Chapter 5

Usefulness and Utilization of Indian Cotton Germplasm

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Additional information is available at the end of the chapter

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1. Introduction

Cotton, jute and similar fibre crops are the key money-makers in Indian agriculture sector. India has the largest area of global cotton cultivation that contributes 23% to the global cotton production. Cotton plays a key role in the Indian economy in terms of income generation in the agricultural and industrial sectors. Textiles and related exports account for nearly 33% of the total foreign exchange earnings (~12 billion dollars) of India and it is projected that there will be a significant increase in the coming year [1].

Cotton is cultivated in three different zones (northern, central and southern) of India. Approximately 65% of India's cotton is produced on dry land and 35% on irrigated lands. The northern zone is almost totally irrigated, while the percentage of irrigated area is much lower in the central (23%) and southern zones (40%). Under the non-irrigated conditions, annual rainfall ranges from less than 400 to more than 900 mm coupled with unusual patterns over the years which lead to large-scale fluctuations in cotton production [2].

It is estimated that around 20 million farmers cultivate cotton in India and about 46 million persons are employed directly by the ginning, pressing, trade, knitting, handloom, processing and cotton related textile industry and thus cotton cultivation and textile utilization is the second largest employer after general agriculture. There are more than 2,500 spinning mills and 250 composite mills in India having an installed capacity of approximately 35 million spindles, 1.7 million power looms/handlooms and thousands of garment, hosiery and processing (dyeing and printing) units [3]. The decentralized sector comprising power looms and handlooms, provide employment to over 2.5 million people [4]. Others include thousands of garment manufacturing units, over 3500 ginning and pressing factories and several marketing organizations of raw cotton, yarns, fabrics and garments.

Since India has a large domestic textile industry, the mill consumption of cotton in the country has been continuously on the raise from the beginning of the 1990s. There was a leap in domestic cotton consumption in 2012-13 from 22.9 (in 2009-10) to 27.6 million bales, and in some cases, cotton lint was imported from China [5]. Since the economic liberalization began in 1991, there has been an impressive increase in the export of cotton. In addition to yarns, fabrics and garments, whose exports have been steadily rising in recent years, raw cotton is also permitted to be exported from time to time [6]. Therefore cotton production in India has boundless impact not only on the livelihood of the farmers and economy of the country, but also on international trade. Further, global textile market demands for increased fibre uniformity, strength, extensibility, and novel value added quality. This clearly justify the importance of new and innovative approaches toward evaluating, understanding and utilizing the available cotton germplasm and they are discussed in this chapter.

2. Historical perspectives of cotton germplasm utilization in India

The time when cotton fibre was first used in India for cloth or other textile fabric making could not be dertemined precisely. The first reference to cotton is found in rig Veda hymn [7]. The stages of seed cotton, spinning the lint and weaving the yarn are covered in various religious texts and thus suggest the implicit use of cotton in India by 1000 BC [8]. The cotton textile trade is considered ancient since it was shown that Indian cotton fabrics have been found in the tombs of the Pharaohs [9]. From time immemorial, India was the only country that was known for its cotton fabrics when the rest of the world was being dressed mostly in wool [10]. The fabrics dated approximately 3000 BC recovered from Mohenjo-Daro excavated in Sind were identified to have originated from cotton plants, closely linked to *Gossypium arboreum* [11], thereby confirming that cotton lint was spun and woven into cloth even before 3000 BC. In some of the ancient literatures, perennial cotton trade was reported in the beginning of the Christian era. Colourful and designer handloom fabrics and apparels of India were regularly imported by Egypt, Greece, Rome and China [12]. All Indian cottons in the 13th century were perennials and they were in cultivation until recently. Bushy perennial forms of cotton are still being maintained in remote villages of Rajasthan, Uttar Pradesh and Andhra Pradesh. The East Indian Company (which was the major trader in exporting the Indian cotton to Inter-Asian and European countries [9]) recognized three trade varieties of cotton during the 18th century: 1. *Tinnies* (which is a mixture of *Karunganni* belonging to *G. arboreum* race *wightianum*) 2. *Salems* (which is also a mixture of perennial native cotton *Nadan* (meaning native) belonging to *G. arboreum* race *indicum* and *uppam;* in addition another perennial cotton belonging to the group of *G. hirsutum* L. race *punctatum* introduced by the East India Company in the late 18th Century was also included in this category) and 3. *Karunganni* (which belongs to *G. arboreum*) cotton [12].

Rozi cottons belonging to *G. arboreum* were supposed to be the ancient commercial type. Vizagapattinam of Andhra Pradesh is the place of differentiation of *indicum*. The perennial *Nadan* cotton of the Southernmost part of Tamil Nadu is the progenitor of *Karunganni* variety (belonging to *G. hirsutum*), which has excellent drought tolerance and can provide significant

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yield under water limited environments. In all the places, selection towards an annual habit type was carried out. Another component is known as *uppam* belonging to *G. herbaceum.* The name *uppam* is synonymous with both *Ukkan* and Udumalpet cottons. Since the early cultivation was centred on Udumalpet in Tamil Nadu, it was named after the place. The other name *Ukkan* has been interpreted to mean that *Vokkalegas* who hailed from Chittaldurg and Dharwad districts of Karnataka and settled in western parts of Coimbatore district in Tamil Nadu, brought the cotton with them during their migration. The women of this community were known to spend their spare time in ginning and spinning cotton. The name *uppam* cotton in Southern tip of Peninsula may have been due to its property of swelling (*uppal* in Tamil) of the kapas by sea breeze (*uppu katru* in Tamil) under whose influence it thrives well in eastern coastal parts of India [12].

Presently, all the four cultivated cotton species (*G. hirsutum, G. barbadense* L., *G. arboreum* and *G. herbaceum* L.) are being commercially cultivated in India. The diploid cotton (*G. arboreum* and *G. herbaceum*) are indigenous to Asia and Africa and are popularly referred to as desi cottons in India. They are mainly cultivated in dry land tracts, though Bengal desi is grown under irrigated situations in the northern states. *G. hirsutum* is known as the American cotton and most popular varieties and hybrids now under cultivation (nearly 90% of plantings) belong to this group. *G. barbadense* is popularly known as the Egyptian cotton and is grown in small area in India. These two new world cottons, i.e., the tetraploid (2n=52) species of *G. hirsutum* and *G. barbadense* were initially introduced into India during the 17^{th} and 18^{th} centuries [13].

Thus it can be clearly conceptualized that the history of cotton and textiles in India is the true representation of the history of the utilization of cotton germplasm and growth of the modern industries in India. It is believed that modern cotton varietal improvement program in India was started as early as 1901. The earlier part of 20^{th} century witnessed cultivation of desi cotton varieties which mature in 200 days and were poor yielding but endowed with resistance to pest, disease and drought. The objectives of breeding program during those days were mainly focused on breeding for short duration and increased yield. Cotton varietal improvement program has employed all the breeding strategies such as introduction, mass selection, pedigree selection, intra-and inter-specific hybridization, backcrossing and induced mutations.

The East India Company made many attempts to improve the native cotton of Tamil Nadu, India. It tried to introduce the American tetraploid cotton. However, all their attempts were unsuccessful. During 1904-05, a chance introduction of an American cotton, cultivated in Cambodia (the present Kampuchea), indicated the possibility of raising it under irrigated conditions. Within three or four years, it spread throughout the Southern Districts of Tamil Nadu and got the name “Tirunelveli American”. Later, it spread throughout Tamil Nadu and came to be known as “Cambodia Cotton” in the Southern peninsula and laid the foundation for strong establishment of cotton ginning, spinning and weaving industry in South India [12]. For example, efforts to release American tetraploids were responsible for the release of a cultivar, CO 2 (a pure selection of Cambodia bulk) and several MCU (Madras-Cambodia-

Uganda) series which formed the basis of all cotton improvement programs in Tamil Nadu and other parts of South India [12].

India is the first country to grow hybrid cotton on a commercial scale since the 1970s. During those periods, hybrid seeds were produced by hand emasculation and pollination and the first intra-*hirsutum* hybrid, Hybrid-4, were released from Gujarat Agricultural University, Surat, India in 1971. In subsequent years, it covered 26.8 percent of the total cotton cultivated area in India and contributed 50 percent of the national cotton production [6]. Considering the importance of hybrids in Indian cotton scenario and its market potential in abroad, several hybrids were released such as Varalaxmi, DCH 32 in successive years. In Tamil Nadu, TCHB213 an inter-specific hybrid with high yield potential with superior qualities (such as high elongation percentage that fit to hosiery, resistant to reiniform nematodes and spinning capacity of 100s counts etc.,) was released in 1990.

3. Cotton germplasm at public institutes

Genetic improvement of cotton for higher yield, superior fibre quality, improved agronomic performance and resistance to pest and diseases is the important research agenda in several agricultural Universities and institutes in India. Collection, storage, maintenance and utilization of cotton germplasm activities in the key institutes are described hereunder:

3.1. CICR, Nagpur

With a view to develop a centre of excellence for carrying out long term research on fundamental problems limiting cotton production and also to provide support to research work on cotton, the Indian Council of Agricultural Research has established the Central Institute for Cotton Research (CICR) at Nagpur in April, 1976. The National Centre for Cotton Genetic Resources, which was re-designated as National Cotton Gene Bank, has been established at CICR, Nagpur as *in situ* species garden.

This bank contains totally 10227 accessions including 7484 accessions of *G. hirsutum*, 263 *G. barbadense*, 1877 *G. arboreum*, 530 *G. herbaceum*, 26 wild species, 32 perennials and 15 races of cultivated species and cytogenetic materials. This is one among the globally recognized centres that maintain large collections of cotton germplasm [2]. According to the genomic groupings, germplasm accessions have organized as primary germplasm pools (comprising germplasm accessions with AD genomes), secondary germplasm pools (including germplasm accessions with A, B, F and D genomes) and tertiary germplasm pools (containing germplasm lines with C, G, K and E genomes) [2, 3]. Each pool contains current and obsolete cultivars, breeding stocks, primitive and wild accessions, land races and subspecies. In accordance with the international board of plant genetic resources, the cotton germplasm has been further classified into core collections and working / active collections. The latter are elite stocks of cultivated species and selected cytoplasmic male sterile derived lines that are actively used in breeding and genetic studies. Germplasm banks were also established under AICCIP in important cotton research centres such as Delhi, Surat, Indore, Akola, Nanded, Nandyal and Coimbatore.

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Few cytomorphologically stable male sterile plants have been identified from the derivatives of multispecies hybrids involving wild species *G. raimondii, G. thurberi, G. hirsutum* and *G. barbadense*. One hundred and thirty seven *harknessii* cytoplasmic male sterile (CMS) lines, 15 *aridum* CMS lines, 19 genetic male sterile (GMS) lines and 57 restorer lines are being maintained through crossing, sibmating and selfing at CICR. For genetic improvement of CMS and GMS lines, they were treated with physical (gamma rays) and chemical mutagen (ethyl methane sulphonate) and being maintained [16].

Desi cotton species have originated in India, particularly the three geographical races of *G. arboreum* L. namely *bengalense, cernuum* and *indicum* and of *G. herbaceum* L. race *wightianum*. Excavations of Mohenjo-Daro and Harappa have shown that cloth of finest quality of about 300 counts was produced from the *G. arboreum*. Such perennial cotton possesses variability in useful traits like fibre, pest resistance and abiotic stress tolerance. CICR has taken initiative to collect and conserve the landraces of desi cotton and perennials with desirable characters from Maharashtra, Madhya Pradesh, West Bengal, Andhra Pradesh, Mizoram, Meghalaya, Tripura, Gujarat and Tamil Nadu. The important cotton landraces like *Ponduru, Karuganni, Commilla, Uppam* and *Wagad* were collected from different states of India [17].

Seeds of 1517 *G. hirsutum* including 289 exotics and 350 accessions of *G. arboreum* are being maintained at National Bureau of Plant Genetic Resources (NBPGR), New Delhi under long term cold storage, while another set of the same germplasm is being kept in medium term cold storage at CICR, Nagpur. Further, three genetic stocks of *G. arboreum* race *cernuum* immune to grey mildew disease have also been stored at NBPGR, New Delhi.

The germplasm accessions available in the gene bank are regularly being evaluated for major economic characters such as high yield, high boll weight, high ginning out turn and lower maturity period besides their reaction to major pests and diseases. Similarly, the new germplasm lines received every year are also evaluated for a set of agronomic and economic characters. The selected superior accessions will be further evaluated in multi-locations and provided to regional breeding program after validating their usefulness.

3.2. CCS-HAU, Hisar

Evaluation and maintenance of American and Desi cotton germplasm is mandate of CCS Haryana Agricultural University, Hisar. Thirty five genetic male sterile lines have been developed in *G. arboreum* (and six genetic male sterile lines of cotton have been registered with NBPGR, New Delhi) and forty four genetic male sterile lines and forty three cytoplasmic genetic male sterile lines have been developed in *G. hirsutum*. Besides these lines, 55 potential restorers and a large collection of landraces have also been identified and maintained at this University.

3.3. TNAU, Coimbatore

At TNAU, Coimbatore, 1012 accessions of *G. hirsutum,* 149 accessions of *G. barbadense* and wild species of *G. aridum* and *G. hirsutum* race *punctatum* are being maintained and routinely evaluated and used in regional breeding program. Genetic improvement of cotton for improved drought tolerance, pest and disease resistance with better fibre quality traits are being taken up with help of contemporary breeding tools (see below). TNAU's Collaboration with national and international institutes ensured introgression of novel alleles from exotic and other donors.

3.4. UAS, Dharwad

Besides conserving large numbers of *G. hirsutum and G. barbadense* accessions, Regional Research Station – University of Agricultural Sciences, Dharwad maintains several cultures of *G. arboreum* and *G. arboreum* genotypes introgressed with *G. hirsutum* genes. Notable examples in this aspect are cultures DLSA 17 and 19 that are having improved fibre qualities and tolerance to cotton pest and diseases.

3.5. PAU, Ludhiana

An exhaustive germplasm collection, storage and maintenance of several *Gossypium* spp., for fibre yield and superior quality parameters and tolerance to cotton leaf curl virus disease is also in progress at Punjab Agricultural University, Ludhiana and they are regularly being utilized in cotton breeding program.

3.6. Role of AICCIP in germplasm evolution, evaluation and conservation

Launching of All India Co-ordinated Cotton Improvement Program (AICCIP) in 1966 funded by Indian Council of Agricultural Research, New Delhi has been considered as the milestone in cotton genetic improvement efforts in India. The AICCIP in collaboration with State Agricultural Universities made tremendous achievements in cotton production during the last five decades. This program has the following three important mandates: 1) to develop genotypes suitable for different agro-climatic conditions 2) to develop manuals to maximize yield from improved genotypes and 3) to develop effective and economic plant protection measures for location-specific strategies for integrated biotic stress management.

Currently, the AICCIP is in operation with its headquarters at Coimbatore and spread over 21 participating centres involving 16 State Agricultural Universities. They are marked as North (Punjab, Haryana and Rajasthan), Central (Gujarat, Madhya Pradesh, Maharashtra and Orissa) and South Zones (Karnataka, Andhra Pradesh and Tamil Nadu) [3]. The CICR, Nagpur and its Regional Stations at Coimbatore and Sirsa provide basic research support and also take part in some of the strategic research and evaluation activities on Cotton. The Central Institute for Research on Cotton Technology (CIRCOT, ICAR), Mumbai and its regional units are closely associated with AICCIP in assessing the fibre quality parameters of cotton cultures under trial. Major activities of the AICCIP include the evolution of novel varieties and hybrids best suited for different agro-climatic zones, development of sustainable and inexpensive agro-techniques for realizing maximum yields from improved cultivars with economic and effective pest and disease management practices under different environmental conditions.

Numerous agronomical, physiological as well as pest and disease resistance attributes have been studied in detail in the germplasm accessions under AICCIP. Subjective tests like metroglyph analysis, D^2 analysis and combining ability have been done on elite germplasm lines to study the genetic diversity and use the most diverse ones in the breeding programs. There are large variations available in the germplasm for yield attributes, plant traits, flower characteristics, fibre characteristics, oil characteristics, biomass characteristics, leaf characteristics, boll characteristics, seedling characteristics, boll and seed setting efficiency. Several wild species and cultivated species have been utilized to improve the *G. hirsutum* genotypes and bring about both quantitative and qualitative changes in the commercial cultivars [3]. For example, introgression of *G. hirsutum* genes into *G. arboreum* genotype has been successfully attempted at Parphani and Dharwad centres. Similarly, *G. anomalum* genes have been introgressed into *G. arboreum* at Akola. In the same way, *G. aridum* has been successfully utilized in the development of new source of cytoplasmic male sterile lines at Akola and Coimbatore [3].

The germplasm accessions assembled from several parts of the world have also been utilized in India. For instance, Hybrid 4 was developed using the American Nectariless accession. The *G. harknesii* cytoplasm conferring male sterility in *G. hirsutum* genotypes and the restorer genes for *G. harknesii* conferring fertility has been successfully transferred to Indian genotypes and they were utilized for development of cotton hybrids such as PKV Hyb-3. Likewise, *G. aridum* cytoplasm was also utilized to diversify the cytoplasmic male sterility source in several hybrids. Development of varieties such as Deviraj and Devitej (derived from *G. arboreum* and *G. herbaceum*) and MCU5 (derived from *G. hirsutum* and *G. barbadense*) were the result of pioneering research on introgression of favourable alleles from the related species into the elite lines. Similarly, introgression of *G. arboreum* into *G. hirsutum* varieties has resulted in the development of new jassid resistant varieties in *G. hirsutum*. Introduction of *G. barbadense* germplasm in the country as well as their systematic evaluation resulted in the development and release of first *G. barbadense* variety Sujatha by a process of reselection from an Egyptian variety, Karnak in 1969 [3].

In upland cotton, *G. hirsutum*, variety MCU 5 VT resistant to Verticillum wilt was released from CICR, Coimbatore. In *G. arboreum* and *G. herbaceum*, all the varieties released after 1967 are resistant to Fusarium wilt. In *G. hirsutum*, some jassid resistant varieties (B 1007, SRT 1, Khandwa 2, DHY 286, PKV 081) and hybrids (PKV hy2 and NHH 44) have also been released.

Specific varieties and hybrids with wide adaptability have also been released from 1970 onwards. Examples of wide adaptable varieties are Bikaneri Narma, MCU 5, SRT 1 and LRA 5166. Variety Bikaneri Narma was developed in Punjab, which has later cultivated in Haryana, Rajasthan and Northern Madhya Pradesh due to its wide adaptability. By the same token, Variety SRT 1 was released initially for Gujarat; now it is also popular in Maharashtra and Madhya Pradesh. Similarly, varieties MCU 5 and LRA 5166 released for Tamil Nadu, now cultivated in Andhra Pradesh, Maharashtra and Madhya Pradesh by virtue of their wide adaptability. Hybrid H 4 was released for Gujarat state; because of its wide adaptation it spread to other states such as Maharashtra, Madhya Pradesh, Andhra Pradesh and Karnataka. Similarly, hybrid DCH 32 (Jayalaxmi) was released for Karnataka state, but due to its wide adaptability it spread to Tamil Nadu, Andhra Pradesh and Western Maharashtra.

The AICCIP has notified more than 220 cotton varieties and hybrids in 2004 that were released for commercial cultivation with different features such as short and medium duration, leaf curl virus disease resistance, jassid resistance, suitable for rainfed tracts, resistance to Verticillium wilt etc., On the other hand, during 2002, the AICCIP has recommended to de-notify 99 varieties and hybrids that are no longer under cultivation or that are inferior in fibre properties [3].

The problems that impede utilization of germplasm for breeding include photosensitivity, mismatching of blooming period, low fertility index, etc. There is a need for rapid screening of geographically diverse germplasm for useful traits such as low cost technology proposed at CICR, Nagpur for rapid evaluation of germplasm for photo-sensitivity [18]. Equally, genetical studies have been often limited mainly to yield contributing characters and fibre properties and a very little work has been reported on seed oil improvement in cotton. Nevertheless, wide range of genetic variability has been reported (15-33%) for seed oil content in global collection of in Indian germplasm collections [19].

In the recently conducted AICCIP meeting, the breeders are requested to submit two packets of 100 g seeds (in case of varieties) in addition to the number of locations finalized in the panel for long term storage of elite breeding materials. In the panel, detailed discussion was also held for promoting the entries from national trials to the zonal trials. So far, the entries are promoted on the basis of zonal mean to the corresponding zone. It is proposed to promote entries on the basis of 'agro-ecological subzone', henceforth. The draft proposal will be circulated among the breeders and based on the consensus the proposal will be submitted to ICAR, New Delhi for further directives. Detailed discussion was also held on formulating certain index based on seed cotton yield, lint yield, 2.5% span length and bundle strength for promoting the entries from national to zonal trials.

In India, various Transfer of Technology (TOT) programs in cotton have been implemented underlining the importance of problem solving, creating effective scientists and farmers linkage and transferring the latest cotton production technologies to the production line. 'Front Line Demonstration (FLD)' is one of the TOT programs which created remarkable impact on cotton production and facilitated excellent scientist-farmer linkage for the effective transfer of latest cotton protection technologies. In addition to this, the AICCIP is also actively involved in FLDs on improved technologies and organising Kisan Melas (Farmer's day) for effective and speedy dissemination of newer production technologies among farmers. During the year 2012-13, FLDs on cotton production technology and FLDs on cotton integrated pest management (IPM) were conducted by 13 AICCIP centres. The main emphasis was given to the demonstrations for enhancing the production of cotton in low productivity areas / problematic areas with improved package of practices. In addition, the cotton breeder seed production and implementation of "Special Component Plan for Scheduled Caste" and "Tribal Sub Plan for Scheduled Tribes" are also monitored through the AICCIP.

4. *Bt* cotton

The development and commercial cultivation of *Bt* cotton hybrid in 2002 is a revolutionary landmark in Indian agriculture after the green revolution during 1960s. With the introduction of *Bt* cotton in India, which confers resistance to key lepidopteron insect pests of cotton, there has been an incredible increase in the cotton production. India cultivated a record 11.0 million hectares of *Bt* cotton in 2013 with an adoption rate of 95% [14]. There is substantial evidence that the adoption of *Bt* cotton provides economic benefits from increased yields due to limited damage from the bollworm pest complex [American bollworm (*Helicoverpa armigera* Hubner) in particular and other bollworms such as spotted (*Earias vittella* Fab.), spiny (*E. insulana* Boisd.) and the pink (*Pectinophora gossypiella* Saunders), in general] and reducing costs through lower use levels of insecticide [15].

In point of fact, *Bt* cotton developed in India is a combination of transgenic and hybrid technologies. *G. hirsutum* represents 90% of the hybrid cotton in India and almost all the current *Bt* cotton hybrids are *G. hirsutum*. The embedded *Bt* gene acts as an *in situ* biological pesticide factory and hence avoid the need for any chemical spray for the suppression of the lepidopteron pests. In order to have maximum effect of *Bt* gene, the host genotype (one of the parent of the hybrid) chosen from the existing stock of hybrids that have a strong yield potential and popular acceptance (in terms of acreage) of its non-Bt version.

On the other hand, release and widespread usage of *Bt* cotton hybrid has resulted a specific bottleneck. The popular Indian cotton varieties such as LRA 5166, LRK 516, MCU 5, MCU 5 VT, SVPR 2, AKA 081, AKA 7, AKA 8, GCot 11, GCot 13, PA 225, RG 8, Sahana and Surabhi (to cite a few) that were cultivated even in the marginal or low-input supplied regions, have become almost extinct after the introduction of *Bt* cotton hybrids. Undeniably, a *Bt* version of these varieties would have been a benefit for resource-poor regions which cannot be provided by hybrids since they require higher inputs and costlier management practices. Further, fortifying such varieites with drought resistance and fibre quality traits has immense benefits for the Indian farmers, since > 60% of the cotton cultivation is under rainfed conditions (where water availability to the crop growth is always uncertain and water stress can occur anytime during the cropping period that greatly affects the fibre yield and quality). The best national average yield of 17000 Kg seed cotton/ha (with almost the whole crop area being under *Bt* hybrids), seems to be insignificance when many countries harvest about 50000–60000 Kg/ha seed cotton as national average through straight varieties [15]. Thus, there is a great scope for genetic improvement of cotton especially the elite varieties, by utilizing the available rich germplasm.

5. Cotton germplasm in private sectors

There are several national and multinational seed companies in India that focus on breeding, development and commercialization of cotton hybrids, including Bt and other beneficial genes. The cotton plant has been transformed with variety of genes expressing different traits such as insect resistance, herbicide tolerance, drought tolerance, improved fibre quality etc. However, only insect resistance genes have been approved, either individually and/or stacked in various combinations, for commercial cultivation. Each private sector has their own germplasm and breeding materials (since they are under propriety right protection, such breeding materials have not been disclosed to the public). Some private sectors that are actively involved in Bt cotton hybrid development and/or cotton research in India include Mahyco, Rasi Seeds, Nuziveedu Seeds, Ganga Kaveri Seeds, Ajeet Seeds, Tulasi Seeds, Prabhat Seeds, Vikram Seeds, Nath Seeds, Vibha Seeds, Bioseeds, Nandi Seeds, Bayer Crop Science, JK Seeds, Dow Agrosciences, Krishidhan seeds, Zurai Seeds, Navkar Hybrids and DuPont India.

6. Genetic diversity analysis of Indian cotton germplasm

It is increasingly believed that the reason for recent stagnation and/or decline in cotton yield and fibre quality in India was mainly due to declining trend in genetic diversity of released cultivars and breeding stocks, emergence of new menace (such as minor pests become major pests) and a greater than before exposure to environmental hassles such as drought, heat, salinity etc., Research on genetic diversity of cotton cultivars and some of its related species conducted in several global laboratories including India using a range of molecular markers that has clearly shown the narrowness of genetic base of cotton cultivars.

For example, a set of 96 core accessions were screened using the informative polymorphic markers at the CICR, Nagpur. Combination of different type of 46 markers such as simple sequence repeats (SSR), sequence related amplified polymorphism (SRAP) and randomly amplified polymorphic DNA (RAPD) markers were employed to assess the genetic diversity. It was concluded that the available diversity was low and more informative markers are required to understand the genetic diversity among the core accessions [6].

Similarly, the genetic divergence among 19 elite lines of cotton that are more frequently employed in TNAU cotton breeding programs was investigated using morphological (multivariate Mahalanobis D2 statistics) and SSR markers [20]. This study grouped all the 19 *Gossypium* accessions into two main cluster *i.e.*, *G. hirsutum* and *G. barbadense* lines and there were narrow inter-specific genetic diversity. In an another study [21], thirty *G. barbadense* accessions and five *G. hirsutum* cultivars belonging to different institutes of India were genotyped with 88 SSR markers and found to be closely related within the species. Genetic diversity amongst 91 upland cotton accessions (50 maintainer, 'B' and 41 restorer 'R' lines) and three wild species such as *G. aridum, G. thurberi* and *G. anomalum* was analysed using SSR and RAPD markers and also revealed a higher level of genetic relatedness [22].

It should be noted that the low genetic diversity, as mentioned above, was not due to the limitation of marker technology since it was invariably concluded in numerous studies that molecular markers has immense potential in germplasm characterization. For example, all the wild species available in the CICR were efficiently characterized by using simple RAPD and inter simple sequence repeats (ISSR) markers. Further, eleven cotton hybrids along with their parents and 13 cultivars were characterized at the molecular level and specific markers were identified for testing genetic purity. Sequence characterized amplified region (SCAR) markers and specific primers were also designed to identify three cotton hybrids such as Savitha, Shruthi and Surya [6]. Thus, the narrow genetic diversity present in the current cultivars/

hybrids is obviously a great bottleneck for cotton breeding and needs to be widened to meet the demands of both farmers and textile industries.

7. Mapping populations for genetic dissection of agronomic and fibre quality traits

Mapping populations, mainly recombinant inbred lines (RILS), have been developed to genetically dissect the agronomic and fibre quality traits in cotton at several Indian institutes including:

a. TNAU, Coimbatore (RILs derived from 1) *G. hirsutum* var. KC3 and *G. barbadense* var. Suvin 2) *G. hirsutum* var. MCU5 and *G. hirsutum* var. TCH1218 and 3) *G. hirsutum* var. SVPR2 and *G. barbadense* var. Suvin),

b. CICR, Nagpur (RILs derived from 1) *G. arboreum* var. Kwan-3 and *G. herbaceum* var. Jayadhar and 2) *G. hirsutum* var. IRH 1-4-4 and *G. hirsutum* var. AKG 2/50),

c. UAS, Dharwad (RILs derived from 1) *G. hirsutum* var. DS-28 and *G. barbadense* var. SB YF425 and 2) *G. herbaceum* var. jayadhar and *G. arboreum* var. DLSA17) and

d. IARI, New Delhi (RILs derived from *G. hirsutum* var. P56_4 and *G. hirsutum* var. RS 2013).

The above said mapping populations are considered as valuable resources for identification of molecular markers linked to key fibre quality traits such as fibre length and strength besides drought tolerance and cotton leaf curl virus disease resistance traits. The major constraint that hampers the precise and early identification of tightly linked markers is the availability of informative polymorphic markers (due to narrow genetic diversity exist in the above mentioned parents; see above) which are essential for the construction of high-resolution genetic map. To overcome this difficulty, a co-ordinated effort is being formulated with a grateful financial support from Department of Biotechnology, Government of India to constitute a network project on developing saturated genetic linkage maps of cotton using different mapping populations available in India and single nucleotide polymorphism (SNP) chip developed at National Botanical Research Institute, Lucknow (Dr. Samir Sawant, personal communication). Development of such saturated genetic linkage map will eventually be utilized for quantitative trait loci (QTL) identification of cotton fibre yield and quality traits.

Among the different types of mapping population, development and employment of RILs is being pursued in selected cotton institutes including TNAU to utilize donor cotton breeding materials for genetic analysis of the desirable characters (see below). Selected superior recombinant line shall be used in enhancement of genetic stocks through molecular breeding and development of more productive and eco-friendly new varieties/hybrids tailored to fit into the future and existing cropping systems.

At TNAU, Coimbatore evolution of new cotton varieties with drought tolerance, jassid resistance and improved fibre quality traits is the major breeding objective. In particular, there is a need to develop ideotype suitable for rainfed cultivation since large cotton cultivating area is under drought conditions. Seed cotton yield under water stress is determined by a combination of factors: boll number, boll size, seed number per boll, and fibre/seed. Thus the main features of proposed ideotypes for rainfed cultivation includes, earliness (135-165 days), fewer small and thick leaves, compact and short plant architecture, moderately indeterminate habit, sparse hairiness, medium to big boll size, synchronous boll development, high response to nutrients, tolerance to water stress and tolerance to insects and diseases. The RILs derived from 1) MCU 5 and TCH 1218, 2) SVPR 2 and Suvin and 3) KC 3 and Suvin were evaluated with three different water regimes (irrigated control, managed water stress (by withholding irrigation during flowering phase) and rainfed conditions) at several locations of Tamil Nadu (including TNAU, Coimbatore, Cotton Research Station, Veppanthattai, Regional Research Station, Arupukottai and Maize Research Station, Vagarai) for drought tolerance and fibre quality traits. Linkage map was constructed and used for QTL analysis of fibre quality traits under water stress environment (Boopathi et al; under preparation). The important outcome of these evaluation trials (for above said ideotype characters), is identification of promising lines of mapping populations that were shown superior fibre yield and quality traits under water stress conditions. Such lines have been proposed for further evaluation to release as varieties that are suitable for rainfed cultivation.

In another study, we are trying to identify the QTLs linked to jassid tolerance in cotton using a RILs derived from 1) KC 2 and Suvin and 2) MCU 5 and Suvin. *G. hirsutum* cultivar KC 2 and MCU5 had shown tolerance to jassid [23] but with relatively poor fibre quality. On the other hand, the *G. barbadense* cultivar, Suvin, and *G. hirsutum* cultivar MCU 5 was vulnerable to jassid attack; however, they registered better fibre quality traits with good yield. Based on the variability studies of different leaf anatomical features, diversity, correlation and path coefficient analysis conducted at TNAU, Coimbatore, the following conclusion were made to explain jassid tolerance in cotton: i) pubescent nature indicates jassid tolerance ii) lower palisade cells in leaf lamina act as physical barrier for feeding and oviposition iii) thicker laminar coupled with absence of pubescence or lower palisade depicts susceptibility, but with them confers resistance to jassid and iv) higher cortex cell density is indicative of resistance [24, 25]. Hence, RILs that are developed from both of these interspecific and intraspecific crosses are being used for genetic mapping of jassid tolerance in cotton. In a parallel study, two different RILs developed from MCU 5 and TCH 1218 and P 56-4 and RS 2013 at TNAU, Coimbatore and IARI, New Delhi, respectively were evaluated at four different national partner institutes. Preliminary studies have identified several number of major QTLs linked to fibre yield and quality traits and they are being fine mapped using SNPs.

8. Coloured cotton

The vast majority of cotton grown commercially in the world, including India, has white lint, but recently there is a growing interest in coloured linted cotton. During the process of bleaching and dyeing of white lint cotton to impart colours, dyeing and textile units regularly use several toxic chemicals including heavy metal. The water from these units is a main source of pollution in drinking water, soil and environment. Many of these chemicals are carcinogenic and can cause allergies, skin rashes and other related health problems to human beings. Hence, it is preferred to have garments made from natural coloured cotton which is free from the dangerous textile chemicals. This has provoked many cotton workers into developing eco-friendly coloured cotton and has led to the revival of growing naturally coloured cotton. Further, coloured cotton cultivation should also be encouraged since it possesses resistances to many pests, diseases, drought and salinity [26]. In India, coloured cotton can be cultivated in Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra and Orissa. Khadi and Village Industries Commission have experimented producing dress material using coloured cotton. The Maharashtra Hybrid Seeds Company (Mahyco), Mumbai, has initiated coloured cotton-seed production. However, the share of the colour cotton to the total Indian cotton production is very negligible (less than 5000 tonnes).

Up to the middle of the 20th Century, coloured cotton cultivars *Cocanada 1* and *2* were commercially cultivated in Andhra Pradesh and exported to Japan. Similarly, cotton with black, brown, creamy white and khaki linted types were grown in Assam. *Kumta* in Karnataka was the home for *G. herbaceum* with dull white colour. Interestingly, globally acclaimed *Dacca muslin* was made from white and colour linted *G. arboreum* [27]. However, the main disadvantage of coloured cotton is its lower yield, shorter staple length, weaker fibre strength and undesirable micronaire value when compared with white linted ones, limiting its commercial cultivation and utilization [28].

Because of the advancement of spinning and textile processing technologies, there is a need for the production of coloured cotton combining high yield and superior fibre qualities. The F_1s obtained by crossing brown coloured and white linted lines are intermediate between the two parents for colour intensity and technological properties. Significant numbers of colour cotton genotypes are being maintained in India at CICR, Nagpur, UAS-Dharwad and TNAU, Coimbatore. Nearly 40 colour linted cotton germplasm accessions are being maintained at National Cotton Gene Bank, CICR, Nagpur. Scientists at the CICR laboratories and Cotton Research Station at Khandwa in Madhya Pradesh, University of Agricultural Sciences at Dharwad, Karnataka and Panjabrao Krishi Vidyapeeth, Akola, Maharashtra are investigating the agronomic, economic, and technical attributes of these strains for suitable hybrid production. Such studies have resulted in the identification of six cultures with desirable properties such as moderate resistance to pests, large boll size, and good fibre qualities with shades of brown and green. Studies at UAS, Dharwad indicated that colour development in the fibre occurs between 30 and 40 days after boll formation. A collection of 11 coloured cotton *G. hirsutum* genotypes (Higginbotham, Parbhani American, Brymer brown, Hirsutum Tashkent, Lousiana brown, Nankeen brown, Algerian brown, Russian brown, Red 5–7, Arkansas green and Texas green) and four white linted genotypes (MCU 5, 7, 9 and 12) were evaluated by RAPD markers at TNAU, Coimbatore, India. Cluster analysis showed clear-cut separation of the colour and white lint genotypes [29]. It has been recognized in several occasions that exploitation of heterosis might be an effective method for improvement in yield and fibre properties in coloured cotton.

9. Future perspectives

In India, there is a large scope for cotton genetic improvement for value added traits: an example is cotton for floor coverings. Currently, cotton contributes less than 2% of the fibres used in floor coverings, although this industry represents the largest single end-user of fibres in today's market. What is needed to fulfill this niche in the marketplace is to develop cotton fibres that have (1) more flame resistance to meet strict government standards (2) longer with reduced short fibre content to prevent shredding and (3) improved resiliency. It is also imperative to genetically improve the cotton fibre properties for other value added properties such as improved white brightness, increased postharvest properties such as moisture uptake, dye uptake, binding and/or retention and introduction of novel properties such as naturally coloured fibres and antimicrobial fibres for medical and pharmaceutical use.

Physical and chemical mutagenesis provides a powerful alternative to natural, polygenic variation for identifying functional pathways and complex disease genes and more importantly to generate novel cultivars with improved agronomic traits. Though there were some attempts in India, by and large, physical and chemical mutagenesis has not been utilized extensively to create new genetic variation.

The utilization of available germplasm in the national cotton gene bank can be further enhanced by adding the most suitable genetic stocks that can be procured from various international sources. Such activity will be useful in the development of breeding lines by introgressing beneficial alleles from the wild species, races and derivatives. Although elite x elite crosses are typical of traditional plant breeding, interspecific crosses are rarely used in cotton breeding because of numerous barriers. The finding that the *G. hirsutum* allele is favourable at some loci and the *G. barbadense* allele at other loci shows that recombination of favourable alleles from each of these species may form novel genotypes than either of the parental species. Similarly, the genomic exploration of other accessions of these species or other wild tetraploid cottons (*G. tomentosum*, *G. darwinii*, and *G. mustelinum*), maintained at national cotton gene bank could yield additional valuable alleles.

The most important agronomic traits such as biotic and abiotic stress tolerance, plant development and consumer quality aspects are genetically and physiologically complex. Moreover, because of the polyploid nature of cotton, breeding for such traits is time consuming and difficult. Further, the paucity of information about genes that control important traits and the need for more extensive usage of diverse germplasm hinder the genetic improvement of cotton. The rapidly expanding knowledge on gene function and the availability of whole genome structural features of cotton is expected to offer new perspectives to solve these complex problems and future cotton genetic improvement strategy should integrate such knowledge in the breeding program. Taking up of multi-population analyses (such as NAM, MAGIC, four-way cross, etc.) can unambiguously resolve several issues in QTL models and tests of epistatic interactions of QTL with the genetic background and environment.

Currently, the transgenic approach is feasible to engineer traits that are controlled by one or a few major genes. However, it is not a panacea for all the problems. Quantitative traits like yield

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are not easily amenable to improvement through transformation. Further, traits that can be routinely modified via conventional breeding need not be targeted for transformation. Availability of molecular markers to track genes controlling complex traits has further reduced the need for transgenic approach to crop improvement. This, however, does not mean that the transgenic approach is unimportant. Since genes can be sourced from any organism for cotton transformation, novel traits can be engineered with ease. Therefore, from a practical viewpoint, deficiencies that severely limit crop production and for which conventional approaches are inadequate, should be accorded high priority for transgenic improvement. At present, almost all of the Indian cotton transgenic technology and products are in private domain. Hence, there is a general worry that the transgenic crops are being promoted solely with profit motive and not for the good of the public. Thus the opposition to transgenic crops is not only on account of biosafety but also due to IPR, ethical, social, economic and moral issues. For technology to progress and reach the farmers, both public and private investments will be essential.

10. Conclusion

Foregoing section highlighted there are many challenges faced by Indian cotton scientists in creating the next generation of designer cotton plants. Fundamental research is still needed to elucidate biochemical and signalling pathways, as well as acquiring a better understanding of the underlying mechanisms that regulate gene expression in cotton. Further, quick and reproducible protocols for rapid screening of germplasm for biotic and abiotic stress resistance, breeding for drought tolerance, naturally coloured cotton, breeding for cotton varieties that suitable for mechanization and exploiting the genetic potential of wild species require urgent attention.

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