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Genetic Alchemy: Unlocking the Untold Potential of Bt -Brinjal for Pest Management

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ABSTRACT: Brinjal, also known as eggplant or aubergine, is a popular vegetable crop belonging to the Solanaceae family, and it originated in India. It is widely cultivated on over 1.847 million hectares of land, with an annual production of more than 52 million metric tonnes. Even though brinjal is a widely cultivated crop, it is vulnerable to various insect-pest attacks. Among them, the eggplant fruit and shoot borer (*Leucinodes orbonalis*) pose a persistent threat to farmers. In countries like Bangladesh, BSFB infestation can cause significant crop loss, up to 86%, These losses have a direct impact on crop yield and are primarily attributed to the utilization of insecticides that target a broad spectrum of insects. The development of genetically modified brinjal, also known as Bt brinjal, was driven by the need for an insect-resistant variety that could effectively control the eggplant fruit and shoot borer pest. This transgenic brinjal has the potential to increase productivity in Bangladesh and other countries. Due to environmental concerns, socio-economic impacts, health and safety concerns, there are challenges faced in the release of Bt brinjal in India. Genetic engineering has led to the development of various biotech/genetically modified crops that are resistant to biotic and abiotic stresses and are beneficial for human health and the conservation of natural resources.

Keywords: Bt Brinjal, Fruit-Shoot Borer, GMO, Transgenic, Resistant.

INTRODUCTION

Vegetable farming is a significant sector of agriculture and a major industry in several countries, such as India. Vegetables are widely recognized as a crucial component of a healthy and nutrient-rich diet. They provide a broad spectrum of essential vitamins, minerals, proteins, and carbohydrates, making them an excellent source of nutrition (Kiranmai *et al*., 2021). Brinjal (*Solanum melongena* L.) is a popular vegetable crop in South Asia, especially in countries such as India, Bangladesh, Nepal, and Sri Lanka. It belongs to the family Solanaceae and is widely cultivated for its edible fruit (Singh *et al*., 2013). It is an ancient vegetable crop that is native to India and has been cultivated there for over 4,000 years. Brinjal is grown on a total of 550,000 hectares by 1.4 million small family farms. Farmers transplant brinjal from nurseries at various times of the year to generate two or three crops, making it a significant income crop (Gianessi and Williams 2012). 8 to 9 million tonnes, or around 25% of global production, are produced in India. An estimated 52,309,119 metric tonnes of eggplants were produced worldwide in 2017. China was the largest producer of brinjal, accounting for over 62% of global production (FAO, 2005). India's production of brinjal is projected to have reached over 12.98 million metric tonnes in the fiscal year 2022 (Statista, 2022).

Brinjal is highly susceptible to insects and pests, and especially vulnerable to damage by *Leucinodes orbonalis*, the fruit and shoot borer (FSB) pest. Marketable fruit yield is decreased by the FSB larvae by 60–70% (Choudhary and Gaur 2009). As FSB belongs to the Lepidoptera family, the larva is the damaging stage of the organism. The larvae, upon hatching, bore into the fruits and shoots causing severe damage and rendering the fruits inedible. Depending on the severity of the infestation, farmers typically use insecticides twice weekly with 15–40 sprays or more in a season; as a result, chemicals continue to build up in fruits (Kumar *et al*., 1998). Exposure to pesticides through consumption has been linked to various health risks in humans, including but not limited to minor cognitive impairment, hormonal imbalances leading to infertility, breast soreness, monthly irregularities, adrenal gland depletion, and early menopause (Xavier *et al*., 2004).

Due to the need for BSFB-resistant brinjal cultivars, the genetically engineered Bt brinjal was subsequently developed. A gram-positive, spore-forming bacterium called *Bacillus thuringiensis* (Bt) creates several insecticidal crystal proteins (ICP) that are poisonous to lepidopteran insects (Kumar *et al*. 1996). The crystal protein gene (Cry1Ac) from the soil bacterium *Bacillus thuringiensis* was inserted into the genome of multiple brinjal cultivars to create the transgenic brinjal. Agrobacterium-mediated genetic transformation is used to install the gene, together with other genetic components for antibiotic resistance, into the brinjal plant. Due to their potential for high production, genetically altered crops may offer an alternative to pesticides, thereby addressing the issue of food security, particularly for small-scale agriculture in poor nations (Azadi and Ho 2010).

Transgenic crops are those that use recombination DNA technology to introduce foreign genes into their cells. In many circumstances, transgenic crops increase crop productivity by reducing crop damage with pest-resistant types. As a means of improving output and quality, these technologies should be utilized in addition to rather than as a substitute for traditional breeding practices (Mahadev, 2010). Transgene flow in native plants or organisms through pollen transfer is one risk associated with transgenic crops. Other risks include plant invasiveness, the emergence of resistant pests and pathogens, and loss of biodiversity (Dale *et al*., 2002).

Although eggplant genetic modification has been practiced for a considerable amount of time, its use for enhancing eggplant genetics is still in its early stage. Only a small number of agronomically important features, such as drought and salinity resistance, production of parthenocarpic fruits, and insect resistance, have been genetically introduced into farmed eggplants to date (Kiranmai *et al*., 2021). This restriction makes it urgently necessary to create transgenic eggplants with a wide variety of unique traits. The agricultural sector could benefit from the introduction of new and improved traits brought about by this technology. To increase the number of features that can be inserted into eggplants by genetic manipulation and additional study.

The target insect-pest: Fruit and shoot borer (FSB). The most destructive and problematic pest in brinjal crop is the fruit and shoot borer (FSB), also known as *Leucinodes orbonalis*. It is a member of the family Pyralidae of the insect order Lepidoptera. It is also found in other vegetables of solanaceous families like potatoes, tomatoes etc. It is a tropical pest that is primarily present in 13 different nations in South Asia, South-East Asia, and African regions (Choudhary and Gaur 2009).

The oviposition take place at the lower surface of younger leaves. After few days of larval hatching, larva bores into the petioles, midribs of leaves, and shoots of a plant, resulting in wilting of shoot tips, leaf drop, and entrance hole is plugged with excreta (Quamruzzaman, 2021). These are the initial symptoms of infected plants. Furthermore, it also damages the flower buds and tender fruits.

The larvae attack in 2 stages, one in the vegetative stage - small larvae eat through the tissues in fragile shoots, paralyzing and withering the damaged shoots. Other in the reproductive stage- the larvae dig into the fruits and eat them and make exist holes before pupae formation. Their preferred food is fruit. This reduces the market quality of fruit, as such fruits are not selected by consumers (Choudhary and Gaur 2009). There are four stages in the life cycle of an insect: egg, larvae, pupae, and adult. As insect infestation is persistent throughout the life cycle of brinjal, farmers typically use insecticides twice weekly with 15–40 sprays or more in a season; as a result, chemicals continue to build up in fruits and is hazardous to human health (Kiranmai *et al*., 2021).

Due to the harmful consequences of regular pesticide application throughout the growing season, farmers have serious health problems. Additionally, these chemicals endanger the pollinators, predatory insects, and parasitoids that are essential for controlling the EFSB pest population (Quamruzzaman, 2021). In addition, the EFSB pest has exhibited growing resistance to numerous pesticides over the past few years, resulting in reduced efficacy of these sprays (Quamruzzaman, 2021).

***Bacillus thuringiensis* with endotoxin proteins (Protein Parasporal Crystal).** A gram-positive, soil-dwelling bacteria called *Bacillus thuringiensis,* also known as Bt, is the most widely used biological insecticide in the world. Additionally, *B. thuringiensis* naturally exists on leaf surfaces, in aquatic settings, in animal excrement, in insect-rich environments, in flour mills, and in grain storage facilities. It is also found in the gut of caterpillars of several types of moths and butterflies (Brock *et al.,* 2003; d du Rand 2009). The feature that distinguishes Bt from the other species is its entomopathogenic properties. The bacterium produces certain crystals known as "cry" proteins (endotoxin proteins) that are found in the spores. These proteins have toxicity for insects (Aronson *et al.,* 1986). Mammals, birds, amphibians, and reptiles are not at risk from these proteins, but they are selective in the insects and invertebrates they target (Schnepf *et al*., 1998). There are several strains of *B. thuringiensis*, each with a unique range of insect hosts (Roh *et al*., 2007). These strains collectively produce more than 150 different forms of "cry" protein crystals, demonstrating the organism's versatility (De Maagd *et al.,* 2001)). The crystal poisons can be divided structurally into two groups:1) Cyt family, which has non-specific cytolytic and hemolytic activity as Cyt1Aa1, Cyt2Aa1, etc., and 2) Cry family, which has specific cytolytic activity as Cry1Aa1, Cry1Ba1, Cry2Aa1, etc (Osman *et al*., 2015). Mostly these proteinaceous substances produced by diverse strains have been shown to be quite effective against the larvae of some Lepidoptera species. However, only a small number of reports of its toxicity against Diptera and Coleoptera species have also been made (Bravo *et al.,* 2013).

These proteins can increase immunogenicity by eliciting a sufficient immune response capable of defending the pest against an experimental infectious challenge. Conversely, the toxin was able to kill the pest when the Bt toxin sprayed on the leaves was consumed. Direct contact or exposure to the toxin had no deadly effects on the insect caterpillar pests

(Kiranmai *et al*., 2021). Crystal protein is created inactively by *Bacillus thuringiensis* bacteria. The insects' alkaline pH aids in the activation of cry proteins after consumption. The protoxin is a Cry toxin's immediate poisonous precursor (Bulla *et al*., 1979). It's interesting to note that the conversion of protoxin to a toxin varies depending on the host, *i.e.*, toxins that kill moths, beetles, or mosquitoes like Cry1A and Cry4 toxins (~ 65 kDA) that primarily kill moths and mosquitoes, respectively (Osman *et al*., 2015).

Cry genes, which are primarily found on large plasmids, encode cry toxins. However, the chromosome may also incorporate the genes. In the year 1993, Carlton and Gawron-Burke gave classification based on the host range for cry toxins, which is accepted universally. This includes four major classes, each class related to a specific family of pests. As give in (Table 1) (Osman *et al*., 2015).

Table 1: Classification based on host range for Cry genes (Hofte and Whiteley 1989).

Gene	Insect Family	Shape of Crystal
Cry I Several subgroups: A(a), A(b), A(c), B, C, D, E, F, G	Lepidoptera	Bipyramidal
Cry II Several subgroups: A, B, C	Lepidoptera and Diptera	Cuboidal
Cry III Several subgroups: A, B, C	Coleoptera	Flat/irregular
Cry IV Several subgroups: A, B, C, D	Diptera	Bipyramidal
Cry V - IX	Various	Various

Cry1Ac: The Gene inserted in Bt brinjal. The genetic material that has been inserted into the plants has been genetically modified to enhance its expression within the plant's system (Perlak *et al.*, 1990). The DNA sequence responsible for coding the Cry1Ac protein from the *Bacillus thuringiensis* subsp kurstaki bacterium underwent deliberate alterations aimed at increasing the quantity of the Cry1Ac protein produced (Quamruzzaman *et al*., 2021). When Bt eggplants produce the insecticidally active Cry1Ac protein, the trypsin-resistant core of the protein is about 600 amino acids long. However, when this particular protein comes into contact with trypsin or the digestive enzymes found in the digestive tract of the intended insect, it will undergo degradation that leads to the elimination of the amino acid located at position 766, resulting in the protein's inactivation. Fortunately, the removal of the amino acid at position 766 and subsequent inactivation of the protein does not have any negative impact on its ability to target the intended host, as well as the remaining active portion of the N-terminal that retains its activity (Bietlot *et al.*, 1989).

Transgenics: Vector-Mediated Gene Transfer. Since Agrobacterium tumefaciens can infect a wide range of host plants by transmitting a single gene copy number, it has been widely employed in the field of genetic engineering for the transfer of genes (Nester, 2015). H. J. Conn had discovered first the Gram-negative bacterial genus Agrobacterium, which employs horizontal gene transfer. Plants that have Agrobacterium tumefaciens suffer from the crown-gall disease. A gall or growth that resembles a tumor can be seen on the affected plant, frequently at the point where the root and shoot intersect. There is a conjugative transfer that leads to the transfer of DNA segment (T-DNA) from bacterial tumor through (Ti) plasmid. The tumor morphology genes on the plasmid T-DNA are expressed, leading to the formation of a gall, and the plasmid T-DNA is integrated rather randomly into the host cell's genome (Francis and Spiker 2005). In particular, genetic engineering for plant enhancement uses Agrobacterium's capacity to transfer genes to plants and fungi (Anonymous, 2022a). It has been shown that A. tumefaciens' used in gene transfer is highly effective in a number of Solanaceae species, including eggplant (Van Eck, 2018).

Although, Traditional plant breeding methods have been important in raising crop yields and improving fruit quality. But, due to sexual incompatibilities, the prevalence of sterility in the progeny, and the scarcity of naturally occurring resistance sources, conventional breeding options for increasing insect resistance for brinjal are limited (Shivaraj and Rao 2010). Therefore, it is vital to implement transgenic techniques to create eggplant with features like insect resistance and resistance to wilt diseases (Singh *et al*., 2014). Starting from the year 2010, the utilization of genetically modified crops that generate Bt toxins, which effectively exterminate the primary pests they are designed to target, has become increasingly prevalent (Yang *et al.*, 2018).

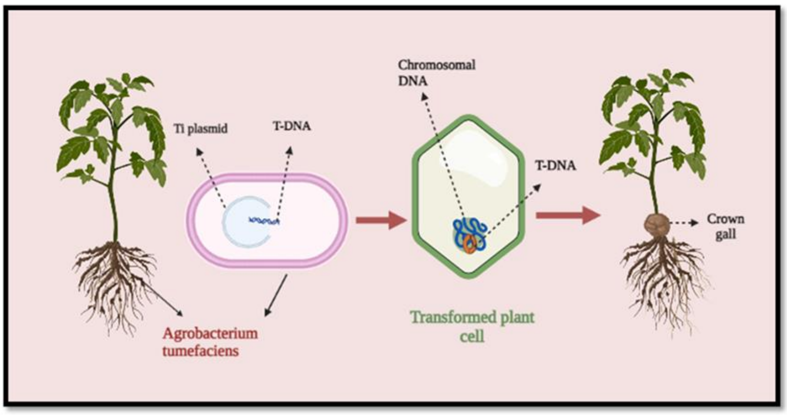


Fig. 1. Step-by-Step Agrobacterium-Mediated Gene Transfer Process.

Mode of Action of Cry proteins. The crystalline Parasporal inclusion bodies which is composed of Cry proteins are in an inactive state at the time of production (Bravo *et al.,* 2007). The toxin proteins get activated when get dissolved in the alkaline medium of the insect's gut lumen. After that, the insecticidal protein sequentially binds to two distinct receptors. The cadherin receptor is the insecticidal protein's first point of interaction, which causes the oligomer structure to develop. The oligomer then exhibits enhanced affinity for amino-peptidase-N, a second receptor (APN) (Choudhary and Gaur 2009). This leads to activity would breaking down the Cry protein into a smaller fragment known as a protease-resistant toxic polypeptide, which cannot be further broken down by a protease. Upon binding to a particular receptor located on the midgut epithelial cells of the insect, these toxins induce the formation of non-specific pores. As a result of the pores formed, there is a flow of ions and other molecules such as amino acids and carbohydrates through them (Palma *et al*., 2014). The presence of pores in the gut membrane leads to the process of osmotic lysis. This, in turn, causes paralysis of the insect's gut and ultimately results in the insect's starvation. And ultimately the insect dies (CERA, 2011).

Ingesting Cry protein has other physiological impacts for insects, such as total paralysis, difficulty in absorbing nutrients, degenerative changes, lack of hunger and food abandonment, gut paralysis, and numerous other physiological illnesses (Schünemann *et al*., 2014). Mammals, birds, and fish, as well as other organisms that lack the specific gut enzymes and receptors required to interact with the Cry1Ac protein, are not affected by the toxic properties of this protein (Quamruzzaman *et al*. 2021).

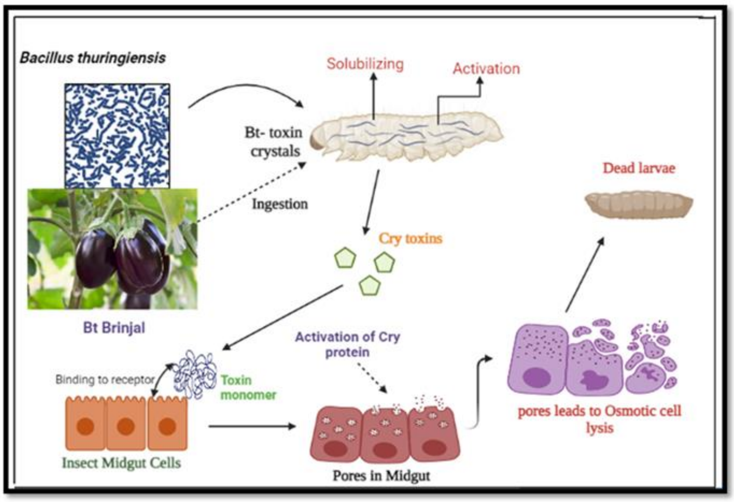


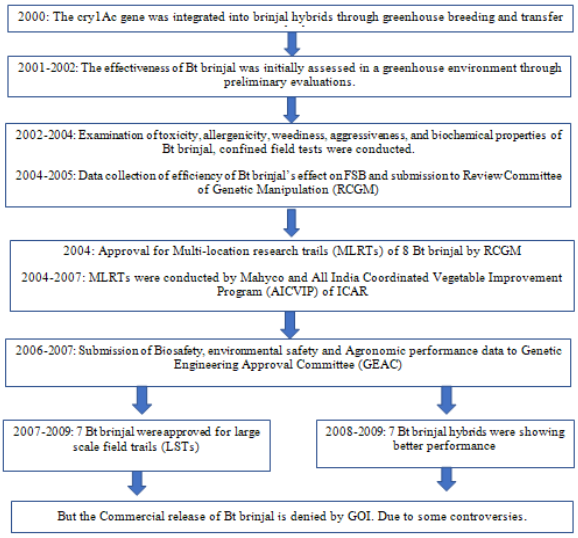
Fig. 2. The Lethal Mechanism: Understanding Cry Toxin's Mode of Action.

History of Bt- Brinjal. FSB-resistant brinjal, often known as Bt brinjal, was created utilising a transformation technique similar to that of Bt cotton. To give resistance to Fruit and shoot borer (FSB), Bt brinjal contains the cry1Ac gene, which produces an insecticidal protein. The *Bacillus thuringiensis* (bt) soil bacteria is the source of the cry1Ac gene. Indian company-Maharashtra Hybrid Seeds Company (Mahyco) first to developed Bt- Brinjal (Choudhary and Gaur 2008). Young cotyledons of brinjal plants were transformed by the firm using a DNA construct including the cry1Ac gene, a CaMV 35S promoter, and the selectable marker genes npt II and aad (Choudhary and Gaur 2009). Mahyco also gave the Bt brinjal technology to the University of Agricultural Sciences (UAS), Dharwad, and the Tamil Nadu Agricultural University (TNAU), Coimbatore (ISAAA, 2008).

The Bt Brinjal event, also known as "EE-1," was introduced to the Bangladesh Agricultural Research Institute (BARI) in collaboration with the Agricultural Biotechnology Support Project II at Cornell University. This initiative was made possible with financial support from the US Agency for International Development. This event was then introduced into a number of regionally and commercially successful open-pollinated brinjal varieties (Shelton *et al.,* 2018). As a result, there were a total of 9 Bt-varieties that they got, which went through preliminary and multilocation yield trials for 7 years by BARI at various locations in Bangladesh. On October 2013, Four of those nine Bt cultivars were given cultivation approval by Bangladesh's National Committee on Biosafety (NCB). Although, initially they were named as Bt- begun, but later named Bt-brinjal (bt brinjal-1, bt brinjal-2, Bt brinjal-3 and Bt brinjal-4) (Shelton *et al.,* 2018).

In 2009, there was the release of EE-1 Bt brinjal in the market approved by report committee (Choudhary and Gaur 2009). This EE-1 was introgressed in various cultivars like Manjari Gota, Udupi Gulla, Rabkavi etc, which were local cultivars of Tamil Nadu and Karnataka. But due to several controversies related to biosafety, Bt brinjal was not accepted (Kiranmai *et al*., 2021). Later it was given to Bangladesh and was approved. Bangladesh then created a few other new varieties, including Ruchira, Poona selection, and Krishna Kathi (Jadhav *et al.,* 2015).

Flow Chart of Development and Regulation of Bt Brinjal in India. (**Adapted from Choudhary and Gaur 2008, GEAC, 2008; MOEF, 2008).**



Bt Brinjal has sparked extensive debate in India, with supporters claiming that its use would benefit small-scale farmers. They contend that Bt Brinjal is a good option for cultivation among small farmers due to its natural insect resistance, capacity to increase crop yields, cost-effectiveness, and minimal environmental effects. But Bt Brinjal has faced significant scrutiny from scientists, farmers, and environmental activists, who have raised various concerns about its cultivation. This includes health risk, farmer's acceptance, environmental impact etc. Out of all health risk has attracted everyone as a major concern (Verma, 2010).

The Central Government of India declared in February 2009 that it would need more time to carry out extensive safety testing of Bt Brinjal before approving its usage for commercial purposes in response to the issues raised by farmers, scientists, and NGOs.

The Indian government approved the trial runs in 2020 to determine whether the product could be sold commercially. From 2020 to 2023, the trials are expected to begin in a number of states, including Madhya Pradesh, Karnataka, Bihar, Chhattisgarh, Jharkhand, Tamil Nadu, Odisha, and West Bengal (Anonymous, 2022b).

The insect resistance management (IRM) strategy. The IRM against Bt insecticidal protein is very encouraging. Frequent exposure of insect pests to chemical insecticides over time has led to the development of resistance to some of the most potent insecticides. This phenomenon has been observed in many different species of insects, which have historically been exposed to these chemicals for extended periods. Mahyco conducted several laboratory and field studies to evaluate various management techniques. These studies aimed to identify effective ways of managing insect pests while minimizing the development of resistance to chemical insecticides. It also consulted the University of the Philippines, TNAU, Coimbatore, East West Seeds, UAS Dharwad, Cornell University in the United States, and the Bangladesh Agricultural Research Institute (BARI) for making IRM strategy (Choudhary and Gaur 2008).

As a strategy to prevent or delay the development of resistance to Bt brinjal, it has been proposed to establish a planned refuge in the fields where Bt brinjal is grown. The planned refuge involves planting a small proportion of non-Bt brinjal (around 5% of the total crop) within the field of Bt brinjal. This indicates that 0.05 acres of non-Bt plants should be planted as a buffer for every acre of BT plants. According to this, farmers are supposed to sow non-Bt plants on either side of Bt plants (as given in fig 3 below). The refuge method aims to delay the onset of resistance by providing a source of susceptible insects for mating with the resistant insects that may emerge in the field (Mahyco 2006; 2008b).

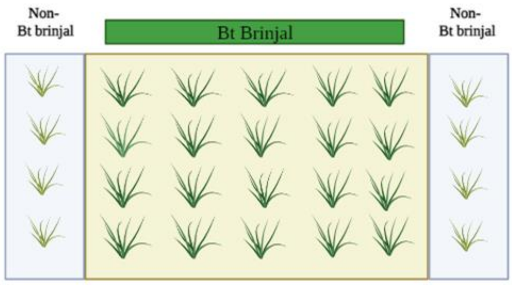


Fig. 3. Implemented IRM strategy for Bt brinjal cultivation (Mahyco 2006; 2008b).

The Adoption and Impact of Bt Eggplant Technology in Bangladesh. On January 22, 2014, for the first time in Bangladesh, Bt eggplant seedlings were provided to twenty farmers across four districts, enabling them to access this technology. BARI (Bangladesh Agricultural Research Institute) provided seedlings to 108 farmers as part of the On-Farm Research Division (OFRD) programme during the second year of Bt eggplant production, allowing them to perform field demonstration trials in 19 different districts across the nation. The number of demonstration trials for Bt eggplant was expanded in the years. 250 farmers from 25 districts took part in the programme in 2015–16, and 512 farmers from 36 districts took part in 2016–17 (Shelton *et al.*, 2018).

During the 2017-18 period, BARI distributed Bt eggplant seeds to 569 farmers across 40 districts of Bangladesh. Additionally, the Department of Agricultural Extension (DAE) distributed seeds to 6,000 farmers in 2016-17 and 7,001 farmers in 2017-18. Furthermore, the Bangladesh Agricultural Development Corporation (BADC) sold Bt eggplant seeds to an additional 17,950 farmers in 2018 (Shelton *et al.*, 2018).

The adoption rate of Bt eggplant technology in Bangladesh has increased significantly in recent years. In 2018, a total of 27,012 farmers cultivated Bt eggplant, marking a significant milestone in the widespread adoption of this first genetically modified crop in the country. The farmers have reported substantial profits from this technology. The expansion of Bt eggplant cultivation among farmers in Bangladesh has been supported by a USAID project, with the Bangladesh Agricultural Research Institute (BARI) leading the entire initiative (Quamruzzaman *et al.*, 2021).

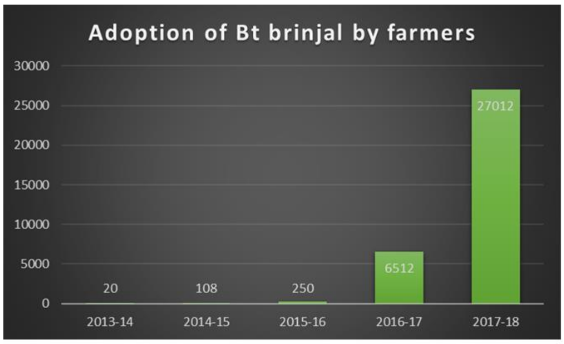


Fig. 4. Bar chart explaining adoption of Bt brinjal from year 2013 to 2018.
(Source: Quamruzzaman *et al*., 2021)

Farmer and Consumer Benefits. Bt brinjal demonstrated a higher level of resistance to FSB when compared to non-Bt varieties, as evidenced by complete insect mortality in fruits and 98% insect mortality in shoots (Shelton *et al.*, 2018). Because of use of Bt brinjal, cost of production of crop is significantly lowered due to lower labour costs and insecticide cost savings from less spraying (Krishna and Qaim 2008). The adoption of Bt brinjal has resulted in a significant reduction in pesticide residues found in the fruit, as a result of the reduced use of insecticides. This has contributed to the overall decrease in the exposure of farmers to insecticides, thereby lowering the potential health risks associated with their use (Chong, 2005; GEAC, 2007). According to scientists, Bt brinjal would provide farmers with a net economic advantage of between Rs. 16,299 (US$330) and Rs. 19,744 (US$397) per acre, with benefits to India's economy totalling more than $400 million annually (Shelton *et al.*, 2018).

It is clear from history that advances in agricultural technology have considerably boosted productivity and improved yields. As a result, farm income has increased significantly nationally, which has helped both farmers and consumers (ISAAA, 2008). As per the Indian Institute of Horticultural Research's 2008 report, the implementation of hybrid technology in brinjal resulted in a yield increase of up to 50%, while tomato and onion yields increased by 75% and 25%, respectively. India holds the position of the world's second-largest vegetable producer, with a cultivated area of approximately 7 million hectares. (James, 2008). Market availability of more brinjal fruits at more affordable prices is predicted as a result of Bt brinjal's potential to significantly increase marketable yield. expected a 15% drop in the price of brinjal at the point of greatest technology implementation (Krishna and Qaim 2007; IIHR, 2008).

The Global Landscape of Biotech Crops. Although the first GM organisms were created in a lab in 1971, it took around 25 years for commercial products to be released. In 1996, the commercial cultivation of genetically modified crops, such as insect-resistant Bt cotton, Bt corn, and herbicide-tolerant soybean, was approved in the USA and a few other countries. This approval paved the way for large-scale commercial plantings of genetically modified crops that were engineered to provide increased protection against insect pests and herbicides. The pioneering nations included the USA, China, Canada, Argentine, Australia, and Mexico (Choudhary and Gaur 2009). The global acceptance of biotech/GMO crops has been remarkably rapid.

Both the economy and the ecology have benefited from GMO crops. Over a very small area of land, the output of food crops worldwide grew by more than 370 million tonnes (Raman, 2017). As GMO crops are frequently created to be resistant to biotic and abiotic stress, farmers can use fewer pesticides, while still producing abundant crop harvests. Further, these traits like resistance and tolerance are combined with other traits called stacking or gene pyramiding (Choudhary and Gaur 2009). According to a 2020 report by the International Service for the Acquisition of Agri-Biotech Applications, 18 million farmers in 26 nations are growing GM crops. This has made it possible for farmers over the world to increase agricultural yields and enhance their standard of living (Raman, 2017).

As a result, its demand has been rising steadily over time. 26 countries produced 191.7 million hectares of genetically modified (GMO) crops in 2018. In 2018, Brazil, Argentina, Canada, and India had a combined total of 174.5 million hectares of genetically modified (GM) crop-growing land, which represents 91% of the world's total GMO crop-growing area. The United States was the largest producer of GMO crops, with 75 million hectares of GM crop-growing land, and these four countries followed closely behind. Therefore, crop biotechnology provided benefits to more than 1.95 billion individuals (Quamruzzaman 2021).

It is worth noting that a significant majority of biotech crops, over 90%, are designed to be either resistant to pests or herbicides. The adoption of these biotech crops has led to improvements in agricultural productivity and increased income for farmers, demonstrating their positive impact on the agricultural sector (Jung *et al.*, 2020).

CONCLUSIONS

Crops that have been genetically modified (GM) have the potential to solve several problems that commercial agriculture is now facing. These crops are anticipated to be among the most inventive and fast-growing industries on the international market, providing advantages to farmers as well as consumers and the economies of significant nations. The introduction of Bt brinjal has elicited varied responses from different committees involved in its development. India, as a developing nation, is grappling with the challenges posed by its rapidly growing population. The escalating demand for food has placed emphasis on the significance of Bt crops, making them a potential solution to address this issue. While there are various concerns and questions regarding the safety and associated issues of Bt brinjal, it is worth noting that Bt brinjal is already being marketed in Bangladesh. Therefore, these concerns should not simply be dismissed, but rather considered and addressed in order to make an informed decision about the product.

FUTURE SCOPE

The future scope of BT Brinjal lies in its potential to provide agricultural benefits, reduce environmental impact, improve crop traits, and enhance disease resistance. By incorporating the insecticidal BT protein, BT Brinjal can help farmers achieve higher crop yields and reduce reliance on chemical insecticides. This can contribute to improved food security and economic viability. Additionally, genetic engineering techniques can be utilized to enhance nutritional content, extend shelf life, and confer tolerance to abiotic stresses. Disease-resistant varieties can also be developed. However, the future of BT Brinjal depends on factors such as regulatory approvals, public acceptance, and scientific advancements in genetic modification.

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