Viewpoint: Cornell prof Anthony Shelton's personal account of the sustainability and economic success of GMO eggplants in Bangladesh

I had the opportunity to work on a project that helped transform the lives of resource-poor farmers in Bangladesh and improved the environment in which they farm. The project had its own challenges and frustrations, but the benefits to those in Bangladesh have been immense. Like many entomologists before me, I have benefitted from the experiences and friendships of working in a country whose people sorely need the knowledge that entomological sciences can provide.

This is the story of the development and adoption of Bt (*Bacillus thuringiensis*) eggplant, *Solanum melongena* Linn. (Solanales: Solanaceae) in Bangladesh, where it has been grown commercially since 2014. It is also the story of how the use of this technology has been stifled in other countries, where it is urgently needed.

An extension meeting in Bangladesh

Working in developing countries requires patience. In March 2018, I was in a minivan on my way from Dhaka to Shibganj, Bangladesh. Traveling a distance of about 180 km would take more than seven hours on paved and dirt roads in stop-and-go traffic through villages typical of rural Bangladesh. We were going to an extension meeting to discuss eggplant (or brinjal, as it is called in Bangladesh and India) that had been genetically engineered to express insecticidal proteins from Bt.

As an entomologist at Cornell University with research and extension responsibilities, I have attended my fair share of extension meetings, and I was anxious to participate in an extension meeting in Bangladesh. Remarkably, the meeting was similar, despite the more exotic location, and it was in a language (Bengali) I could not understand. The local extension leader gathered about 75 farmers under a colorful tent (Fig. 1) for a meeting about a new line of brinjal resistant to the eggplant fruit and shoot borer (EFSB), *Leucinodes orbonalis* Guenée (Lepidoptera: Crambidae). This borer is the main constraint to brinjal production in Bangladesh, India, and many other countries in Asia.

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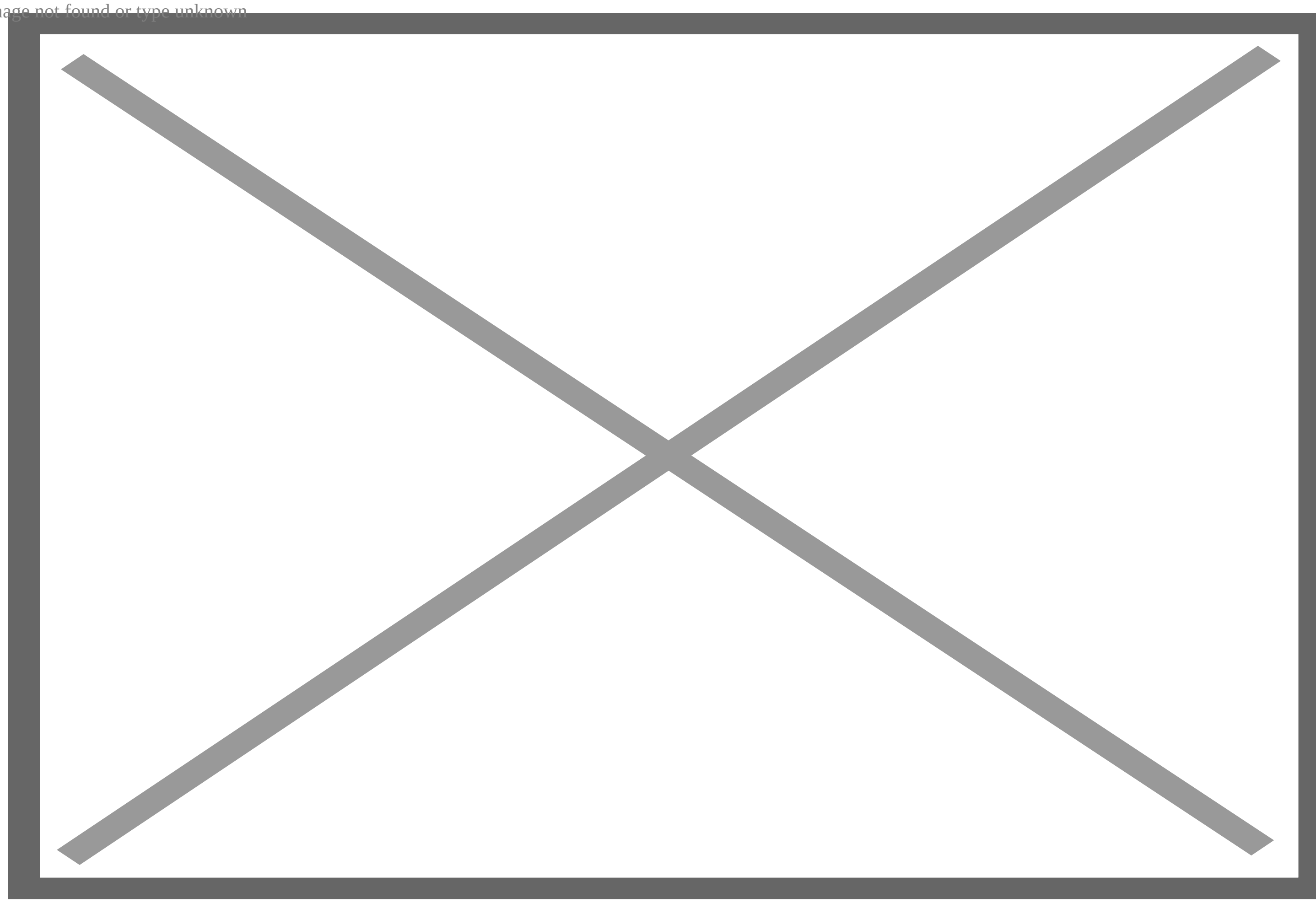

Fig. 1. An extension field meeting about Bt brinjal held at the farm of Md. Abul Hossain in Shibganj in Bogra district, Bangladesh. Credit: Md. Arif Hossain.

The meeting was held on the farm of Mohammad Abul Hossain, who had grown traditional brinjal for years. After recently seeing Bt brinjal production in a relative’s field, he decided to try it himself, a typical adoption scenario seen worldwide. After formal introductions, Hossain took us to one of his fields. His enthusiasm for Bt brinjal was infectious. He told the audience, “I have sold about 8,056 kg of Bt brinjal,” and “there was no [borer] infestation in my crop. I am expecting to harvest another 400 kg of brinjal from the field with the same result.” In six months, he had earned about US $1,600 growing Bt brinjal on 0.6 ha of land and still had fruit in the field to harvest and sell for a higher price during the holy month of Ramadan. This was a princely sum for a small-holder Bangladeshi farmer. In addition to the money, he was pleased that he did not spray for the borer.

Back under the colorful tent during the meeting, Hossain and others told their stories about growing Bt brinjal to the rapt audience. At the end of the meeting, one of the organizers asked for a show of hands of those who wanted to grow Bt brinjal next year. Nearly all hands went up.

A previous field visit

The experiences of Hossain were not unique. In 2016, I had inspected another field of Bt brinjal farmed by Milon Mia and his family. Accompanying me were members of our team: Joe Huesing from the United States Agency for International Development (USAID); Usha Barwale Zehr from the India-based Maharashtra Hybrid Seeds Co. Pvt. Ltd. (Mahyco); Steve Naranjo from USDA ARS, and Jeff Wolt from Iowa State University (Fig. 2). Zehr was particularly excited to be in the field because her company produced the Bt eggplant “event” used to generate the plants we were examining. None of us could find any EFSB-infested fruit in the Bt field. When I asked Mia how many times he had sprayed it, he said, “Twice.” When I checked one of his non-Bt brinjal fields, every fruit I inspected was riddled with the borers. When I asked Mia how many times he had sprayed the non-Bt brinjal field, he replied, “About 100.”

Fig. 2. Project personnel inspecting Bt brinjal in Bangladesh. The woman in yellow is Usha Barwale Zehr, whose company (Mahyco) developed ‘EE-1,’ which was incorporated into BARI-developed brinjal lines. She is holding a Bt brinjal fruit and explaining its characteristics to Jeff Wolt (red hat), Steve Naranjo (far left), Joe Huesing (tan hat), and the author (far right). Credit: Md. Arif Hossain.

How the Bt eggplant project began

In 2005, I became a member of Cornell University’s Agricultural Biotechnology Support Program II (ABSPII) funded by USAID. The goal of ABSPII was to use bio-engineered crops to help boost food security, economic growth, nutrition, and environmental quality in selected countries. Project partners identified pest problems that warranted biotechnology approaches, and eggplant was chosen because it is an important vegetable in the targeted countries (India, Bangladesh, and the Philippines), and its main constraint is the EFSB.

EFSB larvae bore into the petiole and midrib of brinjal leaves and tender shoots, resulting in wilting and desiccation of stems. Larvae also feed on flowers, leading to flower drop or misshapen fruits. But the most serious economic damage is caused by larvae tunneling in fruits and contaminating them with frass, which makes the fruit unmarketable and unfit for human consumption (Fig. 3). Despite decades of traditional breeding, no brinjal lines with sufficient resistance to these borers have been produced.

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Fig. 3. Non-Bt brinjal fruit infested by the eggplant fruit and shoot borer, Leucinodes orbonalis Guenée. Credit: Anthony Shelton.

The insecticide problem in eggplant production in South Asia

In January 2005, I visited brinjal fields in India and heard how farmers tried to control EFSB, using frequent insecticide spraying (sometimes twice a day). Thinking I had misunderstood the frequency, I asked a farmer again and again in different ways, but each time, the answer was the same. The farmer further explained that he often sprayed on the day of harvest. When asked what insecticides he used, he replied it was usually a cocktail of insecticides that included organophosphates, carbamates, and pyrethroids. I learned later that this farmer's practices were not unusual for the 1.4 million small-scale, resource-poor brinjal farmers in India who incur losses of 60 to 70%, even with frequent spraying (Choudhary and Gaur 2009). On average, 4.6 kg of insecticidal active ingredients per hectare per season are applied on brinjal at a cost of Rs 12,000 (US $163) per hectare, not to mention the health and environmental costs.

During my visits to Bangladesh and the Philippines, I heard similar stories and found them documented in the literature. In Bangladesh, EFSB was estimated to cause yield losses of 86% or more (Prodhan et al. 2018), despite frequent insecticide sprays targeting the borers. In the Jessore region of Bangladesh, more than 60% of farmers sprayed their eggplant crop 140 times or more during the season (Rashid et al. 2003). A survey among vegetable growers in southwest Bangladesh found that every farmer considered EFSB the most damaging pest of brinjal, and 98% reported that they relied on insecticides as their main method of control (Rashid et al. 2003). Such practices result in high residues on marketable fruit and affect the health of farmers. In a survey carried out in several districts in Bangladesh, only 4% of farmers reported receiving basic training on the safe use of pesticides, and 87% admitted that they did not wear any protective equipment when mixing and handling pesticides (Dasgupta et al. 2020). The same survey revealed that farmers usually sprayed their crops bare-footed, and only 1% wore sandals, 2% wore gloves, 3% wore protective eyeglasses, and 6% wore home-made cotton masks. As a result of this widespread exposure, 26% reported experiencing multiple health effects, including headaches, eye and skin irritation, vomiting, or dizziness (Dasgupta et al. 2020).

In the Philippines, EFSB damage can reach 80% loss in yield, and farmers spray a mixture of insecticides more than 70 times per season to prevent such losses (Hautea et al. 2016). The most commonly used insecticides are organophosphates, followed by carbamates and synthetic pyrethroids (Lu et al. 2010). Exposure of young children was of particular concern. They are often employed in vegetable production as young as 6 to 9 years old (Lu et al. 2010). Their roles involve pesticide preparation and application, in addition to watering and other tasks. After the use of pesticides, children reported health symptoms including headaches, skin irritation, and abdominal pain.

Development of the Bt eggplant project

Managing the EFSB by spraying insecticides was a losing proposition from the standpoint of control, human and environmental health, and economic costs to growers (Islam and Norton 2007). Consequently, ABSPII partners focused on eggplant as a crop for which biotechnology might provide part of the solution.

Shelton et al. (2018) described the story of Bt eggplant development. In short, development of the Bt eggplant technology was initiated in 2000 by Mahyco using the *cry1Ac* gene that had already been widely used in Bt cotton, *Gossypium* spp., in India. A partnership was formed in late 2003 between Mahyco, Cornell University, USAID, and public sector partners in India, Bangladesh, and the Philippines under ABSPII. All three countries used the resistant EE-1 event created by Mahyco and incorporated it into local eggplant lines.

The ABSPII project ended in 2014 and then USAID reduced the scope to focus on eggplants and potatoes. In September 2015, Cornell University was awarded a three-year, $4.8M cooperative agreement with USAID that focused on eggplant and created the Feed the Future South Asia Eggplant Improvement Partnership (bteggplant.cornell.edu). I became the partnership's director. The focus in Bangladesh included capacity building, seed production, stewardship, and post-commercial communication. The focus in the Philippines was to prepare for commercial release of Bt eggplants through the creation of regulatory dossiers, communication, and advocacy efforts. Although India had been included in ABSPII, it was left out of the new project for the reasons described below. After the initial term, the project received funded extensions from USAID through September 2020. In March 2020, I stepped down as director and became an advisor before my formal retirement from Cornell in September 2020. During my involvement with the project from 2005 to the present, I have had a wild ride on the biotechnology roller coaster.

Regulatory systems, politics and Bt eggplant

In order for farmers to grow a biotech crop, a country must first have biosafety laws and regulations in place. India, Bangladesh, and the Philippines had a National Biosafety Framework in place when Bt eggplant was being developed, but each country varied dramatically in its laws, local challenges, and experiences with biotech crops.

India has a multi-tiered regulatory framework for evaluating the safety of biotech crops with the Genetic Engineering Appraisal Committee (GEAC) as the highest statutory body for review and approval. GEAC approved production of Bt cotton in 2002, resulting in India becoming the second largest cotton producer and the leading exporter in the world. However, despite the success of Bt cotton and more than 20 other biotech crops in various stages of research and field trials in India, Bt cotton remains the only biotech crop cultivated in India at the time of writing this article.

Mahyco had developed and field-tested Bt brinjal lines for the Indian market. Field trials revealed good performance, and GEAC approved the cultivation of Bt brinjal in India in October 2009. The approval immediately elicited opposition from anti-biotech activists and forced the government to delay commercial release until public discussions were held. Opposition groups showed up in force at public discussions, leading the Indian Minister of Environment and Forests, the last gatekeeper on the regulatory road to commercialization, to overrule GEAC and impose a moratorium on 9 February 2010, which remains active at the time of writing this article.

In the Philippines, the regulatory system for importation, field trials, and cultivation of biotech crops has been operational since 2002, and Bt maize, *Zea mays* L., has been commercially cultivated since 2003. In March 2010, the Bureau of Plant Industries issued a two-year Biosafety Permit for field-testing Bt eggplants. Studies revealed that Bt eggplants were virtually immune to EFSB damage (Hautea et al. 2016) and did not have harmful effects on non-target arthropods (Navasero et al. 2016). However, field trials were vandalized in 2011 by anti-biotech activists who forcibly entered the confined field trials and illegally uprooted the plants. These actions were followed by legal challenges in courts over four years, which has delayed the development and commercialization of Bt eggplant in the Philippines.

Bangladesh has a National Biosafety Framework that provides the regulatory basis for the management of biotechnology products. However, unlike India and the Philippines, Bangladesh had no prior experience with biotech crops before Bt brinjal. Bt brinjal lines were tested under confined and open-field conditions for seven consecutive seasons before the Bangladesh government granted approval of four lines on 30 October 2013.

Politics and science meet in Bangladesh

Why was Bt brinjal approved in Bangladesh while it is still under a moratorium in India after 11 years, and not yet commercialized in the Philippines? Two important leaders in Bangladesh, Prime Minister Sheikh Hasina and Minister of Agriculture Begum Matia Chowdhury, provided strong support to move Bt brinjal toward commercialization through the Bangladesh regulatory framework. Such high-level political support, absent in India and the Philippines, was vital to commercialization of Bt brinjal in Bangladesh.

I first met Matia Chowdhury in June 2011 when she visited Cornell University. She spoke of the importance of brinjal in Bangladesh, where 150,000 farmers grow brinjal and the public consumes it daily. We discussed the Bt brinjal project, and she requested continued cooperation with Cornell. This was just a year after India had placed a moratorium on Bt brinjal’s cultivation. When I mentioned this to her, she acknowledged this fact but added that Bangladesh is an independent country with its own rules. When I pressed the issue of anti-GMO groups that might disrupt the project, she responded, “My job as Minister of Agriculture is to feed 160 million people and protect the environment, and if Bt brinjal will help us achieve this, we will move forward with it. Besides, we do not have strong anti-GMO groups in Bangladesh because we are a poor country, and these groups have difficulty raising funds.”

Meanwhile, back in Bangladesh, things were ramping up for the first commercial planting of Bt brinjal. Seeds were being multiplied, agencies were being assigned various responsibilities, and farmers were being trained.

The first commercial plantings

In January 2014, Matia Chowdhury distributed Bt brinjal seedlings to 20 Bangladeshi farmers in four districts. This was a major milestone for the project and biotechnology. However, as the plants were growing in the field, challenges soon appeared. In a Bangladeshi newspaper article published on 7 April 2014, reporters claimed they had visited some of the Bt brinjal fields and found that "25 to 30 percent of the plants were dead" and that the "field now required more pesticides" (Wardad 2014).

Joe Huesing and I were in Bangladesh when the article appeared, and we scrambled to visit one of the fields on 9 April 2014. At first sight, we were concerned when we saw about 10 to 15% of the plants dying. However, it soon became apparent that they were not suffering from EFSB, but from bacterial wilt caused by *Ralstonia solanacearum*, a common disease of brinjal in Bangladesh. Other fields we inspected had similar levels of diseased plants, a discouraging beginning for our project.

During this initial year, Bt brinjal became the target of increasingly active anti-biotech organizations, both domestic and international. Project partners pushed back on their false claims. An important advocate was Mark Lynas, a journalist and former anti-biotech activist, now turned biotech advocate, who was a visiting Fellow at Cornell. Lynas used his earlier experiences working for Greenpeace to fight back by publishing articles and blogs based on his visits and interviews with Bt brinjal farmers in Bangladesh, including an opinion piece in the *New York Times* (Lynas 2015). These and other educational efforts were especially important during the early phases of the project to document the benefits of Bt brinjal.

Adoption of Bt brinjal grows in Bangladesh

From the initial 20 farmers in the 2013–2014 growing season, adoption grew to 108 farmers in the 2014–2015 season and to 250 farmers in 25 districts in the 2015–2016 season (Fig. 4). During the 2016–2017 season, 6,512 farmers in 36 districts grew Bt brinjal. Seed availability was limited, but it improved when the Bangladesh Agricultural Development Corporation (BADC) began to multiply seed. In the 2017–2018 season, BADC sold seeds to 19,430 farmers, for a total of 27,612 farmers growing Bt brinjal in 40 districts. The following year, seed was still limited, but there were 20,602 Bt brinjal farmers, and by the 2019–2020 season, 26,913 farmers in 64 districts grew Bt brinjal. Preliminary data collected by our project in the 2020–2021 season indicated that >65,000 farmers grew Bt brinjal nationally. In addition to these figures, a survey we conducted (unpublished) indicated that 15 to 20% of farmers use seed saved from the previous season or provided it to other farmers. This rate of adoption over seven years is truly remarkable.

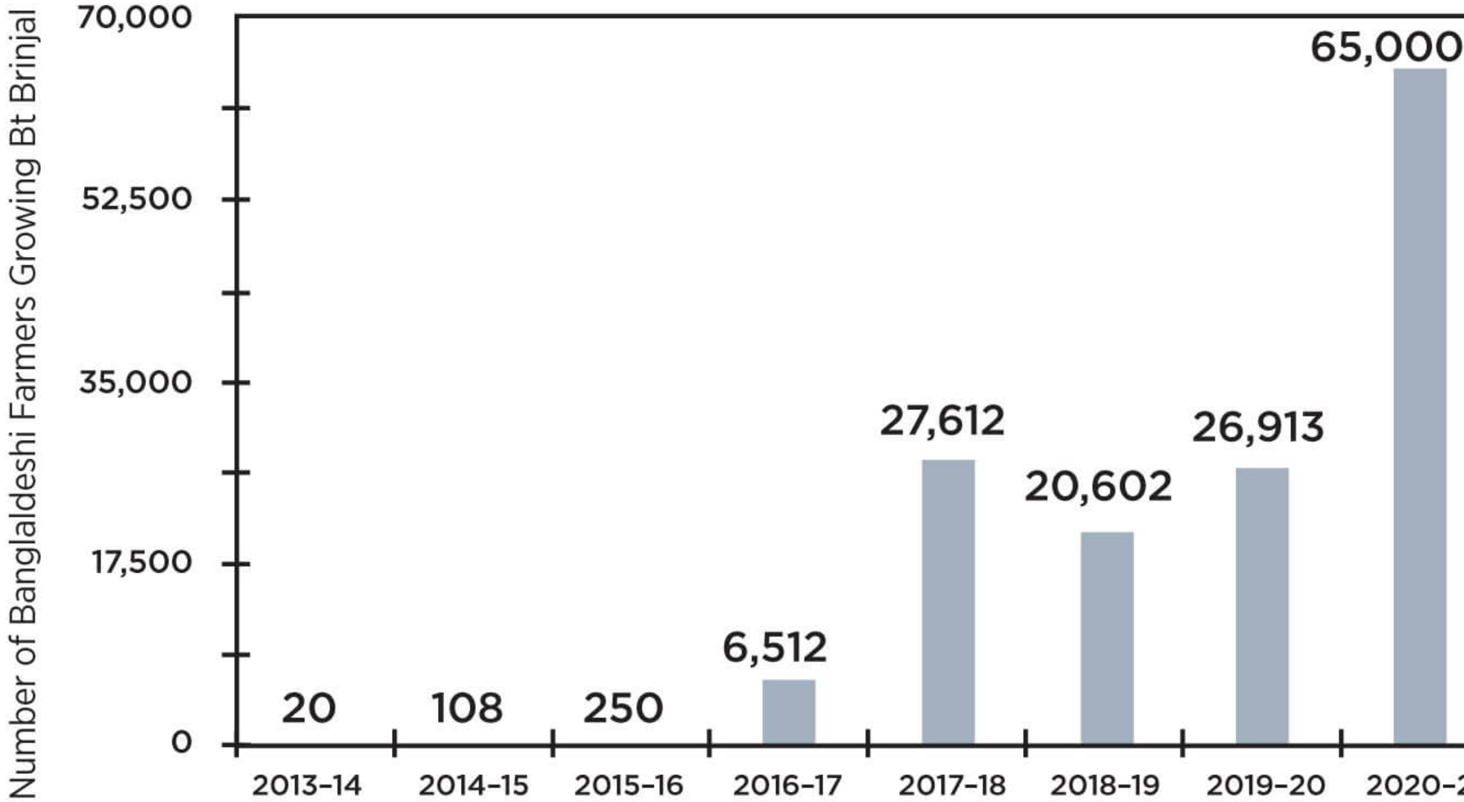

Fig. 4. Number of farmers growing Bt brinjal in Bangladesh by year (* indicates preliminary data). Farmers received seed from the Bangladesh Agricultural Research Institute (BARI), Department of Agricultural Extension (DAE), and the Bangladesh Agricultural Development Corporation (BADC).

Documenting the success of Bt brinjal

Studies in Bangladesh have demonstrated the economic and health benefits of Bt brinjal. In a study conducted by the Bangladesh Agricultural Research Institute (BARI) in 35 districts during the 2016–2017 cropping season, net returns were US $2,151/ha for Bt brinjal, compared with US $357 per ha for non-Bt brinjal: a six-fold difference (Rashid et al. 2018). The same study indicated that Bt brinjal farmers saved 61% of pesticide costs. The International Food Policy and Research Institute (IFPRI) conducted a survey during the 2017–2018 season in four districts (Ahmed et al. 2020), focusing on one of the four commercial Bt lines. Farmers were provided either Bt brinjal or its isoline (same variety but without the *Bt* gene) to produce their marketable crop. The survey showed the Bt brinjal line provided excellent control of EFSB, a 51% increase in yield, a 128% increase in net revenues, a 37.5% reduction in pesticide costs, and an 11.5% decrease in reports of pesticide poisonings. A study conducted in the 2019–2020 season confirmed the enhanced performance of the four Bt eggplant lines in the field and their increased acceptability in the market (Shelton et al. 2020). Compared to non-Bt brinjal lines, the Bt lines had a 19.6% higher yield and obtained 21.7% improved revenue. Furthermore, 80.6% of the 195 Bt brinjal farmers were satisfied with the quality of their fruit, compared with 28.0% of the 196 non-Bt farmers whose fruit was infested by the borers. The survey also revealed that nearly 40% of the non-Bt brinjal farmers had not yet heard of Bt brinjal, but 71.4% of them said they intended to grow Bt brinjal the following year after they had learned about it.

“Don’t let the perfect be the enemy of the good”

This phrase, attributed to the French writer Voltaire, occurs to me when I think about this project. The four approved Bt brinjal lines are not suitable for all the climatic conditions or regional preferences in Bangladesh. However, their use has helped curtail the serious environmental and health concerns caused by intensive insecticide practices farmers have used against EFSB, and has helped farmers provide a fresh supply of abundant harvests and improved quality. Bangladeshi farmers are pleased with their harvests (Fig. 5), but will these benefits last?

Fig. 5. Bangladeshi farmer Md. Khalilur Rahman with a fresh harvest of Bt brinjal in Hijulii of Tangail district, Bangladesh. Credit: Md. Arif Hossain.

Host-plant resistance is a foundation of an integrated pest management (IPM) program, and for the first time, its application has resulted in effective resistance to EFSB. However, as with resistant plants bred through traditional means, there is a threat that insects will overcome such resistance. Our studies on insect resistance management (IRM) have shown the value of using non-Bt refuges (Tang et al. 2001), pyramiding Bt genes (Zhao et al. 2003), and preserving natural enemies on Bt plants (Liu et al. 2014) to delay the evolution of insect resistance. Additionally, Zhao et al. (2005) showed the enhanced durability of introducing two-gene plants, but Bangladesh has commercialized only single-gene Bt brinjals. Furthermore, Bangladesh has no prior experience with the commercial use of Bt cotton or Bt maize, so this is new technology for this developing country. Thus, although Bt brinjal expressing the Cry1Ac protein has helped solve a serious problem, will it be sustainable?

Emphasizing sustainability

Since 2015, the project has introduced practices to enhance the durability of Bt brinjal in Bangladesh. The project partners work with BARI on a quality assurance program to ensure that seeds have proper protein expression before being multiplied and distributed. The seed distribution process is now accompanied by information about planting a border of non-Bt brinjal (refuge) as part of an IRM program, and the need to control mites, thrips, and leafhoppers, which can reduce plant vigor. Although farmers can save seed, they are discouraged from doing so because of the potential of outcrossing that could disrupt IRM. Populations of EFSB are being monitored for changes in susceptibility to the Cry1Ac protein (Prodhan et al. 2019), a fundamental component of an IRM program. At present, only four Bt brinjal lines are commercialized, but many dozens of non-Bt lines are grown that serve as an “unstructured” refuge to maintain Bt-susceptible alleles in EFSB populations. Although no evidence of resistance has been observed, farmers and researchers must remain vigilant.

The future

The Feed the Future South Asia Eggplant Improvement Partnership has ended. At the time of writing this article, it is not clear if USAID funding will continue for Bt brinjal, although a new proposal has been submitted. Although the private sector (Mahyco) donated the original transgenic event, it has not received any financial benefit or played a role in developing new Bt varieties. BARI remains the only producer of Bt brinjal seed in Bangladesh, with BADC multiplying the BARI-produced seed. Whether BARI or other Bangladeshi government agencies can properly oversee the project without the technical and financial support of USAID, or another outside organization, is a topic of current discussion.

Sustaining continued adoption of Bt brinjal requires the development of agronomically superior lines, including second-generation lines with multiple Bt genes, resistance to bacterial wilt, and suitability for different growing regions and consumer preferences. The Bangladeshi government needs to enhance laboratory and field-testing programs, resistance monitoring, and farmers' technical training. Furthermore, the government should create a better enabling environment by promoting an efficient event-based approval, rather than variety approval, to ensure that products move through the regulatory system safely, smoothly, and rapidly. Finally, given the difficulties in securing government funding for the expensive development and safe deployment of new Bt lines, consideration should be given to obtaining private-sector funding. I believe it would be in the best interest for the Bangladeshi government to allow theprivate sector to play a larger role in commercializing Bt brinjal, as the private sector already does forother crops in Bangladesh.

The studies cited herein demonstrate that Bt brinjal has improved the lives of resource-poor farmers in Bangladesh, which should be an indication of the benefits it can bring in other countries. In the Philippines, regulatory dossiers for food-feed and cultivation of Bt eggplant are being submitted to allow it to be grown and consumed there. These dossiers are being developed not only to meet the specific requirements of the Philippines, but also to serve as templates to meet international standards for other countries. India, which produces a quarter of world's eggplants, remains a challenge because of the current political climate. However, Indian farmers have become frustrated with the moratorium, leading to public demonstrations and the illegal planting of Bt eggplant (Deshpande 2019).

Concluding remarks

Bt crops have revolutionized agriculture, but their benefits have largely been confined to field crops such as maize, cotton, and, more recently, soybeans and chickpeas. I believe we need to move forward and use biotechnology—including Bt, other insecticidal proteins, and gene editing—to improve IPM in other crops, especially "orphan" crops such as fruits and vegetables. These are high-value cash crops essential for farmers' income, but with high cosmetic standards and hard-to-manage pest complexes. These crops are also essential for a healthy and diverse diet because they contain nutrients that fight hunger and the hidden threat of malnutrition (Maberly et al. 1994), a major problem in developing countries like Bangladesh. However, farmers of these crops have historically relied on intensive insecticide treatments for their production, with negative effects on humans and their environment. I hope the success of Bt brinjal in Bangladesh will help pave the way forward for other insect-resistant, genetically engineered food crops which can serve as cornerstones in IPM programs.

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