Chapter 2

Institutional Structure of Cotton Research in India

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Additional information is available at the end of the chapter

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Abstract

The chapter traces the landmark events in the contemporary history of cotton in India. The achievements in research and development that transformed India from a chronic importer of cotton to the largest producer and a net exporter of cotton are highlighted. The structure of cotton research undertaken by the institutes under the National Agricultural Research and Education System (NARES) are also elaborated. The institutional mechanism responsible for varietal release, seed production and transfer of technology are briefly described. The immediate challenges facing the cotton sector and approaches to tackle them are also discussed.

Keywords: ICAR-CICR, ICAR-CIRCOT, AICRP on Cotton, cotton research, transfer of technology

1. Introduction

India is the country with primarily an agrarian economy. Despite massive industrialization and rapid growth of tertiary sector following the economic liberations in 1990s, agriculture sector still contributes about 14% to the national gross domestic product (GDP). Agriculture supports the livelihood of about 50% of its population. In the post-independence era, huge investments were made in agricultural research for the expansion of irrigation and soil water conservation and to increase the adoption of new agricultural technologies.

The Indian Council of Agricultural Research (ICAR) is the apex agriculture research organization under the Department of Agricultural Research and Education (DARE), Ministry of Agriculture, Government of India. It coordinates, guides, and manages research, education and extension services in the agriculture sector comprising field crops, horticultural crops, agro-forestry, animal sciences and fisheries. These functions are discharged through the NARES comprising 96 ICAR research institutes, 77 'All India Coordinated Research Projects/ Networks', 4 deemed to be Universities [Indian Agricultural Research Institute (IARI), Indian Veterinary Research Institute (IVRI), National Dairy Research Institute (NDRI) and Central Institute of Fisheries Education (CIFE)], 62 State Agricultural/Veterinary/Horticulture/Fishery Universities and 641 Krishi Vigyan Kendra [1]. The ICAR played a key role in ushering the green revolution and subsequent sector-wise development that transformed in India from a chronic importer to an era of self-sufficiency in food grains and allied agricultural products. The technologies developed through the NARES system helped farmers to increase the production of food grains from 50 million metric tonnes (MMTs) in 1950 to 264 MMTs in 2013. During the same period, there was a 6-fold increase in horticultural crops, 12-fold increase in fish production, 8-fold increase in milk production, 27-fold increase in egg production [1] and an 11-fold increase in cotton production from 0.58 MMT in 1950/1951 to 6.7 MMT in 2013/2014.

2. Role of cotton in the Indian economy

The textile and clothing industry has a long history in India. Today, this sector contributes 6% of the GDP and 14% of India's exports [2]. Around 65% of textile production and over 75% of textile exports are based on cotton. During 2014/2015, India produced 6.5 MMT of cotton fibres from 11.96 million hectares (m ha) area. The cotton cultivation sector engages around 10 million farmers and involves another about 30 million people operations related to cotton cultivation, cotton trade and its processing such as ginning, spinning, weaving and garmenting. Out of the total cotton consumed, 94% is spun into yarn and the rest used in the production of surgical cotton and other applications [3].

Cotton is a multi-component crop, and apart from lint, it provides valuable by-products such as cotton seed, linter, oil, meal and biomass (cotton stalk). Considering the importance of cotton to India's economy, the ICAR supports research on cotton production through the ICAR—Central Institute for Cotton Research (CICR) and All India Coordinated Research Project on Cotton (AICRP on Cotton). Research on post-harvest technology and value addition is led by ICAR—Central Institute for Research on Cotton Technology (CIRCOT).

3. Issues and challenges in cotton production research

During the post-independence period, the cotton sector faced several challenges at different periods and the cotton R&D continuously changed its priorities to address these challenges. The first task of independent India was to ensure sufficient cotton to its domestic mills. During partition, 21% of the prime cotton area that provided 40% of the total production became a part of Pakistan, but 409 out of the 423 cotton mills remained in the Indian Union. This caused a huge shortage of domestic cotton. To tide over this crisis and reduce imports, the 'GROW MORE COTTON' programme was implemented between 1951/1952 and 1960/1961. Special schemes were initiated to increase in area under cotton, increase in area under irrigation, supply improved seeds and fertilizers at subsidized rates and raise the basic ruling price [4]. The net result was an increase in area from 4.3 m ha in 1947/1948 to 7.61 m ha in 1960/1961.

During 1950s, India was producing more of short staple cotton and a huge quantity of long and extra-long staple was imported. Focus of research hence shifted to replace indigenous *Gossypium arboreum* and *Gossypium herbaceum* cotton by Indian *Gossypium hirsutum* varieties. The resulting 'Madras Combodia' series and 'Laxmi' in south India, inter-specific Indo-American varieties 'Deviraj' and 'Devitej' in Gujarat and Maharashtra and the Punjab-American cottons 'P 216F' and '320F' brought about substantial quality improvement [5]. Agronomic field trials to optimize yields from these varieties were initiated. Because of these efforts, the area under *G. hirsutum* cotton increased from 3% in 1947/1948 to 29% in 1960/1961 and 50% in 1970/1971 [6]. Basu [7] has reviewed the cotton genetics and breeding work carried out during the 1970s and 1980s. To further increase the productivity of cotton and widen the quality spectrum, hybrids *viz*. 'Hybrid 4' (intra- *hirsutum*) and 'DCH 32' (*hirsutum* × *barbadense*) were released. These became popular and heralded in the hybrid cotton era in India. Extra-long staple 'Suvin' was introduced in the 1970s.

A large-scale replacement of indigenous cotton with G. *hirsutum* varieties and increase in the application rates of fertilizers changed the pest complex. Whitefly (*Bemisia tabaci*) and American bollworm (*Helicoverpa armigera*) replaced the conventional insect pest-spotted bollworm (*Erias vitella*), spiny bollworm (*Erias insulana*) and pink bollworm (*Pectinophora gossypiella*) and emerged as major pests of cotton [8]. Insecticides were introduced in the 1960s. The availability of carbamates and organophosphates shifted research focus on chemical-based pest control in cotton. Pyrethroids were introduced in 1985. Elimination of natural enemies and subsequent outbreaks of whitefly and bollworms promoted research and development of integrated pest management (IPM) systems [9] in the 1990s. The phase between 1992 and 2002 saw the emergence of private sector as a major contributor to seed and pesticide research. To modernize the entire cotton scenario, the government initiated the 'Technology Mission on Cotton' in 2000. Repeated crop failure and rising pesticide resistance to bollworms led to the promotion of insecticide resistance management (IRM) strategies and subsequently the introduction of *Bacillus thuringiensis* toxin containing (Bt) cotton in 2002.

3.1. Current challenges facing cotton in the post-Bt era

A critical note on the contemporary challenges being confronted by the cotton farmer is available in [10]. Here, we highlight some key challenges:

Declining the total factor productivity and soil health and fertility. A widespread adoption of Bt hybrids converted traditional multi-cropping systems (i.e. inter cropping, crop rotations, mixed cropping, etc.) to mono-cropping systems. An imbalanced application of fertilizers in favour of N and progressive depletion of macro and micro-nutrients has deteriorated soil heath and fertility. From 2002 to 2012, the fertilizer use for cotton cultivation increased about 8.1% per annum [11], but the partial factor productivity (expressed as kg of lint/kg of fertilizer applied) for fertilizers declined. Research is, therefore, necessary to rationalize fertilizer use through soil enriching cropping systems.

Resurgence of leaf hoppers and whitefly, and emergence of minor pests. Minor pests, such as thrips, mirid bugs, mealy bugs, stem weevil, etc., have emerged as serious pests. Bt-cotton seeds are treated with imidacloprid to protect the crop from sucking pests. Repeated over the top application of the same molecule made jassids resistant to this chemical. The resurgence of whitefly caused huge economic loss to farmers in the North India. Alternate pest management strategies are needed.

Pink bollworm resistance to Bt toxin. Transgenic Bt-cotton conferring resistance to bollworms was introduced to provide protection against bollworms. Poor stewardship, such as extending the crop duration from 180 days to 220 or even 250 days by providing additional irrigation and fertilizers, non-compliance of refugia put Indian cotton at the doorstep of an era of resistance to Bt toxins. The damage in Bollgard II® (BG II) and Bt-hybrid in parts of Gujarat and Andhra Pradesh by pink bollworms is compelling researchers to reformulate the pest management strategies.

Increasing the production cost and declining the profitability. During the last decade, there has been a tremendous increase in the input usage particularly fertilizers. There has been a reduction in partial factor productivity of fertilizers (kg yield/kg of fertilizer) and increase in the cost of production [11].

Lack of synchrony between input requirement by crop and input availability/supply in rainfed cotton. About 60% of the cotton is cultivated under rainfed conditions, mostly in the Central and South India. Sowing commences with the onset of the monsoon in June and the monsoon recedes by mid September. The present-day hybrids are of long duration with a long fruiting window beginning from the end of September during the post-monsoon phase. The peak water requirement during early boll development phase coincides with the receding soil moisture phase. This induces moisture stress and reduces yield. Similarly, the peak nutrient requirement is when the crop is 90–120 days old. Lack of nutrient in soil (due to lopsided application schedule) or inadequate soil moisture to solubilize nutrients causes nutrient deficiency adversely affecting yield. Early maturing genotypes and revised nutrient scheduling based on demand/supply synchrony is another challenge.

Labour shortage, delays in sowing and cropping operations that lead to reducing yields. The entire cotton produced in India is handpicked. Non-availability of low-cost machines adoptable by small farmers is another major challenge and will remain the focus of research.

4. Brief history of cotton research and development in India

Indian sub-continent is recognized as the home of diploid cotton and the cotton-based clothing, and textile industry flourished even during the pre-Christian era. India is globally recognized as a traditional home of cotton and cotton textile. The domestication of diploid Asiatic cotton (*G. arboreum* and *G. herbaceum*) for commercial cultivation to meet the clothing needs is

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considered to have begun from Harappan civilization [12]. Only *G. arboreum* and *G. herbaceum* cotton were grown until the middle of eighteenth century.

The East India Company in 1790 first attempted to grow 'Bourbon' (*G. hirsutum* race punctatum) in Bombay and Madras Provinces, but the efforts were not successful. In 1840, trials with *G. hirsutum* cotton was carried out in Gujarat, the Deccan and Konkan regions and the introduction of New Orleans (*G. hirsutum* race latifolium) proved partly successful in Hubli (Karnataka). Attempts to introduce American, Peruvian, Egyptian and Sea Island varieties of *Gossypium barbadense* cotton in 1905 in Coimbatore were also not successful [13].

The first significant research achievement was the successful introduction of *G. hirsutum* (Cambodian cotton) during 1904/1905 in the Madras State [14]. Agriculture Departments in various provinces of India were established in 1904. Staff posted in the Department of Agriculture in Bombay, Punjab, Madras, Central Provinces and Berar and United Provinces initiated cotton improvement work through the selection of superior lines for yield and fibre quality from the existing mixtures. The efforts resulted in the development of 'Co 1', 'Co 2', 'Cawnpore American No. 9', '4 F' in *G. hirsutum*, 'V 262', 'V 434', 'N 14', 'C 520' in *G. arboreum* and 'H 1' in *G. herbaceum* suitable for various cotton growing tracts [15].

The establishment of the Indian Central Cotton Committee (ICCC) in Bombay as a Technical Advisory body to the Government in 1921 is considered as a major landmark in the history of cotton research in India. The Indian Cotton Cess Act was enacted in 1923 to levy a cess on cotton consumed by the domestic textile mills or exported to generate funds to promote systematic research on cotton. The ICCC became a statutory body with funds at its disposal for promoting research in cotton. It established the Cotton Technological Research Laboratory (CTRL) [later rechristened as Central Institute for Research on Cotton Technology (CIRCOT)] at Bombay in 1924 with Dr. A. J. Turner as its founder Director [16]. It undertook two main activities: (1) conducting spinning tests on various strains of cotton received from Agricultural Departments situated in various locations of the country and (2) conducting tests on fibre properties to relate fibre properties with the spinning value of cotton. Emphasis was also given to the development and standardization of testing procedures for fibre evaluation and spinning performance [16].

From 1924 to 1937, the ICCC funded the Department of Agriculture of the Provincial Governments for the improvement of cotton cultivation in the country. Systematic research on cotton breeding, varietal improvement, seed production, agronomy, entomology and physiology were initiated. ICCC organized the first conference of cotton workers in Bombay in 1937 during which a historic decision to intensively pursue cotton breeding and varietal improvement work in *G. hirsutum* cotton for increasing the yield and fibre quality was adopted. This chartered the future of cotton research in India, and it received further impetus after the partition and independence of India in 1947.

The concerted, research and development efforts under the aegis of ICCC helped independent India to increase the cotton area to 7.8 m ha and the production to 5.3 million bales (a bale is equal to 170 kg) by 1966/1967. The ICCC was abolished in 1966, and CTRL was placed under the administrative control of ICAR. The ICAR reorganized its research set-up in 'Crop Sciences' and the 'All India Coordinated Cotton Improvement project' (AICCIP) [now rechristened as All India Coordinated Research Project on Cotton (AICRP on Cotton)] was launched in 1967 with its headquarters in Coimbatore (Tamil Nadu) with a network of cotton research centres. This set-up, along with basic and strategic research on cotton production conducted at the ICAR-Central Institute for Cotton Research (Nagpur) and that on fibre quality testing and post-harvest value chain at ICAR-CIRCOT, forms the present structure of cotton research.

The Ministry of Agriculture, Government of India set up the Directorate of Cotton Development (DOCD) in Bombay in 1966 for implementing developmental schemes on cotton. To cater to the marketing of cotton and to provide remunerative prices to farmers, the Ministry of Textiles, Government of India, established the Cotton Corporation India, in 1970 with its headquarters in Bombay. The launching of Technology Mission on Cotton (TMC) in 2000 to boost research and extension capabilities as well as modernize the marketing and processing sectors was another landmark by the Government of India [12].

5. Present structure of cotton research in India

The ICAR-CICR (Nagpur), ICAR-CIRCOT (Mumbai) along with the AICRP on Cotton together conducts/coordinates the research work on cotton (**Figure 1**). The CICR, a premier national institute under the ICAR, is the nodal agency for cotton production research. With its headquarters in Nagpur and regional stations at Sirsa (north India) and Coimbatore (south India), CICR conducts basic and strategic research on all aspects of cotton production. From 2000, it is also coordinating the TMC (Mini Mission I) being carried out in a networking mode with Agricultural Universities located in the cotton growing regions and sister ICAR institutes. The AICRP on Cotton with headquarters at Coimbatore has a network of 22 cotton research centres located in 11 cotton-growing states. AICRP on Cotton conducts multi-location and multi-disciplinary research on applied aspects of cotton including varietal development and evaluation/site-specific modifications of agro-technologies. Research on post-harvest processing of seed cotton and value addition of cotton is carried out at the ICAR-CIRCOT (Mumbai). Its regional centres assist the AICRP on Cotton for fibre quality analysis of cultures and spinning test of varieties developed.

The Government of India approved the commercial cultivations of Bt transgenic cotton in 2002. Currently, Bt hybrids are developed by private seed companies under license from Monsanto. For their release, one year of field trial in State Agricultural Universities is mandatory. These hybrids are then released by event-based approval mechanism (EBAM) committee under Review Committee on Genetic Manipulation (RCGM)/Genetic Engineering Approval Committee (GEAC) based on criteria laid out by GEAC.

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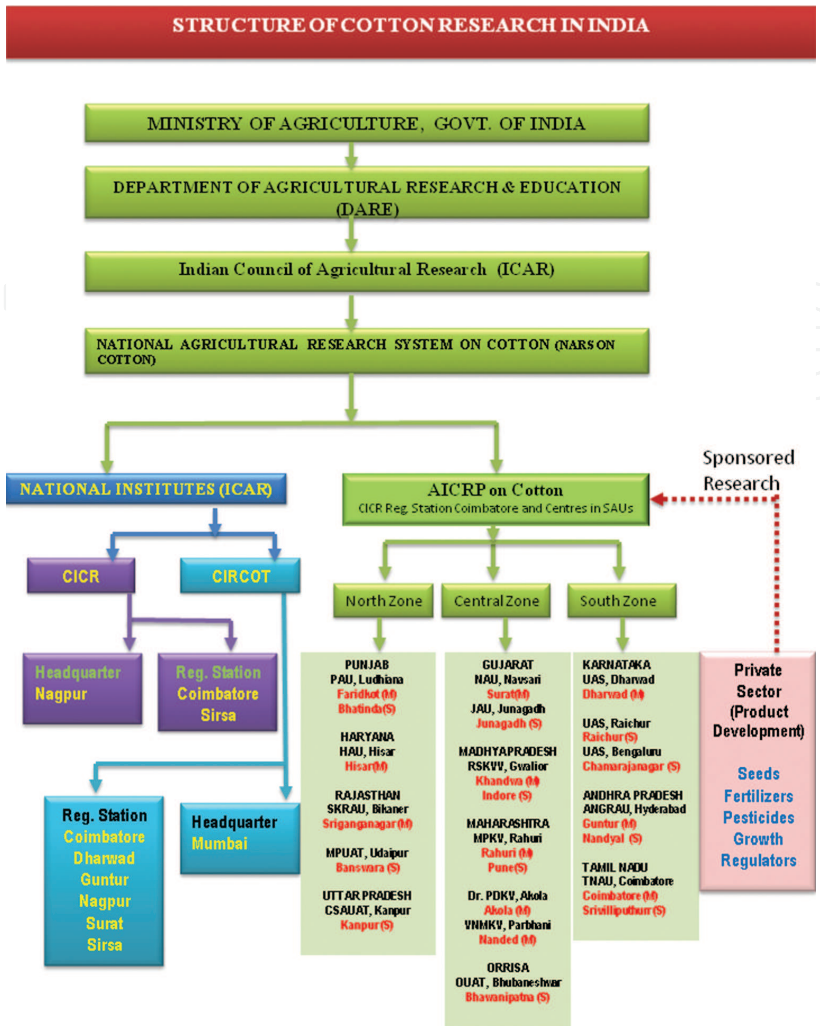

Figure 1. Structure of cotton research in India.

6. Cotton research institutes

6.1. ICAR-Central Institute for Cotton Research (CICR)

The ICAR-CICR was established at Nagpur, Maharashtra (central India), in 1976. ICAR-CICR is **mandated** to conduct basic and strategic research to improve yield and quality of cotton and to create new genetic variability in cotton to facilitate location/cropping system-based adoption. It also facilitates technology transfer to different user agencies and extends consultancy and linkage with national and international agencies.

6.1.1. Research projects/programmes under plan scheme

Details regarding the research programmes undertaken in the past have been made available by International Cotton Advisory Committee (ICAC) [17], and hence it is not presented here.

The programmes being undertaken during XII five year Plan (2012/2013 to 2016/2017) under plan scheme are enlisted here:

1. Genetic improvement and precision breeding of different cotton varieties for specific agro-eco sub-regions with an emphasis on improving the crop architecture, harvest index, ginning outturn, fibre quality, resistant to biotic and abiotic stresses;
2. Documentation of genetic diversity of cotton germplasm through DNA barcoding and utilization of molecular markers in breeding;
3. Discovery of novel genes for resistance to insect pests, leaf-curl virus, water logging and drought for transgenic development;
4. Development of sustainable precision input management systems through consolidation of integrated weed, water and nutrient management strategies;
5. Consolidating ecologically compatible and profitable sustainable crop health management for conventional and transgenic cotton;
6. Priority setting and market intelligence to prioritize 'demand driven research' and appropriate 'technology placement'.

6.1.2. Technology Mission on Cotton (TMC)

The Mini Mission-I (MM-I) of TMC was aimed at strengthening strategic cotton research to provide critical interventions to improve the production, productivity and quality of cotton. ICAR-CICR is the nodal agency for implementing these research programmes through a network of partners under the NARES selected based on human resource/infrastructure present at different centres. The programmes undertaken under TMC MM-I during XII five-year plan period are summarized below:

1. Development of indigenous multi-gene constructs and Bt transgenic varieties:
2. Development of varieties resistant to cotton leaf curl disease (CLCuD), bacterial leaf blight (BLB) and nematodes through marker-assisted breeding;
3. Consolidation of repository of high-strength cotton genotypes. Evaluation of genotypes and standardization of agro-techniques for high-density planting and surgical cotton production;
4. Simulation models/electronic gadgets to predict insect infestation, bollworm resistance to Bt cotton, area, production and price of cotton;
5. Voice call-based e-Kapas network and technology documentation for effective dissemination;
6. Development of cotton picker for small scale cotton production systems.

6.1.3. Structure

ICAR-CICR has its headquarters at Nagpur (Maharashtra) and regional stations at Sirsa (Haryana) and Coimbatore (Tamil Nadu). Presently, there are 65 scientists belonging to 16 disciplines. **Figure 2** describes the organizational structure of ICAR-CICR with details of scientists working in different disciplines.

6.1.4. Research achievements

ICAR- CICR is globally acclaimed for its basic and strategic research outputs that led to the development of several products, processes and technologies. A detailed account of the research achievements is available in ICAR-CICR Vision 2030 and Vision 2050 document and in the Annual Reports uploaded in [18]. A summary is presented here.

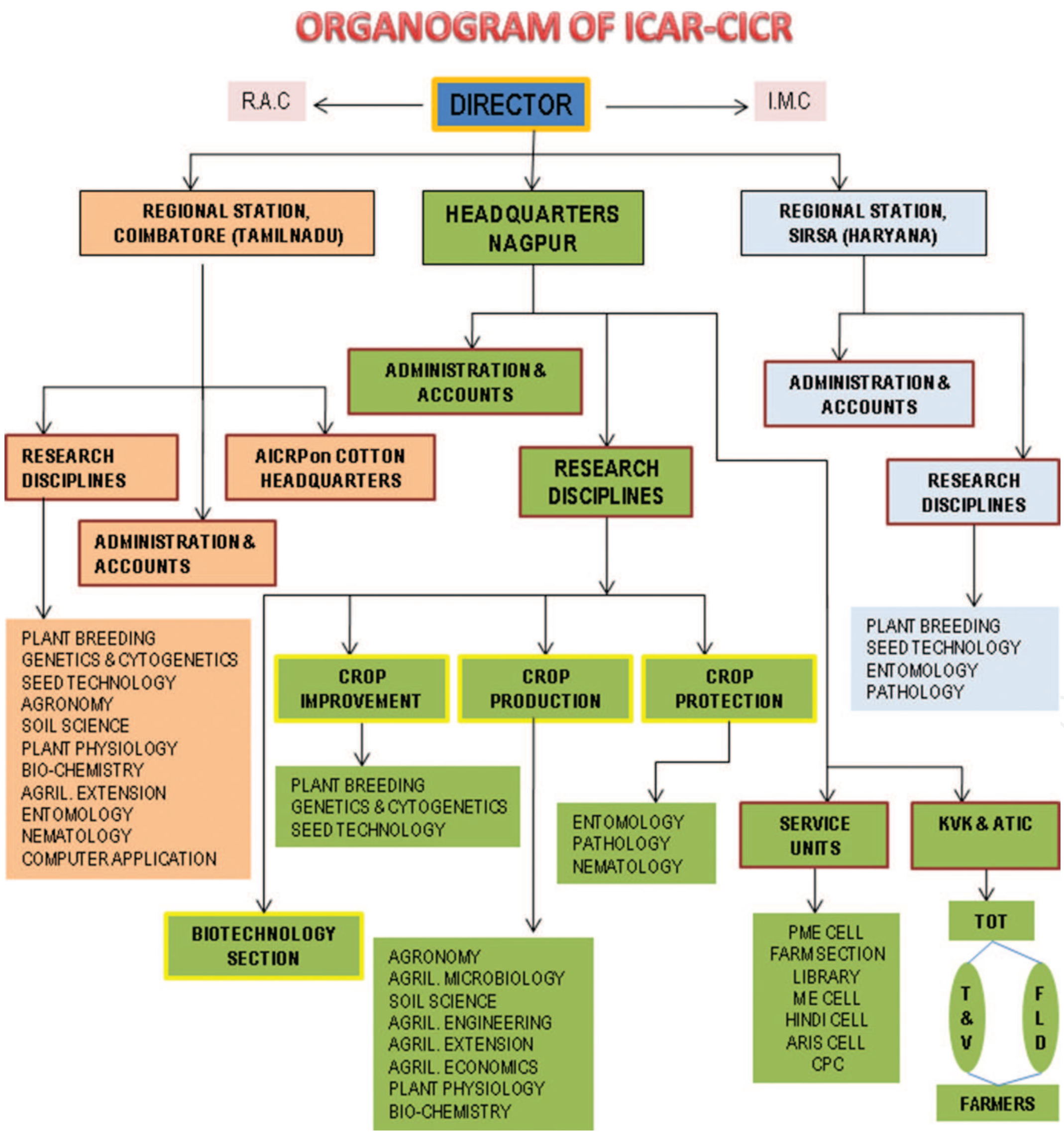

Figure 2. Organogram of ICAR-CICR.

The institute is the custodian of the world's largest germplasm collection on cotton. At present, the repository has 11,543 accessions including 8413 accessions of *G. hirsutum*, 310 accessions of *G. barbadense*, 1936 accessions of *G. arboreum*, 565 accessions of *G. herbaceum* and 40 interspecific derivatives in addition to 26 wild species, 253 accessions of perennials and land races. The collection is being continuously enriched by procuring exotic accessions under the 'Reciprocal Exchange of Germplasm Agreement'. Efforts are underway to characterize them. These serve as valuable resources of biodiversity and are being utilized for developing varieties with economically important traits. All the land races of indigenous cotton are being collected and conserved *ex situ*.

ICAR-CICR has released 30 improved genotypes with high yield potential, excellent adaptability and fibre characteristics (**Table 1**).

Name of species	Name of hybrids/varieties
Intra-*hirsutum* hybrids	'Savitha', 'Suguna', 'Surya', 'Kirthi', 'Omshankar', 'CSHH 198', 'CSHH 238', 'CSHH 243' and 'CSHG 1862'
Interspecific hybrids (*G. hirsutum* × *G. barbadense*)	'HB 224' and 'Shruthi'
Intra-*arboreum* hybrid	'CISAA 2'
G. hirsutum varieties	'MCU 5 VT', 'LRA 5166', 'Supriya', 'Kanchana', 'Anjali', 'CNH36', 'Arogya', 'Surabhi', 'Sumangala', 'CNH 120 MB', 'Suraj', 'CNHO 12', 'CSH-3129' and 'CCH 2623'
G. arboreum varieties	'CISA 310','CISA 614' and 'CNA 1003 (Roja)'
G. barbadense variety	'Suvin'

Table 1. List of hybrids and varieties released by ICAR-CICR for commercial cultivation.

Notable among them are 'LRA 5166', 'LRK 516', 'Surabhi', 'Suraj', 'CISA 2' and 'Suvin'. 'Suvin' is the World's best extra-long staple variety. 'Suraj' has excellent fibre quality and is now being promoted for high-density planting system (HDPS). In addition, researchers have developed 49 genetic stocks (*G. hirsutum*—33, *G. arboreum*—16) that have been registered for their unique, novel and distinct characteristics. For instance, a *G. arboreum* genetic stock with the highest ever fibre strength of 29 g/tex [International Calibration Cotton (ICC mode)] is available. These are being used to develop genotypes with economically important traits and unique morphological markers.

Cytoplasmic genetic male sterile system comprising 137 *Gossypium harknessii*, 15 *Gossypium aridum*, 57 *G. harknessii*–based restorers, and 20 genetic male sterile lines are being maintained at ICAR-CICR. Utilizing male sterility system, 82 genotypes have been converted under cytoplasmic male sterility (CMS) background and, 66 genotypes have been converted under genetic male sterility (GMS) background. To reduce the cost of hybrid seed production, a thermosensitive genetic male sterile line, TGMS 1-1, was identified and characterized in *G. arboreum*. This could be used for hybrid seed production during summer months. Recombinant inbred lines for ginning out turn, fibre quality traits (length, strength, micronaire) and disease

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(BLB) resistance have been developed. These are being used in marker-assisted breeding programme for specific traits.

CICR developed, patented and commercialized 'farmer-usable' immunodiagnostic kits for genetically modified (GM) cotton and insecticide quality. The Bt kits are popular among farmers and seed testing agencies in the country, and these helped to curb the spread of illegal and spurious Bt-cotton seeds. The ELISA and dip stick kits to test the quality and residue of pyrethroids and organophosphates are also popular. The institute has developed 'PCR-based kits' to detect various diseases including the dreaded cotton leaf curl virus.

The institute is globally recognized for its pioneering work on fundamental research on insect resistance to insecticides and Bt toxins. It has developed stochastic models and insecticide resistance management (IRM) strategies. The institute provides leadership for national dissemination of the IRM and integrated pest management (IPM) technologies for conventional and Bt cotton. It has won national and international awards for its contribution in development and dissemination of IRM strategies.

Mealy bugs (*Phenacoccus solenopsis*) caused considerable economic damage to cotton during 2005 to 2008, and ICAR-CICR devised a minimum invention strategy to control this pest. Biological formulations, 'MEALY-KILL' and 'MEALY-QUIT' have been developed and found effective for the control of mealy bug. Three novel lectins have been identified having potential to control sap-sucking insect pests (aphids, leaf hoppers, whiteflies).

The agronomists developed several production technologies. Some promising ones include technology for organic cotton production, poly-mulch techniques, multi-tier cropping systems, innovative inter-cropping systems, conservation tillage system, *in situ* soil moisture conservation, water harvesting and recycling, stale seed-bed technique for weed management, foliar nutrition in cotton, integrated nutrient management in cotton-based cropping system, enhance nitrogen use efficiency (NUE) using coated urea, dry seeding and transplanting technology, etc. A cotton crop simulation model InfoCrop-cotton was developed and validated to simulate cotton growth and yield. This is being put to use in land evaluation and climate change studies.

For sustainable cotton production on marginal soils, the institute developed and demonstrated a new concept of HDPS using non-Bt varieties that has potential to improve yields of rainfed cotton, especially in the states of Maharashtra, Madhya Pradesh and Andhra Pradesh. More than 10,000 demonstrations on HDPS technology were conducted. Results showed that HDPS is a viable option to improve the productivity of cotton particularly under rainfed conditions at reduced production costs.

The effect of elevated CO_2 at ambient and increased temperatures and different soil moisture regimes has been researched. Both dry matter production and seed cotton yields were higher at elevated CO_2 (600 ppm) compared to ambient temperature. Elevated levels of CO_2 significantly increased plant height, node number, sympodia number, leaf number, reduced shedding of bud and bolls and delayed senescence of leaves. The increased biomass production under elevated CO_2 atmosphere also helps in sequestering more carbon.

ICAR-CICR has recently established a 'voice call' weekly advisory system called 'e-kapas' network and connected more than 0.2 million cotton farmers for technology dissemination and backstopping. Advisories and alert services are being issued to these cotton growers in eight regional languages so as to enable them initiate proactive measures. The institute is also engaged in first-line transfer of technology. These include front-line demonstration (FLD), on-campus/off-campus demonstrations, seed village programme, farmer-scientist interaction and training of farmers and extension personnel.

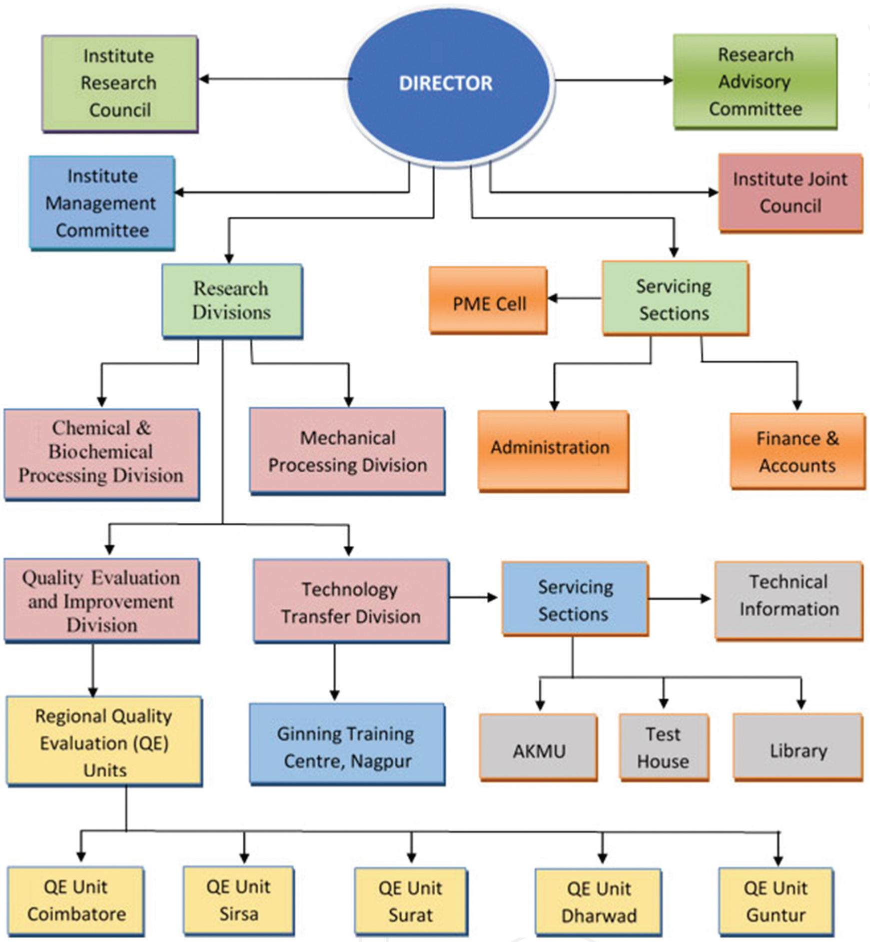

Figure 3. Organizational structure of ICAR-CIRCOT (Source: ICAR-CIRCOT Annual Report 2014–2015 available at [19]).

6.2. ICAR- Central Institute for Research on Cotton Technology (CIRCOT), Mumbai

The ICAR-CIRCOT was established in 1924 for conducting research on all aspects of cotton processing. It houses state-of-the-art research facilities and is notified as a referral laboratory on cotton textile. Its **vision** is to achieve global excellence in cotton technology. Its **mission** is to provide scientific and managerial interventions to post-harvest processing and value addition to cotton and utilization of cotton by-products to maximize economic, environmental and societal benefits. The **mandates** of the ICAR-CIRCOT are as follows: (1) technology development for enhanced utilization of cotton and other natural fibres and their by-products; (2) improve the quality of cotton and other textile products through participatory research in

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national programmes; (3) develop human resource and standard reference materials, undertake technology commercialization, consultancy and testing and function as referral laboratory for cotton and allied sectors.

6.2.1. Core areas of current research programmes

1. Pre-ginning and ginning;

2. Mechanical processing, technical textiles and composites;

3. Characterization of cotton and other natural fibres, yarn and textiles;

4. Chemical and bio-chemical processing and biomass and by-product utilization;

5. Entrepreneurship and human resource development along the cotton value chain.

6.2.2. Structure

ICAR-CIRCOT has four research divisions (**Figure 3**). These are the mechanical processing division (MPD), quality evaluation and improvement division (QEID), chemical and biochemical processing division (CBPD) and transfer of technology division (TTD). It has five regional units at Sirsa (Haryana), Surat (Gujarat), Dharward (Karnataka), Guntur (Andhra Pradesh) and Coimbatore (Tamil Nadu). Additionally, the Ginning Training Centre (GTC) situated at Nagpur (Maharashtra) regional unit also provides training to persons employed in ginning-pressing industries.

6.2.3. Research achievements

The institute is constantly engaged in developing new technologies and machineries for better utilization of cotton and other natural fibres. It provides yeomen service to the cotton trade and industry by providing the quality assessment support for fibre, yarn and fabrics. A glimpse on important research achievements of CIRCOT is as follows. This portion has been adapted from CIRCOT Vision 2050 document.

Since its inception, ICAR-CIRCOT has been guiding cotton breeders of India by fixing norms for fibre characteristics. It also evaluates fibre quality parameters of elite cultures sponsored by breeders into AICRP on Cotton and evaluates the spinning potential of pre-release varieties/hybrids. It has also developed a miniature spinning system for assessing the spinning potential of small quantity of cotton available with researchers and preparation of fibre sliver and yarn samples. Research on rotor spinning has proved its utility in Indian spinning sector for the production of quality cotton and blended yarns. Outputs from its research on yarn faults have helped the textile industry to produce yarn with fewer defects at par with world standards.

ICAR-CIRCOT has conducted pioneering research in revealing the basic structure of cotton and other natural fibres. It has also developed a non-destructive infrared technique to determine the cellulose content in fibres. The institute supplies ‘calibration cotton’, a standard reference material, to spinning mills, cotton-trading houses and various other organizations.

It provides separate sets of standards for conventional fibre testing instruments and for high-volume instrumentation.

The institute undertakes regular cotton ginning and skill training of technicians for ginning industry. The Ginning Training Centre at Nagpur, Maharashtra, with state-of-the-art facility for research and training, is first of its kind in Asia. Designing, development and commercialization of inclined and horizontal pre-cleaners for removal of sticks, bur, etc. for installation in ginning centres was another remarkable achievement. It has also developed an array of pre-cleaning systems for processing machine picked cotton and lowering the trash to 5% in the ginned lint. It was actively engaged in the TMC programme that led to the modernization of over 850 ginneries. This helped in the reduction of trash and other contaminants in Indian cotton.

The institute has developed a variable speed double roller gin where in the speed of both rollers and beaters can be adjusted without any additional demand of power. It has also developed portable ginning machines (Lilliput Gin, CLOY gin, Hipro Gin) for assisting cotton breeders, seed producers, traders and farmers to gin small quantity of seed cotton for assessment of ginning out turn (GOT) and quality of fibres.

The institute has developed a technology for dying of cotton and other cellulosic fabrics using natural (lac) dyes. Its research on the use of natural dyes to achieve uniform shades through machine dyeing has received global appreciation. ICAR-CIRCOT has also developed a technology for bio-scouring of cotton and blended fabrics that saves energy load by 30% and also minimizes the pollution load by 25%.

ICAR-CIRCOT is engaged in basic research on the application of nontechnology, keeping in view the ethical and ecological issues. Research programmes are focusing on the preparation of nano-composites from biopolymers, nano-functional (UV protection, self cleaning, anti-bacterial, file retardant) textiles electro-spinning of nano-fibres for nano-filters and nano-absorbents [3]. It has recently developed a technology for coating of cotton fabrics using zinc oxide nano-particles to impart UV protection and anti-microbial properties.

In the field of bi-product utilization, use of cotton stalks for the production of pulp and paper, kraft paper for the preparation of corrugated boxes, charcoal briquettes and particle boards and bio-methanation from textile waste are some noteworthy achievements. Its technology of aerobic composting of willow dust using NaOH and microbial consortia provides valuable organic manure in 30 days. Solid-state fermentation technology for producing gossypol-free lysine-rich cotton seed cake for feeding non-ruminants has been developed. The institute is also credited with the development of an enzymatic process to prepare peptones from cotton seed meal. Peptones are used for producing enzymes, antibiotics and bio-pesticides.

6.3. All India Coordinated Research Project on Cotton (AICRP on cotton)

The AICRP on Cotton was established in 1967 with Headquarters at Coimbatore. AICRP on Cotton conducts multi-location and multi-disciplinary research with network of centres involving State Agricultural Universities (SAUs) of all the major cotton-growing states of the

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country. The centres of AICRP on Cotton, located in all the major cotton-growing states have researchers from different disciplines to facilitate multi-locational evaluation. Its objectives are to identify and facilitate release of best varieties and hybrids for different agro-climatic situation. The centres also validate and fine tune agro technologies and pest/disease management strategies. After a techno-economic feasibility assessment, these technologies are incorporated into the package of practices for cotton production in the respective location [20].

Figure 4. Structure of the AICRP on Cotton network.

6.3.1. Current cotton research programmes

Currently, the research programmes of AICRP on Cotton is focusing on developing high-yielding (1) high-strength, cotton leaf curl virus disease-resistant varieties/hybrids for north zone; (2) early maturing diploid cotton varieties/hybrids with improved fibre quality; (3) short-duration, high-strength *hirsutum* varieties/intra-*hirsutum* hybrids for central zone and south zone and (4) extra-long staple (ELS) *G. barbadense*/*G. hirsutum* × *G. barbadense* hybrids for central and south zone. The breeders are also entrusted with the responsibility of the maintenance of breeding and production of the required quantity of nucleus and breeder seeds of varieties/parents of hybrids. Agronomists are involved in standardizing planting geometry and fertilizer requirement of pre-release of varieties/hybrids, fine-tuning integrated nutrient management (INM) and integrated weed management strategies, scheduling water delivery through drip and developing production technology for organic cotton production. Entomologists and pathologists are focusing on the seasonal dynamics of pests, pathogens and natural enemies, testing the efficacy of new molecules and fine-tuning of location-specific IPM/IRM strategies and their promotion through FLDs.

6.3.2. Structure

The AICRP on Cotton operates in a multi-locational network mode through 11 main centres and 11 sub-centres involving 17 SAUs (**Figure 4**). This structure facilitates the evaluation of cultures and validation of technologies in different agro-ecological situations.

6.3.3. Research achievements

Since its inception in 1967, the AICRP on Cotton has played a stellar role in shaping the cotton sector in India through the development of several varieties/hybrids and fine tuning agro-eco region-specific cotton production and protection technologies. Detailed account on its past and recent achievements have been published elsewhere [21, 22] and is also available in [23]. The AICRP on Cotton also acts as a nodal centre for transfer of technologies through FLDs. A complete account of the FLDs is available in [20]. Only salient achievements are presented in this section.

Around 250 high-yielding varieties and hybrids of cotton have been developed by the network partners and released. Some popular ones are given in **Table 2**.

Name of species	**Name of hybrids/varieties**
G. hirsutum varieties	'LRA 5166', 'Anjali', 'MCU 5', 'MCU 7', 'SVPR 2', 'H 777', 'Abhadita', 'Khandwa 2', 'Narasimha', 'NDLH 1938', 'Suraj', 'PKV 081', 'NH 615', 'LH 900', 'Surabhi', 'Pusa 8-6' and 'Sahana'
G. barbadense variety	'Suvin'
G. arboreum varieties	'HD 123', 'HD 324', 'PA 255', 'AKH 4', 'AKA 7', 'AKA 8' and 'AKA 8401'
Intra-*hirsutum* hybrids	'NHH 44', 'LHH 144', 'Shresth', 'HHH 287', 'DHH 11', 'H 6', 'H 8', 'PKV Hy 2' and 'JK Hy 2'
Interspecific hybrids (*G. hirsutum* × *G. barbadense*)	'DCH 32', 'TCHB 213' and 'DHB 105'
Intra-*arboreum* hybrid	'AAH 1', 'RAJ DH 9' and 'CISAA 2'
Interspecific hybrids (*G. herbaceum* × *G. arboreum*)	'G cot DH 7' and 'G cot DH 9'

Table 2. Prominent hybrids and varieties released through AICRP on Cotton for commercial cultivation.

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The breeding and varietal release priorities changed with time to meet the changing quality requirements of the textile industry and also to suit specific requirements of the region in terms of maturity, agronomic traits tolerance to biotic and abiotic stresses, etc. The production and distribution of breeder seed of all the varieties and parents of hybrids released by the public sector based on the indent received from the Government of India is coordinated and monitored by AICRP on Cotton. The production has kept pace with the demand.

Location-specific agro-technologies—INM (organic, bio-fertilizers, Azospirillum, Azotobacter) for nutrient management, prevention of boll shedding using naphthalic acetic acid (40 ppm), weed management through pre-emergence application of pendimethalin @ 1.5 kg a.i./ha or fluchloralin @ 1.0 kg a.i./ha, soil moisture conversation using ridges/furrow system, microirrigation and fertigation using drip system, canopy managements using de-topping, diversification through innovative crop rotation/inter cropping, production technology of Bt hybrids (spacing, fertilizer requirement, water management, micro nutrient nutrition through foliar sprays) etc. were standardized, demonstrated and approved for subsequent incorporation into the package of practices for cotton production by the respective Agricultural Universities. A recent review by Venugopalan et al. [24] traces the agronomic research during the last six decades.

Screening for pest and disease resistance has been a regular feature of AICRP on Cotton programmes. Lines showing resistance/tolerance to key pest and diseases were recommended for utilizations as donors in breeding programmes (**Table 3**). Several multi-adversity-resistant lines with high yield have been developed.

Studies on seasonal dynamics of key pests and diseases at different locations over several years led to the development of robust pest and disease forecasting models using weather parameters. These modules are used to forewarn farmers through advisories disseminated using mass media. Economic threshold limits (ETLs) of various pests have been worked out to suggest timing of intervention for pest management. A simple symptom-based ETL was developed for major pests replacing the more cumbersome procedure of counting the number of insect pest. AICRP on Cotton is involved in testing the efficacy of new molecules and biological agents against pests and evaluation of their bio-safety. This has resulted in continuous revision of plant protection strategies using more effective and softer molecules. Location-specific IPM, IRM and disease management strategies have been formulated, validated, demonstrated and incorporated into the package of practices for commercial cotton cultivation in respective agro-climatic regions.

Front-line demonstrations on integrated nutrient management, novel inter-cropping systems, drip irrigation system, seed treatment with bio-fertilizers, maintenance of optimum plant density, *in situ* soil moisture conservation techniques, IPM, disease management, residue management techniques helped in bridging yield gaps, increasing yields and improving farm income. New farm implements and plant protection equipment with better ergonomics were demonstrated to reduce drudgery in cotton farming.

Biotic stress	Variety
Whitefly	Abhadita, LK 861, Kanchana and Supriya
Boll worms	Abhadita
Pink bollworms	Bikaneri Narma, H 777, F 414, F 286 and Ganganagar Ageti
Jassids	B 1007, Khandwa 2, Kirti, Mahalakshmi and CNHO 12
Fusarium wilt	G Cot 13, Eknath and Rohini
Bacterial blight	Arogya
Verticillium wilt	MCU 5 VT and Surabhi

Source: CIRCOT annual reports [19]

Table 3. Varieties conferring resistance to biotic stress.

6.4. Other organizations/societies

Apart from the three institutions discussed earlier, several other government/non-governmental organizations (NGOs) and professional societies are also involved in the development, validation and dissemination of technologies on cotton. Prominent among the government organizations are the Directorate of Cotton Development (DCD), Nagpur, under the Ministry of Agriculture, and Cotton Corporation of India (CCI), Mumbai, under the Ministry of Textiles. While the Cotton Association of India, Mumbai, facilitates cotton testing and trade, its extension unit The Cotton and Allied products (COTAAP) Research Foundation conducts extension programmes to improve cotton productivity. Associations of the textile industries such as Ahmedabad Textile Industry Research Foundation (AITRA), Ahmedabad; Bombay Textile Research Association (BTRA), Mumbai; South India Textile Research Association (SITRA), Coimbatore; Northern India Textile Association (NITRA), Ghaziabad, Uttar Pradesh; and Southern India Mills Association (SIMA) along with Cotton Development and Research Association (CDRA), Coimbatore, are also involved in promoting cotton production and textile research. Three professional societies *viz*. the Indian Society for Cotton Improvement (ISCI), Mumbai; Cotton Research and Development Associations (CRDA), Hisar, Haryana; and the Indian Fibre Society, Mumbai, promote dissemination of research information through its journals and newsletters, and by organizing seminars, conferences and symposia.

7. Institutional mechanisms for transfer of technology, varietal release and seed production

7.1. Transfer of technology

Under the NARES, several institutional arrangements have been made to transfer new products and technologies to cotton farmers. The 'first-line extension system' includes the operational research projects (ORPs), on-farm demonstrations (OFDs), Lab-to-Land Programmes (LLPs), Krishi Vigyan Kendras (KVKs), e-kapas and Institute Village Linkage Programmes (IVLPs). The Directorate of Extension in SAUs also provide a variety of extension services. The General Extension Programmes are sponsored by the Ministry of Agriculture. Government of India comprises package programmes. Training and Visit (T&V), Agriculture Technology Management Agency (ATMA) and Farmer Field Schools (FFS). The 'Special Extension Programmes' with focus on cotton sponsored by the Ministry of Agriculture, Government of India, included 'Grow More Cotton' campaign, Intensive Cotton Development Programme (ICDP), TMC MM-II in the past and IRM—HDPS at present. The ICT-enabled e-kapas is another novel initiative to reach cotton farmers.

Among these institutions, ICDP made remarkable impact in the past [25]. It was launched in 1971/1972 and continued up to 1998/1999. Its objective was to achieve self-sufficiency in raw cotton by improving productivity through the adoption of improved farm practices and modern cotton production technologies. From 2000, these functions were carried out under the TMC MM-II. The ICAR launched Lab-to-Land Programme to transfer latest agro-technologies especially to small and marginal farmers. In cotton, the programme concentrated on promoting the use of improved seeds, IPM, disease management, nutrient management and yield maximization. The FFS, initiated in the 1990s by the Government of India to promote the concept of IPM in cotton through a participatory learning approach was funded by the TMC. The FLD in cotton began in 1996–1997 for demonstrating new cotton technologies and reduce

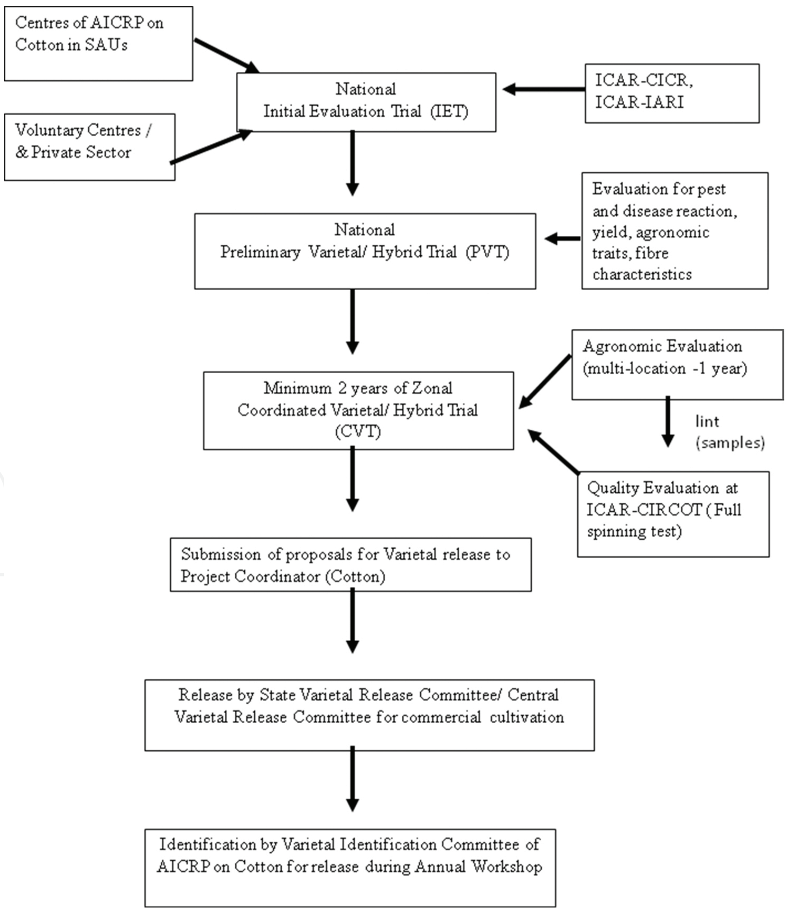

Figure 5. Protocol for testing and release of cotton varieties.

the time gap between technology generation and technology adoption. The AICRP on Cotton is the nodal agency for implementing FLDs, and the funds are provided by Government of India initially through the ICDP and later through the TMC MM-II. In a landmark initiative, the Government of India launched the TMC in 2000, to improve the yield and quality of cotton and increase the income of cotton farmers by reducing the cost of cultivation. Another objective of TMC was to improve the quality of processing of cotton by improving the infrastructure for market yards, for modernizing the existing ginning and pressing units and also to set up new units. Detailed account on the transfer of cotton technology has been discussed by Vithal et al. [25] and Wasnik et al. [26].

7.2. Varietal release

The AICRP on Cotton facilitates the development, evaluation and release of a variety/hybrid of cotton through a multi-location and multi-disciplinary approach. The entire process leading to the release of a variety by the Varietal Identification Committee is given in **Figure 5**. If a variety is indented to be released in a state, it is done by the State Varietal Release Committee. If during the evaluation trials, the variety/hybrid performs well in more than one state, the proposal for release is submitted to the Sub-Committee on Crop Standards Notification and Release of Variety of Central Seed Committee where it is released and notified. Even if a variety is released by the State Committee, it has to be notified by the Central Committee for its notification [27]. The denotification of old/obsolete varieties is also done by the same committee.

7.3. Structure of cotton seed production chain

To meet the requirement of quality seed, it is very much essential to produce large quantity of genetically pure seed which has to be multiplied in the following stages:

1. Nucleus seed is produced by the breeder who developed the variety;

2. Breeder's seed is produced from nucleus seed by the concerned ICAR/Institutes/SAUs as per the state indents;

3. Foundation seed is produced from breeder's seed by National Seed Corporation (NSC)/State Seed Corporations (SSC)/State Farm Corporation of India (SFCI) subjected to certification by a certification agency;

Certified seed/registered seed is produced from foundation seed by SSC and gets it certified by State Seed Certification agency. Alternatively, in the case of shortage of certified seed, truthfully labelled seeds are multiplied under official supervision.

The R&D divisions of various seed companies in private sector are engaged in developing superior Bt-cotton hybrids. These are also tested in multi-location trials through sponsored trials in SAUs, and the companies own research farms for productivity and adaptability. For approved events, these hybrids are released through the EBAM. The mechanism and functional linkages between the different institutions involved in the approval of Bt cotton for

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commercial release is available in [28]. The seed quality testing and marketing of these hybrids are also exclusively undertaken by the private seed companies.

8. Linkages and collaborations

The ICAR-CICR and ICAR-CIRCOT are actively involved in guiding, formulating, monitoring and evaluating the research and technology transfer works undertaken by the collaborating centres of AICRP on Cotton. Need-based research collaborations within the NARES system and with other scientific organizations and universities are common. International collaborations and linkages to strengthen research capabilities and enhance human resource capabilities of ICAR-CICR involved the Indo-Australian Project with the Energy and Resources Institute —Centre for Environmental Stress and Adaptation Research, Melbourne (TERI-CEASAR) 'for insect transgenic detection kits, International Plant Genetic Resource Institute (IPGRI)', Rome for augmenting cotton germplasm, International Centre for Genetic Engineering Biotechnology (ICGEB) for the development of gene construct and International Cotton Genome Initiative (ICGI) for the development of cotton genome.

A collaborative programme on the management of *Helicoverpa armigera* was operating with Central Cotton Research Institute, Pakistan, Nanjing Agricultural University, China, and Natural Resources Institute, UK. ICAR-CICR is also closely involved in the activities of the ICAC and International Cotton Researchers Association (ICRA). It collaborates with the C4 countries, Nigeria, Uganda and Malawi under the Cotton Technical Assistance Programme for Africa for capacity building and human resource development. ICAR-CIRCOT has developed close collaboration with international organizations such as ICAC; Common Fund for Commodities (CFC); United Nations Development Programme (UNDP); World Bank Cotton Development Organization (CDO), Uganda; Ministry of Agriculture and Food Security, Malawi; and *Institut National des Recherches Agricoles du Benin* (INRAB), Benin.

9. Future perspectives

The last two decades witnessed the emergence of private sector as a strong partner to public sector research organizations particularly in the development of transgenic Bt hybrids and seed production. There was a rapid adoption of Bt hybrids. Cotton spread to new areas and the production increased, but today several pointers are being raised at the sustainability of the 'hybrid' technology. High cost of inputs (seed, fertilizer, pesticides), increasing production cost, increasing severity of jassids, whitefly, leaf reddening and resistance in pink bollworms to Cry1Ac and Cry2Ab are the challenges evading solutions. Currently, the cotton varietal seed production chain in public sector is almost defunct, and this needs to be revived. Technologies for future must be based on sustainable practices giving high yield at low production cost.

Immediate challenges in cotton production include but not limited to:

1. Development of novel technologies to reduce cost of cultivation and make cotton farming more profitable by reducing the dependence on chemical fertilizers, pesticides and labour.

2. Delineation of areas not suitable for hybrid cotton and replacement of this area with cotton production systems using straight varieties of *G. hirsutum* or *G. arboreum*.

3. Improvement of the management options to delay the development of resistance of bollworms to Cry toxins and manage sucking pests more efficiently.

4. Mechanization of cotton production 'including mechanical picking' to suit small land holding and reduce drudgery among labour.

5. Application of efficient cropping systems (inter and sequential cropping) preferably with pulses/legumes to enhance atmospheric N fixation and increase pulse production.

6. Utilization of climate resilient technologies to realize stable and sustainable yields on marginal soils under rainfed conditions.

7. Intensification of researches on IRM and host plant resistance to whitefly and cotton leaf curl virus disease to combat biotic stress.

8. Development of human resource for improving research infrastructure and research funding to address emerging challenges.

9. Retention of the competitive edge of cotton over other natural and synthetic fibres.

Research and development expertise available in the public and private sector needs to complement each other to deliver the best solutions to the cotton farmer. There is a need to consolidate international linkage activities with International Rice Research Institute (IRRI), ICGEB, International Maize and Wheat Improvement Center (CIMMYT), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), ICAC, International Board for Plant Genetic Resources (IBPGR), Bio-21 Biodiversity International-Rome, International Food Policy Research Institute (IFPRI), Indo-American Knowledge Initiative, International Centre for Agricultural Research for Dry Area (ICARDA), IITA-International Institute for Tropical Agriculture (legumes, cereals, pulses), Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, through collaborative research programmes.

10. Conclusion

The ICAR-CICR, ICAR- CIRCOT and the AICCIP now renamed as AICRP on Cotton form the pillars of public sector R&D in cotton. A strong public sector R&D set-up backed by a vibrant private sector has provided cutting-edge technological support to enable India to emerge from a chronic importer into a global leader in cotton production over the years. The production of a wide variety of cotton provides the desired raw material to the textile industry at competitive

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price and enables the industry produce apparels and other end-products in a globally competitive environment. The entire value chain of cottonseed to finished products is primarily built on technologies generated by indigenous R&D. The entry of private sector in the development and marketing of Bt hybrids is another feature of Indian cotton sector that enabled it to emerge as the largest cotton producer in the world. Challenges still remain in both cotton production, and processing and these institutions will continue to play a major role in the years ahead.

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