Chapter 4

Cotton Germplasm in India — New Trends

S.S. Narayanan, Parchuri Vidyasagar and
K. Srinivasu Babu

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/58622

1. Introduction

Cotton has played a great role in the global and Indian economies since immemorial time. The antiquity of cotton in the Indian subcontinent has been traced to the 4th millennium BC. The fabrics dated approximately 3000 BC, recovered from the Mohenjo-Daro excavations in Sind (Pakistan), were identified to have originated from cotton plants. The close relatedness of those old fabrics to the *Gossypium arboreum* species was reported by Sundaram and his colleagues [1, 2]. The lint-bearing species of the genus *Gossypium* L. are four, out of which the diploid (2n=26) species *Gossypium arboreum* L. and *G. herbaceum* L. are indigenous in Asia and Africa. The history of introduction of the New World cottons (allo-tetraploid species of *G. hirsutum* L. and *G. barbadense* L. with 2n=52) into India dates back to the 18th century AD [3-5]. By the last decade of the 20th century, India had gained a leading position in the global cotton statistics with the largest cropped area of 8.9 million ha in 1996-97, growing the most diverse cultivars in terms of botanical species and composition, producing the widest range of cotton fiber quality suitable for spinning 6's to 120's counts yarn, and supporting the largest agro-based national industry of the country [2, 6].

Cotton is grown globally on an average in about 33-35 million hectares annually representing less than 2.5% of the world's arable land [7], under a great diversity of agro-climatic conditions and widely varied farming practices. Cotton is reported to be grown in more than 100 countries being an important cash crop for the farmers and having great influence on the economy of such countries [4]. More than 120 million family units are engaged directly in cotton production in the world and about 350 million people are estimated to work in the wider cotton industry each year [8]. The most prominent cotton growing countries include Peoples Republic of China, India, USA, Pakistan, Uzbekistan, Tajikistan, Mexico, Brazil, Turkey, Egypt, Sudan, Australia, some African states, Israel, etc., [9].

There are four cultivated species of *Gossypium* Linn., grown for their fibre and also the seed and its by-products. In the world, *G. hirsutum* cotton is predominant with 92-93% area and production, *G. barbadense* is grown for nearly 4-5% and the diploid cottons *G. arboreum* and *G. herbaceum* accounted for less than 2 per cent [4, 10].

The spinnable fibre (lint) is the primary product for growing cotton for textile use. For each kilogram of lint produced, it also results in output of 1.4 to 1.6 kilograms of cottonseed. The estimated recent annual production of cotton fibre in the world is around 25 to 26 million metric tons of lint roughly valued at US$ 40-42 billion [7]. Cotton is the most important natural fibre used in spinning to produce apparel, home furnishings and industrial products and represents about 35-40% of all fibres used in textiles.

As much as 50-55 million tons of cottonseed is produced worldwide annually in recent times valued at US$ 7-8billion [10]. Cotton has become an important oilseed in the world and can be fed as whole seed to dairy cattle (Ruminant animals) or crushed in oil mills to obtain oil, hulls, meal and linters. The oil is used for human consumption after special refining processes to remove the toxic gossypol. The hulls and meals are good sources of vegetable protein for animal and the linters are used as a chemical cellulose source for manufacturing various personal care products and in high quality paper (used for currency printing in USA and EU) [11]. All these add value to cottonseed at each type of product and processing. Cotton has a significant role in meeting essential needs of clothing, besides food and feed and with a projected 9 billion human population and increase in animal production and the global textile fibre requirements projected at 180 million metric tons, the share of cotton should be increased to 40-50 million metric tons by 2050 [8]. Cotton area in India has increased significantly after the transgenic cotton was introduced in 2002-03 and over 90 per cent of the cotton grown is represented by *Gossypium hirsutum* as *G. hirsutum* x *G. hirsutum* hybrids with Bollgard-II (BG-II) type (Cry1Ac+Cry2Ab) and a small percentage as Bollgard-I (BG-I) with Cry1Ac gene. All the cotton hybrids sold in India are proprietary hybrids of different seed companies with varied parents that are not disclosed due to the proprietary nature of the hybrids and hence it is not possible to know the parents / germplasm used.

In this chapter, the information pertaining to germplasm history, contents and location of germplasm resource, funding sources, sharing within India, characterization, evaluation and utilization of germplasm, data bases, novel trends and perspectives and conclusions have been presented.

2. History of cotton germplasm in India

In India, the collection and conservation of plant genetic resources (PGR) of crop species for utilization in crop improvement programmes were initiated with the establishment of the Imperial Agricultural Research Institute in 1905 at Pusa village, Darbhanga District, Bengal (now in Bihar) state. This institute was shifted to New Delhi in 1936 and later in 1947, was renamed the Indian Agricultural Research Institute (IARI). The early conservation efforts of PGR involved frequent multiplication and storage of seeds of crops by the breeders in the

Botany Division of the Institute [12]. To strengthen these efforts, a unit was set up for the assembly of global germplasm in the division in 1941, which was upgraded as the Division of Plant introduction in 1961. The Plant Introduction Division of IARI provided the necessary impetus and leadership at the national level, particularly for the assembly of PGR through introduction from different parts of the world and their subsequent conservation. The establishment of crop(s) based research institutes further extended and strengthened these efforts. The Central Rice Research Institute, Cuttack was established in 1946. Isolated efforts were also being made by the researchers in the State Department of Agriculture, which got a boost with the establishment of the State Agricultural Universities (SAUs). Govind Ballabh Pant University of Agriculture and Technology, the first SAU, came into being in 1960 [13].

Crop improvement research, including PGR management was greatly strengthened and focused with the establishment of multidisciplinary, multicenter "All India Co-ordinated Crop Improvement Projects" starting with that for maize germplasm set up in 1957. The project had coordinated research centres mostly in SAUs and Indian Council of Agricultural Research (ICAR) institutes located in important crop growing areas. Presently, there are 40 multi-crop or single crop-based institutes, project directorates and national research centres, 37 coordinated projects and 31 SAUs. The All India Coordinated Cotton Improvement Project (AICCIP) was established in 1967 with headquarters at Coimbatore, while the Central Institute for Cotton Research (CICR) with headquarters at Nagpur was established in 1976 simultaneously with the CICR Regional Station for South zone at Coimbatore (including AICCIP headquarters), while the CICR Regional Station for the north zone at Sirsa (Haryana State) came into existence by annexing the IARI Regional Station at Sirsa in 1984. The germplasm accessions available at all the cotton breeding stations of the state agricultural university centres all over the country were collected by forming a national germplasm advisory committee at CICR and the collections were also augmented by exchange from other countries, by germplasm surveys and by accessing the elite breeding material available from time to time at various SAU cotton breeding stations. By periodical evaluation, duplicate germplasm accessions were eliminated by growing in the fields of the CICR and its regional stations. The germplasm purification was followed by characterization for 76 characters as per Germplasm Index Card, catalogued, data computerized and seeds conserved in medium term and short term cold storage at CICR and long term storage at the NBPGR New Delhi by depositing selfed (self-fertilized) seeds. Working collections were constituted in all the four cultivated species germplasm and made available to Indian institutions for breeders' use in crop improvement. Thus CICR functioned as "The National Gene Bank of Cotton for India".

These projects, ICAR institutes and SAUs maintained and conserved working collections of germplasm of different crops through frequent seed regeneration and storage under ambient conditions. For example, the Central Rice Research Institute, Cuttack and Indira Gandhi Agricultural University, Raipur conserved rice genetic resources; the "All India Co-ordinated Maize Improvement Project" and the "All India Co-ordinated Wheat Improvement Project", with the headquarters at IARI, maintained maize and wheat germplasm, respectively. The centres of coordinated projects supported these efforts across the country.

At the national level, the ICAR is responsible for research, initial transfer of technology in agriculture and policies related thereto (including PGR management). The ICAR upgraded the Plant Introduction Division, IARI in 1976 to the status of an institute, the National Bureau of Plant Introduction and later, in 1977, renamed it as the National Bureau of Plant Genetic Resources (NBPGR). The NBPGR has the mandate to manage PGR including collection, introduction, exchange, quarantine, evaluation, conservation and use. Thus, NBPGR, under the umbrella of ICAR, functions as the nodal agency for PGR management and closely collaborates with ICAR institutes and SAUs for PGR management, particularly evaluation, characterization and utilization [13].

2.1. Changing species composition

In India, cotton is grown under widely varying agro-climatic conditions represented by regions falling 8°-32°N latitude, 70°-80° E longitude, elevation range of 0-950 meters and annual rainfall range of 250-1500 mm. Cotton has been cultivated since time immemorial in India. Cotton growing, types of cotton grown and cotton textiles produced in Indian subcontinent have earned global fame for over 5000 years. Until the 17th century, India was growing only the diploid (2n=26) cultivated cottons (also referred to as *Desi* cottons) *Gossypium arboreum* L. and *G. herbaceum* L. and the area under these cottons was as much as 95% of the total area of 4.4 million hectares of cotton at the time of partition of India in 1947. Although attempts were made from about 1750s to introduce the allo-tetraploid (2n=52) species of *G. hirsutum* L. (American Upland cotton) and *G. barbadense* L. (Egyptian, Pima and Sea Island cottons), the area under the Upland cottons reached only about 2-3 per cent by 1947-48 in the country. Gradual breeding and extension efforts resulted in increase in area under the Upland cotton replacing the *desi* (diploid cultivated) cottons on a large scale by 1970s and after the introduction of Bt-transgenic cottons of *G. hirsutum* x *G. hirsutum* hybrids in 2002-03, the species composition in India changed drastically. Egyptian cotton *G. barbadense* cultivars suitable for Indian ecologies especially in South India were released in 1968-70s, but the area coverage was small [10].

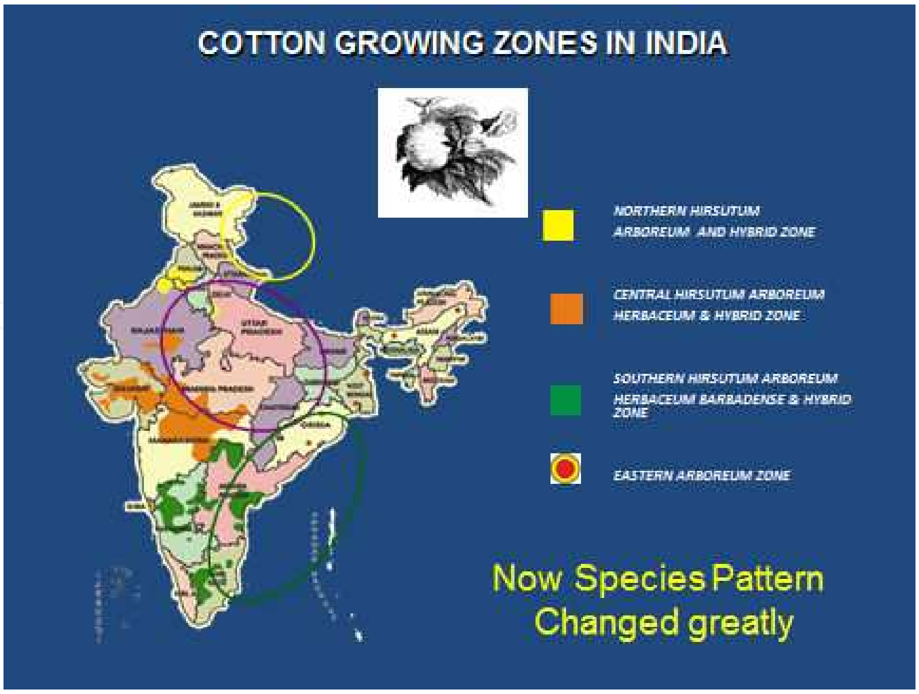
From cultivation of purebred varieties of various species, it changed from 1970s after the H x H and H x B and even diploid *herbaceum* x *arboreum* (*desi*) cotton hybrids were released for cultivation and both hybrids and pure bred varieties were grown commercially. After the introduction of Bt-transgenic cottons as H x H and to a small extent as H x B hybrids, significant change occurred marginalizing the cultivation of diploid cultivated species cottons. Cottons grown today represents mostly superior medium and long staple cottons all over the country. The short desi (diploid species) cotton production was affected drastically due to large scale replacement with *hirsutum* x *hirsutum* cotton hybrids with Bt-gene(s). Extra-long staple cotton production also dwindled largely due to replacement with *hirsutum* x *hirsutum* Bt-cotton hybrids with superior medium and long staple, apart from virtual decline in area under 'Suvin', the only ELS *G. barbadense* cultivar available and also decline in the ELS *hirsutum* x *barbadense* F_1 hybrids on account of maintenance of seed quality and fibre quality problems especially of the *barbadense* parents. MCU5 cotton of the Upland type with superior long staple also gradually declined due to encroachment of its area by the Bt-cotton hybrids.

http://dx.doi.org/10.5772/58622

The current total area under cotton is estimated as 11.7 million hectares and the output as 6.46 million metric tons of lint (along with estimated 13 million tons of cottonseed) in 2013-2014 [10]. The trend of change in species composition is indicated in Table 1 and Figure 1.

Species	1947-48		1989-90		2013-14	
	Area M ha	Production MMT	Area M ha	Production MMT	Area M ha	Production MMT
Total of all 4 cultivated species	4.40	0.39 MMT	7.50.	2.17	11.70.	6.46
G. hirsutum (H)	0.133	0.0273	3.15	0.998	10.647	6.266
G. barbadense (B)	-	-	0.025	insignificant	0.001	insignificant
G. arboreum (A)	2.86	0.253	1.275	0.217	1.17	0.129
G. herbaceum (h)	1.408	o.109	0.975	0.130	<0.585	0.0646
Hybrid cotton (Hybrid cotton era from 1970)All hybrids	-	-	2.10	0.825	-	-
hirsutum x hirsutum Hybrid cotton with Bt-gene(s)	-	-	-	-	10.647	6.266
hirsutum x barbadense hybrids with Bt-gene(s)	-	-	-	-	small	small

Table 1. Species composition / contribution in India to cotton area and production



(Adopted from Dr. V. Santhanam, WCRC-5 Mumbai, 2011)

Figure 1. The current species composition of cotton and distribution in India

2.2. Germplasm needs for India's cotton improvement

Germplasm demand depends on various considerations and criteria. Primarily, it depends on the predominant species grown, genetic constitution of the cultivar / hybrid developed for large scale cultivation, the fibre quality requirements of the textile industry and export needs and incidentally various byproduct utility potential. The future attention of the breeders may be more towards the improvement of the *G. hirsutum* cotton because of the changed species composition involving more than 90 per cent area under cultivation of *G. hirsutum* cotton. Some special interest will be shown to the utilization of *G. barbadense* germplasm in cotton improvement because of the need to develop superior cultivars of *G. barbadense* with extra-long staple coupled with better adaptation to Indian conditions and also in the exploitation of the potential of the *G. hirsutum* x *G. barbadense* F_1 commercial hybrids to develop ELS cotton hybrids with high yield potential. Further, the private seed companies holding a major stake in seed business have great role to play in meeting the needs for high quality seeds of superior varieties of the predominant cultivated species preferred by the farmers. The major breeding goals in cotton are based on conventional and changing cropping practices and industry requirements of the 21^{st} century are as follows:

Wide adaptation: agronomic and ecological stability including-Areas of cultivation and their agro-climatic conditions, soil fertility, temperature both day and night temperatures, rainfall characteristics (onset, duration, intensity and occurrence characteristics), adaptation and other factors (like adaptation to various abiotic stresses such as late sowings, droughts, excess rainfall at critical phases of crop growth and major weather aberrations).

Response to advanced production technologies: this will include higher fertilizer use, higher planting densities, mechanization of cultivation practices with insect resistant cotton, chemical herbicide use for weed management and other practices like constraints management, manual and machine picking of cotton, double cropping patterns, continuous improvement in yield per hectare).

Resistance to biotic and abiotic stresses: this includes resistance/tolerance to various kinds of pest and disease reactions and abiotic factors causing serious recurring yield losses and adverse effects on fibre quality.

Cotton requirements for the textile industry: the total quantitative demands of national textile consumption of cotton, extra-factory consumption and export needs (including qualitative needs in terms of share of various staple types like short staple, medium staple, superior medium, long staple and extra-long staple and fibre quality parameters consistent with the desired levels for each of above staple categories besides for various spinning systems).

Improving the utility of cottonseeds: important aspects include elimination of gossypol, increased oil content and improved fatty acid profiles of the oil and protein in seed etc., to improve the utility value of seed and its nutritional qualities for food and feed.

Specialty cotton requirements: these are based on considerations for production of organic cotton and naturally colour-linted cottons with appreciable fibre quality parameters for spinning and weaving, although the market requirement is low at less than 1% of the global production of cotton at present.

Considerations for newer breeding goals: this is specially for India and elsewhere in the world for the demands of the 21st century including suitability of plant architecture for higher plant densities with high yield per hectare for machine harvesting, tolerance to drought and adverse weather situations related to emerging climate change patterns, resistance to sucking pests, mealy bugs and whitefly induced cotton leaf curl virus disease and reducing the duration of cotton for less water use and fitment into double cropping patterns etc. [4,14,15,10,16].

3. Genetic resources of cotton — Content and location

The details pertaining to all cotton genetic resource holdings and their locations, evaluations and conservation are presented below:

3.1. Wild species and related stocks

Cotton plant belongs to the family *Malvaceae* and genus *Gossypium* L., which comprises about 50 species, 45 of which are diploid (2n=2x=26) and the remaining 5 being allotetraploid (2n=4x=52) and whose geographical distribution spans the tropical and sub-tropical regions of the world [17]. The two 'A' genome diploid and two 'AD' genome allotetraploid species are cultivated for their lint fibre. The four species in cultivation have their botanical and geographical races such as (*africanum, acerifolium, wightianum, persicum, and kuljianum under G. herbaceum; races indicum, bengalense, burmanicum, cernuum, sinense, and soudanense under G. arboreum; races latifolium, punctatum, morilli, yucatanense, marie-galante, palmeri and richmondii under G. hirsutum and races barbadense and brasiliense under G. barbadense* as described by Hutchinson, 1951 [3, 17] are available in distinct accessions of germplasm of cotton maintained in gene banks of CICR Nagpur and its regional station Coimbatore and certain other State Agricultural University Centres like UAS Dharwad, GAU Surat, TNAU etc. Intermediary germplasm-genetic stocks and breeding lines developed out of crosses between wild and cultivated species and between cultivated species have been integrated into the maintenance under germplasm for gene banks at CICR and State Agricultural University (SAU) centers and used for crop improvement programmes. The list of *Gossypium* species and those available in India is given in Table 2.

Genome	Species of *Gossypium*	(if available 'Yes')	Genome	Species of *Gossypium*	(if available 'Yes')
Diploid Species 2n = 2x = 26			**Diploid Species 2n = 2x = 26**		
A_1	*herbaceum* L.	Cultivation	K	*costulatum* Todaro	
A_2	*arboreum* L.	Cultivation			
B_1	*anomalum* W&P	Yes	(In C)	*populifolium* Mueller	
B_2	*triphyllum* Hochreutiner	Yes		*cunninghamii* Todaro	
B_3	*capitis viridis* Mauer	Yes		*pulchellum* Fryxell	

Genome	Species of *Gossypium*	(if available 'Yes')	Genome	Species of *Gossypium*	(if available 'Yes')
Diploid Species 2n = 2x = 26			**Diploid Species 2n = 2x = 26**		
?	*trifurcatum* Vollesen			*pilosum* Fryxell	
C_1	*sturtianum* Willis	Yes		*exiguum* Fryxell	
C_1-n	*nandewarense* Dereda	Yes		*nobile* Fryxell	
C_2	*robinsonii* Mueller			*rotundifolium* Fryxell	
D_1	*thurbei* Todaro	Yes		*enthyle* Fryxell	
D_{2-1}	*armourianum* Kearney	Yes		*londonderriense* Fryxell	
D_{2-2}	*harknessii* Brandigee	Yes		*marchantii* Fryxell	
D_3-d	*davidsonii* Kellog	Yes		*anapoides* Stewart	
D_3-k	*klotzschianum* Andersson	Yes			
D_4	*aridum* Skovsted	Yes			
D_5	*raimondii* Ulbrecht	Yes			
D_6	*gossypioides* Standley	Yes	**Allotetraploids 2n = 4x = 52**		
D_7	*lobatum* Gentry	Yes	$(AD)_1$	*hirsutum* Linn.	Cultivation
D_8	*trilobum* Skovsted	Yes	$(AD)_2$	*barbadense* Linn.	cultivation
D_9	*laxum* Phillips		$(AD)_3$	*tomentosum* Nuttal	Yes
D_{10}	*turneri* Fryxell		$(AD)_4$	*mustelinum* Masters	
D_{11}	*schwendimanii* Fryxell		$(AD)_5$	*darwinii* Watt.	yes
E_1	*stocksii* Masters	Yes	Note: In addition, 82 perennials, 141 land races *(G. arboreum and G. barbadense), 20* distinct *cernuum* race collections with big boll weight , up to 6.4g and 44.4% GOT are available; also 40 synthetic polyploids, 20 male sterile lines from Israel etc., GMS, TGMS and EGMS lines are also maintained at CICR.		
E_2	*somalense* Hutchinson	Yes			
E_3	*areysianum* Deflers				
E_4	*incanum* Hillcoat				
E?	*ellenbickii* Mauer				
E?	*bricchettii* Vollesen				
E?	*benadirense* Mattei				
F1	*longicalyx* Hutchinson & Lee	Yes			
G	*australe* Mueller	Yes			
G	*nelsonii* Fryxell				
G_1	*bickii* Prokhanov	Yes			

Table 2. Species of *Gossypium* and their availability in India (in cultivation or in Species Gardens):-Taxonomic classification of *Gossypium* L. species [18-22].

3.2. Genetic resources of cultivated cottons

The collections-accessions reportedly available mainly in the CICR Nagpur gene bank [or in its regional stations at Coimbatore especially for *G. barbadense* / Sirsa (limited to some diploid cotton accessions] have been described [23, 14, 24, 15]. The total cotton accessions available in India was reported as 7484 in *G. hirsutum*, 263 in *G. barbadense*, 1877 in *G. arboreum* and 530 in *G. herbaceum,* besides wild species and perennials [25]. Additional accessions of *G. hirsutum* and *G. barbadense* acquired after 2011 are to be documented after evaluation and added to the figures; similarly the germplasm additionally available after 2011 for the two diploid species of Asiatic cottons, *G. herbaceum* and *G. arboreum* also have to be incorporated in the total holdings after assessment and characterization. The details of the wild primary, secondary, and tertiary cotton (*Gossypium*) species and the cultivated tetraploid species maintained in several countries has been previously reported [26]. Similar materials of major gene pools including germplasm of the two cultivated tetraploid and the two cultivated diploid species maintained in India are presented in Table 3.

Species	Genome	Collection maintained at CICR Nagpur
Primary gene pool		
G. tomentosum Nuttal ex Seaman	AD_3	1
G. darwinii Watt	AD_5	1
Secondary gene pool		
G. herbaceum L.	A_1	given below
G. arboreum L.	A_2	given below
G. anomalum Wawra	B_1	1
G. triphyllum Hochreutiner	B_2	1
G. capitis viridis Mauer	B_3	1
G. barbosanum Phillips & Clement	B_3?	1
G. longicalyx Hutchinson & Lee	F_1	1
G. thurberi Todaro	D_1	1
G. trilobum (DC) Skovsted	D_8	1
G. davidsonii kellogg	D_2-d	1
G. klotschianum Andersson	D_2-k	1
G. armourianum Kearney	D_2-$_1$	2
G. harknessii Brandigee	D_2-$_2$	1
G. aridum Skovsted	D_4	1
G. lobatum H Gentry	D_7	1

Species	Genome	Collection maintained at CICR Nagpur
G. gossypioides (Ulbrich) Standley	D_5	1
G. raimondii Ulbrich	D_6	1
Tertiary gene pool		
G. sturtianum J.H Wills	C_1	1
G. stocksii Master	E_1	1
G. somalense Hutchinson	E_2	1
G. australe F. Mueller	G	2
G. bickii Prokanov	G_1	1
Cultivated tetraploid species		
G. hirsutum L.	AD_1	
Germplasm		7484
Cultivars		110
Land races/wild stocks		7
Cytogenetic stocks/mutants		32/1
Total		7633
G. barbadense L.	AD_2	
Germplasm		530
Cultivars		3
Land races / wild stocks		1/0
Total		534
Cultivated diploid species		
G. arboreum L.		
Germplasm and all other accessions		1877
G. herbaceum L.		
Germplasm and all other accessions		530

Table 3. Description of the wild primary, secondary, and tertiary cotton (*Gossypium*) species and the germplasm of cultivated cottons of the two cultivated tetraploid and two cultivated diploid cotton species maintained in India

3.3. Germplasm exploration and collection

The exploration of certain regions in India was carried out by the Germplasm Advisory Committee (GPAC) involving the CICR and the NBPGR in seven expeditions. The areas represented formerly predominant areas of Asiatic cotton cultivation in Southern and Central India, NE Hill regions with *cernuum* types of *G. arboreum* and some *G. hirsutum* cotton under the Malwa plateau in Central India representing distinct agro-climate, apart from perennial cottons grown as backyard cottons for house-hold use. Attributes of breeders' interest in the collections included closed boll types in *G. herbaceum* with storm proof nature, big bolls with >6g boll weight, high ginning and high seed number per boll in *G. arboreum* and cold resistance in *G. hirsutum*. The details of the surveys and collections made are given in Table 4.

Year	Organization	Funded by	Regions of expedition	Material collected	Characters observed
1977	CICR/NBPGR	ICAR	Assam and Meghalaya	*Cernuum* types of *G. arboreum*	High ginning, big long bolls, loculi retention after bursting
1978	CICR/GPAC	ICAR	Tinnies tract of Tamil Nadu	Diploid cultivated variants	Introgressed types of early introductions
1979	CICR/ GPAC/UAS/GAU	ICAR	Saurashtra region in Gujarat and Raichur area in Karnataka	*G. herbaceum* types and variants	Closed boll types, round boll, storm proof types
1981	CICR	ICAR	Malwa plateau of Madhya Pradesh	*G. hirsutum*	Local variants, cold resistance
1984	CICR/NBPGR	ICAR	Assam and Manipur	*G. arboreum* race *cernuum*	High seed number per boll, long big bolls, high ginning types
1986	NBPGR	ICAR	Gujarat western tract	*Desi* cotton material	Resistance to moisture stress, high yield potential
1987	NBPGR/CICR	ICAR	Assam regions	*Cernuum* types of *G. herbaceum*	Big boll, higher boll numbers, abiotic resistance

Table 4. Surveys and collections made by the CICR/NBPGR and their description

4. Funding sources for cotton germplasm activities

The Indian Council of Agricultural Research (ICAR), New Delhi is the main funding agency for all the germplasm related activities in cotton and the ICAR is an autonomous body under the Ministry of Agriculture and Department of Agricultural Research and Education (DARE) of the Government of India. The Central Institute for Cotton Research (CICR) Nagpur, the National Bureau of Plant Genetic Resources (NBPGR) New Delhi and also Central Institute for Research on Cotton Technology (CIRCOT), Mumbai are national level Institutes under the ICAR to take care of all cotton research related activities including germplasm related matters. The ICAR may seek collaboration with the FAO in germplasm exploration and collection activities as and when such activities are planned. The responsibility for cotton germplasm is mainly vested with the CICR. The CICR has played a pivotal role in germplasm acquisition, maintenance, evaluation and promoting utilization in breeding and other related researches.

India is probably the third richest country in general and in certain respects probably the richest in the world in its total holdings and diversity of cotton genetic resources including wild species, cultivated species and even certain perennial genotypes of cotton [15]. The National

Gene Bank of Cotton in India is located at the Central Institute for Cotton Research, Nagpur including its regional station at Coimbatore. The total collection represents almost entirely cultivated accessions of *G. hirsutum, G. barbadense, G. arboreum,* and *G. herbaceum*. In addition, the collection also consists of race stock accessions of each cultivated species, 26 wild species, and 32 synthetic introgressed derivatives.

High level of coordination is being achieved in germplasm exchange and utilization with the world level International Institute for Plant Genetic Resources and national level institutions (NBPGR, CICR, CIRCOT and SAUs), The availability of equipment and techniques for mass screening for several parameters in the laboratory, in the fields and glass houses, has made possible to generate precise data in various environments and enabled to have a new-look and re-look at the germplasm for various breeding and gene deployment strategies. It also helped to develop varieties and hybrids for meeting the demands of the farmers, the textiles industry for various end-uses and to overcome inter-fibre competition based on consumer preferences and the cottonseed utilization and biomass utilization industries. Now more information has been accumulated to improve cottonseed yield and quality profile useful for agro-based industrial exploitation. This is to meet human needs for edible oil, protein and cellulose to contribute to enhanced food and nutritional security and also develop various by-products for use as animal feed and further processing in ancillary industries [27, 10].

5. Sharing of germplasm resources

Sharing of germplasm may take place as per Government of India policies and based on inter-country government protocols and exchange programmes on mutual basis of agreements, if any. Within the country, the germplasm is readily available for public sector research institutions carrying out research on cotton and related activities.

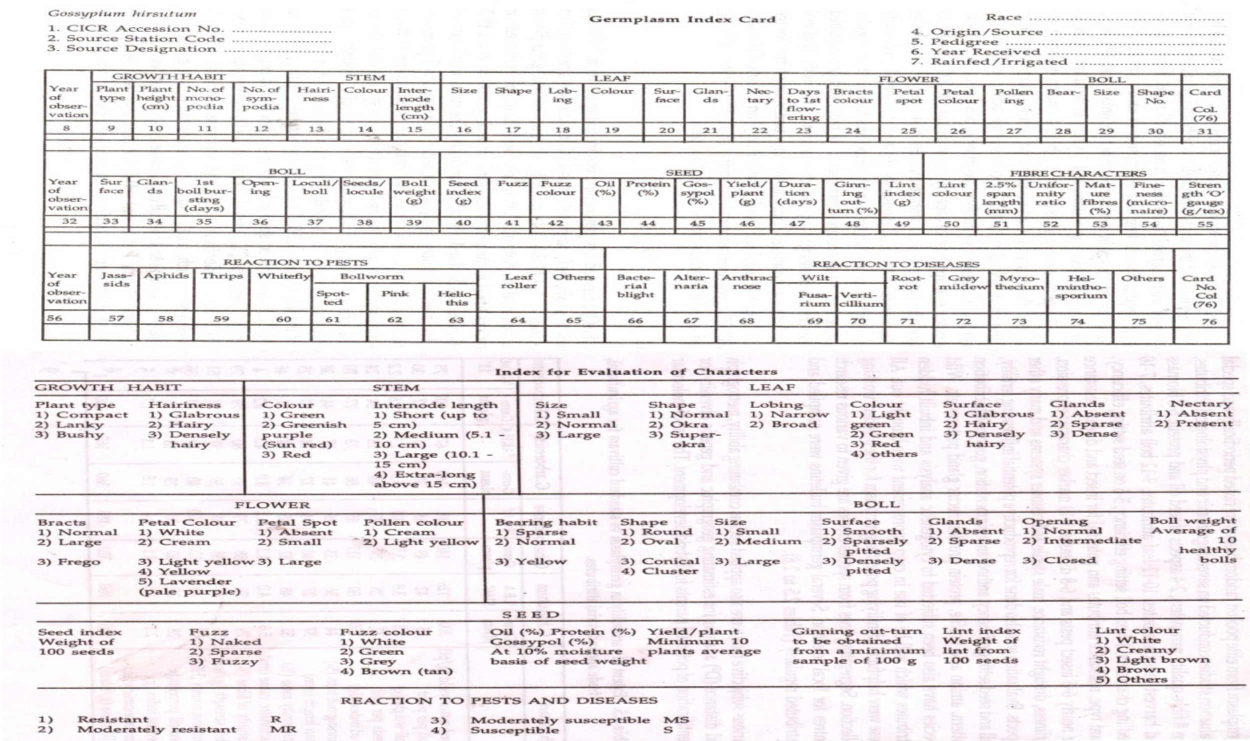
6. Characterization, evaluations and utilization

Based on the work done at the CICR in cooperation with the CIRCOT, NBPGR and SAU Centres over the past few decades, the various aspects have been presented below:

6.1. Germplasm Index Card (GIC)

A GIC was designed and distributed for use by cotton breeders all over India. The GIC was designed by the Central Institute for Cotton Research, Nagpur based on the recommendations of the National Germplasm Advisory Committee on Cotton constituted by the CICR under the Indian Council of Agricultural Research (ICAR). This card contains some 76 important characters of cotton plant and produce and is included in the Cotton Genetic Resources Catalogue published by the CICR in 1990 [23] It is based on the International Board for Plant Genetic Resources (IBPGR) model with suitable modifications and various characters, their descriptors and descriptor states for cotton for precise evaluation of genetic resources of cotton.

Common and standard procedures were also provided for recording observations with comparable uniformity over locations. Provision was made for recording data on all quality attributes of fibre (technological characters) as well as cottonseed and biomass, harvest index etc. (Figure 2).


Gossypium hirsutum

Germplasm Index Card

1. CICR Accession No. ....
2. Source Station Code ....
3. Source Designation ....

Race ....
4. Origin/Source ....
5. Pedigree ....
6. Year Received ....
7. Rainfed/Irrigated ....

	GROWTH HABIT				STEM			LEAF							FLOWER					BOLL			
Year of observation	Plant type	Plant height (cm)	No. of monopodia	No. of sympodia	Hairiness	Colour	Internode length (cm)	Size	Shape	Lobing	Colour	Surface	Glands	Nectary	Days to 1st flowering	Bracts colour	Petal spot	Petal colour	Pollen ing	Bear-	Size	Shape No.	Card Col. (76)
8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

	BOLL							SEED										FIBRE CHARACTERS					
Year of observation	Surface	Glands	1st boll bursting (days)	Opening	Loculi/boll	Seeds/locule	Boll weight (g)	Seed index (g)	Fuzz	Fuzz colour	Oil (%)	Protein (%)	Gossypol (%)	Yield/plant (g)	Duration (days)	Ginning out-turn (%)	Lint index (g)	Lint colour	2.5% span length (mm)	Uniformity ratio	Mature fibres (%)	Fineness (micronaire)	Strength 'O' gauge (g/tex)
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55

	REACTION TO PESTS									REACTION TO DISEASES										
					Bollworm								Wilt							
Year of observation	Jassids	Aphids	Thrips	Whitefly	Spotted	Pink	Heliothis	Leaf roller	Others	Bacterial blight	Alternaria	Anthracnose	Fusarium	Verticillium	Root-rot	Grey mildew	Myrothecium	Helminthosporium	Others	Card No. Col (76)
56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76

Index for Evaluation of Characters

GROWTH HABIT
- Plant type: 1) Compact 2) Lanky 3) Bushy

STEM
- Hairiness: 1) Glabrous 2) Hairy 3) Densely hairy
- Colour: 1) Green 2) Greenish purple (Sun red) 3) Red
- Internode length: 1) Short (up to 5 cm) 2) Medium (5.1 - 10 cm) 3) Large (10.1 - 15 cm) 4) Extra-long above 15 cm)

LEAF
- Size: 1) Small 2) Normal 3) Large
- Shape: 1) Normal 2) Okra 3) Super-okra
- Lobing: 1) Narrow 2) Broad
- Colour: 1) Light green 2) Green 3) Red 4) others
- Surface: 1) Glabrous 2) Hairy 3) Densely hairy
- Glands: 1) Absent 2) Sparse 3) Dense
- Nectary: 1) Absent 2) Present

FLOWER
- Bracts: 1) Normal 2) Large 3) Frego
- Petal Colour: 1) White 2) Cream 3) Light yellow 4) Yellow 5) Lavender (pale purple)
- Petal Spot: 1) Absent 2) Small 3) Large
- Pollen colour: 1) Cream 2) Light yellow 3) Yellow

BOLL
- Bearing habit: 1) Sparse 2) Normal
- Shape: 1) Round 2) Oval 3) Conical 4) Cluster
- Size: 1) Small 2) Medium 3) Large
- Surface: 1) Smooth 2) Sparsely pitted 3) Densely pitted
- Glands: 1) Absent 2) Sparse 3) Dense
- Opening: 1) Normal 2) Intermediate 3) Closed
- Boll weight: Average of 10 healthy bolls

SEED
- Seed index: Weight of 100 seeds
- Fuzz: 1) Naked 2) Sparse 3) Fuzzy
- Fuzz colour: 1) White 2) Green 3) Grey 4) Brown (tan)
- Oil (%) Protein (%) Gossypol (%): At 10% moisture basis of seed weight
- Yield/plant: Minimum 10 plants average
- Ginning out-turn: to be obtained from a minimum sample of 100 g
- Lint index: Weight of lint from 100 seeds
- Lint colour: 1) White 2) Creamy 3) Light brown 4) Brown 5) Others

REACTION TO PESTS AND DISEASES
1) Resistant R
2) Moderately resistant MR
3) Moderately susceptible MS
4) Susceptible S

Figure 2. Germplasm Index Card (GIC) designed by CICR Nagpur for recording data on cotton germplasm

6.2. Cotton genetic resources catalogue

The Germplasm Index Card designed by the CICR was used as the basis for germplasm cataloguing. The Catalogue of Cotton Genetic Resources was compiled based on germplasm data gathered all over the country, particularly at CICR Nagpur, Maharashtra state (Central zone) and its regional centres at Coimbatore in Tamil Nadu (Southern zone) and Sirsa in Haryana state (Northern zone) representing all the three major cotton growing zones of the country. Data for special applications were also recorded by the departments of Pathology, Entomology, Soil Science Agronomy, Physiology, Biochemistry etc. Fibre quality data were generated by the Central Institute for Research on Cotton Technology (CIRCOT), Mumbai and its regional units and that for oil content and seed oil index were obtained at the CICR by using Nuclear Magnetic Resonance (NMR) and other instruments [23].

Close collaboration for data recording and evaluation was ensured between the CICR, the CIRCOT, Mumbai, the National Bureau of Plant Genetic Resources (NBPGR) New Delhi, Indian Agricultural Research Institute (IARI), New Delhi and all the State Agricultural Universities (SAUs) in cotton growing states of the country as partners with the CICR as members of the Germplasm Advisory Committee for Cotton. Average data over 2-3 seasons were taken into consideration for deciding on the potential values of each germplasm accession. The data have been computerized by the CICR. Multi-location data were also generated for field performance, wherever possible and made available to regional breeding centres.

6.3. Selected list of superior germplasm

Based on germplasm evaluation over locations and seasons, the elite accessions for characters of high economic importance in cotton representing all the four cultivated species especially for early maturity, plant architecture, yield influencing attributes like boll number, boll weight and high ginning, seed quality and stress tolerance etc., were sorted out from the total germplasm evaluated. Some of the elite germplasm accessions identified species-wise in the cotton gene pool [15] are indicated in Table 5.

Species	Characters	Elite types identified
G. hirsutum	Early maturity (140-150days)	TXORSC 801-79, Acala 8-1 x Tamcot Sp21, Acala 69/5, D244-10, Riverina poplar. U. aRk, d203-5, d238-13-5,USSR n. Ac.83 (RKS), MCU7, SIMA-1, PKV081, NHS1412, LRA5166, BN, Narasimha, LRK516, PKV442
	Dwarf (below 80cm)	USSR6248, Acala8861 x CA491Early F-8, Acala 1577-7780,TXORSC 80-1-79, TxcaMd21-5-78, SIMA 1, PKV081
	Compact plant type	54727, USSR 6250,PRS72, PRS74,NHS1412, DCI 118
	Bacterial blight resistance	Tx Maroon 2-78, TXORHU1-78, Tamcot CAMDE, Tamcot SP37, Tamcot SP 215, Tamcot SP23, RebaB50, 101-102B, BJA592
	High boll weight "/ >5.5g	T120-76, CP188, Acala 8-1xTamcot SP215, 108F,Hopicala, NC Smooth 1, 133F, Empire WR61, DS56,DS59, Tashkant 1
	High boll number	FTA MDH133, Deltapine 90, MDH 2, LRA 5166, NHS 1412, Narasimha
	High ginning (40%)	Nc177-16-30, Arkot 2-1,Superokra, NC Hairy, IRMA23, U585-12, Half & Half, Kirghis A2, 9030H
	High yield	Reba Pvt9, Delcot 311, Aleppo 40, Deltapine 16, Tashkent 3, Pee Dee 2164, Demeter-iii(1), S1291, 149F, 152F, B4 Empire, DS56, DS 59, SIMA1, LRA5166, MCU5, MCU7, MCU10, F414, NH1412, Suman, Narasimha, Anjali,
G. barbadense	High yield	25-1-3, K3475, CBS34, C 6002-3, ERB4492,ERB 13552, SIV 135, USSR mix 76, CV76, EC I 34390, EC I 32374, SB 289E, SB1085-6
G. arboreum	High seed oil "/ >20%	79/Lohit, Behnoor, AKA12, H4616, Ac733, AKH4, Comilla, 30820, 30840, Gao 16, CB-VIII, Gao 16-CB4, Gao 16-CB7, Coconados 5, Chineese Broad lobe, Chineese Narrow Lobe, Chineese Spotless
	High Yield	G27, Lohit, AKH4, LD 230, LD 133, LD 135, LD 141, LD 143, AKA 28, AKA 8401, H46, H47, Bani 306, Ac types (PAU), Nanded 3883, Desi 52, Coconadas White
	Long staple	LS1, LS2, LS3, 2927, H511,Adonicum, Sel 32-1, K5567, K7, K8, K9, K10
G. herbaceum	General good	5495. Suj M3-3-5, EPSB, Russian 9,Baluchisthan, Kumpta, G. *G. arboreum* COT 11, G. Cot 13, 519-14, Suj 3-3-19, 86-5, 87-2, E2-13-2, 72-34, Suj 22-3-1, LS Early,

Table 5. Some elite germplasm accessions identified for different characters

http://dx.doi.org/10.5772/58622

The estimated numbers of elite types with relatively high performance for various characters in the *Gossypium* gene pool in the CICR were arrived at based on the evaluation in comparison with appropriate local checks (standard cultivars) over seasons with consistent superiority [15] and most of them are included in the breeders working collections for regular use. The details of elite types for various characters are given in Table 6.

Elite character types	*hirsutum*	*barbadense*	*arboreum*	*herbaceum*	Wild and other stocks
High stable yield performance	380	16	300	31	-
High boll weight	145	5	150	20	-
High boll number potential	140	3	60	45	2
High seed weight	330	10	40	20	-
High lint index	249	12	30	12	-
High ginning	120	15	150	40	-
Micronaire value (3.5-4.0)	190	30	2	50	4
High span length	220	60	50	40	-
High fibre strength	145	50	180	55	5
Compact to medium plant type	42	5	10	3	-
High sympodial branching	275	12	40	20	2
High seed oil content	75	10	60	25	-
Early maturity	30	3	75	10	-
High biomass potential	400	10	120	45	12
High harvest index	120	1	15	10	-
High seed number per boll	230	2	20	30	-
Long pedicel	35	-	-	-	-
Morphological markers	185	10	30	2	-
Insect pests & disease resistance	280	10	many	many	50
CMS, GMS and Restorer sources	34	-	2	-	3
High coarse absorbent types	15	-	100	10	-
Drought tolerance potential	50	-	300	150	15
Naked seeded types	5	-	1	-	3
Delayed morphogenesis of gossypol	-	-	-	-	3
Chromosomal variants	-	-	-	-	77
Low gossypol gland types	60	-	10	5	-
High fuzzy types	100	-	200	50	4
Working collections	425	10	130	60	perennials

Table 6. Estimated number of elite germplasm accessions with relatively high performance for various characters in *Gossypium* gene pool.

6.4. Range of variability

The extent of variability was assessed for leaf attributes (shape, pattern of lobes and size), calyx shape and size, burst bolls (shape, size, boll opening type and lint colour), seeds (seed size, fuzz content and fuzz colour) and lint (length, density and colour) and the wide range of variability was portrayed in an exhibit form. Some of the wild species especially for delayed morphogenesis, petal spot pattern and colour-linted sample were also included in the exhibit. The range of variability in cotton germplasm accessions of *G. hirsutum* and *Desi* (Diploid) cottons under Nagpur (India) conditions along with some selected wild species and colour lint [23,15] cotton are exhibited in Figure 3.

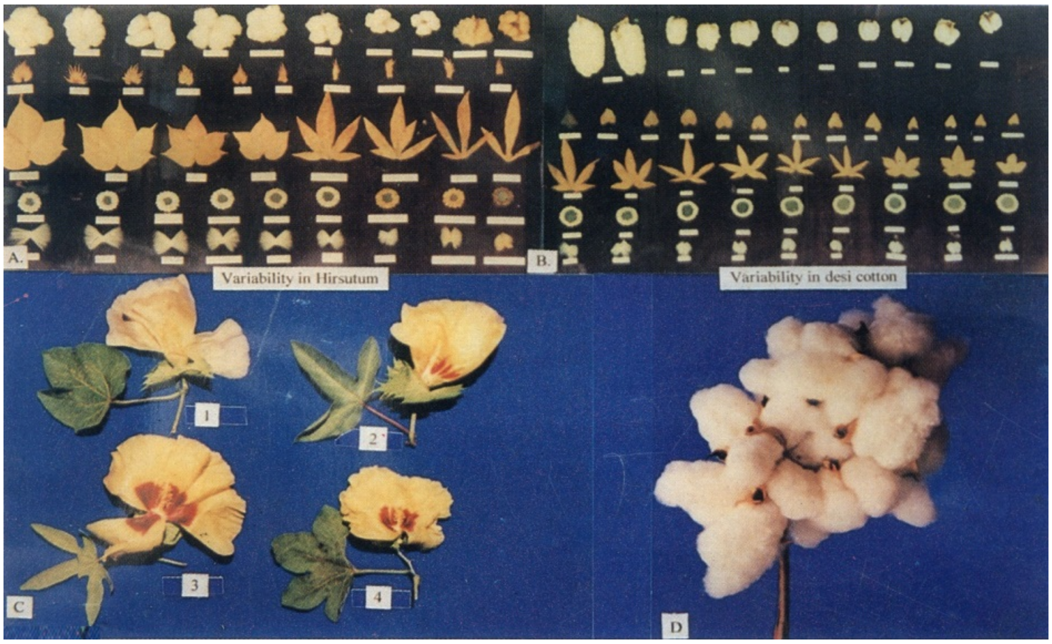


Figure 3. Top: Range of variability in cotton germplasm accessions of A: *G. hirsutum* and B: *Desi* (Diploid) cottons under Nagpur (India) conditions; Bottom: C 1-4 represents selected wild species and D-colour linted cotton.

6.5. Inherent potentiality identified in different wild species

Inherent potentiality identified in different species of *Gossypium* by Indian scientists and others based on [3, 28, 19, 24, 29, 30] for improving the cultivated cottons is briefly summarized in Table 7.

Some useful character transfer into *G. hirsutum* and *G. barbadense* cultivars is described below:

Some useful character transference (introgressions) into cultivars of the two tetraploid species has been achieved and based on [3, 28, 19, 24, 29, 30], some of the achievements include jassid resistance potential from *G. tomentosum*; smoothness for boll weevil resistance from *G. armourianum*; rust resistance from *G. raimondii*; blackarm resistance from *G. arboreum* (into *G. barbadense);* fibre length from *G. thurberi* and *G. raimondii*; fibre strength from *G. thurberi*; cytoplasmic male sterility from *G. harknessii;* drought resistance from *G. arboreum* and *G.*

http://dx.doi.org/10.5772/58622

Improvement of	Character	*Gossypium species*
Fibre quality	Fibre length	*anomalum, stocksii, raimondii, areysianum, longicalyx,*
	Fibre strength & elongation	*stockssii, areysianum, thurberi, anomalum, sturtianum, raimondii, longicalyx*
	Fibre fineness	*longicalyx, anomalum, raimondii*
	Lint yield	*anomalum, sturtianum, australe, stocksii, areysianum*
	High ginning outturn	*australe*
Insect resistance	Bollworms	*thurberi, anomalum, raimondii, armourianum, somalense*
	Helicoverpa	*somalense*
	Jassid resistance	*anomalum, armourianum, raimondii, tomentosum*
	Whitefly tolerance	*armourianum*
	Mite resistance	*anomalum*
	Aphid resistance	*davidsonii*
Disease resistance	Bacterial blight	*anomalum, armourianum, raimondii*
	Verticillium wilt	*hirsutum (var. mexicanum.nervosum), harknessii*
	Fusarium wilt	*sturtianum, harknessii, thurberi*
	Nematode	*darwinii*
Other attributes	Cytoplasmic male sterility (CMS)	*harknessii, trilobum, aridum*
	Drought tolerance	*darwinii, tomentosum, stocksii, areysianum, anomalum, australe, harknessii, aridum, raimondii*
	Frost resistance	*thurberi*
	Delayed morphogenesis of gossypol glands	*bickii, australe*

Table 7. Inherent potentials in wild species of *Gossypium* identified

herbaceum; fibre length from *G. barbadense* (into *G. hirsutum*); fertility restorer gene from *G. harknessii;* high ginning outturn from *G. arboreum*; hairiness from *G. tomentosum* into *G. barbadense* and caduceus bract from *G. armourianum*.

6.6. Germplasm utilization

In cotton, the approximate number of collections maintained in various centres in the four cultivated species and wild stocks including advanced intermediate breeding lines was estimated at 20,750, but it included duplicates and repeat collections since each Centre maintained as per local breeders' needs [29]. Enormous intra and inter-racial variability occurs in-*Gossypium arboreum* including land races of *bengalense* like *sanguineum*, multani cotton, *roseum* and genotypes characterized by high boiling potential, high yields, low boll weight, medium to high ginning out-turn, fine and long fibre, susceptibility to boll worm and late maturity. The race *cernuum* is extremely coarse-fibred, with very high ginning out-turn (up to 50%), boll weight (4.5-6.0g) and seed number (10-16 seeds/locule). Similarly, *G. herbaceum* grown in Gujarat (Wagad, Broach, Lalio and Goghari Cotton) and Karnataka (Kumpta Cotton) differ from each other in plant habit, maturity, leaf lobation, boll size, lint colour, ginning out-turn and seed characters [12].

The Indian *G. hirsutum* types are represented by Punjab American Cotton, Buri types, CTI types, Indo-American types and Madras Cambodia Uganda types. The present day Punjab American Cotton varieties being cultivated in North India are selections from LSS and 216 F (e.g., 320 F, Bikaneri Nerma, H777, F 444, SH 131 etc.). The types Buri 1007 and Buri 0394 are resistant to wilt, jassid and frost. Several CTI varieties (Bandnawar-1, Bandnawar-3 Khandwa-2 etc.) were released through hybridization between Cambodian variety Co.2 with *G. tomentosum* and have high degree of jassid resistance due to hairy leaves. Inter-specific hybridization involving *G. hirsutum* and Asiatic diploid species carried out at Surat in Gujarat gave rise to several Indo-American types (e.g., 170-Co-2, 134-Co 2-M, Gujarat-67, etc.). These varieties are genetically divergent from rest of the *hirsutum* varieties developed in India and are good examples of commercial varieties developed from tetraploid x diploid species for the first time. Pure line selections of Cambodian types at Coimbatore and Tamil Nadu gave rise to variety CO2. This variety was further crossed with two Uganda types, viz. 4-4/4 and A-12, and the selections from these crosses were established as Madras Cambodian Uganda (MCU) types. This resulted in developing long-linted superior quality cottons like MCU-5, MCU-8 and MCU-9.

G.barbadense was introduced in India during the 1930s. However, its cultivation was restricted to limited area in southern states of the country. In 1967, a variety Sujata, a selection from Egyptian variety Karnak, was evolved. The first Indian variety of hybrid origin Suvin was evolved in 1971 from a cross of Sujata and St. Vincent. Therefore, the present day *G. barbadense* cotton in India has these three stocks.

The success in hybrid cotton in India was achieved at Surat where an *intra-hirsutum* cross of Gujarat-67 x American Nectariless (an exotic from USA) was released for commercial cultivation in 1968 as Hybrid 4. The first commercial interspecific hybrid Varalaxmi acceptable to farmers and industry was developed at the University of Agricultural Sciences, Dharwad (Karnataka) in 1972 from a cross between Laxmi (an adapted *G. hirsutum*) and SB 289 E (a Russian *barbadense* variety). Later, a large number of inter-specific hybrids have been developed in India, such as CBS 156, JKHy-1, JKHy-11, Savitri, Godavari, Suguna, H-6, Jayalaxmi, and diploid DDH-2, etc. which are widely grown in different parts of the country [29, 31, 32].

Possession of germplasm in numerical strength in R&D Centres and in a nation is really a great asset. Unless and until the resources are utilized effectively in crop improvement and significant achievements of farming and commercial value is demonstrated, the conservation and maintenance is not really justified. Considering the huge cost involving staff, infrastructure like fields, glass houses and equipment, besides recurring contingencies, a proper strategy should be in place to screen all germplasm and constitute the most elite breeders' working collections for breeders' use. A Memorandum of Understanding (MOU) or Material Transfer Agreement (MTA) basis to enable breeders to obtain germplasm would pay high dividends for the nation in intensifying crop improvement. A suitable global and national policy to share germplasm for breeding requirements may be evolved and adopted for supporting the cotton improvement researches both in the public and private sector R&D Units. Quality of maintenance of germplasm must be kept up at a higher level to maintain purity for the attributes for which each accession is noted for and maintained for original attributes without exercising selection for new attributes [33].

In India, several varieties and hybrid cotton cultivars have been developed through interspecific hybridization and many of them were released for cultivation from time to time in the last sixty years. Some of them also became promising parents for developing superior hybrids. Details of the salient achievements [34] are presented in Table 8.

Cultivars developed	***Gossypium Species involved***	**Research institution involved**
Commercial varieties		
Badnawar 1, Khandwa 1, Khandwa 2	*hirsutum x tomentosum*	JNKVV Indore
SRT1, Deviraj (170 C02), Gujarat 67 (G67)	*hirsutum x arboreum*	GAU Surat
Devitej (134 Co2 M)	*hirsutm* x *herbaceum*	GAU Surat
MCU2, MCU5	*hirsutum* x *barbadense*	TNAU Coimbatore
PKV 081	*hirsutum x anomalum*	Dr. PDKV, Akola
Rajat	*hirsutum* x *(thurberi x anomalum)*	Dr. PDKV, Akola
AKA 8401	*arboreum* x *anomalum*	Dr. PDKV, Akola
Arogya	*hirsutum* x *anomalum*	CICR Nagpur
F1 Commercial Hybrid cottons		
Varalakshmi, DCH 32, DHB 9	*hirsutum* x *barbadense*	UAS Dharwad
DDH2	*herbaceum* x *arboreum*	UAS Dharwad
G. Cot. DH7 & G. Cot. DH 9	*herbaceum x arboreum*	GAU Surat
MDCH 201	*herbaceum* x *arboreum*	MAHYCO Seeds private Ltd Jalna (MS)
NHB 12	*hirsutum* x *barbadense*	Marathwada Aricultural University (MAU) Nanded
TCHB 213	*hirsutum* x *barbadense*	TNAU Coimbatore
HB 224, Shruthi	*hirsutum* x *barbadense*	CICR Regional Station, Coimbatore

Table 8. Some cotton varieties and F_1 hybrids developed through interspecific hybridization and released for cultivation

A large number of *G. hirsutum* x *G. hirsutum* F_1 commercial hybrids and a few *hirsutum* x *barbadense* F_1 commercial hybrids have been released by several private seed companies and marketed as proprietary hybrids during 1980 to 2001. After the introduction of transgenic Bt-cotton in 2002-03, several seed companies developed and marketed as many as 1500 commercial hybrids of *hirsutum x hirsutum* with Bt-background as Cry1Ac (Bollgard-I) and as BG-II (Cry1Ac+Cry 2Ab) and the yield level in the country showed significant increases. Several private H x H hybrids used varieties as superior parents such as-Narasimha, Brahma etc., [31, 24, 15, 10] and the farmers have gotten higher yields and higher income.

The extent of variability in germplasm compared to standard cultivars from agricultural, trade, textile and industrial attributes, approximate number of types with elite performance for various characters of breeding importance in the National Gene Bank have been made accessible to cotton breeders in various centres for guidance and utilization in crop improvement for various agro-climatic zones of India. National Gene Bank of Cotton comprising a significant representation of global pool of genetic variability in India has provided a unique opportunity for cotton breeders and other researcher scientists for accelerating the progress of crop improvement. Studies have been carried out on a significant number of accessions of *G. hirsutum* cotton using the hybrid index scores, metro glyph analysis and Mahalanobis D^2 analysis techniques and the divergent accessions were identified and used in crossing programmes at the CICR, Nagpur, [15]

6.7. Databases of cotton germplasm

The cotton databases are maintained by the CICR, Nagpur. The germplasm holdings maintained undergoes constant change periodically based on additions and deletions. Accordingly, the Cotton Gene Bank of the CICR, Nagpur holds a rich repository and global collection of cotton germplasm numbering 10,597 as reported for 2012-13 including newer accessions consisting geographically and genetically diverse *Gossypium hirsutum* (7542), *G. barbadense* (305), *G. arboreum* (1945) and *G. herbaceum* (566), while another 239 representing about 25 wild species and other wild species, perennials and landraces, races of *G. arboreum*, *G. hirsutum*, *G. barbadense* and *G. herbaceum*, inter-specific hybrids and their derivatives are maintained in the wild species garden *in situ* at CICR, Nagpur [42].

7. Cotton genetic resources conservation

After initial evaluation, till now some purified bulk seeds of a significant number of accessions have been deposited at long term storage modules at the NBPGR New Delhi. The working collections and other accessions are periodically rejuvenated under safe conditions and pure seeds maintained in medium term cold storage modules at the CICR. The elite working collections identified from the gene pool are further screened by various departments of the institute for all unsolved and emerging problems and also used for further up-gradation of attribute expressions by breeding and selection. The species and some perennials are maintained in in-situ conditions. The new accessions have been acquired from various sources periodically including survey and collections in cooperation with NBPGR and IPGRI. Detailed account of conservation of germplasm holdings of all crops in India was reported by [35].

8. Novel trends and perspectives

Cotton is being challenged on two fronts: on the production side, cotton is competing with food, feed and biofuel crops for acreage and on the consumption aspects; cotton's textile

http://dx.doi.org/10.5772/58622

market share is being challenged by man-made and synthetic fibres, in various ways. Cotton has an image of being renewable, environmentally friendly, traceable and comfortable and has still to compete with man-made fibres and synthetic due to the latter's improving technology and functionality. The global cotton industry has been witnessing very dynamic changes since the turn of the 21st century [17, 36, 41). Cotton is an important global commodity and there are incredible efforts in agriculture and cotton to attend to the social, environmental and economic factors and ensure continual improvement, investment, research and sharing of best practices [36].

8.1. Various new considerations for re-evaluation of germplasm

In the context of changing scenario in various aspects concerning cotton, it has become necessary to evaluate the germplasm for several new parameters and enable their utilization in crop improvement for realizing various targeted goals. Some of the aspects requiring examination of old and new germplasm from these perspectives are suggested in Table 9.

New Considerations	Relevant attributes
Quantum jumps in yield of lint	Plant conformation for higher planting densities, high boll weight, compactness of plant type, shorter sympodial branches with synchronous boll bursting, high ginning outturn, high lint index etc.; high harvest index and cost benefit ratios
Fibre quality for competing / coexistence with man-made / synthetic fibres for improving the share of cotton in textile use	High fibre strength, higher fibre elongation of over 6-7, high level of fibre maturity, amenability for imparting easy care properties
Economics of production especially reducing the cost of production and environmental pollution	High level of resistance to biotic stresses, resistance to reemerging sucking pest complex, mealy bugs and other insect pests like whitefly that acts as a carrier of cotton leaf curl virus disease, ability to withstand weed competition and amenability for herbicide tolerance in cultivar development, improved and consistent yield potential under rain fed conditions under low cost technologies in cultivation, improved competitive ability for yield in relation to competing crops
Sustainability of high production levels	Ability to give stable yields under varied environments, adaptation to low cost technologies of crop management, additional advantages from quality and yield of byproducts derived
Contribution to food security in addition to lint fibre production	Higher seed yield from larger planting density & cultivation of hybrids with high vigour, stable and higher levels of oil content, superior nutritional qualities of oil and protein from seed, freedom from gossypol in harvested seeds, higher biomass with higher harvest index, high seed index, non-fuzzy seeds or with low seed hair density
Suitability for mechanization of harvesting cotton	Ideal plant conformations for irrigated and rain fed cotton cultivars, rapid development of bolls to maturity, appropriate plant height stability with amenability for efficient harvesting, boll weight above 5-6g, and high boll load consistent with higher planting densities

New Considerations	Relevant attributes
Organic cotton production (current demand is low, but may increase over time)	High yield potential and stability of yield under organic farming conditions in rain fed and irrigated areas, development of appropriate fibre quality with organic inputs and management systems,
Naturally colour-linted cotton production under isolation from normal cotton growing areas	Expanding the range and intensity / stability of colours of lint fibres, consistent improvement in the fibre properties desired for better spinning like higher strength, optimum maturity with appropriate Mv. (Micronaire value) and improvement in length of fibres for medium, long and extra-long staple categories, higher ginning outturn
Research & development for improving short and extra-long staple cotton production and removing the imbalance in availability in all classes as per textile industry demands	Higher agronomic adaptability of ELS varieties of *G. barbadense* and *hirsutum* x *barbadense* hybrids for commercial cultivation under certain environment constraints, higher yield potential of short staple cotton varieties, hybrids and transgenic cultivars to increase their preference by the cotton farmers with appreciable cost-benefit ratios, improving the ginning outturn in ELS cotton varieties and hybrids and removing certain deficiencies in Micronaire value (Mv.), maturity, strength etc.
Breeding superior *barbadense* cotton varieties	The *barbadense* cotton suffers from low adaptation to the climatic conditions of peninsular India with potential pockets for cultivation, shows fibre quality deficiencies, and need improvement for boll weight, higher ginning, high fibre maturity and optimum Micronaire value (Mv.), and reduction in crop duration
Pre-breeding *barbadense* germplasm lines with improved properties for use as parents of successful commercial hybrids	Higher boll weight, reduced duration, phenotypic stability of plant conformity, high ginning and short sympodial (fruiting) branches with synchronous boll development pattern.
Pest and disease resistance	Compatible parents for hybrids without susceptibility to New wilt / quick wilt in hybrids judged by physiological and agronomic parameters
Compatibility with competing crops in mixed cropping and multiple cropping situations	Increased early vigour, rapid fruiting ability, resistance to interplant competition in the early stage of mixed crops with cotton, optimum leaf area index and resistance tolerance to moisture stress, high photosynthetic efficiency etc.
Breeding for withstanding drought and other climatic aberrations in the context of climate change	Drought resistance attributes and improved physiologically efficient germplasm with high water use efficiency (WUE), reduced crop maturity duration fitting into rainfall patterns.

Table 9. Certain new considerations for re-evaluation of germplasm and development of superior lines

8.2. Role of private seed companies in germplasm development-a new trend

Prior to the formation of National Seeds Corporation and the State Seed Corporations during the 1960s to 1970s in the Public sector, the entire responsibility of cultivar development, seed multiplication and seed distribution coupled with extension rested with the government agencies and even farmer to farmer seed exchanges. After the Seed Corporations were established, the responsibility for producing breeder seeds rested with the original breeder in the research centres, but the further stages of seed multiplication, quality control and distribution were taken over by State Seed Corporations. With the opening up of breeding and seed development to private sector after 1970s, the private sector started developing hybrid cotton genotypes of a proprietary nature and started the seed business right by establishing their own R&D Units approved by the Department of Science and Technology and ICAR. The parental secrecy was sacrosanct for remaining in seed business and the private seed companies started developing their own parental genotypes and developing superior hybrid combinations and undertook supply of quality seeds to farmers after testing under the "All India Coordinated Cotton Improvement Project" (AICCIP) in multi-locations. In 2002-03, when the transgenic Bollgard-I cotton was introduced and followed later by Bollgard-II cotton in 2006-07, Monsanto, the global seed giant and the owner of the gene patent made suitable arrangements with Mahyco-Monsanto Company to make the gene source available to over 25 cooperating seed companies on sub-licensing basis. At this stage, the publicly bred variety and public sector seed distribution became insignificant. The private seed companies devoted attention to more than 95 per cent transgenic hybrid cotton development, predominantly *hirsutum* x *hirsutum* and a small extent of *hirsutum* x *barbadense* hybrids. The planting seed quality control and commercial seed distribution to cotton growers all over India were also intensified with proprietary hybrids by the seed companies and thereby passed on the reins of seed business to the private seed industry. There are over 650 seed companies in India with about 30-40 of them having a modern to good level R&D and hybrids were released after testing under the aegies of the Genetic and Engineering Approval Committee (GEAC) under the Department of Biotechnology (DBT) and Ministry of Environment and Forests (MoEF) implementing as per EPA regulations.

It was in the last 15-18 years after the post GATT scenario, that the germplasm availability to private seed companies faced constraints, besides non-availability. This came as a promising era to develop their own germplasm by breaking down available hybrids and cross combinations in each Seed Company and reverse pedigree breeding approaches coupled with stringent selection and inter-mating to make new character associations. Many major seed companies thus have made huge germplasm sources maintained as proprietary germplasm. Over 1500 hybrids in transgenic constitution were developed and released by the private seed companies in the last one decade [33, 41].

The character modifications in private seed industry germplasm inter-alia included big (5.5 to 7.2g) and medium boll (4-5g) types, sucking pest resistance, higher boll development with synchrony of reduced plant vegetative duration of 160-170days, long, superior medium and extra-long staple fibre categories, resistance to CLCuV for the northern zone cotton growing areas, moderate drought resistance, high fertilizer efficiency coupled with response for superior management technologies etc., as well as bollworm resistance through BG-I and BG-II Cry gene systems. Even plant type concept has been applied in recent years for higher planting densities and suitability for machine harvesting envisaged for adoption in the next five years or sooner. The Round-up Ready herbicide resistance technology and similar ones are also at its nascent stage in approved seed companies for releasing subject to relaxation of moratoriums by Government and releasing for adoption by farmers.

The private seed companies maintain their own germplasm accessions in cold storage modules and germplasm use as per requirements. Secrecy and privacy is maintained. The seed companies also have their own commercial assessment of germplasm potentials and maintain descriptive records as per business requirements and also as per (Distinctness, Uniformity and Stability) DUS characterization evolved by the PPVFR Authority. It is difficult to acquire information on the wealth of new germplasm developed, utilized and maintained by private seed companies, because of their proprietary nature. However, they are immense in number and variability and serve as the most directly usable material in hybrid development. Competition among private seed companies is acute and hence product development by various seed companies for farmers' use should not only be attractive, but also shine in contrast and popularity compared to those of competitors with high performance potentials. In recent years, big boll hybrids with 6-7.5gram boll weight have been developed by private seed companies as available in hybrids like MRC 7351, Mallika, Sigma, Jackpot, Indravajram, Ajeet 99, RCH 530, and Vikram 5.

Public sector developed varieties were popular and some of them became parents of H x H hybrids and also in H x B hybrids, when the hybrid cotton era dawned for the first time in the world only in India since 1970s. Private seed industry started developing since then and gradually became the dominant developer of proprietary hybrids and primary distributer of quality seeds. With the advent of the transgenic Bt-hybrid cottons from 2002, the private seed industry became the primary source of superior hybrids and total supplier of quality seeds all over the country. In transgenic group, Bunny, Mallika, RCH2, other RCH, Sigma, Dyna, Brahma, MECH-series, Thulasi 4, JKCH99, Ankur 651 and others became popular. In all, 590-600 private seed companies existed and more than 1500 Bt-cotton hybrids were released, but only some 20-25 commanded more than 85% in seed distribution. Prominent Seed Companies including Mahyco, Rasi, Nuziveedu, Vibha Seeds Group, Ankur Seeds, Thulasi Seeds, Bioseeds and certain others are leading in cotton R&D and extent of seed distribution amounting to 30-35 million seed packets (400g transgenic seeds and 50g refugee seeds per packet) per year is estimated at approximately US$ 525 million [41]. With seed rates increasing in recent years, the requirement would increase to 50 million seed packets per year in the next few years.

8.3. Pre-breeding and development of advanced breeding lines from existing germplasm

The public sector institutions like the CICR and SAUs are involved in such basic breeding activities and development of a large number of advanced lines are reported and the effort is continuing. Work is targeted towards big boll, plant type for mechanical harvesting by accommodating denser plant populations, reduction of crop duration, higher level of resistance to sucking pests and new maladies, besides high photosynthetic efficiency for high yields and even resistance to drought stress and restricted water use under emerging climate adversities [37]. Some of the SAUs and the CICR have previously developed superior varieties / germplasm like LRA5166, Narasimha, Brahma, and MCU5 in *G. hirsutum* and Suvin, SB 289E and SB 1085-6 in *G. barbadense,* most of which have served as versatile parents for superior hybrid development. A limited number of *G. hirsutum* germplasm and varieties have proved as proven parents in very many hybrids generated by the seed industry. Development of a large number of improved germplasm lines are in progress in various research centres, but precise information on such results are yet to be made available.

http://dx.doi.org/10.5772/58622

8.4. New techniques and new trends in germplasm assessment

Multi-location evaluation of elite proprietary germplasm is also being adopted by seed companies for precise choice for parents of newer hybrids for different regions. Marker-assisted selection and recurrent selections are adopted by forward looking seed companies for superior parent selection and improvement of fibre quality attributes. Biotechnological tools and scouting for alien gene sources like that of Cry genes for various other envisaged character improvements by the multinational seed companies like Monsanto, Bayer CropScience etc., is also gaining importance in new gene source identification and crop improvement. Traditional applications in germplasm evaluation have undergone significant change and new germplasm developed by private sector and under special programmes in Government R&D centres are targeting the challenging sustainability and competition requirements of the 21st century in the field performance and in industrial applications as issues as discussed in this chapter. In the context of hybrid cottons and in the context of transgenic cotton cultivar *vs*. hybrids, germplasm use requires better understanding of the inherent potentials, their genetic performance under the new circumstances and merit based selection for developing new genotypes. DUS characters developed for cotton by the PPVFR Authority is also being adopted for germplasm characterization [38, 33].

8.5. Gaps in collections (quantitative & qualitative)

There are gaps like (1) augmenting the wild species collections to have as many of the total species as may be available in other country centres, except those, which are not available in live collections elsewhere, (2) augmenting the collections of all important cultivars in all the cultivated species from various cotton growing countries including ELS *G. barbadense* and other material, (3) obtaining on exchange basis, the new collections made through recent surveys by various organizations, and (4) advanced breeding material developed in various SAU R&D Centres after 1990 either in possession or as and when developed also may be obtained and added to the national gene pool at the CICR Nagpur, (5) germplasm enhancement and pre-breeding efforts for future needs may be intensified at the CICR, SAUs and also Private seed companies, [24, 29].

Documented standard control varieties are critical for germplasm evaluations. With the current trend in many crops and cotton particularly toward proprietary germplasm, in the future certain "public" germplasm of known pedigree may be primarily important, not for its outstanding agronomic performance, but for its value as a "control". In addition to helping to distinguish environmental from genetic effects on the phenotype, controls may provide a common denominator for standardizing evaluation reports. Instead of presenting raw data, evaluations can be reported as percentages of controls [33].

Marker-assisted selection (MAS) using molecular markers such as single nucleotide polymorphisms (SNPs), is widely used in different agricultural research centers to design genotyping arrays with thousands of markers spread over the entire genome of the crops, especially in interspecific crosses of *G. hirsutum* x *G. barbadense* for fibre quality attributes and also pest and disease resistance. H x B crosses have resulted in H x B hybrids (F_1) with bigger bolls than of *G. barbadense* parent, ELS (35-38 mm), higher lint index, wider adaptability, yield potential and pest tolerance. Elucidating the genetic control of given traits is important to decide the merit in a specific germplasm. The gene action affecting phenotypes is elucidated by crosses and by recombination in progeny of backcrosses or segregating generations. Dominance becomes apparent in F_1, BC and F_2 generations, as do heritability, and deviations from Mendelian ratios resulting from epistasis, pleiotropic and maternal effects. Molecular-marker characterization can assist with "pyramiding" resistance alleles at different loci to produce more durable resistance to biotic/abiotic stresses. Extensive genome mapping projects of *Gossypium* species *via* the co-segregation of molecular markers and important traits of agronomic value can also help to determine the gene action underlying phenotypes. The need for undertaking planned adoption of MAS systems is emphasized especially for improvement of fibre quality parameters and disease resistance attributes to enable choice selection of germplasm for rapid crop improvement.

More effective accessibility and use of plant genetic resources for crop improvement is essential, since conservation at huge cost without use has little merit. Plant genetic resources of crops especially cotton are conserved for use by people as fibre, food, feed, fuel etc. On the contrary, use without conservation amounts to neglecting the genetic base needed by farmers and breeders alike to increase productivity in the future. To be of use, material held in gene banks must be well documented by adopting all modern techniques as well as field evaluation. Only a very small fraction of the genetic diversity residing in *Gossypium* genus is represented in working collections and improved elite cotton germplasm. Genetic diversity in elite germplasm is reported to be narrow and diversity on the farm is still narrower due to preferential planting of successful cultivars and breeding techniques that tend to promote an over-reliance on a few genotypes. Considering the narrow genetic base of cultivars and commercially elite germplasm, it would be necessary to exploit the diversity residing in wild, commensal, and landrace cottons of six allo-tetraploid and forty-three diploid species of *Gossypium* genus as it may be rewarding. Resources including recombinant inbred line (RIL) populations, back-cross introgression line (BIL) populations, near isogenic introgression line (NIIL) populations, chromosome substitution lines, day-neutral converted race stocks, etc., may also be outsourced from global R & D Centres, conserved and used in Indian gene bank and breeding programmes. The importance of building up new germplasm of breeding value through proper utilization of gene pools has also been emphasized by [39, 40].

8.6. Registration of newly developed germplasm

NBPGR New Delhi has established norms for new germplasm registration by the breeders and it could also be got protected under (Protection of Plant Varieties and Farmers' Rights Act (PPVFRA) especially to protect from poaching and breeders may be encouraged to avail of this and increase their efforts, Guidelines for registration of plant germplasm (revised, 2014) NBPGR, New Delhi. The information could be accessed from NBPGR Website <https://www.nbpgr.ernet.in.>. The information will also be published in the Indian Journal of Plant Genetic Resources functioning at its headquarters by the Member Secretary, Plant Germplasm Registration Committee, National Bureau of Plant Genetic Resource, Pusa Campus, New Delhi-110 012,

http://dx.doi.org/10.5772/58622

9. Conclusion

Cotton is a major global agricultural commodity in the World in over 100 countries including India. Cotton is also a widely preferred natural textile fibre for the industry. India is currently the second largest producer, consumer and exporter of cotton with the second largest textile industry after China. Presently, cotton is produced in a little over 11.5million ha in India and all the four cultivated species (*G. hirsutum, G. barbadense, G. arboreum,* and *G. herbaceum*) are still grown, but *G. hirsutum* cotton predominates in over 90 per cent of the area. From 1970, in addition to varieties, F_1 commercial hybrids of *G. hirsutum* x *G. hirsutum* and in small extent *G. hirsutum* x *G. barbadense* F_1 hybrids were also grown in a sizable area. The diploid interspecies F_1 hybrids of *G. herbaceum* x *G. arboreum* were also developed and made available for cultivation, but their cultivation by farmers remained stagnant due to hybrid seed production constraints. Cytoplasmic male sterility based (*G. harknessii*) source with USA based restorer sources were used for developing few *G. hirsutum* x *G. hirsutum* hybrids with a view to reduce cost of hybrid seed production and this strategy did not meet with the expected level of success in seed production, area coverage and yield gains. USA line "Gregg GMS" based genetic male sterility was also used for developing a few hybrids and the adoption rate was low for various reasons. A local GMS source was identified in *G. arboreum* background for the production of diploid cotton hybrids by the SAU at Hisar (Haryana state), but not much headway was made.

In 2002-2003, the transgenic cotton (genetically modified cotton) was introduced into cultivation in India first with Bollgard-I (Cry1Ac) and subsequently the Bollgard-II (Cry1Ac+Cry2Ab) and the transgenic cottons were all based on proprietary germplasm and hybrids were predominantly of *G. hirsutum* x *G. hirsutum* combinations. As a result, predominantly *G. hirsutum* x *G. hirsutum* based transgenic cotton hybrids are grown in more than 10.0 million ha corresponding to over 90 per cent of the total area under cotton [16].

Since 1960, the Indian collection has grown with the establishment of the Indian Central Cotton Committee, the All India Coordinated Cotton Improvement Project, and the Central Institute for Cotton Research (CICR). In 1976, the Central Institute for Cotton Research was established with a mandate to function as National Centre for Cotton Genetic Resources collection, documentation, and utilization. Hence, the Central Institute for Cotton Research functioning under the Indian Council of Agricultural Research, New Delhi, an autonomous body under the Government of India is looking after the major responsibility for collection, conservation, evaluation, characterization, documentation and utilization of cotton genetic resources in India with the National Gene Bank at Nagpur. The CICR is collaborating with the National Bureau of Plant Genetic Resources (NBPGR) New Delhi for planning germplasm surveys, exchange, collection and conservation under long term storage facility established for all crops at NBPGR. The entire cotton germplasm collection (total cotton gene pool available in India) is primarily maintained in short and medium storage conditions at the Central Institute for Cotton Research (CICR), Nagpur and its Regional station at Coimbatore (additional set of *G. barbadense* collection). Funding for the CICR and the NBPGR is provided by the Indian Council for Agricultural Research that is an autonomous organization of the Indian Ministry of Agriculture-Department of Agricultural Research and Education (DARE), New Delhi.

The total collection exceeding 10, 000 accessions including small additions in the last couple of years represent almost entirely cultivated accessions of *G. hirsutum, G. barbadense, G. arboreum,* and *G. herbaceum*. In addition, the collection also consists of race stock accessions of each cultivated species, 26 wild species, and 32 synthetic introgression derivatives. Long-term storage of cultivated species are managed by NBPGR in New Delhi and maintained at minus 20°C. A working collection of all cultivated accessions, excluding *G. barbadense* accessions, is stored at Nagpur and maintained at 4°C. *G. barbadense* accessions are stored at Coimbatore and maintained. Wild species and race stock working collections are exclusively maintained at Nagpur *in vivo* under natural field conditions as a species garden. Seed of germplasm accessions are renewed by planned seed increases that include forced self-pollination. The accessions are multiplied in phases to keep fresh seeds without losing viability for a period of three years under short term storage and for frequent use by the breeders and other scientists.

Regular collection expeditions were organized by the National Germplasm Centre in collaboration with the NBPGR in various parts of the country. In recent years, plant explorations have covered a large part of India, and several plant exploration trips are planned through in the future. These include exploration of Mizoram, Sundarban (West Bengal), Assam (Kamroop hills and Jayanti hills), Meghalaya (East Garo Hills), and Tripura. The collection has also grown through exchange with the United States of America, France, Uzbekistan, and Czechoslovakia. The FAO-organized germplasm expeditions also provide opportunities to expand the germplasm collection.

Evaluation and characterization of cultivated germplasm accessions are performed based on cotton descriptors and index card developed by the CICR. Evaluation and characterization of cultivated germplasm include morphological, taxonomical, yield, and yield-contributing characters, fiber quality parameters, and reaction to biotic and abiotic stresses. Basic studies are also performed on the structural variation of gossypol and nectar glands, pollen grains, stigma receptivity, cytogenetic studies, and cross-compatibility among various species (wild and cultivated). Accessions of *G. hirsutum* and *G. arboreum* are evaluated in multi-location evaluation trials conducted at three locations within India (Sirsa, North zone-irrigated; Nagpur, Central zone-rain-fed; and Coimbatore, South zone (irrigated). Accessions are evaluated for yield, boll weight, ginning out-turn fiber properties, and reaction to pests and diseases, and promising genotypes are distributed to breeders and researchers at various cotton research stations and government Institutions within India for research purposes only. Germplasm accession data are maintained by the NBPGR and data are freely available only to Indian government organizations. Official germplasm seed requests are made through NBPGR and a special application form is required to procure exotic germplasm. The NBPGR then determines if a Material Transfer Agreement is already available with the requesting country and makes the necessary correspondence. The seed material is subsequently distributed through NBPGR and Central Institute for Cotton Research on the basis of request. New germplasm is also being generated by the CICR and other SAUs and frequently added to the National Gene Bank at CICR. There are gaps, which are sought to be augmented by inter-country exchanges, explorations and from own development through breeding efforts. There is till now no International Institute for Cotton Research under the CGIAR system. In the era of transgenic cultivars/hybrids, the maintenance of original (unconverted) germplasm receives priority attention so as not to lose the valuable germplasm collected and maintained over several decades. Molecular marker tools are recommended for the evaluation of germplasm in India for identification of various hidden potentials and some work has already been initiated by certain private seed companies and the NBPGR / the CICR and certain SAUs in the country.

Acknowledgements

The authors are grateful to anonymous reviewers of the manuscript and the book editor for critically going through the manuscript and offering valuable suggestions and editorial corrections for improving the quality and content of this chapter.

Author details

S.S. Narayanan[1*], Parchuri Vidyasagar[2] and K. Srinivasu Babu[3]

*Address all correspondence to: narayananss@rediffmail.com

1 Central Institute for Cotton Research (CICR), Nagpur, India

2 Vibha Seeds Group Ltd; Hyderabad, India

3 Namdhari Seeds Private Ltd., Bangalore at Hyderabad, India

References

[1] Sundaram V. Antiquity of cotton, In: 50 Years of Research at Cotton Technological Research Laboratory; Indian Council of Agricultural Research, New Delhi, India, 1974 p. 212.

[2] Santhanam V, Sundaram V. Historical perspective of cotton in India, In: Hand book of Cotton in India eds. Sundaram V, Basu A K, Krishna Iyer K R, Narayanan S S, Rajendran T P. pub: Indian Society for Cotton Improvement, Mumbai, 1999, pp.1-17

[3] Sikka, SM. Joshi AB. Cotton breeding-In: Cotton in India, A Monograph-Vol. I. pub: Indian Central Cotton Committee, Bombay, India1960 pp. 137-335.

[4] Fred E Gillham M, Thomas M. Bell, Tijen Arin, Graham A. Matthews, Claude Le Rumeur,, and A. Brian Hear-Cotton Production Prospects for the Next Decade, pub:

The International Bank for Reconstruction and Development / The World Bank 1818 H Street, N.W. Washington, D.C. 20433, U.S.A.1995, p.1-300

[5] Santhanam V. Sundaram V. Agri-history of Cotton in India-An Overview; in: *Asian Agri-History* 1997 Vol.1, No.4, pp. 235-251.

[6] Anupam Barik. Cotton Statistics at a Glance, Pub. Directorate of Cotton Development, Ministry of Agriculture, Government of India, Mumbai and Director, National Centre for Integrated Pest Management, New Delhi; 2010, pp.148

[7] Terry P. Townsend. “A Balanced Perspective on Cotton: Responding to Valid Problems, Challenging Irresponsible Critics” Report of the Executive Director to the 69th Plenary Meeting of The International Cotton Advisory Committee, Lubbock, TX, USA September 20-25, 2010

[8] Agarwal O P. Cotton Economy in India (1780), pub. COTAAP Research Foundation, (Cotton Association of India) MUMBAI, India February 2012, p.1-12

[9] Armelle Gruère. ICAC Reprint from Cotton: Review of the World Situation, Volume 64-No 5 May-June 2011

[10] Narayanan SS. Exploitation of the potentials of *hirsutum* cotton for cottonseed oil and other by-products, Asian Textile Journal, 2014 (*In Press*).

[11] Wikipedia 2013 Euro bank Notes paper and currency economy in the world

[12] Singh M. Raut RN. Genetical research on Cotton and Jute 1983 pp. 154 191; In GENETIC RESEARCH IN INDIA Eds., Jaiswal PL. and Wadhwani AM.). Publications and Information Division, ICAR, New Delhi

[13] Anonymous. ‘Research achievements A decade’ In: Scientific Monograph No. 11, 1987, Eds. Chandel, KPS &. Singh, BM); pub: National Bureau of Plant Genetic Resources, New Delhi 110 012; India.

[14] Narayanan SS. Singh VV. Kothandaraman R. Cotton Genetic Resources in India; In: Cotton Scenario in India A Souvenir, pub: Central Institute for Cotton Research (ICAR), Nagpur 1990 pp.9 20.

[15] Singh VV. Punit Mohan. Narayanan SS. Cotton Genetic Resources, In: HAND BOOK OF COTTON IN INDIA, Eds: Sundaram V. Basu A K. Krishna Iyer K R. Narayanan S S. Rajendran T P. pub: Indian Society for Cotton Improvement, Mumbai, 1999 p18 40.

[16] Clive James, Global Status of Commercialized Biotech/GM Crops: 2013; Cotton Statistics & News, 2014 No. 51 p1 12

[17] Mare Gilband. Dominique Dessauw. Paulo AV. Barroso. Part 1. Cotton Taxonomy, Breeding & Production Chapter 1. Cotton Taxonomy, Origin and Domestication, In: Cotton Technology for the 21st Century pub: International Cotton Advisory Committee, USA 2010 pp. 5 17.

[18] Fryxell PA. Natural History of the Cotton Tribe, College Station, 1979 Texas A&M University Press.

[19] Narayanan SS. Singh J. Varma PK. Review of genetic wealth in *Gossypium* with special reference to wild species; *Indian society for Cotton Improvement Journal (ISCIJ)*: 1985 p: 51 64.

[20] Fryxell PA. A revised taxonomic interpretation of *Gossypium L. (Malvaceae)*: *Rheedea* 1992: 2(2) p108 165.

[21] Endrizzi JE, Turcote EL, Kohel RJ. Genetics, Cytology and Evolution of *Gossypium Adv. Genet*. 1985 23, 271 335.

[22] Percival AE. Wendel JF. Stewart, JM. Taxonomy and germplasm resources. In: Smith CW and Cothren COTTON: ORIGIN, HISTORY, TECHNOLOGY & PRODUCTION, New York John Wiley & Sons Inc.1990 pp. 33 63

[23] Anonymous. A CATALOGUE OF COTTON GENETIC RESOURCES IN INDIA, Ed. Narayanan, SS. *et al*. 1989 pp.484; pub: Central Institute for Cotton Research, Nagpur (India).

[24] Basu AK, Narayanan SS. Genetics, Cytogenetics and Breeding of Crop Plants (Cotton), Vol.2 Cereal and commercial crops – Cotton, Eds. Bahl PN, Salimath PM and Mandal AK Pub: Oxford & IBH Publishing Co. Pvt. Ltd, New Delhi, 1997 pp: 267 318.

[25] Tripathi KK. Govila OP. Ranjini Warrier. Vibha Ahuja. Biology of *Gossypium spp.* (Cotton): pub: Department of Biotechnology, Ministry of Science & Technology and Ministry of Environment and Forests, Government of India New Delhi 2011 pp:1 50.

[26] Campbell BT, Saha S, Percy R, Frelichowski J, Jenkins JN, Park W, Mayee CD, Gotmare V, Dessauw D, Giband M, Du X, Jia Y, Constable G, Dillon S, Abdurakhmonov IY, Abdukarimov A, Rizaeva SM, Adullaev A, Barroso PAV, Pádua JG, Hoff Mann LV, & Podolnaya L. Status of the Global Cotton Germplasm Resources, *Crop Science,* Vol. 50 July–August, 2010 (*www.crops.org 1179*).

[27] Paopla Fortucci The contribution of cotton to economy and food security in developing countries, Report by ICAC, 2002, p1 10

[28] Narayanan SS. Singh J. Varma PK. Introgressive Gene Transfer in *Gossypium* Goals, Problems, Strategies and Achievement, *Cot. Fib. Tropicales*, 1984 39(4) p123 135

[29] Bhale NL, Narayanan, SS. Need for augmenting Genetic Resources of Cotton Indian Perspective In: "PLANT GENETIC RESOURCES INDIAN PERSPECTIVE" Eds. Paroda RS, Arora RK, Chandel KPS. NBPGR New Delhi 1988 pp.220 231.

[30] Gotmare V. Singh P. Tule BN. Wild and Cultivated Species of Cotton, 2006 *CICR Technical Bulletin* 5, pp.21, Nagpur, India.

[31] Basu AK, Paroda RS. 'Hybrid Cotton in India – A Success Story' Asia Pacific Association of Agricultural Research Institutions, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand, 1995 pp. 38.

[32] Bhale N L. Heterosis Breeding In HAND BOOK OF COTTON IN INDIA eds. Sundaram V. Basu A K. Krishna Iyer K R, Narayanan S S. Rajendran T P. pub: Indian Society for Cotton Improvement, Mumbai, 1999, pp.57 78

[33] Narayanan SS. Innovative research under IP regimes with special reference to cotton *Asian Textile Journal* December, 2013 pp.65 72

[34] Phundan Singh. Narayanan SS. Cotton Improvement Procedures In: HAND BOOK OF COTTON IN INDIA, Eds: Sundaram V. Basu A K. Krishna Iyer K R. Narayanan S S. Rajendran T P. pub: Indian Society for Cotton Improvement, Mumbai, 1999 p.41 56.

[35] Anurudh K. Singh. Dhillon BS. Chapter 52, National Network on Conservation of Plant Genetic Resources SEED IN INDIA, SEED CONSERVATION: TURNING SCIENCE INTO PRACTICE, Eds. Smith RD, Dickie JB, Linington SH. Pritchard HW. and Robert RJ. London: The Royal Botanic Gardens, Kew, 2003 pp. 1023.

[36] Cotton International Annual; New Frontiers envisioning cotton's future, Meister Publication, 2014 pp.145.

[37] Loknathan TR. Phundan Singh. Agarwal RJ. Punit.Mohan. Suman Bala Singh. Vinita Gotmare. Singh VV. Genetic Enhancement of Cotton, 2003, *CICR Technical Bulletin* 26 pp. 16, Nagpur, India.

[38] Rathinavel K. Manickam S. Gururajan N. Deshmukh RK. Shanthy V. Draft National Guidelines for the conduct of DUS Test of Cotton (*Gossypium* Spp.), compiled by AICCIP; 2006 pp1 40, Central Institute for Cotton Research, Regional Station, Coimbatore, India.

[39] Malik SS. Singh SP. Role of plant genetic resources in sustainable agriculture *Indian J. Crop Science*, 2006, 1(1 2) p.21 28.

[40] Percy G. *Gossypium* Germplasm Resources for Cotton Improvement Genomics and Biotechnology, ARS USDA, 2009 pp18.

[41] Parchuri Vidyasagar. "Cotton Improvement in India – Contribution and Perspectives of Private Seed Industry" Dr. V. Sundaram Memorial Lecture Series (2011), 09 June 2011 pp 1 26 pub: Indian Society for Cotton Improvement (ISCI) at Central Institute for Research on Cotton Technology (ICAR) Mumbai (India).

[42] CICR Nagpur "The Cotton Innovate – CICR Newsletter" weekly publication (June 2013) by Central Institute for Cotton Research Post Bag No. 2, Shankar Nagar PO, Nagpur 440010 Phone : 07103 275536 Fax : 07103 275529; email: cicrnagpur@gmail.com; CICR Official website: www.cicr.org.in.