court of India, 2006, 2008). These conditions included:

- All trials should have a lead scientist's name with contact details who would be responsible for all aspects of the trials including regulatory requirements.
- An isolation distance of 200 m should be maintained during field trials.
- Prior to bringing out the GM material from the greenhouse for conduct of open field trial, the company should submit a validated event specific test protocol with the Level of Detection (LOD) being at least 0.01% so as to detect and confirm any contamination.

In light of the above order, the second meeting of the 'Expert Committee' was convened on 3 July 2007 (GEAC Minutes of Second Expert Committee). After detailed deliberations, the 'Expert Committee' concluded that large-scale field trials of Bt brinjal may be allowed subject to certain conditions as described below. GEAC approved the recommendations of the Expert Committee in its 79 meeting held on 8 August 2007 (GEAC 79 Meeting).

- The 'Expert Committee' confirmed that biosafety data generated by Mahyco was in accordance with the protocols and procedures stipulated by the regulatory authorities. The committee concluded that Bt brinjal is safe and equivalent to its non-Bt counterpart. However, the committee directed Mahyco to conduct more independent studies especially with respect to toxicity assay in NABL accredited laboratories and additional environmental safety and socio-economic aspects. This would help to explicitly conclude benefits from Bt brinjal and superiority of the technology over the existing technologies for insect-pest management, reducing use of insecticide sprays and pesticide residues in food crop.
- The large-scale field trials should be conducted in the research farm under the control of

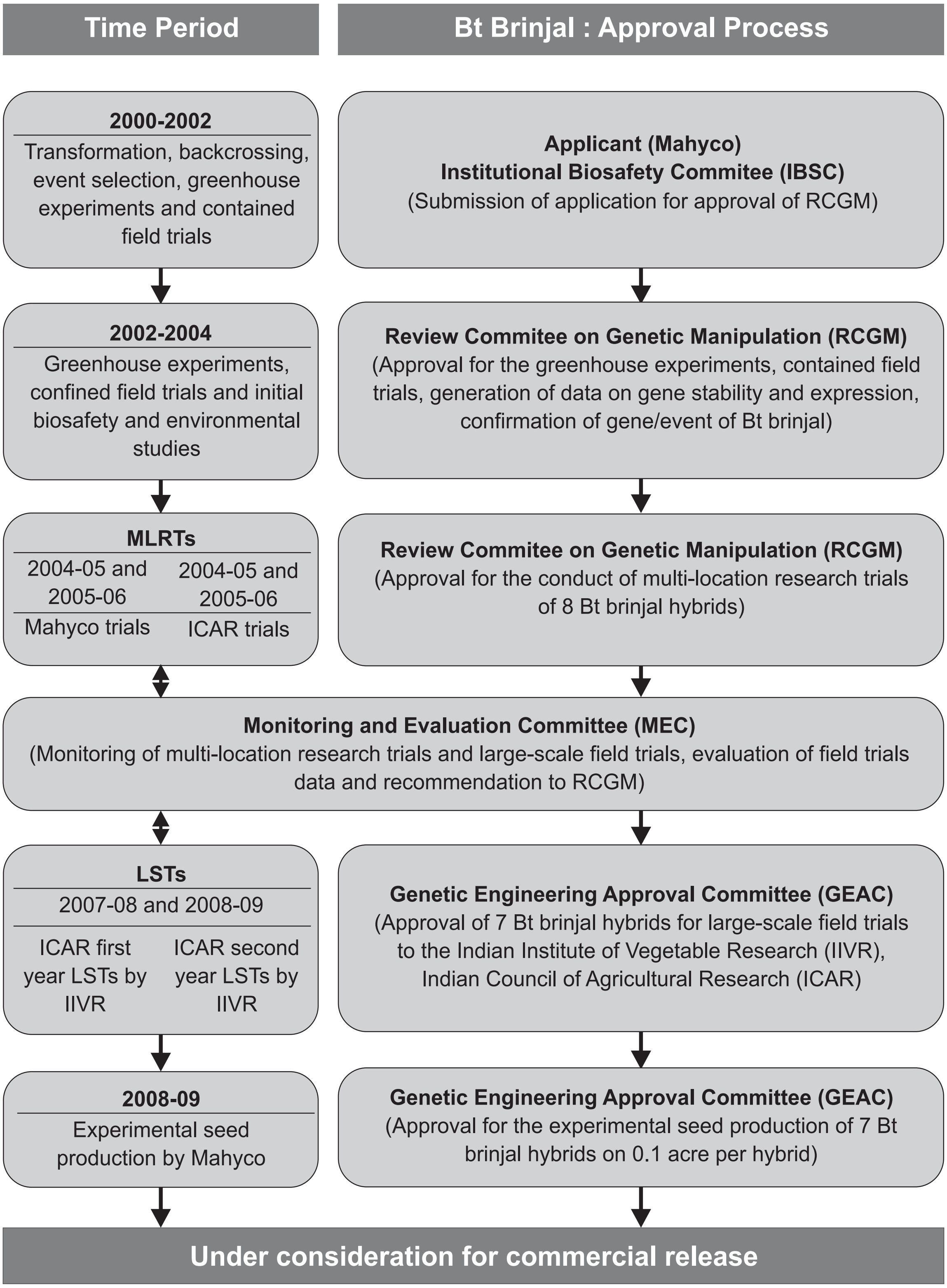
the Indian Institute of Vegetable Research (IIVR), Varanasi, of the Indian Council of Agricultural Research (ICAR). The trials should be conducted under the direct supervision of the Director, IIVR.

- The protocol for field trials shall be designed by the Indian Institute of Vegetable Research, Varanasi in consultation with the Review Committee on Genetic Manipulation.
- Socio-economic studies as prescribed by the three members committee on socio-economic impact of Bt brinjal shall be conducted.
- Additional toxicity, allergenicity and nutritional studies, if any, as recommended by Director, National Institute of Nutrition (NIN), Hyderabad, of the Indian Institute of Medical Research (ICMR), Ministry of Health and Family Welfare (MoH&FW) may be conducted.
- Additional studies prescribed by the 'Expert Committee' shall be conducted, and
- All field trials shall strictly comply with the Supreme Court order dated 8 May 2007 as mentioned earlier.

Based on GEAC directive, the Indian Institute of Vegetable Research accepted the responsibility of undertaking large-scale field trials for assessing the environmental safety and agronomic advantages of Bt brinjal. These trials conducted at a minimum of 10-11 locations for two seasons representing different agro-climatic zones. Accordingly, the Indian Institute of Vegetable Research developed protocols for conducting these trials in consultation with the Review Committee on Genetic Manipulation. The first year large-scale field trials were conducted in the *rabi* season of 2007-08, and second year trials were conducted in the *kharif* season in 2008-09. The data generated for both the trials was monitored by the Monitoring and Evaluation Committee for submission to GEAC. Assigning the large-scale field trials to the Indian Institute of Vegetable Research was a step forward in the direction of developing a new regulatory procedure through a public-private partnership mode. This new arrangement would strengthen public-private partnership for developing and regulating GM crops in India. At the same time, it would also help in building public confidence in the existing regulatory system.

Keeping in view the results of large-scale field trials, GEAC in its 85 meeting held on 28 May 2008 approved experimental seed production of 7 Bt brinjal hybrids, MHB-4 Bt, MHB-9 Bt, MHB-10 Bt, MHB-11 Bt, MHB-39 Bt, MHB-80 Bt and MHBJ-99 Bt (GEAC 85 Meeting). Mahyco conducted the experimental seed production on 0.5 acre per hybrid as per the protocol approved by IIVR at its research farm located at Jalna, Maharashtra in the *kharif* season of 2008-09. The Director, Horticulture Research and Director (Research) of the State Agriculture University (SAU) located in proximity to the experimental seed production area facilitated monitoring and supervision of the trial as per GEAC directive. The experimental seed production is a penultimate step in the regulatory procedure for commercialization of GM crops. Therefore, it is anticipated that Bt brinjal hybrids would be approved for commercial cultivation in the near future.

Figure 19. Protocol followed for regulatory approval of Bt brinjal, 2000 to 2008



(Source: Compiled by ISAAA, 2008)

8.2 Food safety and nutritional assessment

The Review Committee on Genetic Manipulation (RCGM) is the statutory body under the EPA Rules 1989 which is housed in the Department of Biotechnology. RCGM guides, oversees and reviews the biosafety, food safety and nutritional concerns related to genetically modified crops on a case-by-case basis. It also recommends the outcome of safety studies to GEAC for its consideration. In this regard, RCGM has developed the guidelines and protocols in consultation with the Indian Council of Medical Research (ICMR). Way back in 1990, RCGM formulated a standard safety document called 'Recombinant DNA safety guidelines' which was subsequently revised in 1994. To assess the unintended effects of GM crops, RCGM also introduced 'Guidelines for toxicity and allergenicity evaluation' in 1998 which were again revised as 'Guidelines for the safety assessment of food derived from genetically engineered plants, 2008'. A list of guidelines and protocols to address safety concerns is highlighted in Table 17 (DBT, 2007, 2008a, 2008b, 2008c). These guidelines and protocols have been prepared to address key elements of the safety assessment of food and livestock feeds that may be derived from GM crops (Indian Biosafety Rules and Regulations, 2008; IGMORIS, 2008).

As regard to Bt brinjal, the safety testing for Bt protein was based on the presumption that there is unlikely to be a problem as a number of Bt proteins have been widely used for many years in microbial sprays and in other biotech crops without any incidence of human toxicity. Nevertheless, Bt brinjal was subjected to various human health and animal feed tests as categorized in Table 19.

Table 19. Standard categories of human health testing

Health- effects assessment	Human safety assessment
• Mammalian testing • Digestibility assessment • Allergenicity testing • Homology with known food allergens and toxins	• Compositional analysis • Nutritional assessment (concentrations and effects on bioavailability) • Unexpected or unanticipated effects • Dietary exposure assessment • Determination of substantial equivalence • Animal-feed consideration

(Source: American Academy of Microbiology, 2002; National Academy of Press, 2001)

It is concluded that Bt protein in all Bt plants and sprays registered for food consumption break-down rapidly in simulated digestive systems, do not resemble any known food allergen or protein toxin and have no oral toxicity, even when administered in high doses. Laboratory tests have failed to show toxicity of Bt protein to birds, fish and invertebrates, including earthworms (American Academy of Microbiology, 2002). Nevertheless, a number of defined safety tests are needed to determine potential impact on human and animal health based on plant modification of the proteins, or based on the use of Bt protein. So, Bt brinjal was subjected to toxicity, allergenicity and feeding tests from 2003 to 2008, which included acute, sub-chronic and chronic testing. More precisely, Bt brinjal was tested on fish, chicken, rabbit, rats, goats and cows. No signs of toxicity were reported in the toxicity tests. Bt brinjal was also tested to ascertain that it contains no new allergenic compounds and is non-allergenic. The foliage and fruit feeding studies were undertaken in goat and cow. Other studies included protein expression and quantification, substantial equivalence and protein estimation in cooked food. All these studies concluded that Bt protein expressed by *cry1Ac* gene in brinjal causes no adverse effect when consumed by domestic and wild animals, non-target organisms and beneficial insects (Mahyco, 2008b). This confirms that Bt protein is absolutely safe for human consumption. The detailed analysis of various studies on toxicity, allergenicity and nutritional composition and feeding is available on GEAC website at: http://www.envfor.nic.in/divisions/csurv/geac/bt_brinjal.html. A brief summary of toxicity, allergenicity, food and feed safety evaluation is given in Table 20.

Table 20. Summary of toxicity and allergenicity assessment and nutritional studies

Year	Study	Result	Institute/Location
2003	Acute oral toxicity studies in Sprague Dawley rats.	Acute oral administration of Bt brinjal expressing cry1Ac protein to Sprague Dawley rats at the limit dose of 5000mg/kg showed that cry1Ac protein did not cause any toxicity.	Intox, Pune
2004	Mucous membrane irritation test in female rabbit.	Application of Bt brinjal to the vaginal mucous membrane of the female rabbit did not cause any erythema or edema as observed for 72 hours after application. Based on the average irritation index (0.0), Bt brinjal was classified as non-irritant to mucous membrane in rabbit.	Intox, Pune
	Primary skin irritation test in rabbit.	Bt brinjal applied to intact rabbit skin for 4 hours did not cause any skin reaction throughout the observation period. The irritancy index was zero. Bt brinjal proved non-irritant to skin in rabbit.	Intox, Pune
	Substantial equivalence (compositional analysis) studies.	The substantial equivalence studies confirmed that the chemical compositions in the fruit, leaf, stem and root tissues of Bt brinjal is similar to non-Bt brinjal. No statistical differences between Bt brinjal and non-Bt brinjal were observed in the chemical constituents in terms of moisture, proteins, oil, ash, carbohydrates and calories for fruit tissue and nitrogen, ash and crude fibre contents in leaf, stem and root tissues.	Mahyco Research and Life Sciences Centre (MRC), Kallakal, Andhra Pradesh
2005	Sub-chronic oral toxicity study in Sprague Dawley rats.	The sub-chronic study indicated no adverse effect on body weight gain and average food and water intake. The no-observed-adverse-effect-level (NOAEL) of Bt brinjal following oral administration for 90 days in Sprague Dawley rat was found to be more than 1000 mg/kg body weight. This demonstrated that Bt brinjal is non-toxic to Sprague Dawley rats by oral route.	Intox, Pune
	Assessment of allergenicity of protein extract using Brown Norway rats.	The study concluded that there were no biological differences between the allergenicity response to all Bt and non-Bt brinjal hybrids.	Rallis, Bengaluru

Year	Study	Result	Institute/Location
	Responses, as a dietary feed ingredient to common carp (fish-*Cyprinus carpio*) for evaluating growth performances.	The study showed that there were no significant differences in terms of growth patterns, food conversion ratio, feed efficiency ratio and protein efficiency ratio among different Bt and non-Bt brinjal meal fed to fish (common carp) for 45 days. Different treatments of Bt and non-Bt brinjal were statistically similar on the basis of isocaloric and isoproteinaceous feeds in terms of fish growth responses, and histopathological alterations in gill, liver, intestine and kidney tissues.	Central Institute of Fisheries Education (CIFE), Mumbai
	Food cooking and protein estimation in cooked fruit.	The results of the study revealed that Bt protein was undetectable in the cooked fruits at the first sampling time-point irrespective of the cooking method used (roasted, shallow-fried, deep-fried or steamed). The first sampling time-point was 5 min for roasted fruit and 1 min for other forms of cooking methods.	Mahyco Research and Life Sciences Centre (MRC), Dawalwadi, Maharashtra
2006	Sub-chronic feeding studies using New Zealand White rabbit.	The study showed that there were no significant differences between the rabbit groups fed with Bt brinjal and non-Bt brinjal fruits. Laboratory analysis of health, growth and physio-pathological parameters showed no significant differences.	Advinus Theraputic, Bengaluru
	Effect on performance and health of broiler chickens.	The study demonstrated that Bt brinjal is as safe as non-Bt brinjal in terms of responses of chickens fed with Bt brinjal diets. Results showed that body weight gain, feed intake and feed conversion ratio did not differ between the birds after addition of dried Bt and non-Bt brinjal in the trials at 5 or 10% levels of isocaloric diets. Various blood biochemical constituents did not differ statistically due to treatments of Bt and non-Bt brinjal diets.	Central Avian Research Institute (CARI), Izatnagar
	Sub-chronic feeding studies in goats.	The study concluded that there were no significant differences between the goat groups fed with Bt brinjal and non-Bt brinjal fruits based on the health, growth and physio-pathological parameters analyzed during the experiment.	Advinus Theraputic, Bengaluru
	Feeding studies in lactating crossbred dairy cows.	The study concluded that Bt protein was not detected in milk and blood of lactating cross-bred cows fed with Bt brinjal fruits. It was concluded that the nutritional value of both Bt brinjal and non-Bt brinjal fruits were similar in terms of feed intake, milk yield and milk constituents without any adverse affect on health of lactating crossbred cows.	G. B. Pant University of Agriculture and Technology (GBPUAT), Pantnagar

Year	Study	Result	Institute/Location
	Chemical fingerprinting of Bt and non-Bt brinjal (alkaloids).	The study involved isolation and identification of major alkaloids in fruits and roots of Bt and non-Bt brinjal hybrids. The alkaloid profile from powder samples of fruit and roots of Bt and non-Bt brinjal were the same with no significant variation in their relative abundances.	Indian Institute of Chemical Technology (IICT), Hyderabad
2004-2008	Protein expression studies.	The concentrations of cry1Ac protein in various tissues (root, shoot, stem, leaf, flower and fruit) were quantified. The levels of concentration were sufficient for effective control of FSB. All the hybrids over all locations stably expressed cry 1Ac protein well above the MIC_{95} value during the entire life of the Bt brinjal.	Mahyco Research and Life Sciences Centre (MRC), Dawalwadi, Maharashtra

(Source: Compiled by ISAAA, 2008; Mahyco, 2008a, 2008b)

9. Bt Brinjal - Environmental Concerns

9.1 Background

A comprehensive evaluation of the new technology in terms of its environmental impact that contributes towards sustainable agriculture forms an integral part of India's regulatory system for the approval of GM crops. A unique additional feature is to ensure that no GM crops is allowed for commercial release until its agronomic superiority is assessed vis-à-vis traditional best checks in farmers' fields. A series of open field trials are mandatory to meet regulatory requirements for agronomic performance once safety and efficacy has been established. The open field trials are divided into three categories: confined field trials; multi-location research trials known as MLRTs (now called Biosafety Research Level-I or BRL-I trials) and large scale field trials known as LSTs (now called Biosafety Research Level-II or BRL-II trials). These trials are spread over a period of 5-6 years. The initial information is generated based on laboratory and greenhouse trials in a contained environment with the permission of the Institutional Biosafety Committee (IBSC).

After the submission of preliminary biosafety data, the confined field trials are conducted under specific terms and conditions with the permission of the Review Committee on Genetic Manipulation (RCGM). These trials are conducted over a very small area, usually one hectare to select the elite event. The material produced is used for experiment purpose, biosafety and food safety studies in the close vicinity of research laboratory. One year multi-location research trials (MLRTs or BLR-I) are allowed on 1 acre per trial site and a maximum cumulative total of 20 acres. These trials are conducted either on the company research farm or on long leased farmers' fields. The locations of these trials are decided by RCGM for each plant/species/construct combination per application per crop season. The purpose of MLRTs is to carry out biosafety and environmental impact assessment studies. These studies include pollen escape, outcrossing, aggressiveness, germination and weediness, effect on non-target organisms, presence of targeted protein in soil, effect of targeted protein on soil micro-flora, baseline susceptibility studies and initial agronomic performance and other studies as required by RCGM. RCGM is empowered under the EPA Rules 1989 to review, analyze and suggest any other safety studies as decided by the committee.

Two year large-scale field trials (LSTs or BLR-II) are conducted on 2.5 acre per trial site. The number of locations is decided on a case-by-case basis for each plant species/construct combination per applicant per crop season. These trials are conducted to assess agronomic superiority and environmental impact under the norms as stipulated by GEAC. In addition, GEAC also assigns parallel multi-location and large-scale field trials under the All India Coordinated Program of the Indian Council of Agricultural Research (ICAR). This is to compare and validate field trials data submitted by the technology developer. Both the MLRTs (BLR-I) and LSTs (BLR-II) are closely monitored by the Monitoring and Evaluation Committee (MEC) - a statutory body under the EPA Rules 1989 (DBT, 2008a).

The greenhouse and confined field trials of Bt brinjal were undertaken during 2001 to 2003 at the Mahyco Research and Life Sciences Centre, Jalna, Maharashtra and at a few other important locations as prescribed by the regulatory bodies. These trials were conducted for the selection of elite event and assessing preliminary biosafety, food safety and environmental impact. The environmental impact studies were undertaken by Mahyco, the Indian Institute of Vegetable Research, and different public sector institutions and accredited private laboratories from 2001 to 2008. These included pollen flow, germination, aggressiveness and weediness, soil analysis covering effect on soil micro-biota and presence of cry1Ac protein in the soil, effect on non-target and beneficial insects and baseline susceptibility (Mahyco, 2008b). The major issues related to the effect of Bt brinjal on environment are briefly described below:

9.2 Centre of origin

Many botanists and taxonomists differ on the exact centre of origin of brinjal. There are reports that suggest South America is the centre of origin of the species of the genus *Solanum*, to which both potato (*S. tuberosum*) and brinjal (*S. melongena*) belong. It probably originated from the African wild species *S. incanum. S. melongena* was first domesticated in South-East China and taken to the Mediterranean region during the Arab conquests in the seventh century. There are also studies reporting that brinjal originated in the Indo-Burma region. If brinjal was mentioned in the ancient Indian literature, it only indicates that it was domesticated a long time ago, but this in itself is not an evidence of its origin in India. There is no doubt that India has contributed to its diversification through domestication and breeding. India may be a secondary centre of diversity while Africa may be the primary centre of diversity. It may be noted that cultivated brinjal (*S. melongena*) does not occur in the wild and is not weedy like other species of the genus (GEAC Minutes of Second Expert Committee, 2007). Given the contradictory research reports, the exact origin of cultivated brinjal is uncertain.

It is known that pollen transfer between *S. melongena* and other wild species of *Solanum* such as *S. insanum, S. incanum and S. integrifolium* is possible. However, Bt gene incorporated in brinjal, if at all transferred to wild species, will not confer any fitness advantage to the wild species because no major insects have been found feeding on them. It will also not benefit the wild species in terms of aggressiveness or growth characteristics. Further, no instances of natural inter-specific hybridization between the cultivated and wild species of brinjal have been reported so far. Nevertheless, keeping in view the concerns raised by certain NGOs and other stakeholders, the 'Expert Committee' on Bt brinjal recommended that out-crossing studies be conducted under confined conditions at one location by the Indian Institute of Vegetable Research, Varanasi, to check any possible successful cross-pollination and also weediness and invasiveness (GEAC Minutes of Second Expert Committee, 2007; Rao, 2008).

9.3 Pollen flow and gene transfer

The pollen flow studies are one of the important experiments to establish the pollen behavior of GM crop vis-à-vis its non-GM counterparts. These studies estimate out-crossing frequencies, determine the possibility of gene transfer in closely related species and assess weediness characteristics of GM crops. In case of Bt brinjal, all these studies were carried out as per the protocol approved by the regulatory authorities. These pollen flow studies were conducted at 12 locations in different zones during 2004-2006, 2007-08 and 2008-09. These studies showed that maximum distance travelled by pollen was between 15-20 meters and outcrossing varied from 1.46-2.7%. It also indicated that Bt brinjal does not show any weediness characteristics and behaves in a similar fashion as any of its non-Bt counterparts (Mahyco, 2008b).

The 'Expert Committee' noted that there are several species of *Solanum* that occur in the wild in India. In nature, species of *Solanum* do not normally hybridize, as they are predominantly (over 90%) self-pollinated. Anthers that open by small apical pores are the characteristic feature of the genus *Solanum,* unlike in many other plant species where the anthers open longitudinally to fully expose the pollen to air and pollinators. *Solanum* pollens are sticky and do not travel long distances even if they become airborne as observed in Bt brinjal pollen flow studies. Insects visit *Solanum* flowers but their role in pollination is insignificant as observed (GEAC Minutes of Second Expert Committee, 2007).

The 'Expert Committee' observed that many cytogeneticists have artificially produced inter-specific hybrids of *Solanum.* It was not so difficult to produce the first generation hybrids, but they generally suffered from chromosomal instability and pollen sterility, hardly resulting in any fertile progeny. The Random Amplification of Polymorphic DNA analysis (RAPD) has shown that *S. incanum* and *S. viarum* are closest to *S. melongena*. *S. incanum* and *S. viarum* occur infrequently in the wild in India, but are hardly sympatric and panmictic with the cultivated varieties. When artificial hybrids were produced, the progeny were sterile, leaving no chances for gene flow among these related species (GEAC Minutes of Second Expert Committee, 2007; Rao, 2008).

There are many cultivated varieties of brinjal in India, some of which are restricted to specific regions, as for example 'Udupi gulla' variety of Mangalore. Different cultivated varieties and hybrids of *Solanum melongena* co-exist. However, farmers and scientists are not conscious of any hybrids between two groups and no effort is made to protect different varieties of cultivated brinjal from hybridizing among themselves or with wild solanums. The floral structure and reproductive biology of brinjal and experience in cultivating them for several centuries in India, does not suggest any possibility of gene flow from transgenic brinjal to normal brinjal as observed by the 'Expert Committee'. However, as a precautionary measure, GEAC suggested assessing pollen flow on the weedy species of *Solanum* found in ruderal communities such as road side, vacant lands, agriculture fields and forest fringe (GEAC Minutes of Second Expert Committee, 2007). Table 21 illustrates the findings of the pollen flow studies conducted by Mahyco in collaboration with the Indian Institute of Vegetable Research.

Figure 20. Transgenic greenhouse facilities at TNAU, Coimbatore

(Source: ISAAA, 2008)

Table 21. Summary of environmental impact studies

Year	Environmental impact study	Impact	Location
2000-2001	Greenhouse evaluation	Growth and development of Bt brinjal was routinely monitored in all the greenhouse and field trials. The results confirmed that Bt brinjal does not exhibit any different agronomic or morphological traits as compared to non-Bt brinjal.	1 location
2001-2003	Pollen flow studies	Pollen flow studies noted that maximum distance travelled by pollen was 20 meters and and 15 meters at Jalna (Maharashtra) and Ranebennure (Karnataka), respectively. It was also found that 10 out of 681 and 18 out of 663 progenies showed the presence of the gene giving an out-crossing percentage of 1.46% and 2.7% at both the locations, thus indicating no possibility of gene transfer.	2 locations
	Germination, aggressiveness and weediness	Fields were monitored for three months after crop harvest and the results demonstrated that Bt brinjal does not show any aggressiveness or weediness. The study exhibited that Bt brinjal hybrids behave in a similar fashion as other non-Bt brinjal hybrids.	1 location
2004-2005 and 2007-08	Soil analysis	There were no differences between Bt and non-Bt brinjal plots vis-à-vis soil bacteria and fungal count, both at the rhizosphere and soil beyond the rhizosphere. Bt protein residue in the soil was not detected in any of the soil samples tested after the harvest of the crop. Also, no significant variation was observed in the population of soil invertebrates like earthworms and collembola.	8 locations
2004-2005 and 2005-06	Effect of Bt-protein on non-target organisms	The multi-location research trials involved the assessment of the effect of Bt brinjal on non-target pests (sucking pest, secondary lepidopterans) and beneficial insects of brinjal. The data collected from all the field trials conducted at various locations indicated no significant variation in the non-target sucking pest counts (aphids, jassids, white fly, leafhoppers and thrips) among Bt and non-Bt brinjal hybrids. The beneficial insects namely chrysopa, lady beetle and spiders were also observed to be active in both Bt and non-Bt brinjal crops. However, Bt brinjal may have positive effects on beneficial insects in long run with reduced usage of insecticides.	17 locations
	Baseline susceptibility study	Baseline susceptibility data revealed 12-fold variability in LC_{50} value of 29 populations tested for cry1Ac susceptibility. The field populations demonstrated 70-fold inter population variation in the insect susceptibility to the Cry1Ac protein indicated by MIC_{50}. The variability was 14-fold when MIC_{95} was considered and values ranged from 0.020-0.138 ppm of diet.	29 locations

Year	Environmental impact study	Impact	Location
		Average MIC_{95} was found to be 0.059ppm. There was 100% mortality among most populations at the highest concentration used in the bioassays. LC (lethal concentration) indicates mortality of insects and MIC is molt inhibition concentration.	
2007-08 and 2008-09	Pollen flow study Crossability of Bt brinjal with *S.incanum*	IIVR to submit data to GEAC IIVR to submit data to GEAC	10 locations 1 location
	Weediness and invasiveness	Completed in 2007-08 and 2008-09	1 location
	Baseline susceptibility study (2 seasons for 2 years)	Completed in 2007-08 and 2008-09	10 locations
	Soil impact assessment	Completed in 2007-08 and 2008-09	1 location

(Source: DBT, 2004, 2005; GEAC Minutes of Second Expert Committee, 2007; GEAC 79 Meeting; Mahyco, 2008b)

9.4 Soil impact assessment

The soil studies were conducted over 8 locations in two seasons in 2003-04 and 2004-05 by Mahyco. The Indian Institute of Vegetable Research conducted soil impact studies at 2 locations in 2007-08 and 2008-09. These studies covered different agro-climactic zones as per the protocol approved by the regulatory authorities and are indicated in Table 21. These studies also included analysis of Bt protein in soil at root-zone and non-root-zone as well as pre and post-harvest soil samples to assess impact on soil microflora and invertebrates.

The soil impact studies assessed the presence of Bt protein in soil at regular intervals in the rhizosphere and non-rhizosphere zones from plots where Bt brinjal plants and non-Bt brinjal plants were cultivated. The study was continued even after the crop was removed from the field at every 30 days interval. The study reported half-life of cry1Ac protein to be 9.3 to 40 days depending on the soil types. However, Bt protein was undetectable at all time-points in the study indicating that levels of protein in soil, if any, were below detectable levels. In addition, laboratory populations of the insect larvae were used for the bioassays and ELISA for detection of Bt protein in the soil. Both methods showed no detectable Bt protein in any of the samples tested. Similarly, non-target effects were analyzed for soil micro-flora and invertebrates. The root-zone and non-root zone samples were analyzed at all locations where soil impact studies were conducted. These studies observed no differences in soil micro-biota and invertebrate populations. Also, no differences were reported in cultivable bacterial and fungal populations, collembola and earthworm populations and soil nematode populations in Bt and non-Bt brinjal fields (GEAC Minutes of Second Expert Committee, 2007; Mahyco 2008b).

Based on the 'Expert Committee' recommendation, some studies were repeated to include tests on the counts related to *Rhizobium* in the soil of Bt vis-à-vis normal plots and for the presence/absence of cry1Ac protein at up to one meter depth in the soil at one location. It was also recommended to record changes in fertility and impact on next crop and also assess the impact of Bt brinjal on anti fungal metabolite (AFM) and earthworms in soils. These studies were conducted by IIVR in 2007-08 and 2008-09 during the large-scale field trials of Bt brinjal and the data was submitted to GEAC. A summary of the findings of the soil impact studies conducted by Mahyco in collaboration with Indian Institute of Vegetable Research is given in Table 21.

9.5 Impact on non-target organisms

The naturally occurring biological control agents play a significant role in the control of brinjal pests. These include predators like chrysopa, ladybeetle, spiders and parasitoids like *Trathala flavo-orbitalis*. It is reported that continuous spraying of insecticides to control FSB is harmful and kills these beneficial organisms. Unlike most insecticide sprays which kill more than just the target pest, evidence from Bt crops grown in other countries has shown a greater biodiversity of insects where such spraying is greatly reduced (ABSP II; Talekar, *et al.,* 2003). In this context, Bt brinjal offers greater advantage by controlling only the target insect and the reduced use of insecticide sprays allows beneficial insects to thrive.

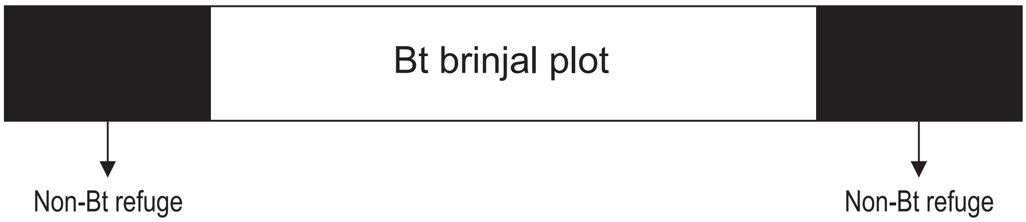
Given the importance of beneficial insects in brinjal crop, the regulatory authorities in India directed Mahyco to conduct studies on the effect of Bt protein on non-target organisms. These studies were conducted at 17 locations during multi-location research trials from 2004-05 to 2005-06. In addition, the soil impact assessment studies were undertaken at one location each by the Indian Institute of Vegetable Research during large-scale field trials in 2007-08 and 2008-09. These studies observed that beneficial insects such as chrysopa, lady beetles and spiders were active in both Bt and unsprayed non-Bt brinjal crops. It was also reported that Bt brinjal does not affect non-target sucking pests including aphids, jassids, white-fly, leafhoppers and thrips as well as secondary lepidopterans. Therefore, while Bt brinjal effectively takes care of FSB, it is advisable for farmers to use alternative methods to control other insect-pests as and when required (Mahyco, 2006, 2008b). A summary of findings of the studies on impact of Bt protein on non-target organisms conducted by Mahyco in collaboration with the Indian Institute of Vegetable Research is given in Table 21.

9.6 Insect resistance management against Bt insecticidal protein

Although Bt crops like Bt cotton and Bt corn have been cultivated on millions of acres in several countries year after year since 1996, there has not been any proven evidence of field resistance to Bt protein by any target pest anywhere in the world so far. While this is very encouraging, it cannot be taken for granted. History has revealed that many insect-pests have developed resistance to some of the deadliest chemical insecticides when exposed regularly. Therefore, this should be taken as a warning that they have the potential to develop resistance to Bt crops also in future. This calls for necessary precautionary measures to avert such an eventuality. This has been done for Bt cotton and Bt corn and the same needs to be also extended to Bt brinjal. In view of the above, proactive insect resistance management (IRM) strategies have been proposed to prevent or delay resistance development by FSB to Bt brinjal. Mahyco in collaboration with leading pest and insect resistance management researchers from academia, government and extension conducted various laboratory and field studies to evaluate strategies for managing the resistance. One of the proposed strategies is to deny resistant insects (FSB) opportunity to mate with other resistant insects (FSB), thereby preventing the creation of a resistant population. This can be achieved by ensuring that there are numerous susceptible insects in the vicinity to mate with the resistant-ones. This can be achieved by planting refuge crop (non-Bt crop) along with the Bt crop, in this case Bt brinjal, in a specified manner (Krattiger, 1996).

The insect resistance management (IRM) strategy proposed by Mahyco in consultation with TNAU, Coimbatore, UAS Dharwad, Cornell University, USA, the University of the Philippines, East West Seeds and Bangladesh Agricultural Research Institute (BARI) suggests a structured refuge in Bt brinjal field where 5% of the crop will be planted with non-Bt brinjal. This means that for every one acre planting of Bt plants there should be 0.05 acre of non-Bt plants as refuge. The implementation of proposed strategy will require farmers to plant a non-Bt bracket on two sides of the Bt brinjal field as illustrated in Figure 21. The refuge strategy is designed to ensure that Bt susceptible insects will be available to mate with Bt resistant insects, resulting in Bt susceptible offspring, thus mitigating the spread of resistance in the population (Mahyco, 2006, 2008b).

Figure 21. Proposed IRM strategy for Bt brinjal



(Source: Mahyco, 2006, 2008b)

It is suggested to adopt stringent insect resistance management (IRM) strategies and to implement integrated pest management (IPM) techniques in order to delay the development of resistance to Bt protein in FSB. This would help increase the life span of Bt brinjal technology. In this direction, Mahyco has conducted preliminary studies in 2004-05 and 2005-06 and IIVR conducted the same in 2007-08 and 2008-09. These studies assessed and established the baseline susceptibility of FSB population to Bt protein. These studies would continue every season even after the commercialization of Bt brinjal. The key studies designed to delay the development of resistance against Bt protein are highlighted in Table 22.

Table 22. Proposed IRM strategies

IRM strategy	Measure
Monitoring for baseline susceptibility	Monitoring for baseline susceptibility is to alert for potential failure in the field due to resistance and detect lower expression level of Bt protein in the plant.
Resistance monitoring	Monitoring and surveillance is necessary to detect or follow resistance development in FSB.
Assessment of level of control	To ensure adequate control of the target pest.
Refuge design and placement	To implement refuge as the most promising and practical strategy to ensure long term resistance management.
Integrated pest management (IPM)	To encourage appropriate IPM strategy to address specific regional resistance management concerns.

Farmers' awareness programs	To organize field days and conduct educational and training programs for compliance of recommended practices.

(Source: Mahyco, 2006, 2008b)

Keeping in view the nature of technology, Bt brinjal would offer encouraging benefits. The expected benefits to ecology and environment are described below:

Benefits to ecology and environment

- Reduction in pesticide residues in soil and water in brinjal fields.
- Lesser pollution of air and local environment due to decreased use of insecticides.
- Protection of naturally occurring predators and parasitoids and other beneficial organisms due to reduced use of insecticides.
- Reduction in soil and ground-water contamination.
- Safeguarding soil microflora and invertebrates from damage caused by unintended and excessive use of insecticides.

Figure 22. Large-scale field trials for evaluation of Bt brinjal hybrids, MAU, Parbhani

(Source: ISAAA, 2008)

10. Bt Brinjal - Socio-Economic Implications

10.1 Agronomic performance

A large number of field trials and studies were conducted from 2004 to 2008 to ascertain the agronomic benefits of Bt brinjal hybrids vis-à-vis non-Bt counterparts in different agro-climatic zones. These studies were undertaken by two organizations, Mahyco and All India Coordinated Vegetable Improvement Program (AICVIP) of the Indian Council of Agricultural Research (ICAR). These studies were conducted to comply with regulatory requirements that stipulate two years of multi-location research trials (MLRTs) and two years large-scale field trials (LSTs) in addition to the greenhouse experiments and confined field trials.

Accordingly, Mahyco conducted two years of multi-location research trials for 5 Bt brinjal hybrids, MHB-4 Bt, MHB-9 Bt, MHB-10 Bt, MHB-80 Bt and MHBJ-99 Bt, at 11 locations in 2004-05 and 2005-06. Simultaneously, AICVIP conducted the first year multi-location research trials at 12 centres in 2004-05. The second year AICVIP trials for 5 Bt brinjal hybrids were conducted at 11 centres in 2005-06. In 2005-06, AICVIP also conducted multi-location research trials for additional 3 Bt brinjal hybrids, MHB-11 Bt, MHB-39 Bt and MHB-112 Bt, at 6 locations and these were repeated in 2006-07 as noted in Table 24. These trials were conducted at locations representative of the major brinjal growing states in India.

The Genetic Engineering Approval Committee (GEAC) directed the Indian Institute of Vegetable Research (IIVR) to conduct two years of large-scale field trials of 7 Bt brinjal hybrids namely MHB-4 Bt, MHB-9 Bt, MHB-10 Bt, MHB-11 Bt, MHB-39 Bt, MHB-80 Bt and MHBJ-99 Bt in 2007-08 and 2008-09. IIVR is a premier vegetable research institute of the Indian Council of Agricultural Research (ICAR), Ministry of Agriculture, Government of India which is located in Varanasi, Uttar Pradesh. IIVR conducted the first year large-scale field trials (LSTs) at 11 centres located in different vegetable growing zones in the *rabi* season in 2007-08 which were repeated in the *kharif* season of 2008-09. The first year large-scale field trials in 2007-08 generated very promising results of Bt brinjal hybrids in controlling the fruit and shoot borer and increasing gross and marketable yield as compared with non-Bt counterparts and national best check (Pusa Hybrid-6). The first year LSTs data indicated a substantial difference in fruit infestation levels between the Bt brinjal hybrids, non-Bt counterparts and national best check Pusa Hybrid-6. Across all locations, the mean fruit infestation during the peak infestation period was 3.52% in Bt brinjal hybrids compared to 23.30 % in non-Bt counterparts and 35.55% in national best check. Overall, the cumulative mean fruit infestation was observed to be very low at 1.76% in Bt brinjal hybrids compared to 12.23% in non-Bt counterparts and 15.06% in national best check. Thus, on average the fruit damage was 7-fold less in Bt brinjal hybrids compared to its non-Bt counterparts and 8.5-fold less than national best check. Incidentally, the fruit infestation rarely crossed economic threshold limit (ETL) in Bt brinjal hybrids compared to 5 times each in non-Bt brinjal hybrids and national best check. A marked difference was also observed in the levels of shoot infestation with mean shoot infestation varing between 0-1.56% in Bt brinjal hybrids compared to 0-6.96% in non-Bt counterparts and 0-11.17% in national best check. Therefore, Bt brinjal hybrids demonstrated a high degree of resistance to fruit and shoot borer.

Notably, these results confirmed 98% control of FSB in shoots and up to 100% control in fruits at various locations. All 7 Bt brinjal hybrids tested at 11 locations out-yielded their non-Bt counterparts and national best check. It was noted that the marketable yield of Bt brinjal hybrids was substantially higher in locations where the pest infestation was comparatively high, which suggests that Bt technology was effective in controlling FSB. The mean marketable yield of 7 Bt brinjal hybrids was 32.93 tons per hectare compared to 26.28 tons per hectare of non-Bt counterparts and 25.15 tons per hectare of national best check. The mean marketable yield increased by 25% and 31% compared to non-Bt counterparts and national best check respectively as highlighted in Table 23.

Table 23. Summarized results of first year large-scale field trials (LSTs) with Bt brinjal hybrids conducted by IIVR/ICAR, 2007 to 2008

Field Trials	Mean marketable yield (tons/ha)			Increase in marketable yield over	
	Bt brinjal hybrids	Non-Bt counterparts	National best check (Pusa Hybrid-6)	Non-Bt counterparts	National best check (Pusa Hybrid-6)
2007-08	32.93	26.28	25.15	25%	31%

(Source: IIVR, 2008)

The results from multi-location research trials conducted by Mahyco revealed that Bt brinjal hybrids suffered significantly less damage due to fruit and shoot borer when compared with its non-Bt counterparts and the best hybrid check. These studies showed a significantly lower number of FSB larvae on Bt brinjal, 0-20 larvae, as compared to 3.5-80 larvae on non-Bt counterparts. Notably, the percent damage to shoots was considerably lower for Bt brinjal hybrids as compared to non-Bt hybrids. The efficacy studies demonstrated that Bt brinjal is highly effective with insect mortality of 98% for FSB as compared to less than 30% mortality in non-Bt brinjal shoots. The fruit bioassay results demonstrated mortality rates of FSB larvae upto 100% in Bt brinjal fruits. The studies observed no differences between Bt and non-Bt brinjal fruit when evaluated for their physical characters including shape, size and color.

The agronomic performance studies indicated that on average, the amount of insecticides used to control FSB was reduced by 80% which translated to 42% reduction in total insecticides sprayed on Bt brinjal. These studies also exhibited an average increase in marketable yield by 100% over its non-Bt counterpart hybrids, 116% over popular hybrids and 166% over popular

Table 24. Summarized results of the agronomic performance in the different field trials conducted by Mahyco and IIVR

Year	Study	Impact	Location/ Centre
2004-05	Mahyco first year multi-location research trials for five hybrids (MHB-4 Bt, 9, 10, 80, 99)	Bt brinjal hybrids suffered significantly less damage due to FSB when compared with non-Bt counterparts and the best hybrid check. Bt brinjal hybrids provided adequate level of tolerancel to FSB and showed good yield potential. Percent increase in marketable yield in Bt brinjal hybrids over non-Bt counterparts was found to be in the range of 100 to 166%.	11 locations
	ICAR first year multi-location research trials with five hybrids (MHB-4 Bt, 9, 10, 80, 99) under AICVIP	Marketable yield in Bt brinjal hybrids was found to be in the range of 19.95 to 33.78 tons per hectare. Average marketable yield across different Bt brinjal hybrids tested was 24.69 tons per hectare as against 21.31 tons per hectare in popular check hybrid.	12 centres
2005-06	Mahyco second year multi-location research trials for five hybrids (MHB-4 Bt, 9, 10, 80, 99)	Bt brinjal hybrids provided adequate level of tolerance to FSB and showed good yield potential. Percent increase in marketable yield in Bt brinjal hybrids over non-Bt counterparts and popular check were found to be in the range of 19 to 264 and 7 to 658% respectively. Bt brinjal hybrids also showed a significantly lower damage resulting from FSB infestation in comparison to non-Bt brinjal.	6 locations
	ICAR second year trials with five hybrids (MHB-4 Bt, 9, 10, 80, 99) under AICVIP	Marketable yield in Bt brinjal hybrids was found to be in the range of 17.6 to 31.3 tons per hectare. Average marketable yield across different Bt brinjal hybrids evaluated was 23.2 tons per hectare as against 15.7 tons per hectare in non-Bt counterparts and 18.2 tons per hectare in popular check hybrid.	11 centres
	Mahyco first year trials with additional three hybrids (MHB-11 Bt, 39 and 112)	Not available	11 locations
	ICAR first year trials with additional three hybrids (MHB-11 Bt, 39 and 112) under AICVIP	Marketable yield in Bt brinjal hybrids was found to be in the range of 19.8 to 24.6 tons per hectare. Average marketable yield across different Bt brinjal hybrids evaluated was 22.3 as against 19 tons per hectare in non-Bt counterparts and 19.3 tons per hectare popular check hybrids.	11 centres

Year	Study	Impact	Location/ Centre
2006-07	Mahyco second year trials with additional three hybrids (MHB-11 Bt, 39 and 112)	Not available	11 locations
	ICAR second year trials with additional three hybrids (MHB-11 Bt, 39 and 112) under AICVIP	Not available	11 locations
2007-08	ICAR first year large-scale field trials of 7 Bt brinjal hybrids were undertaken by the Indian Institute of Vegetable Research (IIVR), Varanasi	Study completed, report submitted to GEAC by IIVR	11 centres
2008-09	ICAR second year large-scale field trails of 7 Bt brinjal hybrids were undertaken by the Indian Institute of Vegetable Research (IIVR), Varanasi	Study completed, report to be submitted to GEAC by IIVR	11 centres
2008-09	Experimental seed production of 7 Bt brinjal hybrids: MHB-4 Bt, MHB-9 Bt, MHB-10 Bt, MHB-11 Bt, MHB-39 Bt, MHB-80 Bt and MHBJ-99 Bt, on 0.5 acres each hybrid as per the protocol approved by the IIVR/ICAR and other conditions of seed production as stipulated by GEAC	Experimental seed production in progress	1 location

(Source: DBT, 2004, 2005; GEAC 79 Meeting; Mahyco, 2006, 2008b)

OPVs. Using contingent valuation technique, Krishna and Qaim (2007, 2008) reported net benefit ranging from Rs. 16,299 to Rs 19,744 per acre from Bt brinjal hybrids ($370 to $440 per acre). Table 25 gives the results of the multi-location research trials of Bt brinjal hybrids conducted by Mahyco from 2004-05 to 2005-06.

Table 25. Summarized results of multi-location research trials with Bt brinjal hybrids conducted by Mahyco, 2004 to 2006

Field Trials	Reduction in insecticide use		Increase in fruit yield over					
	For FSB (%)	For all insect-pests (%)	Non-Bt counterparts		Popular hybrids		Popular OPVs	
			Yield Increase (tons/ha)	%	Yield Increase (tons/ha)	%	Yield Increase (tons/ha)	%
2004-05 (n=9)	80	44	29.4	117	28.4	120	35.9	179
2005-06 (n=6)	79	40	–	76	–	110	–	147
Average	80	42	–	100	–	116	–	166

(Source: Mahyco, 2008b; Krishna and Qaim 2007a, 2007b, 2008)

Similarly, the results of multi-location research trials conducted under AICVIP of ICAR in 2004-05 and 2005-06 indicated that Bt brinjal hybrids outperformed their non-Bt counterparts and popular hybrids. The results also confirmed significantly less FSB larvae on Bt brinjal hybrids compared to their non-Bt counterparts. This allowed Bt brinjal hybrids to bear tender and healthy shoots and save fruits from damage resulting in a large positive yield effect. Noticeably, the number of damaged fruits was considerably lower in Bt brinjal hybrids compared to their non-Bt counterparts in all the field trials conducted by AICVIP and IIVR. Table 26 highlights a 77.2% reduction in insecticides used to control FSB and a 41.8% total reduction in pesticides. The marketable yield increased by 133.6% over its non-Bt counterparts which was more than double in most cases.

ABSP II projections indicate that the potential benefits that the technology offers to resource-poor farmers in India are significant and include the following: a 45% reduction in the number of insecticide sprays, with positive implications for health, and environment and a significant reduction in production costs; a 117% increase in yield with implications for more affordable vegetables; an estimated US$411 million per annum increase in net benefits to Indian brinjal

Table 26. Summarized results of multi-location research trials with Bt brinjal hybrids conducted by AICVIP/ICAR, 2004 to 2006

Field Trials	Reduction in insecticide use (%)		Increase in fruit yield (%) over	
	For FSB	For all insect-pests	Non-Bt counterparts	Popular hybrids
2004-05	80.0	40.4	154.2	–
2005-06	74.5	43.2	113.0	214.2
Average	77.2	41.8	133.6	–

(Source: AICVIP, ICAR, 2007)

farmers and consumers at the national level (ABSP II, 2007; James, 2007), which could make a contribution to the alleviation of poverty by increasing the income of resource-poor farmers growing brinjal and provide a more affordable source of vegetables for consumers. Another study conducted by Tamil Nadu Agricultural University projects benefits similar to the study conducted by ABSP II. The Tamil Nadu Agricultural University study is on the "Economic and environmental benefits and costs of transgenic crops: Ex-ante assessment" estimates the enormous benefits, welfare and distribution effects of Bt brinjal at national level. The net estimated benefit of Bt brinjal to Indian farmers and consumers ranges from US$25-142 million per annum assuming only 10% adoption of Bt brinjal in the first year of commercialization (Ramasamy, *et al.,* 2007).

With the outstanding performance of Bt technology, as demonstrated by Bt cotton, it is expected that Bt brinjal hybrids will also be adopted by the vegetable farmers with more or less equal enthusiasm. Bt brinjal is resistant to FSB and will allow farmers to bring down insecticides consumption significantly as described earlier. This will not only help farmers to improve marketable yield by saving losses caused to fruits by FSB but also reduce pesticide residues in harvested Bt brinjal fruits and farmers' exposure to insecticides.

10.2 Benefits to farmers

Farmers are expected to benefit at multiple levels. Some of these include:

- Considerable reduction in cost of production by saving on cost of insecticides and lower labor cost as a result of reduced spraying.
- Manifold increase in yield per unit area by saving fruits from damage caused by FSB.
- Significant improvement in marketable fruits thereby increasing income per unit area.
- Reduction in direct exposure to insecticides leading to lesser health problems. Undoubtedly, it offers invaluable health benefits to farmers.

While there may be need for using a small amount of insecticides for control of FSB, farmers may have to use the same for control of other insect-pests not controlled by Bt brinjal.

(Ramasamy, *et al.,* 2007; Chong, 2005; Krishna and Qaim, 2007b and 2008; GEAC 79 Meeting; GEAC 85 Meeting)

10.3 Benefits to consumers

It is evident from the history that the technological changes in agriculture have contributed significantly to yield improvement and growth in production. As a result, there has been a considerable increase in farm income at the national level that has benefited both farmers and consumers. The most noticeable technological change in agriculture was the introduction of high-yielding open pollinated varieties (OPVs) along with the quality farm inputs such as fertilizers and chemicals in the late 1960s. This was followed by hybrid seed technology in 1980s, deployment of varieties/hybrids resistant to diseases and pests in 1990s and introduction of Bt technology in cotton in 2002. A classical example of technological change in cotton that led to doubling of cotton yield is highlighted in Table 27.

Table 27. A classical example of technological change in cotton

Year	Introduction of technology in cotton
1950s-60s	Improvement of desi cotton.
1960s-70s	Introduction of *Gossypium hirsutum* varieties of cotton.
1970s-80s	Deployment of cotton hybrids developed from intra-species and interspecies combinations.
1980s-90s	Introduction of pyrethroide based insect control mechanism.
2002-2008	Commercialization of Bt technology (with single as well as stacked genes) in cotton hybrids.
2010 Onwards	A milestone year to introduce Bt technology in other crops and also efficient weed management technology, improvement of fibre quality and development of drought tolerant crops.

(Source: Mayee, 2008)

Noticeably, the hybrid vigor technology has been exploited in several vegetable crops. The Indian Institute of Horticultural Research (2008) reported a sizeable increase in yield up to 50% in brinjal, 75% in tomato and 25% in onion that was attributed to the hybrid technology. Bt technology coupled with the hybrid technology would further boost marketable yield and contribute to welfare of small farmers who may get an additional income around Rs. 20,000 (or

$450) per hectare per season. Table 28 showcases the adoption of hybrid technology by vegetable farmers in India.

Table 28. Adoption of hybrid technology by vegetable farmers in India, 2005 to 2006

Vegetable	Area (million ha)	% Hybrid	Production (million tons)	Yield (tons ha)
Brinjal	0.55	50	9.14	16.5
Cabbage	0.26	90	5.92	22.1
Cauliflower	0.29	33	5.26	18.0
Okra	0.37	60	3.68	9.8
Onion	0.69	5	9.25	13.3
Peas	0.31	-	2.29	7.3
Potato	1.55	-	29.09	18.8
Sweet potato	0.13	-	1.14	8.9
Tapioca (Cassava)	0.25	-	7.92	31.4
Tomato	0.53	90	9.36	17.5
Other	2.19	-	25.97	11.8
Total	7.16	-	109.05	

(Source: NHB, 2008; Seed Industry, 2008)

Most progressive farmers in India have been using hybrid seed technology for many years. There is a well established private sector that caters to the demand of hybrid vegetables along with well known public sector institutions involved in developing and commercializing different varieties and hybrids. The early adoption of hybrid vegetables has resulted in higher yield and production. However, Indian vegetable sector has to go a long way to catch up with advances in the vegetable sector worldwide. India ranks second in vegetable production as it has over 7 million hectares - one of the largest areas under vegetables production in the world. Nevertheless, most of the vegetables available in market are out of reach for the common man as a result of skyrocketing prices. It has been reported in the Rajya Sabha- the Upper House of the Parliament of India - that per capita availability of vegetables in the country is 190 gm per day as against the ideal requirement of 280 gm per day per person. Thus, there is a vegetable deficit of 90 gm per day per person, which means the need for substantial increase in production to meet minimum daily vegetable requirements. The biggest challenge is not only to bridge the gap but also to produce more to feed a rapidly increasing population. Therefore, innovation in agriculture, adoption of improved seed and crop technologies, advanced farm practices, integrated warehousing with cold chains and reduction in transportation losses are key measures to doubling production in vegetable sector. This will enable us to meet ideal per capita requirement and also cater to the ever-increasing demands for quality vegetables (Rajya Sabha, 2003, 2006).

Benefits to consumers and society:

- Consumers will have a choice to buy non-infested, undamaged and good quality brinjal fruits.
- Different studies have showed high levels of pesticide residues in a large number of vegetables that we eat daily. Sometimes, as large as 10% of the samples contained pesticide residues higher than the maximum permissible residual limit (MRL) prescribed under the Prevention of Food Adulteration Act, 1954 of the Ministry of Health and Family Welfare. Bt brinjal will offer consumers fruits with almost no or significantly reduced level of pesticide residues, well within the prescribed MRL.
- More affordable brinjal fruits in the market - it is expected that Bt brinjal may improve marketable yield manifold resulting in availability of more brinjal in the market at affordable price. Krishna and Qaim (2007) predicted a 15% decrease in market price of brinjal at maximum technology adoption.
- The Indian Institute of Horticultural Research (IIHR) projects that yield loss due to FSB reduces marketable yield, and price fluctuation is a major constraint in brinjal production. It is expected that Bt brinjal would help stabilize the market price (IIHR, 2008).

Figure 23. Farmers' market, Coimbatore

(Source: ISAAA, 2008)

11. Looking Ahead

Improved seeds have been a key contributing factor for growth in agricultural crop production in India during the last 5 to 6 decades. There have been three major developments in improved seed and crop technologies in the 60 years of independence which have changed the Indian agricultural landscape and contributed to food security for the ever-growing population of the country which is expected to increase from the present 1.1 billion to about 1.4 billion by 2026. The first was deployment of high-yielding self-pollinated varieties of important food-grain crops, particularly the semi-dwarf wheat and rice of the Green Revolution in the 1960s and 1970s. The second was the introduction of hybrid seeds, primarily in vegetable crops such as tomato, capsicum, brinjal, bottlegourd, okra and chilli, and also in some field crops such as corn, sorghum, pearl millet and cotton in the 1980-90s. The third development was in 2002, with the commercialization of Bt technology in the fibre crop cotton which is a very important cash crop in India, touching the lives of 60 million people, or more. Now the focus is on other pest-prone vegetable and food crops to control insect infestation and increase yield. Importantly, one common element in all of the changes has been the willingness of farmers to change and adopt the new technologies in order to overcome production constraints and increase their income to sustain their livelihoods. Indian farmers have always been receptive to new technologies as and when they were made available to them, though the pace of introduction of new technologies has been abysmally slow in agriculture as compared to other sectors.

The rapid progress in advanced biology in the last two decades has opened new opportunities to introduce new technologies in agriculture. The tools of biotechnology allow a better understanding of the function of genes and their introduction and expression in a diverse range of crops. This offers an exciting opportunity to solve a multitude of problems in agriculture. It is the right time to leverage biotechnological breakthroughs to transform agriculture and crop production in India. The trend, to date, has been commercialization of the first generation insect-resistant or herbicide tolerant traits mainly in fibre and oil crops such as cotton, soybean and canola and in the important field/feed crops, such as corn. Bt crops are the first generation biotechnology products that help plants to repel insect-pests. The single gene Bt crops control one targeted pest where as the stacked (multiple) gene Bt crops control more than one targeted insect-pest. Thus, Bt crops relieve farmers of the burden of spraying insecticides to control targeted insects, coincidentally reduce farmers' exposure to insecticides and minimize the risk of pesticide residues in marketable fruits. Since 1996, Bt for insect resistance along with herbicide tolerance (HT) traits have been successfully deployed in biotech crops in over 20 countries around the world. The second-generation biotech crops that are being developed go beyond insect control to confer tolerance to abiotic stresses and improved quality attributes (Burrill and Company, 2008). More specifically these new biotech crops will confer tolerance to the very important abiotic stresses of drought and salinity, increase efficiency of nitrogen usage, provide in-built resistance to multiple insect-pests, ensure efficient management of weeds, and enhance the nutritional content of crops such as golden rice with higher levels of vitamin A.

In India both public and private sector institutions have been involved in the R&D of biotech vegetables and food crops, this balanced contribution from the two sectors is very important given that, national food security is a strategic issue. There are two main reasons why there has been so much emphasis on the development of biotech vegetable crops. Firstly, insect-pests such as fruit and shoot borer (FSB) in brinjal, fruit borer in okra and tomato and diamond back moth (DBM) in cauliflower and cabbage are unmanageable with the available conventional technologies and, moreover, they significantly reduce the yield of marketable fruits. Secondly, pesticide residues in fruits and vegetables often exceed the permitted limits and there is no effective means to reduce them to an acceptable level. This might lead to long term health implications for farmers and consumers.

Bt technology deployed in various crops has proved safe for food and feed purposes and has been effective in controlling target insects globally in corn and cotton over the last twelve years. In addition, Bt has a long history of use in spray formulations over the last 40 years and is considered a safer pesticide because it is highly specific for targeted insect-pest. Many academies of science and international institutions, based on scientific evidence have confirmed that Bt protein in all Bt crops and sprays registered for food consumption break-down rapidly in digestive systems, do not resemble any known food allergen or protein toxin and have no oral toxicity, even when administered in high doses. Bt crops have not had any known significant harmful effects on mammals since they were first commercialized in 1996. Many rigorous studies have confirmed that the toxicological database on Bt shows no mammalian health effects attributable to Bt protein and that the use of Bt as an insecticide and in Bt crops has proven safe to non-target organisms, animals and human beings (USEPA, 1998; American Academy of Microbiology, 2002; Mahyco, 2006; OECD, 2007; Soberon and Bravo, 2008).

India has experienced remarkable success with Bt cotton. Apart from safety and benefits to human beings and environment, Bt cotton has also contributed to a more sustainable agriculture. Bt technology offers unprecedented benefits and there has not been credible evidence to the contrary in relation to safety of animals and human health. Almost 4 million Bt cotton farmers in India have accepted and demonstrated their full confidence and trust in Bt technology because of the consistent and significant multiple benefits that the technology offers. In this context, the development of Bt brinjal is an appropriate and timely step because it will extend the proven significant benefits of Bt from a fibre crop to a food crop that is important for farmers, consumers and Indian society at large. The adoption of Bt brinjal by farmers and consumers in India will be a very important experience from which India and the world can benefit enormously by better facilitating the harnessing of the immense power that biotechnology offers global society to: ensure an adequate supply of safe, more nutritious, and affordable food; mitigate some of the challenges associated with global warming; and contribute to the alleviation of poverty and hunger in India and other developing countries of the world.

List of vegetable improvement programs/centres in India

No.	Institute/university	Division/ centre	Address	Contact person
1	Acharya N.G. Ranga Agricultural University (ANGRAU)	Faculty of Agriculture	Rajendranagar, Hyderabad-500030 Andhra Pradesh	Dr. P. Raghava Reddy
2	Allahabad Agricultural Institute (AAI)	Department of Horticulture	Naini Allahabad-211007 Uttar Pradesh	Dr. D. B.Singh
3	Anand Agricultural University (AAU)	Vegetable Res. Station	College of Agriculture Anand-388001, Gujarat	Dr. K. B. Kathiria
4	Assam Agricultural University (AAU)	College of Agriculture	Jorhat-785013, Assam	Dr. S. S. Baghel
5	Bidhan Chandra Krishi Vishwa Vidyalaya (BCKVV)	Department of Vegetable Crops	P. O. Krishi Vishwavidyalaya, Mohanpur, Nadia-741252 West Bengal	Dr. T. Mukhopadhyay
6	Birsa Agricultural University (BAU)	College of Agriculture	P. O. Kanke Ranchi-834006, Jharkhand	Dr. A. K. Sarkar
7	CCS Haryana Agricultural University (CCS-HAU)	Department of Vegetable Science	College of Agriculture Hisar-125004, Haryana	Dr. B. S. Dudi
8	Central Agricultural University (CAU)	College of Horticulture and Forestry	Pashigat Arunanchal Pradesh	Dr. S. N. Puri
9	Central Agricultural Research Institute (CARI)	Vegetable Science	PB No. 181, Port Blair-744101 A&N Islands	Dr. Sharavan Singh
10	Central Institute for Subtropical Horticulture (CISH)	Crop Improve-ment and Production	Rehmankhera, P. O. Kakori, Lucknow, Uttar Pradesh	Dr. B. M. C. Reddy
11	Central Institute of Arid Horticulture (CIAH)	Division of Crop Improvement	Sri Ganganagar Road, NH-15, Beechwal, Bikaner, Rajasthan	Dr. D. G. Dhandar
12	Ch. Sarvan Kumar H. P. Krishi Vishwavidyalaya (CSKHPKV)	Department of Vegetable and Floriculture	College of Agriculture, Palampur-176062 Himachal Pradesh	Dr. N. K. Pathania
13	C.S. Azad University of Agriculture & Technology (CSAUAT)	Department of Vegetable Science	College of Agriculture, Kanpur-208002 Uttar Pradesh	Dr. J. R. Yadav
14	Dr. B. S. K. Krishi Vidyapeeth	Faculty of Agriculture Science	Dapol Ratnagiri-415712, Maharashtra	Dr. Vijay B. Mehta
15	Dr. Y. S. Parmar University of Horticulture and Forestry	Vegetable Crops	Solan-173230 Himachal Pradesh	Dr. A. K. Joshi

16	G. B. Pant University of Agriculture and Technology (GBPUAT)	Department of Horticulture	Pantnagar, Nainital-263145, Uttarakhand	Dr. K. K. Mishra
17	Horticulture and Agroforestry Research Program (HARP)	Department of Horticulture	ICAR Research Complex for Eastern Region Plandu, Ranchi-834 010, Jharkhand	Dr. S. Kumar
18	Indian Agricultural Research Institute (IARI)	Division of Vegetable Science	Pusa, New Delhi-110012	Dr. A. S. Sidhu
19	Indian Council of Agricultural Research (ICAR)	Horticulture Division	KAB-II, Pusa, New Delhi-110012	Dr. H. P. Singh
20	Indian Institute of Horticultural Research (IIHR)	Division of Vegetable Crops	255, Upper Palace, Orchards, Bengaluru-560080 Karnataka	Dr. Meenakshi Sreenivas
21	Indian Institute of Vegetable Research (IIVR)	Vegetable Crops	P. O. Jakhani (Shanshapur) Varanasi-221305 Uttar Pradesh	Dr. Mathura Rai Dr. Major Singh
22	Indira Gandhi Krishi Vidyalaya (IGKV)	Department of Vegetable Science	Krishaknagar, Labhandi, Raipur-492006, Chhattisgarh	Dr. Nandan Mehta
23	Jawarlal Nehru Krishi Vishwa Vidyalaya (JNKVV)	Department of Horticulture	Jabalpur- 482004 Madhya Pradesh	Dr. A. K. Naidu
24	Junagadh Agricultural University (JAU)	Division of Vegetable Research	Junagadh-362001 Gujarat	Dr. D. B. Kuchadiya
25	Kerala Agricultural University (KAU)	Faculty of Agriculture	Thrissur-680656, Kerala	Dr. K. Harikrishan Nair
26	Maharana Pratap University of Agriculture and Technology (MPUAT)	Department of Horticulture	College of Horticulture and Forestry Jhalawar-326001 Rajasthan	Dr. L. K. Dashora
27	Maharathwada Agricultural University (MAU)	Horticulture Research Station	College of Agriculture Parbhani-431402, Maharashtra	Dr. S. B. Rohidas
28	Mahatma Phule Krishi Vidyapeeth (MPKV)	Department of Horticulture	Phulenagar, Rahuri-413722 Maharashtra	Dr. B. V. Garad
29	National Bureau of Plant Genetic Resources (NBPGR)	Germplasm Evaluation Division and Gene Bank	NBPGR, New Delhi-110012	Dr. S. K. Sharma
30	Narendra Deva University of Agriculture and Technology (NDUAT)	College of Horticulture	Kumarganj, Faizabad-224229 Uttar Pradesh	Dr. Room Singh
31	National Research Centre on Plant Biotechnology (NRCPB)	NRCPB	NRCPB, Lal Bahadur Shastri Building, Pusa, New Delhi-110012	Dr. P. A. Kumar
32	Navsari Agricultural University (NAU)	Vegetable Crops	Aspee College of Horticulture and Forestry, Navsari, Gujarat	Dr. M. N. Patel

33	Orissa University of Agriculture and Technology (OUAT)	College of Horticulture	Siripur, Khurda-751003 Bhubaneswar, Orissa	Dr. Dibakar Naik
34	Punjab Agricultural University (PAU)	Department of Vegetable Crops	College of Agriculture, Ludhiana -141004, Punjab	Dr. A. S. Dhatt
35	Punjabrao Deshmukh Krishi Vidyapeeth (PDKV)	College of Agriculture	Krishinagar, Akola-444104 Maharashtra	Dr. S. A. Nimbalkar
36	Rajasthan Agricultural University (RAU)	Department of Horticulture	Shri Ganganagar Road, Beechwal, Bikaner-334006 Rajasthan	Dr. B. L. Punia
37	Rajendra Agricultural University (RAU)	Horticulture (Vegetable)	Bihar Agriculture College, Samastipur, Bihar	Dr. D. N. Choudhary
38	Sardarkrushinagar Dantiwada Agricultural University	College of Agriculture	Krishi Nagar, Banaskantha-385506 Gujarat	Dr. S. B. S. Tikka
39	Sardar Vallabh Bhai Patel University of Agriculture and Technology	College of Horticulture and Agroforestry	Meerut-250110 Uttar Pradesh	Dr. I. B. Singh
40	Sher-e-Kashmir University of Agricultural Sciences and Technology	Faculty of Agriculture	Jammu, Tawi-180012 J&K	Dr. N. Sharma
41	Tamil Nadu Agricultural University (TNAU)	Department of Vegetable Crops	Horticulture College and Research Institute, Coimbatore-641003 Tamil Nadu	Dr. I. Pugalendhi
42	University of Agricultural Sciences (UAS), Bengaluru	Faculty of Horticulture	GKVK, Bengaluru-560061 Karnataka	Dr. H. V. Nanjappa
43	University of Agricultural Sciences (UAS), Dharwad	Division of Horticulture	Dharwad-580005 Karnataka	Dr. R. M. Hosamani
44	Uttar Banga Krishi Vishwa Vidyalya	College of Agriculture	Pundibari Coochbehar-736165 West Bengal	Dr. M. K. Mazumder

(Source: Compiled by ISAAA, 2008)

List of important vegetable seed companies in India

No.	Name of the company	Contact detail
1	Advanta India Ltd	493/A, 27th Cross, 18th Main,Judicial Layout GKVK Post, Bengaluru-560 065, Karnataka Website: www.advantaindia.com
2	Ajeet Seeds Pvt. Ltd.	2nd Floor, Tapadia Terraces, Adalat Road Aurangabad, Maharashtra Website: www.ajeetseed.co.in
3	Ankur Seeds Pvt. Ltd.	27, New Cotton Market Layout, Nagpur-440018, Maharashtra Website: www.ankurseed.com
4	Arya Hybrid Seeds Pvt. Ltd.	Tapadia Terracess, Adalat Road Aurangabad- 431001, Maharashtra
5	Avestha Gengraine Technologies Pvt. Ltd. (Avesthagen)	Discoverer, 9th Floor, International Tech Park, Whitefield Road Bengaluru-560066, Karnataka Website: www.avesthagen.com
6	Bejo Sheetal Seeds Pvt. Ltd.	Bejo Sheetal Corner, Mantha Road Jalna-431203, Maharashtra Website: www.bejosheetalseeds.com
7	Bioseeds Research India Pvt. Ltd	Plot No. 206H No. 8-2-293/82/A/206, Road No. 14 Jubilee Hills, Hyderabad-500033, Andhra Pradesh Website: www.shrirambioseed.com
8	Biostadt India Ltd.	Poonam Chambers, A-Wing, 6th Floor, Dr. A.B. Road Worli, Mumbai-400018, Maharashtra Website: www.biostadt.net
9	Clause Tezier India Ltd	#6-1-20/2 Walker Town, New Bhoiguda Secunderabad-500025, Andhra Pradesh
10	Century Seeds Pvt. Ltd.	BA-22, Phase - II, Industrial Area Mangolpuri, Delhi-110034 Website: www.centuryseeds.com
11	D.J. Damani and Co.	P. O. Box 954, Shivaji Nagar, Pune-411000, Maharashtra
12	Eagle Seeds and Biotech	117, Silver Sanchora Castle,7, R.N.T. Marg Indore-452008, Madhya Pradesh Website: www.eagleseeds.com
13	Ganga Kaveri Seeds Pvt. Ltd.	Suit 1406-1407, Babu Khan Estate Bashir Bagh Hyderabad-500001, Andhra Pradesh
14	Green Gold Seeds Pvt. Ltd.	Gut No. 65, Naryanpur - Shivar, Near Waluj Taluka Gangapur, Aurangabad-431005, Maharashtra Website: www.greengoldseeds.com
15	Golden Seeds Pvt. Ltd.	B-22, Block B, Brigade MM building, K.R. Road Yediyur, Bengaluru-560082, Karnataka

16	Indo-American Hybrid Seeds (India) Pvt. Ltd.	7th Kilometer, Banashankari-Kengeri Link Road Channasandra Villege, Subramanyapura Post Uttarahalli Hobli, Bengaluru-560061, Karnataka Website: www.indamseeds.com
17	JK AgriGenetics Pvt. Ltd.	1-10-177, 4th Floor, Varun Towers, Begumpet Hyderabad-500016, Andhra Pradesh Website: www.jkseeds.net
18	Kaveri Seed Company Pvt. Ltd.	513-B, 5th Floor, Minerva Complex, S.D Road Secunderabad- 500003, Andhra Pradesh Website: www.kaveriseeds.in
19	Kohinoor Seed Fields Pvt. Ltd.	AB-26, Shalimar Bagh, New Delhi- 110088
20	Krishidhan Seeds Pvt. Ltd.	Krishidhan Bhavan, D3 to D6, Aurangabad Road Jalna-431213, Maharashtra Website: www.krishidhanseeds.com
21	Limgrain India Pvt. Ltd	24/1 Sankey Road High Grounds Bengaluru-560052, Karnataka Website: www.limagrain.in
22	Maharashtra Hybrid Seeds Company Pvt. Ltd. (Mahyco)	Dawalwadi, PO Box 76 Jalna-431203, Maharashtra Website: www.mahyco.com
23	Metahelix Life Sciences Pvt. Ltd.	Plot No. 3, KIADB, 4th Phase, Bommasandra Bengaluru-560099, Karnataka Website: www.meta-helix.com
24	Nath Seeds Limited	Nath House, Nath Road, Aurangabad-431005, Maharashtra Website: www.nathseeds.com
25	Namdeo Umaji Agritech Pvt. Ltd.	1205/4, Alankar, Shivaji Nagar, Pune-411004, Maharashtra Website: www.pyramidseeds.net
26	Namdhari Seeds Pvt. Ltd.	# 119, 9th Main Road, Ideal Homes Township Rajarajeshwari Nagar, Bengaluru-560098, Karnataka Website: www.namdhariseeds.com
27	Nandi Seeds Pvt. Ltd.	# 5-2/2 , Koil Konda, X Roads Mahabubnagar-509001, Andhra Pradesh
28	Navkar Hybrid Seed Corporation	Baker Ali Wadi, Mirzapur Cross Road Mumbai-380001, Maharashtra
29	Nirmal Seeds Pvt. Ltd.	P.O. Box No. 63, Bhadgaon Road, Pachora Jalgaon-424201, Maharashtra Website: www.nirmalseedsindia.com
30	Nunhems India Pvt. Ltd. (Bayer Cropscience Pvt. Ltd.)	Opp: Brahma Kumari Ashram, Pataudi Road, BhoraKala, Bilaspur Gurgaon-122413, Haryana Website: www.nunhems.com
31	Nuziveedu Seeds Ltd.	NSL ICON, 4th Floor, Road No. 12, Banjara Hills Hyderabad-500034, Andhra Pradesh Website: www.nuziveeduseeds.com

32	Plantgene Seeds Limited	36-B, Edmonton Mall, The Bristol Hotel Gurgaon-122002, Haryana Website: www.plantgeneseeds.com
33	Pravardhan Seeds Pvt. Ltd.	3-4-754, Baghlingampally, X Road Hyderabad-500027, Andhra Pradesh
34	Rasi Seeds Pvt. Ltd.	273, Kamarajanar Road, Salem District Attur-636 102, Tamil Nadu Website: www.rasiseeds.com
35	Safal Seeds and Biotech Ltd.	PO. Box 39, A-2, Old M.I.D.C., Jalna-431203, Maharashtra Website: www.safalseeds.org
36	Seed Works India Pvt. Ltd.	437 Avenue 4, Banjara Hills, Hyderabad-500034, Andhra Pradesh Website: www.seedworksindia.com
37	Seminis Vegetable Seeds Pvt. Ltd (Monsanto India Ltd)	24, Chitegaon, Paithan Road, Aurangabad-431105, Maharashtra Website: www.seminis.in
38	Sungro Seeds Pvt. Ltd.	3rd Floor, Sungro Chamber, Local Shopping Centre B.N. Block, Shalimar Bagh, Delhi-110088 Website: www.sungroseeds.com
39	Syngenta India Ltd	Royal Insurance Building No. 12, J. Tata Road, Churchgate Mumbai-400020, Maharashtra Website: www.syngenta.co.in
40	Tokita Seed India (P) Ltd.	E - 301, Sushant Shopping Arcade Sushant Lok Gurgaon-122016, Haryana Website: www.tokitaindia.com
41	Tulasi Seeds Pvt. Ltd.	"Tulasi House" 6-4-6, Arundelpet 4/5 Guntur-522002, Andhra Pradesh
42	Unicorn Agrotech Ltd.	1-7-139/3, Sarojini Devi Road, Secundarabad-500003, AP Website: www.hybridproduction.com
43	United Genetics India Pvt. Ltd.	No. 527 "F" Block, 60 Feet Road, Sahakarnagar Bengaluru-560092, Karnataka Website: www.unitedgeneticsindia.com
44	Vibha Agrotech Pvt. Ltd.	"Inspire", Plot No. 21, Sector-1, HUDA Techno Enclave Hitec City Road, Madhapur, Hyderabad - 500 081, Andhra Pradesh Website: www.vibhaseeds.com
45	Yashoda Hybrid Seeds Pvt. Ltd.	248, Near Civil Line, Hinganghat, Wardha-442301, Maharashtra Website: www.yashodaseeds.com
46	Zuari Seeds Pvt. Ltd.	# 805, 13th 'A' Main , 80 Feet Road, Yelahanka New Town Bangalore- 560064, Karnataka Website: www.zuari-chambal.com

(Source: Compiled by ISAAA, 2008)

List of brinjal varieties released at national and state level, 1975-2008

No.	Variety	Developed by	Area of Adaption	Year of Release
1	ABH-1	GAU	Northern and Southern India with parts of Maharashtra and Gujarat	n/a
2	ABH-2	GAU	Northern and Southern India with parts of Maharashtra and Gujarat	n/a
3	Annamalai	Annamalai University	Tamil Nadu	1985
4	Arka Kusumkar	IIHR	Karnataka and Southern region of India	1984
5	Arka Sheel	IIHR	Karnataka	1954
6	Arka Shirish	IIHR	Karnataka and Southern region of India	1986
7	Arka Nidhi	IIHR	Karnataka	1992, 2006
8	Arka Neelkanth	IIHR	Karnataka	1990
9	Arka Keshav	IIHR	Karnataka	1990, 2006
10	Aruna	PRKVV	Zone VII	1998
11	ARU 1	VPKAS	North Region	n/a
12	ARU 2 C	VPKAS	Zone I	n/a
13	Azad Brinjal-1	CSAUAT	North and North-West regions	1983
14	Azad Brinjal-2	CSAUAT	North and North-West regions	1996
15	Azad Brinjal-3	CSAUAT	North and North-West regions	1998
16	Bagyamathi	ANGRAU	Andhra Pradesh	1982
17	BR 112	n/a	Haryana	n/a
18	CHBR-1	CHES	n/a	n/a
19	CO-1	TNAU	Southern districts of Tamil Nadu	1985
20	CO-2	TNAU	Western zone of Tamil Nadu	n/a
21	Green Long	RAU	n/a	n/a
22	Gulabi (Sel 4)	ANGRAU	n/a	n/a
23	Gujarat 6	n/a	Gujarat	1984
24	Gujarat Brinjal Long-1	n/a	Gujarat	2003
25	Gujarat Oblong Brinjal-1(GOB-1)	n/a	Gujarat	2006

26	Hisar Jamuni	HAU	Haryana	n/a
27	Hisar Pragati (H-7)	HAU	Zone IV, Zone VI	1994
28	Hisar Shyamal (H-8)	HAU	Zone II, Zone IV, Zone V, Zone VI	1993
29	Haritha	KAU	Central Zone of Kerala	n/a
30	Improved Long Shalimar	Vegetable Research Station, Srinagar	J&K, Himachal Pradesh, Uttarakhand	n/a
31	Junagarh Long	JAU	Gujarat	1984
32	Junagarh Oblong	JAU	Gujarat	1984
33	Jamuni Gole Baingan	PAU	Punjab, Haryana	1978
34	Jamuni Gola	PAU	Punjab, Haryana	1987
35	JB 15	JNKVV	Madhya Pradesh, Maharastra	n/a
36	JB 64-1-2	JNKVV	Madhya Pradesh	n/a
37	K 202 9	n/a	Uttar Pradesh	n/a
38	Kalyanpur Type-3	Vegetable Research Station, Kanpur	Uttar Pradesh	1982
39	Kashi Prakash (IVBR-1)	IIVR	Uttar Pradesh	2006
40	Kashi Taru (IVBL-9)	IIVR	Uttar Pradesh	2006
41	KKM-1	TNAU	Tamil Nadu	n/a
42	Kt-4	IARI, Regional Station, HP	J&K, H.P.	n/a
43	KS-224	CSAUAT	Zone IV	n/a
44	KS-331	CSAUAT	Uttar Pradesh	n/a
45	Manjari Gota	MPKV	Western Maharashtra	1965
46	MDU-1	Agriculture College and Research Institute, Madurai	Tamil Nadu	1982
47	Mysore Green	n/a	Karnataka	n/a
48	Narendra Baingan-1	NDUAT	Uttar Pradesh	1996
49	NDB 25	NDUAT	Zone II, IV, VII	n/a
50	Pant Samrat	GBPUA&T	All over India including hilly areas	1985
51	Pant Rituraj	GBPUA&T	All over India including hilly areas	1985
52	Pant Brinjal-4	GBPUA&T	Northern hills and plains	n/a
53	PBR 129-5	GBPUA&T	Zone IV	n/a
54	PLR 1	TNAU	Zone IV, VI, VII	n/a

55	PKM 1	TNAU	Tamil Nadu	n/a
56	Pusa Purple Long	IARI	All over India	1978
57	Pusa Purple Round	IARI	U.P., Punjab, Haryana	1985
58	Pusa Purple Cluster	IARI, Regional Station, Himachal Pradesh	Southern States and Northern hills	1978
59	Pusa Kranti	IARI	All over India	1975
60	Pusa Bhairav	IARI	All over India	n/a
61	Pusa Anupam	IARI	All over India	n/a
62	Pusa Bindu	IARI	Northern plains, Gujarat and Maharashtra	1999
63	Pusa Uttam	IARI	Northern plains, Gujarat and Maharashtra	1997
64	Pusa Upkar	IARI	Northern plains, Gujarat and Maharashtra	1997
65	Pusa Ankur	IARI	Northern India	1999
66	Pragati	MPKV	Maharashtra	1988
67	Punjab Haryana Brinjal-4(PH-4)	PAU and HAU	All over India	1978
68	Punjab Bahar	PAU	Punjab	1974
69	Punjab Chamkila	PAU	Punjab	1978
70	Punjab Barsati	PAU	Zone IV	1989
71	Punjab Sadabahar	PAU	Punjab	1987
72	Punjab Neelam	PAU	Punjab	1988
73	Punjab Moti	PAU	Punjab	1993
74	S-16	PAU	Karnataka	n/a
75	Shyamala Bhagyamati	ANGRAU	Andhra Pradesh	n/a
76	Surya	KAU	All over India	1990
77	Swetha	KAU	All over India	1996
78	Swarna Mani	HARP	Punjab, Uttar Pradesh, Bihar, Jharkhand	2004
79	Swarna Pratibha	HARP	Punjab, Uttar Pradesh, Bihar, Jharkhand	2004
80	Swarna Shyamali	HARP	Punjab, Uttar Pradesh, Bihar, Jharkhand	2006
81	Swarna Shree	HARP	Bihar	2006
82	T-3	CSAUAT	Uttar Pradesh	n/a
83	Utkal Tarini (BB 77)	OUAT	Chhattisgarh, Orissa and Andhra Pradesh	1992

84	Utkal Jyoti (BB 13)	OUAT	Chhattisgarh, Orissa and Andhra Pradesh	2004
85	Utkal Anushree	OUAT	Chhattisgarh, Orissa and Andhra Pradesh	n/a
86	Utkal Kesari	OUAT	Chhattisgarh, Orissa and Andhra Pradesh	1998
87	Utkal Madhuri (BB 44)	OUAT	Chhattisgarh, Orissa and Andhra Pradesh	1998
88	Vaishali	MPKV	Madhya Pradesh, Maharashtra	1985

(Source: Agricultural Research Data Book, 2001; Central Seed Committee, 2007; Gopalakrishnan, 2007; Handbook of Horticulture, 2007; National Horticulture Board, 2008; Law of Seeds, 2005; Ram, 2005; Singh, 2007)

List of brinjal hybrids released at national and state level, 1975-2008

No.	Variety	Developed by	Area of Adaption	Year of Release
1	ABH-1, ABH-2	Ankur Seeds	Zone IV, VI, VII	n/a
2	ARBH-201	Ankur Seeds	Zone IV, V, VI, VII	n/a
3	Arka Navneet	IIHR	Karnataka, J&K, West Bengal, Delhi, Rajasthan and Maharashtra	1982
4	Arka Anand	IIHR	n/a	n/a
5	Azad Hybrid	CSAUAT	Uttar Pradesh	1999
6	Azad Kranti	CSAUAT	North and Central India	1983
7	Brinjal Hybrid (BH-1)	PAU	Punjab	1996
8	Brinjal Hybrid (BH-2)	PAU	Punjab	1996
9	Brinjal Hybrid-2 (GBH-2)	PAU	Punjab	2004
10	Krishna	MPKV	Maharashtra	1991
11	Kashi Komal (IVBHL-54)	IIVR	n/a	n/a
12	Kashi Sandesh (VRBHR-1)	IIVR	Rajasthan, Gujarat, Haryana, Delhi	2006
13	Manju	Syngenta	Karnataka, Tamil Nadu and Kerala	n/a
14	MHB- 1	Mahyco	n/a	n/a
15	MHB-9	Mahyco	n/a	n/a
16	MHB-10 (Kalpataru)	Mahyco	Zone IV, VI, VII	n/a
17	MHB-39	Mahyco	Zone IV, VI, VII	n/a
18	Narendra Hybrid (Brinjal-1)	NDUAT	Zone IV, VI, VII	1996
19	Narendra Hybrid (Brinjal-6)	NDUAT	Zone IV	n/a
20	Neelima	KAU	Central zone of Kerala	1998

21	Phule Harit	MPKV	Maharashtra	2006
22	Pusa Anmol	IARI	n/a	1980
23	Pant Brinjal (Hybrid-1)	GBPUA&T	Suitable for hills and plains	1994
24	Pusa Hybrid-5	IARI	Zone IV, VII, VIII	1994
25	Pusa Hybrid-6	IARI	Zone IV	1993
26	Pusa Hybrid-9	IARI	Maharashtra and Gujarat	1997
27	Swarna Shobha	HARP	n/a	2006
28	Swarna Ajay	HARP	n/a	2006

(Source: Agricultural Research Data Book, 2001; Central Seed Committee, 2007; Gopalakrishnan, 2007; Handbook of Horticulture, 2007; Law of Seeds, 2005; National Horticulture Board, 2008; Ram, 2005; Singh, 2007)

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