

Bt Eggplant: A Genetically Engineered ‘Minor’ Crop Comes of Age in Bangladesh and the Philippines

A. M. Shelton, K. E. Hokanson, D. M. Hautea, M. J. Hossain, M.A. Hossain, V. Paranjape, R.A. Hautea, L. McCandless, and S. H. Sarwer

It has been more than 20 years since the first genetically engineered (GE) crops were commercialized. GE crops are grown in 26 countries, and GE corn, cotton, and soybean now dominate their respective crops in the global commodity market¹. Insect-resistant Bt crops have revolutionized integrated pest management (IPM) by providing an exceptional degree of host plant resistance, the foundation of IPM, through traits that make the crop effectively immune to the target pest^{2,3}. Cumulatively on a global basis from 1996 to 2014, Bt corn and Bt cotton have provided \$41.4 billion and \$44.8 billion in economic benefit and have reduced the use of insecticides by 51.6 and 27.9%, respectively⁴. A reduced need for pesticides is very important to resource-poor farmers who often lack the training and protective equipment to use them properly. Bt crops have also been shown to conserve natural enemies and other valuable arthropods that contribute to ecosystem services^{5,6}.

While the advent of GE crops was a transformative success story in agriculture—indeed, the 2013 World Food Prize was awarded to pioneers in the field—the use of Bt crops has largely been limited to large acreage commodity crops. Biotechnology for use in the so-called ‘minor’ crops, sometimes referred to as ‘orphan’ or ‘neglected’ and ‘underutilized’ crops, has not been as forthcoming. Whatever term is used, minor crops are important for local and regional food security and historically lag behind large acreage crops in development of crop protection products. This is unfortunate since this group of crops includes fruits and vegetables that are critically needed for a balanced, nutritious diet and diversified farm income. Most people are surprised to learn that more insecticides are used on fruits and vegetables than on the large acreage crops of corn, cotton, and rice combined⁷. The pesticide application rate is driven by the higher value of fruits and vegetables and their higher cosmetic standards, as well as the diverse insect complexes that cause various maladies. Furthermore, biological control and other tactics rarely are sufficient to control insect pests of fruit and vegetables in open field conditions.

These factors should make fruits and vegetables suitable candidates for GE technologies that control

insect pests or the pathogens they vector; however, there is only a small number of GE fruits and vegetables that have been commercialized. The poster child for the success of a GE minor crop is the GM papaya developed by Gonsalves and colleagues at USDA that controls the insect-transmitted virus causing papaya ringspot disease⁸. Although GM papaya is still opposed by some activist groups, all acknowledge that without the GE trait, economically profitable cultivation of papaya in Hawaii would not be possible⁹. A few more GE fruits and vegetables have proved to be useful for pest management, e.g., GE virus-resistant squash and insect-resistant Bt sweet corn in North America^{10,11}, and virus resistant beans in Brazil¹². But now there is a new crop that is playing a pivotal role in the future success of GE technology for ‘minor’ crops in developing countries—Bt eggplant.

Eggplant’s Big Insect Problem

Solanum melongena L. (eggplant, also known as brinjal in India and Bangladesh, and talong in the Philippines) is one of the most important, inexpensive, and popular vegetable crops grown and consumed in Asia. Eggplant is low in calories and fat, rich in vitamins and minerals, and a good source of dietary fiber. It has abundant total water-soluble sugars, free reducing sugars, anthocyanin, phenols, and amide proteins, which provide medicinal benefits (<http://www.medicalnewstoday.com/articles/279359.php>). Eggplant production provides an important source of cash income, particularly for small, resource-poor farmers.

The biggest constraint to eggplant production throughout Asia is chronic and widespread infestation by the eggplant fruit and shoot borer (EFSB), *Leucinodes orbonalis* Guenée. The caterpillars damage eggplant by boring into the petiole and midrib of leaves and tender shoots, resulting in wilting and desiccation of stems (**Fig. 1**). Larvae also feed on flowers, which results in flower drop or misshapen fruits. The most serious economic damage caused by EFSB is to the fruit, because the holes, feeding tunnels, and frass (larval excrement) make the fruit unmarketable and unfit for human consumption (**Fig. 2**).



Figure 1. EF SB larva in an eggplant shoot, causing it to die and no fruit to be produced.



Figure 2. EF SB larva in the fruit, rendering it unfit for market.

Building a Better Eggplant

The development of Bt eggplant was initiated in 2000 by the India-based Maharashtra Hybrid Seed Company (Mahyco) under a partnership with the Monsanto Company. Mahyco used a *Bacillus thuringiensis cryIAc* gene that had already been widely used in Bt cotton in India. The GE Bt eggplant (termed ‘event’ EE-1) demonstrated control of EF SB in contained greenhouse trials. In late 2003, a partnership was formed between Mahyco, Cornell University, the United States Agency for International Development (USAID), and public sector partners in India, Bangladesh, and the Philippines under the Agricultural Biotechnology Support Project II (ABSPII; <http://absp2.cornell.edu>). Bt eggplant was selected for the countries based on a priority setting process by representatives in each country. Each partner in ABSPII shared in the responsibility to get Bt eggplant into their respective markets.

This project had the unique vision to use two market channels to satisfy a diverse farming community^{13,14}—a ‘pro-poor’ channel for the distribution of open pollinated (OP) lines, and a commercial channel through which the higher priced hybrid varieties would be sold. The belief at the time was that low resource farmers would not adopt hybrid eggplant. However, hybrid eggplant has proved to be immensely popular over time with resource-poor farmers in India, so future GE eggplant products may be incorporated straight into hybrid backgrounds in future.

ABSPII also operated in Bangladesh and the Philippines; however, different market channels created different requirements (see below). All three countries used the resistant EE-1 event created by Mahyco. When ABSPII ended in 2014, USAID re-competed the award, with emphasis shifting to the regulatory issues, scaling-up methods, and means of deployment/stewardship for farmers in Bangladesh and the Philippines. The Feed the Future South Asia Eggplant Improvement Partnership (<http://btggplant.cornell.edu>) housed at Cornell University is the implementing partner working in partnership with the Bangladesh Agricultural Research Institute (BARI), the University of the Philippines Los Baños, the University of Minnesota, and Sathguru Management Consultants. The project has unfolded in different ways in the three countries.

To control this insect, farmers routinely spray broad-spectrum insecticides, often 2–3 times per week, and, in some cases, twice a day. Consequently, over 100 sprays per season may be applied, resulting in high residues on the marketable fruit. Such an insecticide-dependent strategy poses both environmental and health concerns. Environmental concerns include killing natural enemies that can help reduce pest populations, leaching of active pesticide ingredients into the soil and water, and harming pollinators. Health concerns include harm to the applicator and farm workers, as well as harm to the consumer from high pesticide residues on the crop. These problems have been well documented in Bangladesh and the Philippines (<http://btggplant.cornell.edu/content/facts>; <http://bic.searca.org>).

The Indian Stalemate

After extensive field trials and safety evaluations conducted by the Indian biosafety body the Genetic Engineering Appraisal Committee (GEAC) recommended commercialization of Bt brinjal. However, responding to challenges from activist groups, the Indian Minister of Environment and Forests imposed a moratorium on release on February 9, 2010, until a political consensus was reached. That moratorium is still in place today¹⁵.

Bangladesh Steps Forward

As in neighboring India, eggplant (brinjal) is an important vegetable crop in Bangladesh, where it is second only to potato in production and is grown on nearly 50,000 hectares. Similarly, EFSB is the main pest in Bangladesh, and the crop is intensively sprayed with insecticides that have limited efficacy against boring insects. The insecticides have negative impacts on humans and the environment, and are applied by often poorly trained farmers (<http://bteggplant.cornell.edu/content/facts/pesticide-use-bangladesh>). In addition, more than 40 years of conventional breeding has failed to produce highly resistant eggplant cultivars¹⁶. Consequently, the crop is a good candidate for genetically engineered host plant resistance. An ex-ante study indicated that the introduction of Bt eggplant into Bangladesh would result in a net benefit of \$1868/ha¹⁷. This benefit compares to the household income per capita of \$277.95 in December 2005 (<https://www.ceicdata.com/indicator/bangladesh/annual-household-income-per-capita>).

Unlike India, which commercialized Bt cotton in 2002, Bangladesh had not released any GE crops. Mahyco donated the EE-1 event to the Bangladesh Agricultural Research Institute (BARI) where it was incorporated into nine local eggplant lines. Breeding and efficacy trials were conducted from 2005 to 2012; subsequently, BARI applied to the National Technical Committee on Crop Biotechnology (NTCCB) to release Bt eggplant. Following the recommendation from the NTCCB, the application for release was forwarded to the National Technical Committee on Crop Biotechnology (NTCCB) Core Committee followed by the National Committee on BioSafety (NCB). The Bangladesh government granted approval for release of four varieties on 30 October 2013. On 22 January 2014, Bt seedlings were distributed among 20 farmers in four districts. The following year, demonstration trials

were conducted in 108 farmer fields in 19 districts. In 2015 and 2016, demonstration trials were conducted in 230 farmer fields in 23 districts¹⁸ and 512 farmer fields in 40 districts¹⁹, respectively. According to BARI, the performance of Bt eggplant in these demonstration trials was far superior to non-Bt eggplant, with fruit infestations in Bt eggplant ranging from 0.04 – 0.88% compared to 48 – 57% in the non-Bt eggplant¹⁸.

The field demonstrations conducted from 2013 to 2017 clearly showed the benefit of Bt eggplant for control of EFSB, and growers were highly satisfied with their experiences (interviews with growers can be seen on the project's website, Bteggplant.cornell.edu, and readers are urged to view the 22 June 2017 video "Bt brinjal in Bangladesh: Voices from the Field."). The results from these trials are being prepared for publication. Meanwhile, additional trials were conducted in 2017, including a large-scale study by the Department of Agricultural Extension that included more than 5,000 farmers.

Good stewardship practices for Bt eggplant have been developed. As with any insect control crop, Bt eggplant must be incorporated within an Integrated Pest Management (IPM) program. The Bt protein controls the main pest, EFSB, but does not affect other eggplant pests such as leafhoppers, whiteflies, aphids, and thrips, all of which can damage eggplant. Studies are being conducted to develop thresholds for these other pests. Baseline susceptibility of EFSB to Cry1Ac is being determined as part of an Insect Resistance Management (IRM) program to ensure the long-term benefit of this technology. Farmer demonstration trials have incorporated refuges as an important component of IRM. Most importantly, farmer-training programs are being conducted and refined, since farmers are ultimately the ones who will need to protect this valuable technology.

The Philippines: Bt Eggplant in a Changing Regulatory Environment

Farmers and government regulators in the Philippines have considerably more experience with GE crops because Bt maize has been commercialized and widely cultivated (65% of the 2016 national corn acreage) since 2003¹. As in India and Bangladesh, eggplant is an important vegetable crop in the Philippines, where it ranks as the number one vegetable crop, and it is also severely damaged by EFSB. Ex-ante studies have indicated considerable economic benefits and

pesticide savings if Bt eggplant is introduced into the Philippines, resulting in increased income to farmers ranging from US\$2,339 to \$5,302/ha^{20,21}. Mahyco sub-licensed EE-1 to the University of the Philippines Los Baños, where the EE-1 technology was incorporated into local OP lines and hybrids. Field studies conducted from 2010 to 2012 (**Fig. 3**) demonstrated the stable expression of CryIAC protein and outstanding control of EFSB²², and a lack of negative effects on non-target arthropods²³.



Figure 3. Second season confined field trial of Bt OP (open-pollinated) lines and their non-Bt comparators in UPLB Experimental Site, Bay, Laguna, Philippines. Photo shows field layout of the replicated experiment. Photo credits: ABSPII UPLB Bt eggplant team; December 14, 2010.

However, as in India, commercialization has encountered some roadblocks. Anti-biotech groups tried to stop the Bt eggplant field trials through extensive negative media campaigns and “direct action” (e.g., picketing and vandalizing field trials). A legal challenge was also launched when anti-GM activist groups filed a petition in May 2012 to the Supreme Court calling for the imposition of the *Writ of Kalikasan* and issuance of a Temporary Environmental Protection Order to stop the Bt eggplant field trials²⁴. After considerable discussion, the Supreme Court decided on 8 December 2015 to permanently stop the field trials of Bt eggplant. It also declared null and void the existing biosafety regulations and temporarily stopped all biosafety approvals for all GMOs pending promulgation of new biosafety approval guidelines. However, on 26 July 2016, the Supreme Court granted all motions for reconsideration filed by Bt eggplant proponents and other interested parties, and

unanimously reversed its December 2015 decision. At the same time, a new inter-agency set of regulatory guidelines was put into place. The Bt eggplant project will prepare a regulatory package to submit to the authorities according to the new set of regulatory guidelines.

Looking Ahead

The success of large acreage GE crops has facilitated the adoption of future GE minor crops. Bangladesh has decided to allow the cultivation of Bt eggplant and in 2017, as many as 6,500 farmers are growing Bt eggplant and reaping its benefits (**Fig. 4**). For farmers, these benefits include higher income, less insecticide exposure, and increased biodiversity in their fields. For consumers and the general public, benefits include improved food safety, a more consistent supply of a highly nutritious vegetable, and less insecticide in the environment.



Figure 4. Md. Shahajahan Ali grows Bt brinjal in 2017 with high yield from his 0.16 acre field.

In Bangladesh, the Minister of Agriculture, the Honorable Agriculture Minister Begum Matia Chowdhury, MP, has been a strong supporter of biotechnology and this has made the difference for farmers across the country (**Fig. 5**). In a workshop held in March 2017 in Bangladesh, she made her position clear:

“Development of brinjal fruit and shoot insect resistant Bt brinjal is a success story of local and foreign collaboration. We will be guided by the science-based information, not by the nonscientific whispering of a section of people. Good science will move on its own course keeping the anti-science people down.



Figure 5. Honorable Agriculture Minister of Bangladesh, Begum Matia Chowdhury, MP, providing Bt brinjal seedlings in presence of dignitaries from USAID and BARI in 2014.

As human beings, it is our moral obligation that all people in our country should get food and not go to bed on an empty stomach. Biotechnology can play an important role in this effect.” (<http://bteggplant.cornell.edu/content/news/blog/workshop-bt-eggplant-brings-researchers-and-journalists-together>).

Stakeholders are closely watching the success of low resource Bangladesh farmers to see how they use Bt eggplant to combat the eggplant fruit and shoot borer and reap its environmental and economic benefits.

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*A. M. Shelton, K. E. Hokanson, D. M. Hautea, M. J. Hossain
M.A. Hossain, V. Paranjape, R.A. Hautea, L. McCandless, and S. H. Sarwer*

Author Associations: All authors are associated with the project, Feed the Future South Asia Eggplant Improvement Partnership (Bteggplant.cornell.edu). In addition, the authors listed below have the following associations:

A. M. Shelton: Department of Entomology, Cornell/NYSAES, Geneva, New York, 14456, USA

K. E. Hokanson: Department of Horticultural Sciences, University of Minnesota, Saint Paul, MN 55108, USA

D. M. Hautea: Institute of Plant Breeding/CSC, College of Agriculture, University of the Philippines Los Baños, College, Laguna, 4031, Philippines

V. Paranjape: Sathguru Management Consultants Pvt Ltd, Plot 54, Sagar Society, Road No.2, Banjara Hills, Hyderabad, India 500034

R.A. Hautea: International Service for the Acquisition of Agri-biotech Applications c/o 3/F Khush Hall, IRRI, Los Baños, Laguna 4030, Philippines

L. McCandless: International Programs, Cornell University, Ithaca, New York, 14850, USA

Author Contributions

All authors participated in the drafting of this paper as individual subject matter experts in their fields, and the authors are solely responsible for the content. Any views expressed in this paper are the views of the authors and do not necessarily represent the views of any organization, institution, or government with which they are affiliated or employed. The authors declare no competing financial interest.