Science, Technologie, Développement
2025, vol. 5, n° 1, 84-98 pages, DOI : 10.21494/ISTE.OP.2025.1339 ISTE OpenScience

The erosion of agrobiodiversity of cotton in India: interplay of politics, science, and technology

L'érosion de la biodiversité agricole du coton en Inde : interaction entre politique, science et technologie

Avik Ray[1]

[1] Center for studies in Ethnobiology, Biodiversity, and sustainability (CEiBa), B.G. Road, Mokdumpur, Malda – 732103, West Bengal, India, avikray@ceibatrust.org, [ORCID ID: 0000-0003-1662-7679]

ABSTRACT. The dissection of the contemporary cotton crisis in India has cast light on knowledge and deskilling, capitalism and commodification, biotechnology and public policy, Bt cotton and yield, diseases and management, etc. Whereas how agricultural-technology, plant breeding and biotechnology, have influenced cotton agriculture reciprocating to global demand is rarely invoked in the political-ecological analyses. Here, employing various data, I reconstructed the trajectory of cotton agrobiodiversity and underlying drivers nestled in the broad technopolitics of the last century.

It revealed that a major change in the twentieth century was steered by cotton improvement through breeding when a few varieties of American cotton with industry-set staple-length have gained precedence, causing the continued abandonment of native species. The process was exacerbated by the large-scale adoption of the hybrids in the seventies and eighties. Increasing genetic homogeneity unleashed bollworm infestation that raised the pesticide application and cost of cultivation. Later, genetically modified Bt cotton was widely adopted in the twenty-first century to circumvent this problem. Genetic erosion driven by global technopolitical change has raised the vulnerability to major diseases, especially bollworm, wreaking havoc across geographies and culminating in agrarian distress. The study seems to lay a foundation for future research on the entanglement between technopolitical, bio-cultural, and agrarian change.

RÉSUMÉ. L'analyse de la crise actuelle du coton en Inde a mis en lumière les questions de connaissances et de déqualification, de capitalisme et de marchandisation, de biotechnologie et de politique publique, de coton Bt et de rendement, de maladies et de gestion, etc. En revanche, l'influence de la technologie agricole, de la sélection végétale et de la biotechnologie sur la culture du coton en réponse à la demande mondiale est rarement évoquée dans les analyses politico-écologiques. Ici, à l'aide de diverses données, nous avons reconstitué la trajectoire de l'agrobiodiversité du coton et les facteurs sous-jacents nichés dans la technopolitique générale du siècle dernier.

Il en ressort qu'un changement majeur au XXe siècle a été induit par l'amélioration du coton grâce à la sélection, lorsque quelques variétés de coton américain dont la longueur des fibres était fixée par l'industrie ont pris le dessus, entraînant l'abandon progressif des espèces indigènes. Ce processus a été exacerbé par l'adoption à grande échelle des hybrides dans les années 1970 et 1980. L'homogénéité génétique croissante a favorisé l'infestation par le ver de la capsule, ce qui a entraîné une augmentation de l'utilisation de pesticides et du coût de la culture. Plus tard, le coton Bt génétiquement modifié a été largement adopté au XXIe siècle pour contourner ce problème. La dégradation génétique induite par les changements technopolitiques mondiaux a accru la vulnérabilité aux maladies majeures, en particulier au ver de la capsule, qui a causé des ravages dans différentes régions et a abouti à la crise agricole. Cette étude jette les bases de futures recherches sur les liens entre les changements technopolitiques, bioculturels et agricoles.

KEYWORDS. Indian cotton, *Gossypium arboreum,* agrobiodiversity, cotton landraces, genetic erosion, cotton hybrids, Bt cotton.

MOTS-CLÉS. Coton indien, Gossypium arboreum, agrobiodiversité, variétés locales de coton, érosion génétique, hybrides de coton, coton Bt.

1. Introduction

Cotton has been intertwined with the socio-cultural history of South Asia. The illustrious cotton culture is reflected in various historical accounts that included their areas of cultivation, agro-ecological condition, and approximate yield (Mackenna & Wadia, 1920; Pearse, 1913-14; Ray, 2022b) Such perennial cotton possesses high variability in several culturally and economically useful traits like fiber color and quality, staple length, finesse, pest resistance, and abiotic stress tolerance. It enabled its dominance in the global trade of cotton textiles, capitalizing on fine craftsmanship, efficient indigenous tools and technologies, and established local and global trade networks (Parthasarathi, 2001; Parthasarathi, 2009; Menon & Uzramma 2017; Ray, 2022b; Riello & Roy, 2009; Roy, 2012).

However, the flamboyant socio-cultural history of cotton contrasts with its current fate. The decline commenced following the introduction of American cotton and discriminatory policies adopted by the then-ruling British administration (Menon & Uzramma, 2017; Prasad, 1999). Going slow, it surreptitiously decimated the production of native cotton and largely replaced indigenous small-scale handlooms with the American cotton gin. From then on, cotton production in India remained at the helm of controversy. The New World cotton offered economic incentives owing to its high yield potential, industry-desired fiber properties, and linkage to the global commodity chain, but required input-intensive cultivation (Flachs & Stone, 2019; Suresh & al., 2014). The area under native cotton drastically diminished in the post-independence era (Kulkarni & al, 2009).

Given the enormous significance of the cotton industry, several scholars have interpreted the socio-economic impact of cotton cultivation, and its downfall, yield issue, costs of production and profitability, Bt cotton and pesticide application, biotechnology and public policy, and farmers' death, thereby attempting to find a proximal causal mechanism mostly nested in a broad political ecology framework (Flachs & Stone, 2019; Glover, 2010; Gutierrez & al., 2015; Gutierrez & al, 2020; Kranthi and Menon & Uzramma, 2017; Scoones, 2006; Stone, 2012; Stone, 2020; Suresh & al., 2013). In contrast, I propose that one of the core reasons for the crisis is also rooted in historical development that facilitated the gradual expansion of non-native species, the crowding out of native species, and the selection of even fewer improved varieties. It was largely maneuvered by agricultural technology, plant breeding and biotechnology, situated in the interplay of global trade and politics. The net outcome was the erosion of diversity and the increased vulnerability to pests or climate that have been plaguing Indian cotton for the last couple of decades or more.

The erosion of the diversity of cultivated crops has become a norm and the process has been instrumental over the last centuries, embedded in a broad-scale agrarian change brought about by new technology implemented in tandem with geopolitics and trade (Khoury & al,. 2022; Ray, 2023; Stone, 2022; Thrupp 2000). The global commodity, cotton, also falls in line and seems to have undergone seminal changes; severe genetic erosion is one of them. Although diversity is integral to the resilience of any farming system, it remained an underappreciated realm in cotton and the surrounding crisis. In this article, I investigated the broad history and political ecology of the agrobiodiversity erosion of Indian cotton from the historic period (Figure 1) and sought answers to these specific questions: How has it eroded phase-wise with the core geopolitical, technological, and policy changes over the last centuries, specifically with the application of plant breeding and biotechnology? Lastly, I concluded with a note on the broad social and biological repercussions of this change.

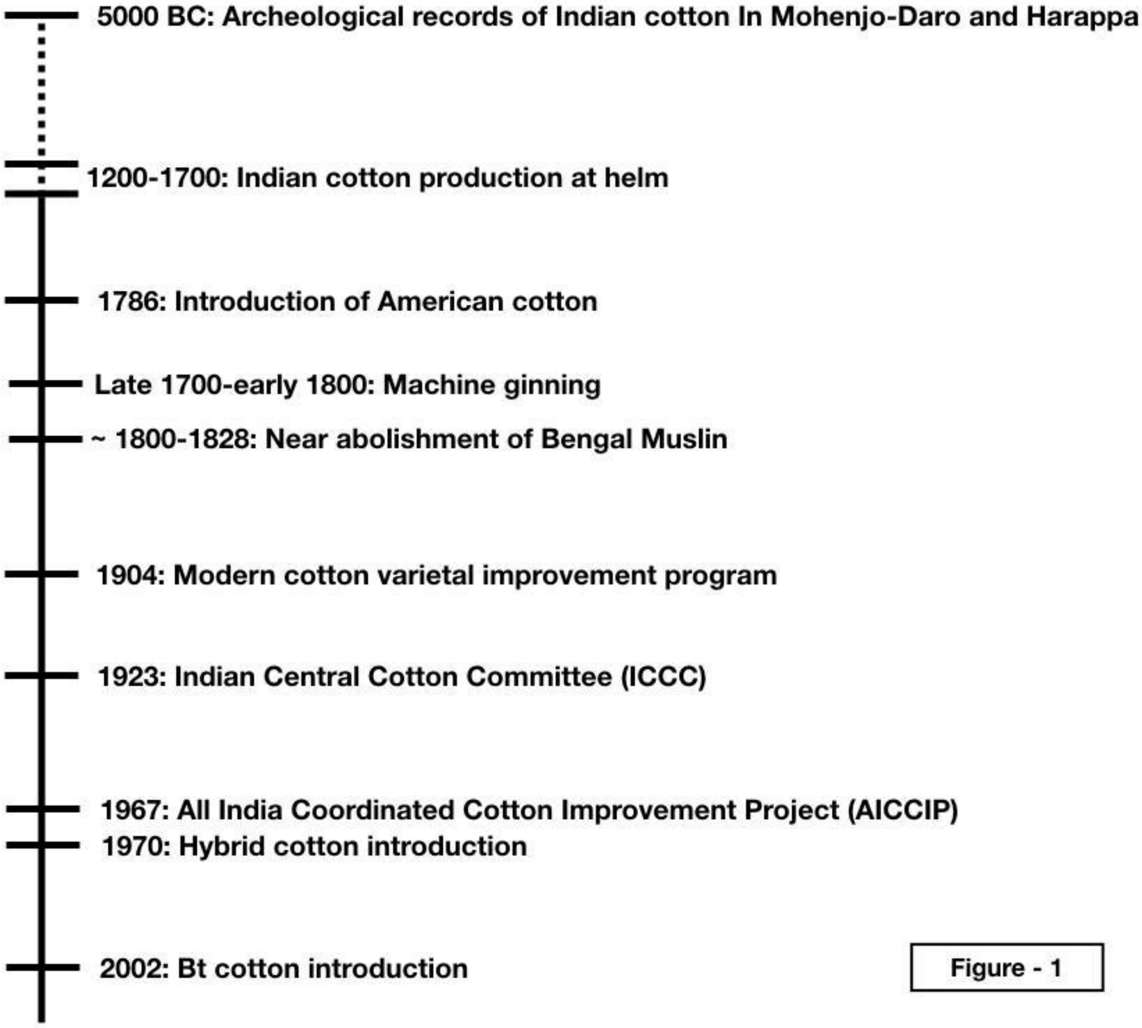

Figure 1. *The timeline of major events of cotton of the Indian subcontinent*

2. Research methodology

Agricultural biodiversity loss has become a widespread problem plaguing agrarian systems. Cotton, a globally important cash crop, is not an exception and has undergone gradual but significant changes responding to technological, market preferences, and global demand. It presents us with a unique case study to tear apart to untangle the processual development which is embedded in history, the application of technology, and the political context. The research is a review and synthesis work; hence, it is built on the existing body of literature on the agricultural history of cotton (Chandra, 1998; Chatterjee & al., 1987; Guha, 2007; Hazareesingh, 2012; Mackenna & Wadia, 1920; Pearse, 1913-14; Prasad, 1999; Menon & Uzramma, 2017; Ray, 2022b; Spielman, 1950; Taylor, 1851; Watt, 1989 [1907]), technology and its implementation (Flachs & Stone, 2019; Glover, 2010; Gutierrez & al., 2020; Suresh & al. 2013, 2014), the nature of cotton improvement programs, plant breeding and biotechnology (AlCCIP, 2003; Kairon & al., 2000; Kranthi, 2012; Manickam & Baghyalakshmi, 2019; Raveendran & al., 2002; Singh & Kairon, 2001), and agrobiodiversity management (Harlan & Gepts, 2012; Howard, 2010; Hufford & al., 2019; Khoury & al., 2022; Kulkarni & al., 2009; Nautiyal & al., 2008; Ravera & al., 2019; Ray, 2023.; Teklu & Hammer, 2006; Wendel & al., 1989; Witcombe & al., 2011; Wood & Lenne, 1997). The objective is to synthesize and describe the role of technology, politics and policy, history underlying the cotton agrarian change, especially its agricultural biodiversity that has long-standing social, ecological, and economic repercussions.

3. Management of cotton agrobiodiversity

In the subcontinent, two biological species were historically cultivated; diploid *Gossypium arboreum* was perhaps more abundant than *G. herbaceum.* In contrast, *tetraploid G. hirsutum, G. barbadense* were introduced later in the late eighteenth century. Three geographical races or ecotypes of *G. arboreum* L., namely *bengalense, cernuum*, and *indicum,* and of *G. herbaceum* L. race *wightianum* have possibly originated and diversified in India (Kulkarni & al., 2009). They also evolved into several landraces, colloquially known by many local or trade names and distinguished based on their characteristics.

Cotton had been grown in more or less every corner between 1200 and 1800, from the north-western provinces, Multan, Punjab, to the mainland of north and western India, and Bengal, encompassing the greater part of the black soil-rich southern Deccan plateau (Parthasarathi, 2001; Parthasarathi, 2009). The cotton plant was, therefore, an integral part of the decentralized peasant agricultural economy and a means of subsistence for most Indian farmers (Parthasarathi, 2009). The myriad types of clothes were manufactured from cotton that itself varied widely in color, texture, staple length, yield, and also in terms of the ease of harvest, e.g., dark brown in Bengal, yellow-green in the Garo hills, light pink in peninsular India (Chandra, 1998; Ray, 2022b). In addition to the many races or ecotypes, there were several local varieties [e.g., *photee, bairaiti, bhoga, hansi, coconadas, karannganny,* etc), which were presumably various local landraces of *G. arboreum,* mostly *or G. herbaceum* evolved as a result of selection in specific agro-ecological conditions (Mackenna & Wadia, 1920; Pearse, 1913-14; Ray, (in press); Schmidt, 1911-12; Taylor, 1851). In the historic period, the agrobiodiversity of indigenous cotton rested on the local diversity of landraces that perhaps had been selected, conserved, and cultivated for generations (Ray 2022b). Although the biological process of evolution underlies the creation of variants of domesticated biota, the artificial selection by farmers nurtured and utilized cotton agrobiodiversity. It kept the cycle rolling. Generally, managing and conserving the diversity of crops or their varieties or landraces is often driven by non-biological factors that operate differently. For example, the basis of choice of farmers' selection and management of crop variants or landraces could stem from a plethora of social, cultural, or economic reasons. The underlying economic factors may range from yield of the crops, their pest susceptibility, cropping duration and maturity time to tolerance to stress and unpredictable agro-climatic conditions which directly or indirectly affect their production; the socio-cultural factors may be the cultural attributes like texture or color, the ease of storability and downstream processing, taste and other cooking properties (for edible species), creation of specific products or value addition that influence their acceptance (Barker, 2011; Brush, 2008.; Emperaire & Peroni, 2007; Howard, 2010; Nautiyal & al., 2008; Ray & al., 2013). In many instances, women often take active part in decision-making of crop and seed management and related tasks which favors agrobiodiversity and raises their social status (Ravera, 2019). Therefore, agrobiodiversity is also dynamically maintained on-farm through the deep interaction of farmers' knowledge, hunt for novelty, and nestled in larger socio-economic settings of the farming systems (Brush, 2008; Wood & Lenne, 1997) and it is often constructed and reconstructed responding to farmers' biophysical or socio-cultural environment (De Boef & al., 2012). Based on existing evidence on cotton and other crops, a couple of cultural practices could have been instrumental in agrobiodiversity conservation and management.

1. Conservation of seeds: Various cultural practices, like seed conservation, were facilitators in the maintenance of the purity of local landraces. It was performed at the household level in a decentralized manner. Seed harvest, conservation, and regeneration were the lifeline of cotton cultivation, and any break in the recurring cycle could put their subsistence at stake. Taylor [1851] wrote about the seed storage procedure followed by farmers in Bengal. Another account described a similar exercise, picking seeds, drying, and preserving in earthen pots in airtight conditions (Watt, 1907).
2. Local and decentralized hand-ginning facilitated seed conservation by farmers before the mechanical and centralized ginning facility. Hand-ginning was mostly run by households all across the cotton-growing region and enabled the manual separation of seeds from lint. The advantage was that the seeds were also returned to the cultivator along with the lint. Local hand-ginning may be

slow, but this cycle acted to sustain farmers' seed selection, cotton diversity, and seed network. Machine-ginning, though faster, damaged the seeds in the separation process (Menon & Uzramma, 2017). Also, by mixing diverse cotton brought to the mass ginning facility, the centralized system of mechanical ginning undermined the inherent diversity of cotton. So, it abolished the seed network and indirectly selected the varieties producing more lint.

3. Taking allusions to the creation and maintenance of agrobiodiversity in general (Brush, 2008), it seems that various economic and cultural attributes may have played a crucial role in cotton diversity. Since the cotton textile industry was highly decentralized, local and largely rural-livelihood-based, it fed the divergent needs of consumers from various economic strata. It produced fabric of general (coarse or modest) to special (fine or superfine) usage value. While the quality of fiber (staple length, softness, color) and its processing (ease of harvest, ginning, making yarn, and ease of dying) were the prime factors, the various other factors were instrumental. The resistance to various pests or diseases, the ability to grow in marginal conditions (especially water- and labor-limiting conditions), and climate resilience were the other attributes that have motivated peasants to save, manage, and grow certain varieties. These traits enabled farmers to reap a harvest even under unfavorable periods and insulated them from crop failure.
4. The aspirations of farmers to maintain the purity of the ecotypes or races could have also been met by the demand in the local, formal, or informal, and decentralized textile market, largely controlled by farmers, spinners, and weavers before the surge of the British textile industry (Menon & Uzramma, 2017). Since a significant fraction of the textiles were made locally in handlooms, it was likely that cotton was locally sourced to feed the manufacturing units. For example, the cotton to weave famous *muslin* was grown around the *Dacca* and *Mymensingh* districts of Bengal province. An inferior quality, *bairaiti* or *biretti, was* also cultivated and woven in Bengal. On the other hand, there is also overwhelming evidence that cotton was transported distantly by traders or middlemen to the textile production centers (Parthasarathi 2009).

We perhaps can hypothesize that the quality of cotton (color, staple length, strength, softness, etc), other economic and cultural attributes, and decentralized production systems were some of the underlying factors that motivated farmers to grow various types for the divergent needs of the consumers, rich or poor, local or abroad.

4. Techno-political milieu of the agrobiodiversity change

The gradual dwindling of indigenous cotton began with the global socio-political development that triggered a chain of historic events, the gradual consolidation of power of the East India Company, the rise of Manchester as the textile production hub, the introduction of American cotton in the late eighteenth century, the slow decline of indigenous textile industry especially in the eastern part of the subcontinent, and the progressive shrinkage of native cotton acreage. The twentieth century observed a rapid change with the general implementation of technology and its conducive policy environment that began to exert profound impacts on agricultural performance (Alauddin & Quiggin, 2008; Ray, 2023). Likewise, cotton cultivation has been governed by the changes in technology and policy actions, more specifically following independence (Suresh & al., 2014).

4.1. *The early phase of changes - institutionalization*

After the introduction, the performance of the introduced species was tested across various parts of India (Guha, 2007; Hazareesingh, 2012). Despite repeated trials and errors, the introduced species did not succeed much, and the acreage reached only about 2-3 percent by 1947-48. But the attempts went on undiminished. A few are noteworthy; for example, the East India Company sought to improve the native cotton of Tamil Nadu by introducing tetraploid cotton, but met with little success at the initial stage. During 1904-05, an American cotton variety cultivated in Cambodia was brought and tested with irrigation. With some success, it was accepted in a few districts of Tamil Nadu as '*Tirunelveli American*' and subsequently expanded throughout the state as '*Cambodia Cotton*'. Later, it became a preferred variety for the southern textile industry (Raveendran & al., 2002). Guha's (2007) account also resonates with the early cotton trials, experiments, and failures. One such variety, 'New Orleans' (an upland American variety), was forced to cultivate in northern Karnataka around 1840 but with little success. The persistent trials bore fruit later; one small-scale experiment by local peasants with *G. hirsutum* was successful, and the variety later assumed the trade name of '*Dharwar-American*'. Hence, trials with success and failure were carried out and paved the path for the establishment of American cotton.

The modern cotton varietal improvement program in India began as early as 1904 when the agricultural departments were established in various states. They were later supported by the institutionalization of the Indian Central Cotton Committee (ICCC) in 1923 (Singh & Kairon, 2001). The period, early 20th century to the seventies, was the pre-hybrid improvement phase. The policy thrust was to intensify production through the steady area expansion (4.42 and 5.88 million hectares in 1947-48 and 1970-71, respectively). Various programs, the 'Grow More Cotton program' and the cotton extension schemes of the early 1950s, perhaps acted as catalysts to exert necessary impetus (Kairon et al. 2000). From a political ecology perspective, these techno-political developments mark the slow but irreversible change in agrarian relations. Seeds were no longer a common resource but began to be produced *en masse* away from the field, in laboratories, in more centralized facilities, and governed by industry-set standards and controlled by cotton mills, national and global trade.

The early improvement trials were conducted with indigenous varieties, which were of long duration and relatively low yielding but were resilient to diseases and precarious weather. However, they were shunned since the objective was to breed fast-growing, early maturing, and higher-yielding varieties of desired staple length, mostly long-stapled. The cotton mills required specific staple length (average length of fibers), micronaire (fiber's air permeability, which is related to its fineness and maturity), and strength - the primary characteristics that determine yarn quality. Hence, long and extra-long staple cotton cultivation went on to rise (Manickam & Baghyalakshmi, 2019). Further technological intervention and varietal improvement gained momentum with the inception of the All India Coordinated Cotton Improvement Project (AICCIP) in April 1967 by the Indian Council of Agricultural Research (ICAR) (AICCIP, 2003). Emphasis was given to the improvement of yield as well as quality, leading to a spurt in the production of long and extra-long staples (Table 1). Consequently, several varieties, mostly American upland, have been released for commercial cultivation in many Indian states. The continuously rising preference for longer staples uncovers a pattern that demonstrates how certain pre-set industry standards have slowly accelerated the erosion of diversity. By the 1970s, breeding complemented with extension efforts increased the area under upland cotton, replacing the indigenous cotton on a large scale. Introduced *G. barbadense* cultivars suitable for Indian agroecology were released in the 1968-70s, though the acreage remained small (Narayanan & al., 2014).

Period	Production in Million bales (170 kg each)			
	Long and Extra long	Medium	Short	Total
1947-48	–	1.53 (67)	0.76 (33)	2.29
1961-66	0.92 (17)	3.70 (68)	0.82 (15)	5.44
2016-17	27.03 (77)	7.02 (20)	1.05 (3)	35.10

Table 1. *Year-wise change in the production of cotton of three different staple length (adapted from Manickam & Baghyalakshmi, 2019) (Figures in parentheses indicate the percentage of the total)*

4.2. *Post-1970 interference of technology: hybrids*

In contrast to the pre-hybrid phase, the situation began to change rapidly after 1970, responding to the cutting-edge technology in crop breeding, i.e, the development and cultivation of hybrids following the trials of purebred varieties. It was temporally segmented into conventional hybrid and male sterility-based hybrid, depending on the technology. India emerged as the first country to grow hybrid cotton, Hybrid-4 (*hirsutum* x *hirsutum*), commercially. It was soon followed by various intra- and interspecific hybrids, tetraploids *hirsutum* x *hirsutum* and *hirsutum* x *barbadense,* and diploid *herbaceum* x *arboreum*. Afterwards, many superior hybrids, mostly of short duration, were released for cultivation. There were a few simultaneous developments that pushed cotton research further: the establishment of the Central Institute for Cotton Research at Nagpur in 1976 and a regional station at Sirsa in 1982 to support the research in the North Zone.

Early seventies onward, the efforts were channelized to release newer varieties and hybrids with a higher yield, 'better' industry-standard fiber quality, short maturation time, disease resistance, and wide adaptability. The first extra-long staple variety of *G. hirsutum,* MCU5, was released, followed by MCU9. Wider adoption and expansion of acreage shaped the dynamics of a few varieties, e.g., *Bikaneri Narma*, LRA5166, MCU5, and SRT1. Many have disseminated even beyond their region of initial introduction. For example, *Bikaneri Narma,* originally developed for Punjab but spread to Haryana, Madhya Pradesh, and Rajasthan, owing to its wide adaptability. Similarly, both MCU 5 and LRA5166, released for Tamil Nadu, have been cultivated in Andhra Pradesh, Maharashtra, and Madhya Pradesh. By 2004, the concerted effort of AICCIP had pioneered the commercial release of nearly two hundred varieties and hybrids with different economically important characteristics such as short to medium duration, resistance to diseases (leaf curl virus, jassid), adaptation to rainfed tracts, etc (Singh & Kairon, 2001). Despite all progress, profitability began to decline by the early 1990s owing to rising cultivation costs.

On the institutional front, there was major progress in cotton marketing, e.g., the establishment of the Intensive Cotton Development Programme (ICDP) in 1971-2 and the Cotton Corporation of India (CCI) in early 1970 (Suresh & al., 2014). All these developments in policy ecosystems conjointly pushed cotton research in a new direction and significantly impacted cotton production.

4.3. *Late-hybrid phase: 1990-1 to 2001-2*

The late-hybrid phase encountered a gradual rise of the private sector, which emerged as the sole contributor to seed and pesticide research. The Cotton Technology Mission by the Government of India began its operation in the late 1990s. It was accompanied by the Agreement on Textiles and Clothes (ATC) as part of the WTO agreements in 1995. Despite all these efforts in the policy landscape, yield and profitability were on the decline, driven by subsequent reforms on the farm front that raised input costs and led to farmers' distress, especially in rainfed regions (Raghavan, 2008). The cotton bollworm has wreaked havoc in many geographic regions since no existing cotton varieties were immune. It necessitated heavier application of pesticides that not only raised the costs of cultivation but also unleashed a set of related processes, e.g., environmental pollution, public health problems, pesticide resistance among the bollworm populations, a resurgence of minor pests, and chemical residues in the food chain. All of these greatly affected the social ecological systems of cotton cultivation.

4.4. *A new era of technology: bt-cotton-post-2002*

The intensified bollworm menace and rampant usage of pesticides during the late hybrid era soon made space for the new technology of genetically modified cotton or Bt cotton hybrid in 2002. It was developed by the introduction of the genes of a soil-borne bacterium, *Bacillus thuringiensis.* Since it was resistant to the key lepidopteran insect pests, it was expected that the ravages by bollworm could be contained without pesticide application. As a result, the cost of cultivation can be reduced with environmentally sustainable measures.

The newly engineered seeds were developed, patented, and sold to farmers by private companies, mostly in a monopolistic manner. As a result, an increase in cotton production across farm sizes, cropping systems, and regions was achieved (Suresh & al., 2013, 2014); though, whether the success can be attributed to Bt cotton adoption inspired scholarship (Kranthi & Stone, 2020). Gradually over time, more than a thousand Bt hybrid varieties of variable quality were planted in the majority of the cotton cultivating area (Kranthi, 2012). In India, nearly 90% of the hybrid cotton and almost all the current Bt cotton hybrids are derivatives of introduced *G. hirsutum.* After the introduction of Bt-cottons (largely as H x H and to a small extent as H x B hybrids), diploid cultivated species of cotton have been made an outcast. Cultivated cotton nowadays mostly produces superior medium and long staples. The production of short-stapled diploid species and extra-long staple cotton was replaced with H x H cotton hybrids with Bt-gene(s). In a nutshell, except for a minor acreage of *G. arboreum* and *G. herbaceum*, *G. hirsutum* and its various hybrid derivatives dominate the cotton fields of the country (Table 2). Essentially, it tells a story of severe genetic erosion of cotton and therefore predisposing it to greater risks emanating from pests and pathogens, and climate vagaries. The socio-ecological side of this technological progress is that the cotton farmers became increasingly dependent on external agencies for their seeds that demanded fertilizers or other agrochemicals, irrigation water, etc, and thereby remain embedded in this global commodity chain of cotton (Flachs & Stone, 2019). In contrast, the hybrid Bt cotton has been portrayed as a triumph by government agencies, seed manufacturers, other allied companies, and a large section of the research community (Manickam & Baghyalakshmi, 2019; Kathage & Qaim, 2012; Krishna & Qaim, 2012). However, yields have stagnated and production costs have shot up 2.5–3-fold. The low and unpredictable yield, coupled with the spurious seeds of the hybrid cotton farming system of India, contributed to thousands of suicides of debt-ridden farmers (Gutierrez & al., 2020). The crisis has also been compounded by the emergence of newer resistant pests of Bt cotton and a precarious climate. At the back, a narrow genetic base of the cotton crop, a result of the last hundred years of techno-political interference, also played out as an underlying driver but rarely invoked in the dissection of the crisis.

	Acreage (%)		
Species	**1947-48**	**1989-90**	**2013-14**
***G. hirsutum* (H)**	3	42	91
***G. barbadense* (B)**	very less	0.003	0.0001
***G. arboreum* (A)**	65	17	10
***G. herbaceum* (h)**	49.2	13	5
Hybrid cotton (Hybrid cotton era from 1970)All hybrids	-	28	very less
***hirsutum x hirsutum* Hybrid cotton with Bt-gene(s)**	-	-	91
***hirsutum x barbadense* hybrids with Bt-gene(s)**	-	-	very less

Table 2. *Changing species composition of cotton acreage in India (from Narayanan & al., 2014)*

5. Genetic narrowing of Indian cotton: the process and drivers

Loss of agricultural biodiversity due to modern crop improvement programs and large-scale technology transfer has been a common pattern observed across crops or countries (Ray, 2022a; Ray, 2023; Teklu & Hammer, 2006). One of the measures in gauging genetic erosion is to evaluate the diffusion and adoption of modern cultivars at the cost of indigenous varieties (Pingali 2017; Ray, 2022a;

Ray, 2023). The episodes of the Green Revolution exhibit one such example, which introduced high-yielding varieties of seeds over several decades and caused the decline of traditional varieties or landraces of rice, wheat, and maize across countries and continents (Pingali, 2017; Ray, 2022a; Teklu & Hammer, 2006; Witcombe & al., 2011). Likewise, in the case of cotton, the improvement programs that started in the early twentieth century and ramped up from 1950 drastically reduced the genetic diversity by prioritizing only one species, *G. hirsutum,* for producing long staples. However, I hypothesize that the seed of erosion had been sown much before, in the early phases of tetraploid cotton introduction and their slow spread. Though comparable to other crops undergoing improvement, the long process of genetic erosion in cotton has been complex and multi-phased, reciprocating with many technological and socio-political developments.

5.1. *The initial phase - American cotton entry (late 18th - late 19th)*

An early introduction of tetraploid *G. hirsutum* and *G. barbadense* in the late seventeenth century, their trials and preference over indigenous varieties created the stage. At the outset, the two native species dominated (Figure 2a), introduced species were restricted to a few corners, and their acreage was minuscule compared to the indigenous varieties even until the early 20th century (Table 2). However, the trials were in full swing despite their vulnerability to pests and diseases, marginal climatic conditions, higher input requirements, etc. During this phase, two domineering diploid species still held the sole acreage, and *G. arboreum* was in the lead. The heat of global techno-political changes riding on the industrial revolution was felt in the subcontinent. Coupled with the consolidation of power by the British East Indian Company, it affected many fronts of socio-cultural life, cotton being an economically important crop was not an exception. Industrial ginning facilities were rapidly replacing hand ginning, and demand for their long-staple varieties suited to the new machine was rising fast. The preclusion of hand ginning and the popularization of machine ginning turned the selection for various fiber qualities futile. Besides, the perception of quality had been changing among the cultivators, from color, softness, and durability of the fabric to machine-led industry standard, i.e., longer staple length, the diameter of the fiber, its strength, hygroscopic quality, etc (Menon & Uzramma, 2017). It signals the initiation of the bigger agrarian change and the relationship between the farmers and the cotton plant induced by technopolitical progress. It probably flags an early corporatization cotton value chain and commodification.

With these events operative at the backdrop, a general decline in the vast diversity of traditional varieties has already begun. Since most of the indigenous varieties produced shorter staple length, they were unfit for ginning in industrial looms that preferred relatively longer-stapled *G. hirsutum* and *G. barbadense* varieties. The burgeoning competition with machine-made and cheaper material from Lancashire and discriminatory tariffs against indigenous handloomers worsened the situation (Chatterjee & al., 1987). As a result, the cotton textiles produced by Britain flooded the Indian market at the cost of native handloom textiles, which were prohibited through various unfair policies like over-taxation. A chain of events was unleashed, the demise of the Bengal Textile Industry in the early 1800s, and the cultivation of various landraces around undivided Bengal.

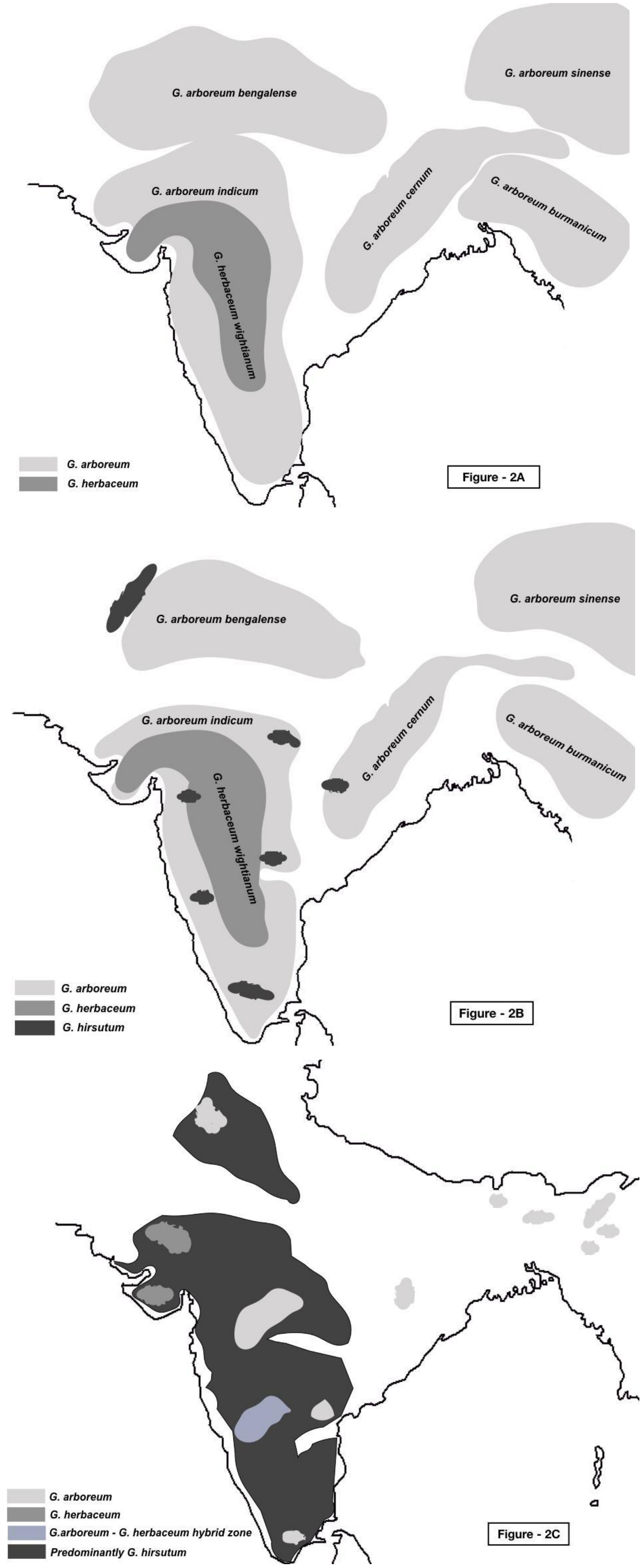

Figure 2. *The probable (schematic) change in cotton acreage held by Gossypium species (G. arboreum, G. herbaceum, G. hirsutum) in three phases and its genetic erosion: a) domestication, naturalization, and cultivation of native species (early phases to 18th century), b) Introduction and expansion of introduced species (around 19th century - middle 20th century), c) Current cotton acreage (post-1970 - 2000).*

5.2. *Intermediate phase - pre-hybrid era (1900 - 1970)*

The overall country acreage also began to shoot up during the early 20th century, from 3.88 million hectares to 4.42 and 5.88 million hectares, in 1947-48 and 1970-71, respectively (Figure 2b) (Ray 2022b). It was likely that the increment in acreage gained its impetus from the establishment of CICR and a country-wide improvement program that was in full swing from the early twentieth century. The rate of yield increment happened slowly from 100 Kg/hectare in 1900 to 132 Kg/hectare and 127 Kg/hectare in 1947-48 and 1970-71, respectively. Still, by 1946-47, *G. hirsutum* was only restricted to 3% while *G. arboreum* and *G. herbaceum* occupied 65% and 32% of total acreage, respectively; yet the surge in acreage and yield does not entirely capture the nuances of the continued erosion.

5.3. *Penultimate Phase or hybrid era*

The acreage under indigenous species began to shrink rapidly after the introduction and commercial cultivation of the first *hirsutum* x *hirsutum* hybrid cotton in 1970 followed by various intra- and interspecific tetraploid hybrids. In contrast, the hybrid diploid cotton, owing to the low seed setting property, restricted their availability. Moreover, the coordinated cotton improvement program has been inclined towards specific industry-set parameters for quality, i.e., higher yielding, improved fiber (long and superior-medium staple length), and short-duration varieties. Keeping pace with the requirement, proclaimed 'high-quality' cultivars were widely promoted and disseminated; it further marginalized the use of indigenous cotton landraces to a meager cultivated area (*G. arboreum* and *G. herbaceum* encompassing 17% and 13% of the acreage in 1989-90). Not only diploids but even various derived varieties of *G. barbadense* were also reduced to a mere 0.3% of the acreage (Figure 2c) (Narayanan & al., 2014). The yield also skyrocketed between 1970 and 2002, reaching from 127 Kg/hectare to nearly three hundred kilograms per hectare (Ray 2022b). The persistent effort to intensify the production through yield increment through newer (hybrid) seeds created a socio-economic 'lock-in' scenario that essentially molded the decision-making process of the farmers, the yield factor won their preference. The quintessential consequence was reflected in the choice of mostly high-yield varieties grown in monocultures in input-intensive production systems.

5.4. *Final phase - Bt-cotton*

The introduction and expansion of Bt-cotton after 2002 invaded Indian cotton fields like wildfire, now encompassing 90% of the overall acreage. At the same time, the yield continued to spurt, reaching almost 500 kg/ ha. Simultaneously, the total acreage rose to 12.23 million hectares in 2018-19. The extensification of cotton cultivation, especially in the last 100 - 120 years, is also significant in terms of total production, which multiplied from 3.34 (in 1947-48) to 36 (in 2018-2019) million bales (of 170 kgs each). It may look like the yield increase and Bt adoption as co-occurring phenomena, and therefore Bt cotton as a causal agent, though this may not be the case (Kranthi & Stone, 2020). The genetic constitution of cotton grown today in the country is mostly of *G. hirsutum* (*hirsutum x hirsutum* Bt cotton hybrids), and it is also represented by a few selected commercial varieties with a specific range of fiber, i.e., superior medium and long staple. Hence, not only native species, many popular cotton varieties such as AKA 081, AKA 7, GCot 11, GCot 13, LRA 5166, LRK 516, MCU 5, SVPR 2, PA 225, RG 8, Sahana, and Surabhi, etc that were once cultivated even in the marginal conditions, have been swept out by Bt cotton hybrids. Furthermore, the production of cotton varieties with extra-long staples also dwindled largely due to the replacement with Bt-cotton (Singh & Kairon, 2001). The acreage of *hirsutum x barbadense* Bt-hybrids remained tiny compared to *hirsutum x hirsutum* Bt-hybrids (Narayanan & al., 2014). Widespread dissemination and adoption of the Bt cotton hybrid led to further narrowing of the genetic base.

The genetic diversity of a crop is an outcome of its evolutionary history where domestication, range expansion, and selection play a critical role (Hufford & al., 2019; Ray & al., 2013; Wendel & al., 1989; Wood & Lenne, 1997). On the other hand, farmers have always been the central performers, and agricultural activities nestled in sociocultural or economic factors (Brush, 2008; Hufford & al., 2019; Khoury & al., 2022). The creation and maintenance of agricultural biodiversity is an outcome of the complex interplay of biological, socio-political, and economic factors (Harlan & al., 2012). Aligning the context to cotton allows us to gain nuanced insights into these patterns and processes. The phases of the trajectory of Indian cotton effectively illustrate a continuous process of genetic erosion that has been shaped by global trade and politics, technological development, and finally, the lowest unit of operation, the farmers. The shift in global trade and technological advancement following the industrial revolution, coupled with the rising demand for longer staples, initially fueled the introduction and the establishment of tetraploid cotton at the cost of the decimation of native species. In the last century, the rapidly changing technology to improve some specific traits of cotton (longer staples) and the formation of facilitating institutions were instrumental in further abandoning native species and promoting hybrids instead. Importantly, the necessary thrust to hike productivity has also been integral to agrarian change. We observe a slow rise in productivity initially from early 1900 (~100 kg/ hectare) to 1947-48 (132 kg/ hectare), then to the eighties-nineties; but a steep spurt from 2001-02 (308 kg/hectare) that continued more or less unreduced till 2005-2006 (472 kg/hectare). Afterward, yield almost stagnated and went on more or less the same till 2016-17 (542 kg/ hectare). The rise in productivity has not been achieved until the twentieth century; so, overall productivity increase in the last two thousand centuries looks minuscule (Ray, 2022b). Whereas, in the other cotton-growing parts of the world, production had not gained pace before the Industrial Revolution (Beckert, 2015).

Conclusions

Genetic diversity of the cultivated species infuses with the power to combat altered environmental conditions, from disease resistance to drought tolerance. In contrast, loss of genetic variation makes them susceptible to various abiotic and biotic stresses. In light of this, I note the pest problem of cotton in the Indian subcontinent has not been very old, but rather co-occurred and intensified with the newly introduced tetraploid species in the early nineteenth century and turned out to be a menace in recent times. Various historical accounts reiterate the pest incidence and its intensified ravage on the introduced species while heirloom varieties were nearly spared (Nangpal & al., 1948); Pearse, 1913-14; Spielman & al., 1950). On a similar note, native species were able to survive resource-poor environmental conditions and can offer low to moderate yields, whereas introduced varieties were quite sensitive to climatic fluctuations. Gradual loss of many landraces, marginalization of the native species, and over-reliance on a few cultivars of American upland cotton manifested in severe genetic narrowing. Evolutionarily, it ripped them from their intrinsic ability to adapt to environmental perturbations, be it pests, extreme climate, or water conditions. Moreover, the new Bt technology emerges as a panacea to combat lepidopteran pests and underlies the rise in cotton yield, though it could never remain effective for a longer time, since pests acting against strong selection pressure could evolve new strategies to evade toxins and survive. Pertinently, the rise in insect resistance to transgenic Bt crops, in general, has already been reported (Tabashnik & al., 2023). In India, the infestation of Bt cotton by pink bollworm has been widely documented in Maharashtra (Jain, 2017), the central part (Fand & al., 2019), Karimnagar district, Telangana (Najork & al., 2021), and Punjab (Kamal, 2021). Similarly, a rise in resistance allele frequency in field populations of cotton bollworms from Telangana and Andhra Pradesh has been uncovered (Kukanur & al., 2018). So, it would create sporadic demand for newer varieties that might fight off the pests; eventually, the pest would develop resistance, and an evolutionary arms race would go on; therefore, spiraling the requirement for newer technology, pesticides, and costlier seeds. The perils of genetic homogeneity created as an outcome of long-term social-ecological technological and economic change are central to agricultural sustainability, but it is hardly accounted for in the popular narratives of cotton pest recurrence, crop failure, and farmers' distress. With climate change looming large, it is anticipated to threaten cotton cultivation further, restricting its potential to adapt and survive, and thus aggravating the chances of crop loss and social crisis.

Acknowledgments

I would like to acknowledge the comments by Rajasri Ray on various avatars of the manuscript, as well as for figure 2. I received no funding for this study.

References

[ALA 08] Alauddin, M., Quiggin, J., “Agricultural intensification, irrigation and the environment in South Asia: Issues and policy options”, *Ecological Economics*, nº 65(1), p. 111-24, 2008. https://doi.org/10.1016/j.ecolecon.2007.06.004

[AlC 03] AlCCIP., India Coordinated Cotton Improvement Programme, Annual Report, Central Institute of Cotton Research Regional Station, Coimbatore, 2003.

[BAR 11] Barker, R., “The origin and spread of early-ripening Champa rice: it’s impact on Song Dynasty China”, *Rice,* nº4(3), p. 184-186, 2011. https://doi.org/10.1007/s12284-011-9079-6

[BEC 15] Beckert S., *Empire of cotton: A global history*. Vintage, 2015.

[BRU 08] Brush S.B., *Farmers’ Bounty: locating crop diversity in the contemporary world*. Yale University Press, 2008.

[CHA 98] Chandra M., “Costumes Textiles” in Satyaprakasa Sangara (ed.), *Indian Textiles in the Seventeenth Century,* New Delhi, 1998.

[CHA 87] Chatterjee R., “Cotton Handloom Manufacturers of Bengal, 1870-1921” *Economic and Political Weekly*, p. 988-997, 1987.

[DEB 2012] De Boef, W.S., Thijssen, M.H., Shrestha, P., Subedi, A., Feyissa, R., Gezu, G., Canci, A., Fonseca Ferreira, M.A.J.D., Dias, T., Swain, S. and Sthapit, B.R., “Moving beyond the dilemma: practices that contribute to the on-farm management of agrobiodiversity”, *Journal of Sustainable Agriculture*, nº 36(7), p.788-809, 2012. https://doi.org/10.1080/10440046.2012.695329

[EMP 07] Emperaire, L., Nivaldo, P., “Traditional management of agrobiodiversity in Brazil: a case study of manioc” *Human Ecology* 35, nº 6: 761-768; 2007. https://doi.org/10.1007/s10745-007-9121-x

[FAN 19] Fand, B.B., Nagrare, V.S., Gawande, S.P., “Nagrale, D.T., Naikwadi, B.V., Deshmukh, V., Gokte-Narkhedkar, N., Waghmare, V.N., Widespread infestation of pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechidae) on Bt cotton in Central India: a new threat and concerns for cotton production”, *Phytoparasitica* nº 47, p. 313-25, 2019. https://doi.org/10.1007/s12600-019-00738-x

[FLA 19] Flachs, A., Stone, G.D., “Farmer knowledge across the commodification spectrum: Rice, cotton, and vegetables in Telangana, India”, *Journal of Agrarian Change* nº 19(4), p., 614-634, 2019. https://doi.org/10.1111/joac.12295

[GLO 10] Glover, D., Is Bt Cotton a pro-poor technology? A review and critique of the empirical record. *Journal of Agrarian Change* nº 10(4), p. 482-509, 2010. https://doi.org/10.1111/j.1471-0366.2010.00283.x

[GUH 07] Guha, S., “Genetic Change and Colonial Cotton Improvement in Nineteenth and Twentieth Century India. In *Situating Environmental History*, R. Chakrabarti, (ed.) 307–322. Manohar, 2007.

[GUT 15] Gutierrez, A.P., Ponti, L., Herren, H.R., Baumgärtner, J., Kenmore, P.E., “Deconstructing Indian cotton: weather, yields, and suicides”, *Environmental Sciences Europe*, nº *27*(1), p.12, 2015. https://doi.org/10.1186/s12302-015-0043-8

[GUT 20] Gutierrez, A.P., Ponti, L., Kranthi, K.R., Baumgärtner, J., Kenmore, P., Gilioli, G., Boggia, A., Cure, J.R., Rodríguez, D., “Bio-economics of Indian hybrid Bt cotton and farmer suicides”, *Environmental Sciences Europe,* nº 32(1), p. 1-5, 2020. https://doi.org/10.1186/s12302-020-00406-6

[HAR 12] Harlan, J.R., Gepts, P., *Biodiversity in agriculture: domestication, evolution, and sustainability*. Cambridge University Press, 2012

[HAZ 12] Hazareesingh, S., “Cotton, climate and colonialism in Dharwar, western India, 1840–1880”, *Journal of Historical Geography,* nº 38(1), p. 1-7, 2012. https://doi.org/10.1016/j.jhg.2011.10.003

[HOW 10] Howard, P.L., “Culture and agrobiodiversity: understanding the links”, In *Nature and culture*, pp. 181-202. Routledge, 2010.

[HUF 19] Hufford, M.B., Berny, Mier, y Teran, J.C., Gepts, P., “Crop biodiversity: an unfinished magnum opus of nature”, *Annual review of plant biology* nº 70, p. 727-51, 2019. https://doi.org/10.1146/annurev-arplant-042817-040240

[JAI 17] Jain, B., “Bt cotton falling to pest, Maharashtra tensed”, The Times of India. July 5, 2017. http://timesofindia.indiatimes.com/articleshow/59449010.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst, 2017.

[KAI 00] Kairon, M.S., Ramasundaram, P., and Venugopalan, M.V., “*Cotton Production: Agenda for Action in New Millennium*,” Survey of Indian Agriculture, The Hindu, Chennai, pp. 109-12.

[KAM 21] Kamal, N., 2021., "Pest infestations: Punjab farmers question BT seed claims", The Times of India. September 28, 2021. http://timesofindia.indiatimes.com/articleshow/86568301.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst

[KAT 12] Kathage, J., Qaim, M., "Economic impacts and impact dynamics of Bt (*Bacillus thuringiensis*) cotton in India", *Proceedings of the National Academy of Sciences* nº 109(29), p. 11652-6, 2012. https://doi.org/10.1073/pnas.1203647109

[KHO 22] Khoury, C.K., Brush, S., Costich. D.E., Curry, H.A., de Haan, S., Engels, J.M., Guarino. L., Hoban, S., Mercer, K.L., Miller, A.J., Nabhan, G.P., "Crop genetic erosion: Understanding and responding to loss of crop diversity", *New Phytologist*, nº 233(1), p. 84-118, 2022. https://doi.org/10.1111/nph.17733

[KRA 12] Kranthi, K.R., Bt cotton-questions and answers. Mumbai, India: Indian Society for Cotton Improvement (ISCI). 2012.

[KRA 20] Kranthi, K.R., Stone, G.D., "Long-term impacts of Bt cotton in India", *Nature Plants* nº *6*(3), p.188-196, 2020. https://doi.org/10.1038/s41477-020-0615-5

[KRI 12] Krishna, V.V., Qaim, M., "Bt cotton and sustainability of pesticide reductions in India", *Agricultural Systems*, nº 107, p. 47-55, 2012. https://doi.org/10.1016/j.agsy.2011.11.005

[KUK 18] Kukanur, V.S., Singh, T.V., Kranthi, K.R., Andow, D.A., "Cry1Ac resistance allele frequency in field populations of Helicoverpa armigera (Hübner) collected in Telangana and Andhra Pradesh, India", *Crop Protection,* nº 107, p. 34-40, 2018. https://doi.org/10.1016/j.cropro.2018.01.008

[KUL 09] Kulkarni, V.N., Basavaraj, M.K., Manjula, S.M., Deshapande, L.A., Narayanan, S.S., "The worldwide gene pools of Gossypium *arboreum* L. and G. *herbaceum* L., and their improvement", In: , A.H. Paterson (ed), *Genetics and Genomics of Cotton. Plant Genetics and Genomics: Crops and Models,* vol 3. Springer, New York, NY. p. 69-97, 2009.

[MAN 19] Manickam, S., Baghyalakshmi, K., High Yielding Cotton Varieties and Hybrids. Lecture Notes of Exposure Visit cum Capacity Building Program on Cotton Production Technologies held at ICAR-Central Institute for Cotton Research, Regional Station, Coimbatore during Nov 18-21, 2019

[MAC 20] Mackenna, J., Wadia, P.N., Report of the Indian Cotton Committee Report, 1919. Calcutta, Superintendent Government Printing; 1920.

[PAR 01] Parthasarathi, P., *The transition to a colonial economy: weavers, merchants, and kings in South India, 1720-1800.* No. 7. Cambridge University Press, 2001.

[PAR 09] Parthasarathi, P., Cotton Textiles in the Indian Subcontinent, 1200–1800, in G Riello, P Parthasarathi (eds) *The Spinning World: A Global History of Cotton Textiles,* 1200-1850; United Kingdom: OUP, 2009

[PEA 13-14] Pearse, A.S., "Indian Cotton. Secretary, on his Third Visit to India", October, 1913—February, 1914;

[PRA 99] Prasad, C.S., "Suicide deaths and quality of Indian cotton: Perspectives from history of technology and khadi movement", *Economic and political weekly* PE12-PE21.

[MEN 17] Menon, M., Uzramma., *A Frayed History: The Journey of Cotton in India*. Oxford University Press, New Delhi, India, 2017.

[NAJ 21] Najork, K., Gadela, S., Nadiminti, P., Gosikonda, S., Reddy, R., Haribabu, E., Keck, M., "The return of pink bollworm in India's Bt cotton fields: Livelihood vulnerabilities of farming households in Karimnagar District", *Progress in Development Studies*, nº 21(1), p. 68-85, 2021. https://doi.org/10.1177/14649934211003457

[NAU 08] Nautiyal. S., Bisht, V., Rao, K.S., Maikhuri, R.K., "The role of cultural values in agrobiodiversity conservation: a case study from Uttarakhand, Himalaya", *Journal of Human Ecology* nº 23(1):1-6, 2008.

[PIN 17] Pingali, P.L., "The Green Revolution and crop biodiversity", in Hunter D, Guarino L, Spillane C, McKeown PC (eds) *Routledge Handbook of Agricultural Biodiversity,* pp. 213-223. Routledge, New York, London, 2017.

[NAR 14] Narayanan, S.S., Parchuri, V., Srinivasu, Babu, K., Cotton Germplasm in India - New Trends; In: Abdurakhmonov I (eds) *World Cotton Germplasm Resources*, p 87–118, 2014.

[NAN 48] Nangpal, H. D., Insect Pests of Cotton in India. *Insect Pests of Cotton in India,* 1948

[RAG 08] Raghavan, M., "Changing Pattern of Input Use and Cost of Cultivation," *Economic and Political Weekly*, nº 28(26-27), p. 123-9, 2008.

[RAV 19] Ravera, F., Reyes-García, V., Pascual, U., Drucker, A.G., Tarrasón, D., Bellon, M.R., "Gendered agrobiodiversity management and adaptation to climate change: differentiated strategies in two marginal rural areas of India", *Agriculture and human values* nº 36, p. 455-74, 2019. https://doi.org/10.1007/s10460-018-09907-w

[RAV 12] Raveendran, T.S., Mohan, S., Ravikesavan, R., Surendran, C., Meyyazhagan, N., Parthiban, V.K., Cotton, The White Gold. Department of Cotton, CPBG, Tamil Nadu Agricultural University. Coimbatore, India, 2002.

[RAY 13] Ray, A., Deb, D., Ray, R., Chattopadhayay, B., "Phenotypic characters of rice landraces reveal independent lineages of short-grain aromatic indica rice" *AOB plants* Jan 1; 5, 2013. https://doi.org/10.1093/aobpla/plt032

[RAY 22a] Ray. A., "The darker side of agricultural intensification - the disappearance of autumn or aus rice, entry of HYVs, and implications in terms of environmental sustainability in a 'Green Revolution' state of eastern India" *World Development Sustainability*, https://doi.org/10.1016/j.wds.2022.100028, 2022a.

[RAY 22a] Ray, A., "Revisiting the Culture of Cotton in the Past: Historical Cultivation Practices, Farmers Decision Making, Intensification of Production" *South Asian History, Culture and Archaeology,* nº 2(2), p. 229-242, 2022b.

[RAY In Press] Ray, A. (In Press). Domestication, Cultivation, and Diversification of Crops in Shifting Cultivation Systems across the Highlands of India – A Cross-Cultural Investigation, in Cairns, M.F. (ed), *Farmer Innovations and Best Practices by Shifting Cultivators in Asia-Pacific*, Wallingford, UK: CAB International.

[RAY 23] Ray A. 2023. The decline of Agrobiodiversity: the process of crop improvement, consequent homogenization, and aftermath, in Ghosh S, Panda, A. K., De Mandal, S., Jung, C., Bisht, S.P. S., (eds), *Emerging Solutions in Food and Nutrition Security* , Springer Nature, New York.

[RIE 09] Riello, G. and Roy, T., 2009. *How India Clothed the World: The World of South Asian Textiles, 1500-1850 (Volume 4)*. Brill.

[ROY 12] Roy, T., Consumption of cotton cloth in India, 1795–1940. *Australian Economic History Review*, nº *52*(1), p. 61-84, 2012.

[SCH 11-12] Schmidt A. Cotton growing in India. Secretary, on his second visit to India. December 1911- January 1912.

[SCO 06] Scoones, I., *Science, agriculture and the politics of policy: The case of biotechnology in India*. Orient blackswan; 2006.

[SIN 01] Singh, P., Kairon, M.S., Cotton varieties and hybrids. CICR Technical Bulletin No: 13. Central Institute for Cotton Research, Nagpur, 2001.

[SPI 50] Spielman, H.W., Cotton production in India Foreign Agriculture Report No, 45. 1950

[STO 12] Stone, G.D., Constructing facts: By cotton narratives in India. *Economic and Political Weekly* (2012): 62-70, 2012.

[SUR 13] Suresh, A., Ramasundaram, P., Samuel, J., Wankhade, S., "Impact of technology and policy on growth and instability of agricultural production: The case of cotton in India", *Indian Journal of Agricultural Sciences*, nº 83(8), p.939-48, 2013.

[SUR 14] Suresh, A., Ramasundaram, P., Samuel, J., Wankhade, S., "Cotton cultivation in India since the green revolution: Technology, policy, and performance" *Review of Agrarian Studies*, nº 4(2), 2014

[TAB 23] Tabashnik, B.E., Fabrick, J.A., Carrière, Y., "Global patterns of insect resistance to transgenic Bt crops: The first 25 years" *Journal of Economic Entomology*, nº 116(2):297-309, 2023. https://doi.org/10.1093/jee/toad013

[TAY 51] Taylor, J.A., *Descriptive and Historical Account of the Cotton Manufacture of Dacca in Bengal*, John Mortimer, London, 1851.

[TEK 06] Teklu, Y., Hammer, K., "Farmers' perception and genetic erosion of tetraploid wheats landraces in Ethiopia" *Genetic Resources and Crop Evolution* nº 53(6):1099-113, 2006. https://doi.org/10.1007/s10722-005-1145-8

[THR 00] Thrupp, L.A., "Linking agricultural biodiversity and food security: the valuable role of agrobiodiversity for sustainable agriculture" *International Affairs* nº 76(2), p. 265-281, 2000. https://doi.org/10.1111/1468-2346.00133

[WAT 07] Watt, G., *The Wild and Cultivated Cotton Plants of the World: A Revision of the Genus Gossypium*, 1st Indian edition. New Delhi: Sagar Book House, 1989 [1907].

[WEN 89] Wendel, J.F., Olson, P.D., Stewart, J.M., "Genetic diversity, introgression, and independent domestication of old-world cultivated cottons" *American Journal of Botany* 76(12), p. 1795-806, 1989. https://doi.org/10.1002/j.1537-2197.1989.tb15169.x

[WIT 11] Witcombe, J.R., Joshi, K.D., Virk, D.S., Sthapit, B.R., Impact of the introduction of modern varieties on crop diversity, in: Lenné and D Wood (eds) *Agrobiodiversity management for food security: A critical review*, JM CABI Publishing, UK, p87-98, 2011.

[WOO 97] Wood, D., Lenne J.M., The conservation of agrobiodiversity on-farm: questioning the emerging paradigm. *Biodiversity & Conservation* nº 6(1), p.109-29, 1997. https://doi.org/10.1023/A:1018331800939