BT COTTON: ENHANCING SUSTAINABLE COTTON PRODUCTION THROUGH BIOTECHNOLOGY

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ABSTRACT

Cotton (*Gossypium hirsutum* L**)** is a significant cash crop on which millions of farmers rely for their lives as well as the advancement of agriculture and industry. Sustainable cotton production has been severely reduced by bollworm infestations and farmers' over-reliance on chemical insecticides. Bacillus thuringiensis (Bt) is a beneficial soil bacterium whose genes are used to develop insect-resistant crops by producing cry proteins. Scientists transfer the gene responsible for producing these proteins into the cotton plant. As a result, a genetically modified plant continuously produces the Bt protein in its tissues. The target insect, bollworm, feeds on the plant and ingests the Bt protein. In the insect's alkaline gut, this protein becomes active and damages the insect's gut lining. Resultantly, the insect stops feeding and dies. In this article, the concept, varieties, mechanism of action, and process of Bt cotton, which selectively target insect pests while reducing the need for frequent insecticide applications, are highlighted.

Keywords: Bt cotton, Agricultural biotechnology, Genetic engineering, Bollworm management, Sustainable cotton production, Integrated pest management (IPM)

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Introduction

One of Pakistan's most significant cash crops, cotton is essential to the nation's industrial and agricultural economies [1, 20]. It provides raw materials to the textile industry, a large source of employment and export revenue, and makes a substantial contribution to the value addition of agriculture [2]. There are currently 15 nations that have adopted this technology, including China, India, and the United States, despite some disagreements on its sustainability and long-term advantages. In the upcoming years, several more nations are anticipated to be included on this list [4]. Improvements in cotton yield and pest control are crucial for sustained agricultural growth since cotton agriculture provides a living for millions of farmers. In the past, farmers primarily used chemical insecticides to control these pests, which raised production costs and put the environment at risk. Key bollworm species can now be effectively controlled with less reliance on chemical insecticides due to Bt cotton, a genetically engineered cultivar that produces insecticidal proteins derived from the bacterium Bacillus thuringiensis [3, 20].

In many regions of the world, this invention is now a crucial aspect of sustainable cotton production. Since its introduction into the world, Bt-cotton technology has rapidly spread throughout both developed and developing nations. It has been demonstrated to have benefits in numerous domains. Specifically, economic growth is becoming more significant every year. By cutting labour costs and working fewer hours in the fields, it helps farmers become more profitable. Additionally, it has been demonstrated that this method boosts cotton yield. Farmers have profited millions of dollars from using fewer pesticides since the commercialization of Bt-cotton technology was initially authorized and seeded fifteen years ago. The contribution of Bt-cotton technology to the economics of the top cotton-producing nations, its commercialization, and the current techniques for plant transformation are all covered in detail in this paper.

The first step in the Bt cotton process is the genetic engineering of a Bt gene from the Bacillus thuringiensis bacteria into the cotton plant. After integration, the cotton plant's tissues including its leaves, stems, and bolls continue to produce Bt protein. A susceptible bollworm consumes both the plant tissue and the Bt protein when it feeds on these plant sections. The Bt protein is activated in the alkaline environment of the insect's gut and attaches itself to certain receptors on the cells that line the midgut. The integrity of the digestive system is compromised by this binding, which results in the formation of pores in the gut wall. Consequently, the insect stops feeding, sustains damage to its stomach, and ultimately perishes. The cotton crop is shielded from bollworm damage since the pest is removed before it causes serious harm, which results in healthier plants, higher yields, and less reliance on chemical insecticides [5]. In certain instances, Bt cotton has decreased target insect feeding, contributed to a decrease in pest abundance, and has not been linked to pest resistance in the US. Bt cotton has proven to be an essential tool for the management of pink bollworm in the southwestern United States, leading to reductions in feeding damage and insecticide applications. Additionally, the planting of Bt cotton made it possible to eradicate pink bollworm from the United States when combined with sterile insect release [3, 21].

Bt cotton and its types

Bt cotton is a genetically modified (GM) cotton type that was created by inserting one or more genes from the soil bacterium Bacillus thuringiensis into the cotton plant [5]. There are several types of Bt cotton, such as CryAc Bt cotton, Cry1Ac + Cry2Ab Bt Cotton, and Vip3A Bt cotton that produce various types of Bt proteins [19]. The types of Bt cotton, Bt gene(s), target insects, and characteristics are given below in Table 1.

Table 1: Types based on Bt proteins

Sr No.	Type	Bt Gene(s)	Target insects	Characteristics	References
1.	Cry1Ac Bt cotton	Cry1Ac	Bollworms	Effective against major bollworms	[16]
2.	Cry1Ac + Cry2Ab Bt Cotton	Cry1Ac, Cry2Ab	Wider range of bollworms	Enhanced effectiveness and control of resistance	[17]
3.	Vip3A Bt cotton	Vip3A(alone or with cry genes)	Resistant bollworms and other caterpillars	Improved defense in areas where Cry protein resistance has emerged	[18]

Mechanism of Bt cotton

Bt is a gram-positive, spore-forming bacterium recognized for its capacity to make crystal proteins (Cry). Cry proteins are known to be harmful to many insects, and that is why Bt is utilized as a microbial insecticide for enhanced resistance in plants by genetic modification. The toxin is activated by the digestive enzymes in the insect larvae's gut when they consume the proteinaceous crystal. This leads to the creation of pores in the gut's cell membrane, paralysis of the gut, and ultimately the larvae's death. The Integrated Pest Management approach, which favors non-chemical pesticides for pest control, includes the use of Bt as a biopesticide because it is equally effective as chemical pesticides [15]. These genes enable the plant to create Bt proteins (Cry proteins) that are toxic to specific insect pests, mainly bollworms, while remaining harmless to humans, livestock, and most beneficial insects when used as intended [7]. The Bt protein is consumed by vulnerable insect larvae that consume Bt cotton, such as the American, pink, or spotted bollworm [8].In the alkaline environment of the insect's gut, the protein becomes activated and binds to receptors in the gut lining, forming holes that harm the intestinal cells [9]. As a result, the bug stops feeding and eventually perishes, preventing serious harm to the cotton crop [10].

Key features of Bt cotton

Bt cotton offers a reduction in the application of insecticides to target insects on a regular basis integrated defense against common bollworm pests [11]. Bt cotton reduces insect damage, which aids in raising cotton yield. Bt cotton reduces the cost of manufacturing related to pest management [12]. Bt cotton can improve farmers' net income by lowering the pesticide use. Bt cotton can improve fiber quality, which can increase market value. Bt cotton reduces the need for chemical pesticides, which helps to produce cotton in an environmentally sustainable manner [13, 21]. Bt cotton works best when combined with IPM practices such as regular pest monitoring, crop rotation, and biological control.

Challenges and Future Prospects

Bt cotton faces several challenges that may affect its long-term effectiveness. Continuous cultivation without proper refuge planting has led to the development of resistance. Protection against sucking pests such as whiteflies, aphids, and jassids. The availability of counterfeit seeds, high seed costs, and climate-related stresses also pose challenges to sustainable production. Looking ahead, the future of Bt cotton depends on the development of improved varieties with multiple Bt genes and enhanced tolerance to drought and heat. Integrating Bt cotton with integrated pest management (IPM), precision agriculture, and modern biotechnological tools such as CRISPR gene editing can further improve its effectiveness [14, 21, 22, 23, 24]. In addition, strengthening farmer education, promoting responsible resistance management, and ensuring access to quality seed will help maximize the long-term benefits of Bt cotton for sustainable cotton production. seed. Despite the advantages, resistance in insects to transgenic cotton is a big problem in transgenic cotton places all over the world. Although the extensive use of Bt cotton around the world has produced benefits, including efficient pest control and financial gains, it also puts a lot of pressure on target cotton pests to develop resistance to the Bt toxin, which lessens its efficacy [14, 21, 24]. Farmers have not had access to Bt cotton seeds because of supply chain interruptions brought on by the COVID-19 pandemic, high shipping prices, cumbersome seed import procedures, and a lack of foreign exchange. In order to give farmers sustainable access at a reasonable price, stakeholders are looking for local seed production.

Conclusion

Bt cotton is a significant innovation in modern agricultural biotechnology, through which we can manage bollworm infestations and also improve cotton yield and productivity. By inserting Bt gene into the cotton plant, we can produce an insecticidal protein in the cotton plant that is involved in the protection against pests. As a result of this technology, farmers can reduce their reliance on chemical insecticides, which leads to lower production costs, reduced environmental protection, improved biodiversity, and enhanced safety for farm workers. The benefits of Bt cotton adoption include an increase in the crop yield and also improved the quality of crop and increase in the income of cotton producing countries. Because of these benefits, Bt cotton is considered an important component of sustainable cotton production and a valuable tool for ensuring food and fiber security. In conclusion, Bt cotton is a major development in agricultural biotechnology and also plays a major role in the transformation of cotton farming making it more productive, profitable and environmentally sustainable. Bt cotton can continue to play a vital role in achieving sustainable cotton production for present and future generations.

References

[1] Hussain I, Butt TM, Fatima N, Rahman WU, Ullah MK. Causes of cotton decline in pakistan: A comprehensive review. Acad Int J Social Sci. 2025;4(1):1191-203.

[2] Tokel D, Dogan I, Hocaoglu-Ozyigit A, Ozyigit II. Cotton agriculture in Turkey and worldwide economic impacts of Turkish cotton. Journal of Natural Fibers. 2022 Nov 23;19(15):10648-67.

[3] Gassmann AJ, Reisig DD. Management of insect pests with Bt crops in the United States. Annual Review of Entomology. 2023 Jan 23;68(1):31-49.

[4] Tokel D, Genc BN, Ozyigit II. Economic impacts of Bt (Bacillus thuringiensis) cotton. Journal of Natural Fibers. 2022 Dec 2;19(12):4622-39.

[5] Razzaq A, Zafar MM, Ali A, Li P, Qadir F, Zahra LT, Shaukat F, Laghari AH, Yuan Y, Gong W. Biotechnology and solutions: Insect-pest-resistance management for improvement and development of Bt cotton (Gossypium hirsutum L.). Plants. 2023 Dec 4;12(23):4071.

[6] Kumari P, Jasrotia P, Kumar D, Kashyap PL, Kumar S, Mishra CN, Kumar S, Singh GP. Biotechnological approaches for host plant resistance to insect pests. Frontiers in genetics. 2022 Jun 2;13:914029.

[7] Ghimire BK, Yu CY, Kim WR, Moon HS, Lee J, Kim SH, Chung IM. Assessment of benefits and risk of genetically modified plants and products: current controversies and perspective. Sustainability. 2023 Jan 16;15(2):1722.

[8] Paul S, Das S. Natural insecticidal proteins, the promising bio-control compounds for future crop protection. The Nucleus. 2021 Apr;64(1):7-20.

[9] Chowdhury SK, Banerjee M, Basnett D, Mazumdar T. Natural pesticides for pest control in agricultural crops: An alternative and eco-friendly method. Plant Sci. Today. 2024;11:433-50.

[10] Ghimire A. A review on integrated management of cotton and sugarcane pest. Revista de Tecnología INWASCON. 2023;5.

[11] Riaz S, Johnson JB, Ahmad M, Fitt GP, Naiker M. A review on biological interactions and management of the cotton bollworm, Helicoverpa armigera (Lepidoptera: Noctuidae). Journal of Applied Entomology. 2021 Jul;145(6):467-98.

[12] Zhou W, Arcot Y, Medina RF, Bernal J, Cisneros-Zevallos L, Akbulut ME. Integrated pest management: an update on the sustainability approach to crop protection. ACS omega. 2024 Sep 28;9(40):41130-47.

[13] Zhang Z, Huang J, Yao Y, Peters G, Macdonald B, La Rosa AD, Wang Z, Scherer L. Environmental impacts of cotton and opportunities for improvement. Nature Reviews Earth & Environment. 2023 Oct;4(10):703-15.

[14] Nagaraj S, Rajasekaran R, Palaniappan J, Rangasamy S, Narayanasamy C, Narayanan MB. Emerging technological developments to address pest resistance in Bt cotton. Journal of Cotton Research. 2024 Sep 3;7(1):30.

[15] Kumar P, Kamle M, Borah R, Mahato DK, Sharma B. Bacillus thuringiensis as microbial biopesticide: uses and application for sustainable agriculture. Egyptian Journal of Biological Pest Control. 2021 Dec;31(1):95.

[16] Wan P, Huang Y, Wu H, Huang M, Cong S, Tabashnik BE, Wu K. Increased frequency of pink bollworm resistance to Bt toxin Cry1Ac in China. PLoS One. 2012 Jan 4;7(1):e29975.

[17] Tabashnik BE, Dennehy TJ, Sims MA, Larkin K, Head GP, Moar WJ, Carriere Y. Control of resistant pink bollworm (Pectinophora gossypiella) by transgenic cotton that produces Bacillus thuringiensis toxin Cry2Ab. Applied and environmental microbiology. 2002 Aug;68(8):3790-4.

[18] Gupta M, Kumar H, Kaur S. Vegetative insecticidal protein (Vip): a potential contender from Bacillus thuringiensis for efficient management of various detrimental agricultural pests. Frontiers in microbiology. 2021 May 13;12:659736.

[19] Tokel D, Genc BN, Ozyigit II. Economic impacts of Bt (Bacillus thuringiensis) cotton. Journal of Natural Fibers. 2022 Dec 2;19(12):4622-39.

[20] Mustafa MS, Fatima K, Khan NA, Noor R, Idrees L, Shafiq S, Rasool S, Ateeb M, Hameed MB, Mustafa M. Nanotechnology in pest management: a focused review on the role of silver nanoparticles against cotton pest Pectinophora gossypiella.

[21] Mustafa MS, Ali MF, Naveed A, Manzoor MA, Mustafa M, Nasir MT, Aziz F, Arshad S, Ashraf MF, Saleem U. Integrating biodiversity in agroecosystems: a multidisciplinary approach linking entomology, biotechnology, crop improvement, and plant health. In: Jamil M, Abbas A, Tariq A, Zahra I, editors. Explicable Agriculture: Microbial Ecology, Bio-Innovations and Crop Production. Faisalabad (Pakistan): Unique Scientific Publishers; 2026. p. 282–289. https://doi.org/10.47278/book.TL/2026.469

[22] Hameed MB, Asghar K, Ahmed S, Iqbal U, Ahmed M, Abbas T, Murtaza A, Muneeb-ul-Rehman M, Hayyat M, Samad N. Multidisciplinary approaches to enhance rice yield in South Asia and contrasting agroecosystems: genetic, agronomic, and environmental perspectives. In: Jamil M, Abbas A, Tariq A, Zahra I, editors. Explicable Agriculture: Microbial Ecology, Bio-Innovations and Crop Production. Faisalabad (Pakistan): Unique Scientific Publishers; 2026. p. 170–176. https://doi.org/10.47278/book.TL/2026.307

[23] Hameed MB, Tariq N, Batool H, Shabbir A, Hameed H, Tariq M, Bano N, Abid J. AGRONOMIC AND GENETIC STRATEGIES FOR ZINC BIOFORTIFICATION OF MAIZE FODDER: IMPLICATIONS FOR DAIRY COW NUTRITION AND HEALTH. Genetics and Molecular Research. 2026 Jul 7.

[24] Afzal MA, Shahzadi N, Saadat S, Seemab R, Sajjad I, Tariq N, Ashraf SR, Tahir S, Kharl HA. CRISPR-Cas9 genome-editing technology: a transformative tool for curing human disorders. Journal of Medical & Health Sciences Review. 2025 Jul 29;2(3).