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Bt Cotton in India: Two Decades of Progress and New Challenges

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For generations, cotton has been known as "White Gold" in India. It is far more than a fibre crop. It supports millions of farming families, anchors one of the world's largest textile industries, and feeds a large share of the national economy. But behind every good harvest sat a problem farmers knew intimately. Each season brought an enemy that worked quietly, boring into developing bolls and wiping out months of labour within days.

Through the 1980s and into the 1990s, bollworms were the pest cotton growers feared most. Farmers fought the American bollworm, the spotted bollworm and the pink bollworm with round after round of chemical sprays, until pesticide application stopped being an emergency measure and became routine. Even as spending on crop protection climbed, damage kept rising, because the insects were gradually building resistance to the chemicals used against them. A fix meant to solve the problem had turned into part of it, and farmers were stuck even the costs went up, yields stayed uncertain, and the sprays worked less each year.

Something other than a new insecticide was needed. Around this time, researchers looked closely at a soil bacterium, *Bacillus thuringiensis* (Bt), which produces proteins that kill certain insects but leave humans, animals and most beneficial species untouched. The question was whether this defence could be built into the cotton plant itself. Answering it led to one of the more consequential advances in agricultural biotechnology.

India approved Bt cotton for commercial cultivation in 2002, and it did more than add a new variety to the market. For the first time, the cotton plant could defend itself against bollworm attack, cutting the need for repeated spraying. Farmers took to it fast, and within a few years Bt cotton had become one of the most quickly adopted farm technologies in the country's history. It reshaped how cotton was grown and showed what biotechnology could do against a problem that had resisted every other fix.

That was not the end of the story, though. Resistance began to develop, pest patterns shifted, and researchers found themselves back at work on the next solution. Two decades on, Bt cotton is less a single success story than an ongoing account of adaptation, of lessons taken on board, and of the continuing effort to keep cotton farming sustainable.

The science behind Bt cotton

The breakthrough traces back to *Bacillus thuringiensis*, a bacterium found naturally in soil. It produces insecticidal proteins called Cry proteins, which are effective against specific pests, bollworms among them, while doing no harm to humans, animals or most beneficial insects. By inserting the Cry gene into cotton through genetic engineering, scientists gave the plant the ability to make this protein in its own tissue and defend itself against the major bollworm species.

Here is how it works: when a susceptible bollworm larva feeds on Bt cotton, the Cry protein activates in the insect's alkaline midgut, binds to receptors along the gut wall, and punches pores into the intestinal cells. Digestion breaks down, the larva stops feeding, and it

dies. Because this depends on receptors that humans and other mammals simply don't have, Bt proteins are considered selective and safe for non-target organisms.

India's first generation of Bt cotton carried the Cry1Ac protein, sold as Bollgard®. To extend how long the protection would last and broaden its effect against bollworms, a second generation, Bollgard® II, added a second protein, Cry2Ab, in 2006. Combining the two genes slowed resistance development and strengthened pest control, and Indian farmers took to it accordingly.

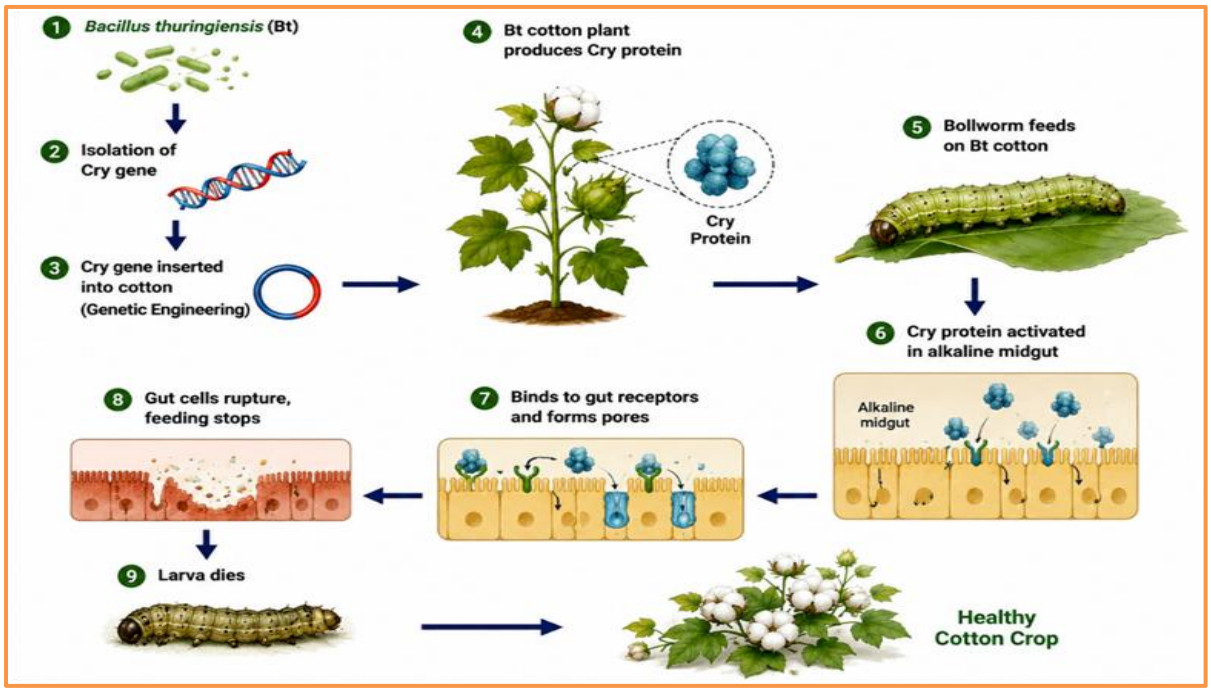

Fig. 1: Mode of action of Bt cotton against bollworms

Bt cotton in India: from laboratory innovation to farmers' fields

Bt cotton's path in India started well before it ever reached a field here. The world's first genetically modified Bt cotton went commercial in the United States in 1996, after years of research had shown the technology worked against bollworms. That result got scientists and policymakers looking at what it might do for Indian cotton, where bollworm infestation was already a serious drag on yields. The turning point came in March 2002, when India approved commercial cultivation of Bollgard®, a Bt cotton hybrid carrying the Cry1Ac protein, the country's first genetically modified crop cleared for commercial use. Farmers who had spent years battling bollworm losses and rising pesticide bills saw the benefit quickly. Bt cotton controlled the major bollworm species and cut the need for repeated spraying, and that was enough to drive rapid adoption across the country's cotton belt. In 2006, Bollgard® II arrived, carrying both the Cry1Ac and Cry2Ab genes, aimed at broader and longer-lasting protection and at slowing resistance. It won farmers over quickly. Within a little over a decade, Bt cotton covered more than 90% of India's cotton-growing area, one of the fastest technology adoptions in the country's agricultural history, and one that changed cotton production at its core.

Two decades of transformation: how Bt cotton changed Indian agriculture

The 2002 rollout of Bt cotton was a turning point for Indian cotton farming. Within a few years it had spread across nearly every major cotton-growing state, changing how farmers dealt with insect pests. Because the crop could protect itself against bollworms, growers needed fewer insecticide rounds, saw better yields, and ran more profitable farms. More than twenty years on, Bt cotton is still among the most widely used agricultural biotechnologies anywhere, and it has shaped India's cotton sector in lasting ways.

Year	Milestone	Significance
1996	First commercial cultivation of Bt cotton in the United States	Global introduction of Bt cotton paved the way for its adoption in other cotton-growing countries, including India.
2002	India approves *Bollgard*® (Cry1Ac), the country's first GM crop	A historic milestone—Bt cotton becomes the first genetically modified crop approved for commercial cultivation in India.
2006	Introduction of *Bollgard*® *II* (Cry1Ac + Cry2Ab)	Second-generation Bt cotton with two genes provided broader and more durable protection against bollworms.
2010–2014	Rapid adoption across major cotton-growing states	Bt cotton area expanded quickly as farmers experienced higher yields and lower pesticide use, making it one of the fastest-adopted technologies.
2015 onwards	Reports of pink bollworm resistance emerge	Over-reliance on Bt cotton led to the evolution of resistance in pink bollworm in several regions, raising new challenges.
2024	More than two decades of Bt cotton cultivation in India	Two decades of transformation, learning and innovation continue to shape the future of sustainable cotton production.

Fig. 2: Major milestones in the journey of Bt cotton in India

Reduced dependence on chemical insecticides

One of the first changes farmers noticed was how much less they needed to spray. Before Bt cotton, protecting a crop through the season often meant frequent pesticide applications. Built-in protection from the Bt proteins cut that need sharply, which lowered costs and reduced farmers' exposure to hazardous chemicals. Fewer sprays also meant fewer losses among pollinators and natural predator insects, which helped the broader farm ecosystem.

Improved cotton productivity and farmer income

Better protection against bollworms meant healthier plants, more bolls retained, and higher seed cotton yields. Combined with lower spending on pesticides and labour, this made cotton farming considerably more profitable in many regions. Higher output also fed more raw cotton into India's textile industry, reinforcing the country's place among the world's top cotton producers and exporters. Yield gains were not uniform; they depended on climate and how well the crop was managed locally, but Bt cotton was a major factor in improving both productivity and the financial stability of cotton farming.

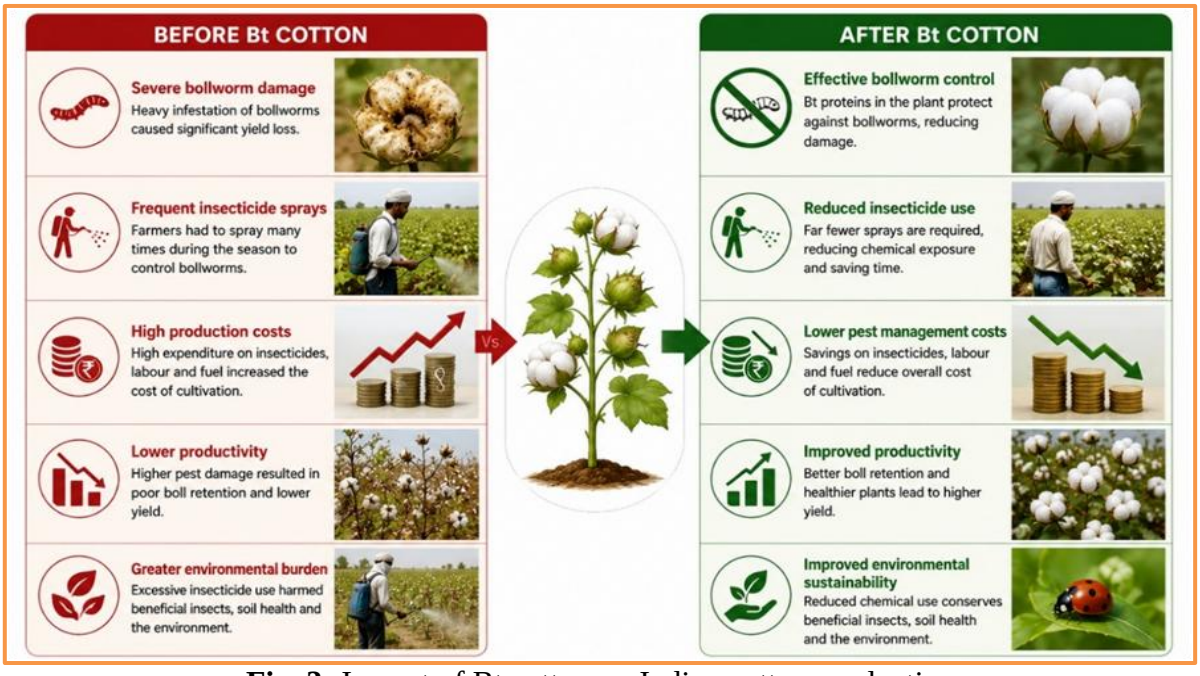

Fig. 3: Impact of Bt cotton on Indian cotton production

A rapidly adopted agricultural innovation

How fast Bt cotton spread says a lot about the confidence farmers placed in it. Within a decade of its commercial release, it covered more than 90% of India's cotton-growing area, making it one of the fastest-adopted agricultural technologies in the country's history. Its success shows what happens when scientific innovation is paired with solid regulation, reliable seed supply, and farmers willing to try something new: change can happen at national scale, and quickly.

Challenges after two decades

Bt cotton's success proved what biotechnology could do in modern farming. But like any pest-management tool, how well it keeps working depends on how it's used and on continued innovation. As it became the standard across India's cotton belt, new biological and management problems began to surface. None of this erases what Bt cotton achieved, it simply reflects how agricultural ecosystems keep changing and why resistance management has to keep pace.

The emergence of pink bollworm resistance

The biggest challenge has been resistance building up in the pink bollworm (*Pectinophora gossypiella*). Year after year of exposure to the same Bt proteins let a small share of naturally tolerant insects survive and breed. Over time their numbers grew, and Bt cotton became less effective against pink bollworm in several growing regions. It's a textbook case of natural selection, and it underlines why refuge planting, regular crop monitoring, and new insecticidal genes matter for keeping resistance in check.

Changing pest dynamics

As bollworm numbers fell, other pests moved in to fill the gap. Sucking insects like whiteflies, aphids, jassids and mealybugs became bigger problems in cotton fields. Bt cotton was built to fight bollworms, not these species, so it offers no protection against them. Farmers have had to lean on integrated pest management and targeted insecticide use to keep these pests in check.

The importance of resistance management

What Bt cotton's history shows is that biotechnology on its own doesn't solve pest problems permanently. Planting non-Bt refuge areas, watching pest populations regularly, and using integrated pest management remain necessary to slow resistance and keep the technology working. Farmer awareness and responsible use of the technology will matter just as much going forward as the science itself.

The road ahead: building the next generation of insect-resistant cotton

Twenty years of Bt cotton show what biotechnology can do against some of farming's toughest problems and that resistance eventually catches up with any single technology. The way forward isn't to replace Bt cotton, but to keep improving it alongside better crop management.

One promising avenue is the Vip (Vegetative Insecticidal Protein) gene family, particularly Vip3A, which works through a different mechanism than the Cry proteins currently used. Because Vip proteins bind to different receptors, they offer a real option for managing bollworm populations that have already developed resistance. Gene pyramiding, or stacking several insecticidal genes into one variety, is another route to broader, longer-lasting protection.

Newer tools such as RNA interference (RNAi) and CRISPR-based gene editing are opening up further possibilities for precise, sustainable pest control. Paired with progress in genomics, molecular breeding and precision agriculture, these should help produce cotton varieties better equipped to handle pests as they evolve. None of this works in isolation, though integrated pest management, refuge planting, regular monitoring and responsible stewardship all have to back up the science if these tools are going to last.

Conclusion

Twenty years after its commercial launch, Bt cotton remains one of the most consequential agricultural innovations in India's history. It cut bollworm damage, reduced insecticide use, lifted farm productivity, and strengthened the cotton economy. At the same time, resistance and shifting pest pressures have made one thing clear: sustainable agriculture takes more than a good technology. It takes responsible stewardship and ongoing scientific work to match it.

Bt cotton's story, then, isn't just about one genetically modified crop. It's about how science, paired with sound farming practices, can solve hard problems in agriculture while still adapting as nature responds. As India looks toward the next generation of crop protection tools, the lessons from Bt cotton will keep shaping how the country builds more resilient, productive and sustainable cotton production.

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