Beating The World Fibre Crisis with Bt-Cotton

Executive Summary

Despite being limited in size, the world is constantly expanding in terms of its population. As a result, there is tremendous stress on agriculture to cater to the growing population's food, fibre, and fuel needs. It is estimated that the world population will reach approximately ten billion by 2050 (Ahmar *et al.*, 2020). This poses a huge challenge for the agriculture industry, which is already struggling with decreasing farmers and reducing agricultural land to sustainably cater to the population's growing needs (Turnbull *et al.*, 2021). Increasing crop yield while battling various biotic and abiotic stresses is a huge challenge. Farmers must choose between conventional breeding techniques and genetically modified plants to overcome this challenge.

The cotton plant is the most important source of natural fibre. It has also found application for cottonseed and cottonseed oil. However, cotton production was previously associated with high economic and environmental costs due to using large amounts of pesticides (Rocha-Munive *et al.*, 2018). The pest problems, environmental concerns, and high production costs had caused a reduction in cotton production. According to the FAO, the arable land available by 2050 will be reduced to approximately 0.18 hectares per person (Oliver, 2014). With a decrease in arable land, global yield needs to increase to cater to future demands. GM cotton can help solve the world fibre problem by providing better yield from limited acreage. Since GM cotton confers resistance to various insect pests, it helped revive the cotton crop. It provides higher fibre yield while reducing insecticide and pesticide usage. Selective gene silencing in cotton has resulted in the production of ultra-low gossypol cottonseed. GM cotton can thus help increase the yield and quality of food, feed, and fibre while significantly lowering chemical pesticides' use.

Description

An increase in population strains natural resources. Feeding and clothing the population are basic problems that require novel solutions because this increasing population has caused a reduction in the agricultural land. The increase in population has also caused an increase in the number of vehicles. This has resulted in the depletion of non-renewable natural resources and forced us to search for alternatives.

Increasing global warming and the continuous use of chemicals to tackle pests and increase yield have aggravated abiotic stress. Moreover, chemical insecticides and pesticides have also resulted in the evolution of pathogens to add to the biotic stress factors. As a result, there is a demand to look for novel strategies to combat biotic and abiotic stresses while increasing the yield of crops. There are two ways in which the food, fibre, and fuel problems can be tackled:

1. Conventionally breeding crops that can provide resistance to various biotic and abiotic factors without compromising on the yield.
2. Opt for genetically modified crops resistant to pests and increase crop yield.

While both techniques work towards the same goal, their approaches are different. As a result, there are pros and cons associated with both.

Conventional plant breeding

Plant breeding has been used since the 20th century for developing plants with the desired traits (Shiferaw *et al.*, 2013). These traditional breeding methods have contributed to the development of various crops, including wheat, maize, potato, rye, sugar beet, etc. However, long crop durations, several phases for selecting parent plants, crossing them for the desired trait, and testing the progeny for stability is a long process. releasing a new cultivar through conventional plant breeding can take up to a couple of decades. As a result, increasing agricultural productivity through these techniques has its limitations.

Traditional breeding techniques have also caused a reduction in the genetic variability of crops. However, traditional plant breeding methods have improved with time and advances in science and technology. Novel breeding strategies have made it possible to search for the desired trait within the germplasm of the crop using techniques like marker-assisted breeding (MAS), linkage QTL (quantitative trait locus) analysis, double haploids, genomic selection, speed breeding, etc. As a result, many farmers use these breeding techniques while growing crops.

Genetic modifications

The yield of staple crops (food, fibre, and fuel) must match the growing population's needs. Since arable land for agriculture is limited, novel solutions must be developed to fulfil the requirement. Genetic modification of crops has the potential to tackle the food, fibre, and fuel problems plaguing the world, as conventional breeding cannot help meet the required target. Advances in molecular biology and biotechnology have made it easy to alter the genome of any organism. A specific trait from an unrelated organism can be combined with the crop's genome to get the desired results. These genetic modifications can introduce disease resistance, pest resistance, insect resistance, etc., in crops or help provide additional nutrition, tackle food allergies, etc. One of the most popular genetically modified crops is cotton.

Analysis & Evaluation

Bt cotton and its advantage over conventionally bred cotton

Cotton was one of the crops domesticated around 5,000 years ago (Qandeel-E-Arsh *et al.*, 2021). While earlier, cotton was only used for its fibre, the usage has been extended to cottonseed (as livestock feed) and cottonseed oil (used in a wide range of food products, soap, cosmetics, etc.). Biotic and abiotic stresses had caused a decrease in cotton production. However, genetic engineering has helped address these problems. The production of GM crops has increased 100 times in the past 25 years (Mathur *et al.*, 2017). Among the various GM crops cultivated on around 190 million hectares area, cotton accounts for almost 13%. Among the total cotton grown globally, GM cotton accounts for 79% (Townsend, 2019) and thus is a significant contributor to solving the world's fibre problem.

Many consumers prefer non-GM or traditionally bred cotton. This is because there exists a misconception that GM crops are not safe. Conventionally bred cotton derives its features by crossing naturally obtained species. Since it does not contain any foreign element (unlike Bt-cotton), it reduces the chances of an allergic reaction. Although the demand for organic cotton is high, there are certain disadvantages associated with conventional cotton breeding. These include:

1. Since the cotton germplasm is limited, using the same genetic sources cannot yield much variability.
2. Conventional breeding can occur only in sexually compatible species. Thus, sexual incompatibility does not allow you to get the desired results even if you find two plants with the chosen traits.
3. Selecting the parent plant by screening germplasm and crossing the parent plant to get desired progeny is time-consuming.

4. Even if insect-resistant plants are obtained through conventional breeding techniques, evolution in pests can cause them to become resistant to newer varieties.

The loss in cotton yield due to insect pests was one of the reasons for the popularity of GM cotton. Genetically modified cotton has a gene from a bacterium (*Bacillus thuringiensis*) that produces a toxin that, when ingested by pests, causes their death. However, it does not harm pollinating insects. Bt cotton has helped farmers reduce insecticide usage, lowering production costs and environmental pollution. High yields with easier pest management and reduced chemical usage have helped in the popularity of GM cotton.

Since GM crops are regulated as per the Cartagena Protocol globally, they are safe for usage. Different countries have varied approaches regarding the regulation of GM cotton. China and India, two of the top GM cotton producers, have allowed the cultivation of non-food GM cotton. Cottonseed produced globally contains approximately 10.8 trillion grams of protein that can be used to fulfil the basic protein requirements of nearly 590 million people at a 50 g/day rate. However, the presence of a toxic terpenoid (gossypol) in seed glands made it unfit for human consumption. Modifications in the cotton genome have reduced the gossypol levels in seed by 97% without affecting its levels in other parts of plants. In the U.S., this GM cotton with ultra-low gossypol content has been approved for human consumption. Transgenic cotton, which has eliminated gossypol from cottonseed, makes it fit for consumption without altering its defence against insects and diseases (Rathore *et al*., 2020).

Despite the advantages of GM cotton over conventionally bred cotton, there are a few problems associated with it. These include:

1. GM cotton seeds are expensive and cannot be reused, which increases the cost of production.
2. Transgenic Bt-cotton affects enzyme activity and nutrients. While cotton is primarily cultivated for fibre, cottonseed and cottonseed oil are also extracted from it. Thus, this alteration can affect the feedstock.
3. Leakage of the implanted Bt gene to non-GM plants through cross-pollination is a cause of concern.
4. Evolution in insects can cause them to become resistant to the Bt gene. Lepidopteran insects became virulent to Bt-cotton within eight years (Ali *et al.*, 2006; Liu *et al.*, 2010).

Stakeholders

Although a small global cotton producer, Australia is one of the largest exporters of raw cotton globally. More than 90% of cotton produced in Australia is exported (Egan & Stiller, 2022). Commercial cotton-producing regions of Australia include New South Wales, central and southern Queensland, and northern Victoria. Apart from these areas, trials are ongoing in northern Western Australia and northern territory. Since its commercialisation in 1996, GM cotton has been grown commercially in Australia. Most GM cotton plants grown here are herbicide tolerant or resistant to major insect pests, mostly belonging to *Lepidoptera* spp.

Sustainable agriculture requires that the monetary benefits of farmers are not at the cost of the environment. Sustained cotton production strategies aim to improve factors that limit environmental degradation, prevent biodiversity loss, soil erosion, leaching of nutrients from the soil, evolution of new pathogens, etc. GM cotton has helped Australian farmers increase their productivity and earnings while ensuring that the environment is protected. Planting Bt-cotton has dramatically reduced insecticide usage in Australian cotton crops. A decrease of 97% in insecticide usage has been observed here. Farmers do not use more than 0-3 insecticide treatments per cotton crop.

Despite several advantages of Bt-cotton for the environment and the farmers, there are concerns regarding it. This is majorly because it is a transgenic crop that needs to be regulated accordingly. While most concerns are regarding edible transgenic crops, and since cotton is primarily used for fibre production, not much emphasis has been made on it. Organic cotton is obtained from non-GM crops; however, the cost of producing it is high, making it less profitable for farmers than Bt-cotton.

Action plan

Traditional and GM cotton have been the focus of several studies that have come up with many improvement methods. With advancements in genetic analysis and manipulation techniques, novel solutions can improve crop yield while tackling various biotic and abiotic factors. Combining genetic engineering with conventional breeding techniques (genomic analysis) can help develop cotton crops that provide insect resistance with better quality and yield can be done in the future.

Traditionally bred cotton has a huge market as currently, there is a high demand for organic (non-GM) cotton. To improve their yield, farmers can opt for genotype screening of cotton to select possible selection markers for future crops (Din *et al.*, 2016). In cotton plants, traits such as frego bract, okra leaf, and red leaf colour effectively restrict insect pest populations. These traits can be incorporated into commercial cultivars to provide resistance against a variety of cotton pests.

The first generation of Bt-cotton cultivated by farmers had only one gene (*Cry1Ac*), which provided insecticide resistance to the cotton plant. Advances in genetic engineering provided second-generation Bt-cotton, where crop improvement occurred by introducing additional genes. This resulted in improved insecticide resistance and the introduction of herbicide resistance. Currently, the third generation of Bt-cotton uses more precise and widely accepted techniques like CRISPR/Cas9 to produce transgene-free Bt-cotton. These are more widely accepted and allow farmers to reduce further environmental pollution caused due to insecticide and herbicide usage. Other genetic manipulations, like selective silencing of gossypol in cottonseed to make it fit for human consumption without altering its insect and disease resistance abilities, are likely to help considerably solve the world's food and fibre problems.

Consequences

While transgenic cotton offers resistance against bollworms, identifying and planting insect-resistant varieties of cotton can naturally help farmers tackle the pesticide problem without having to worry about GMO regulations. Since the crops produced are organic, they can fetch a good price, thereby being economically viable for the farmers.

Bt-cotton obtained using insect-resistant genes from indigenous resistant cultivars using the CRISPR/Cas9 technique can provide additional resistance to sucking insect pests. Thus, the farmers can reduce insecticide usage, lowering production costs considerably. Moreover, the fibre quality and quantity of such crops are also high, thus, being economically beneficial for the farmers. Reducing chemical insecticide, pesticide, and herbicide usage also benefits the environment and can benefit human health in the long run.

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