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Indian Cotton – Yearning to Lead

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Indian cotton scenario has witnessed dynamic changes over the years, from cultivation of predominantly diploid varieties in pre-independence era to cultivation of allotetraploid *hirsutum* varieties and hybrids and subsequently, to present transgenic cotton. Each period had its own rationale for acceptance and adoption. Although this positioned India as leading producer of cotton and has maintained its position amongst top three cotton producing countries of the world, India's productivity status is ranked well below the global average due to apparent reasons of holding size, monsoon dependence and adoption of semi-mechanized and low input cultivation practices in the central and south zone.

Today, about 70% of global cotton production comes from four countries viz. India, China, USA and Pakistan. At present, cotton cultivation area in the world is 34.1 M. ha and is expected to remain between 32 to 35 M. ha in the coming decade. Cotton consumption for textile is expected to increase with the growing demand for natural fibers. With shifting acreages in cotton growing countries around the world, focus will be primarily on India for meeting the increasing demand forcotton.

Climate change is likely to bring a noticeable increase in surface air temperature in future, which might become more conspicuous after 2040. It is likely to bring significant changes in the hydrological cycles. As a result major river basins are expected to experience water shortages. Studies have indicated that enhanced CO_2 levels up to 650 ppm and increased temperatures up to 40°C have been found to be optimum for cotton crop growth, but climate change is also expected to bring changes in disease and pest dynamics in the cotton ecology. These changes are also going to influence competing weeds and therefore, will need suitable measures to control them.

A brief plant taxonomy and flower structure

The place of origin of the genus *Gossypium* is not known, however the primary centers of diversity are west-central and southern Mexico (18 species), north-east Africa and Arabia (14 species) and Australia (17 species). There are four cultivated species of cotton, two diploid (2n=26) *Gossypium arboreum* and *Gossypium herbaceum* limited only to Asia and allotetraploid (2n=4X=52) *Gossypium hirsutum* and *Gossypium barbadense*. The former two species are termed as 'old world cotton' while later two are known as 'new world cotton'. Today more than 95% of the cotton grown globally is *G. hirsutum* species while the area under *G. barbadense* is around 3 %. Diploid cotton is majorly in India with a very small area under cultivation. *G. hirsutum* has originated in North America whereas *G. barbadense* hadits origin in South America. Cotton is an often cross-pollinated crop and tolerates inbreeding to a certain extent. It does not express high level of heterosis. By nature, cotton is a perennial crop but has been adapted as an annual crop by breeding and agronomy.

Cotton flowers are extra-axillary, terminal and solitary and are borne on the sympodial or fruiting branches. The flower is surrounded by an involucre of three unequal leaf like bracts. In some cases, bracteoles are present, alternating with the bracts, on the inside of the involucre or standing on either side of the small bract. The calyx, consisting of five undiverged sepals, is persistent and shaped

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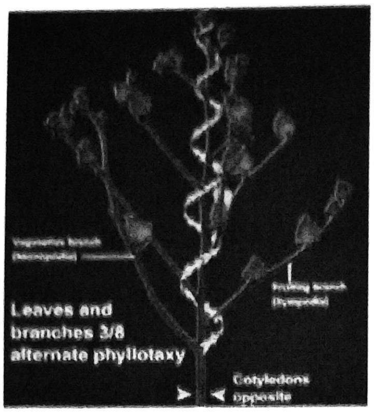

Fig. 1. Plant architecture (Source Extension Publ., University of Georgia)

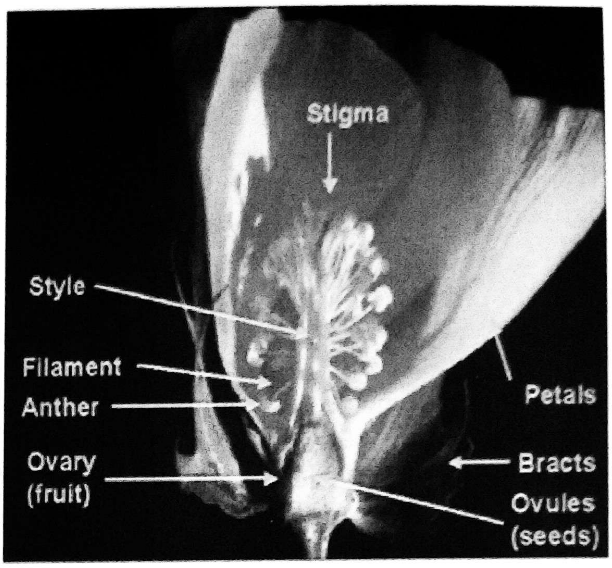

Fig. 2. TS of cotton Flower (Source Extension Publ., University of Georgia)

as a shallow cup. It adheres tightly to the base as the boll develops. The corolla is tubular, consisting of five obcordate petals alternating with calyx lobes and overlapping the next in a series, in a convolute manner. In some varieties in *G. hirsutum* and majorly in *G. barbadense*, *G. arboreum* and *G. herbaceum* a reddish spot also called as petal spot is found at the base of the petals. On the next day after anthesis, the corolla changes into a pinkish colour and subsequently turn reddish purple. Corolla withers and falls off after 3-4 days along with the staminal column and stigma, leaving the ovary, calyx and involucre intact. The stamens are numerous and united to form a tubular sheath which surrounds the pistils except for the exposed portion of style and stigma at the tip. The pistil consists of 3-5 undiverged carpels corresponding to the locular composition of a fully mature dehisced boll. The ovules are attached to parietal placenta of each locule. The style varies in length and splits near the apex into three, four or five parts depending on the number of carpels. Cotton pollen is relatively large, heavy, and sticky. Pollen remains viable for 24 hrs post-anthesis. Cross-pollination in cotton may vary from zero to more than 20 per cent. Many insects especially honey bees are attracted to the cotton flowers and they are responsible for cross-pollination. Pollination takes place usually in the morning during opening of flower and anther dehiscence. Fertilization takes place between 24-30 hours after pollination [1]. In the initial stages, the boll development is slow and later the growth rate is rapid and steady. About 40-50 days are required from fertilization to boll bursting, maturation of fibers and seed formation.

Importance of cotton in Indian economy

The size of Indian textile and apparel market stood at US$ 140 billion in 2013 which is 7.5% of country's GDP. The domestic usage and exports have grown at CAGR (compound annual growth rate) of 11-12% in the last decade and is projected to grow at CAGR of 20% for the next decade. India has installed capacity of 50 million spindles which is 20% of the global spindleage capacity. In cotton, India has 1/3rd of the global cotton area and the production of raw cotton has grown at CAGR of 7% since advent of Bt cotton. In terms of consumption, 22% of the global cotton is processed in India and has grown at CAGR of 3.5% in the last decade. Cotton provides means of livelihood for close to 6 million farmers and employment for close to 50 million people directly or indirectly, thus emphasizing its importance in Indian economy.

Breeding history

India has many firsts to its credit in cotton. It developed and commercialized first *intra-hirsutum* cotton hybrid 'Sankar 4' in 1971 and first inter-specific ELS cotton hybrid named 'Varalaxmi' in the year 1972. It had the distinction of developing first commercial cotton hybrid based on genetic male sterility - 'Saguna'in 1978 and in 1984, the first commercial hybrid 'MECH 4' was developed using cytoplasmic genetic male sterility. The first insect resistant Bt cotton was released in India in the year 2002. If we look at the sequence of events, seventies and eighties were dominated by varieties and hybrids from public sector, which heralded the birth of Indian seed industry. Hybrids such as Sankar 4, Sankar 6 and NHH 44 made a big dent in the market in late seventies and eighties whereas the cotton variety LRA5166 made a big impact in the early nineties. Starting with seed production of public bred hybrids, the industry initiated investments in research and by nineties there was aresurgence of seed sector due to production of research cotton hybrids. During this decade, hybrids such as Ankur 651, Ankur 09, RCH 2 and Bunni got notified through the All India Co-ordinated Cotton Improvement Project. This period also witnessed change in the packing size from 750g for public bred hybrids to 450g for research hybrids developed by seed industry. Availability of delinted and fungicide/insecticide treated seed in the market became a standard for Indian farmers. In the non-Bt era, area under hybrids was close to 45%, with Maharashtra, Gujarat and Andhra Pradesh being major cultivating states of hybrid cotton.

During late nineties, Mahyco, in joint venture with Monsanto brought the first insect resistant transgenic technology in the country. India witnessed a phenomenal change in the productivity, with de-regulation of first insect resistant transgenic cotton hybrid having *cry1ac* gene, in 2002. This gene offered protection to the cotton crop against a class of lepidopteran pests without application of pesticide and reduced insecticide consumption in the crop by more than half. In 2006, twin gene transgenic technology containing *cry1ac* x *cry2ab2* was deregulated in the country and that offered protection against wider spectrum of lepidopteran pests appearing on cotton as well as delaying the development of resistance to the Bt toxins (i.e. *cry* proteins) by target insects. This gave a boost to Ag-biotech research and investment in the country. So far, more than five events of insect resistance have been de-regulated in India, all producing *cry* proteins in cotton plants. However, today, 99% per cent of cotton area in the country is covered by twin gene technology of Mahyco-Monsanto. With introduction of Bt cotton in the country, productivity of cotton lint increased from 322 (2002-03) to 537 Kg/ha (2014-15) (Annual Report, Project Coordinator, AICRP-Cotton). Today India has the largest global area under GM cotton. Pricing of the produce in the county is based on seed cotton for which minimum support price (MSP) is declared every year. As a result, the breeding focus has been on improving seed cotton yield. Ginning turnout which is per cent of lint obtained from a unit weight of seed cotton is getting a secondary focus as a trait of improvement. In India, heterosis is mainly exploited for seed cotton yield and hence the productivity increase is mainly on account of increased seed cotton yield rather than due to increased ginning turnout.

Table 1. Bt cotton events approved for cultivation in India

S.No.	Event	Gene	Year of release	Applicant
1	MON531	*cry1Ac*	2002	Mahyco
2	GFM Cry1A	*cry1Ab+ cry1Ac*	2006	Nath Seeds Ltd.
3	Event 1	*cry1Ac*	2006	JK Seeds Ltd.
4	MON15985	*cry1Ac x cry2Ab2*	2006	Mahyco
5	BNLA-601	*cry1Ac*	2008	CICR & UAS Dharwad. Event withdrawn.
6	MLS9124	*cry1C*	2009	Metahelix Life Sciences

Transgenic technology for insect resistance was introduced in the country in hybrid background and as a result area under hybrid cotton increased from 45% in the non-Bt era to nearly 95 per cent at present.This has given a boost to hybrid seed production activity in the country and has created a good opportunity for the farmers to improve their per acre income. It is also generating assured employment for the farm workers in the hybrid seed production areas. The varietal research has been mostly confined to the public institutions and few local seed companies in the north zone. In the absence of technologies, it is going to be a challenging task to promote varieties in the market, in spite of their cost effectiveness.

Seed Production systems

Hybrid seed production in cotton is traditionally done using Doak's method [2]. In this method a flower bud that is going to open next day is emasculated in the afternoon hours. Emasculation is done manually and the petals along with staminal column are removed in the process. This is a skilled job and it is to be ensured that the ovary and the stigma are not damaged in the process. Emasculated flower is marked by using straw tubes or coloured plastic foils for easy identification. The emasculated flower buds are pollinated next morning post-anthesis. Morning hours between 9 to 11 AM are best for pollination when anthers are dehisced and stigma is receptive. This method engages labour for the whole day, in the morning for pollination activity and in the afternoon for emasculation.

Although commercial hybrid seed production started in early seventies, work on male sterility systems began earlier to that. First source of genetic male sterility was identified by Justus and Leinweber in 1960 [2]. This gene, annoted as ms_1, was recessive monogenic but was not useful because the male sterility was partial. Till date, 12 different sources of genetic male sterility have been identified, of which Ms_4, Ms_7, Ms_{10} and Ms_{11} are monogenic dominant and practically of not much use in hybrid seed production. The ms_3 gene identified in 1963 is monogenic recessive but sterility is partial. Of the available system, ms_5ms_6 is found to be stable and has been successfully used in India. Both these genes in homozygous recessive state express male sterility and exhibit duplicate dominant epistasis. Presence of one of the genes in heterozygous dominant condition and other gene in homozygous recessive condition maintains the sterility of the system. One of the limitations of the genetic male sterility system is identification and roguing of the male fertile plants at flowering, before start of the hybrid seed production. Agronomy has to be worked out to ensure more population of sterile plants at the end of rouging in a GMS system. The advantage with genetic male sterility is freedom to use any pollen parent to develop a hybrid and the resultant hybrids are fully fertile. If isolation distance is properly followed and roguing of male fertile plants is meticulously done, the genetic purity of resultant seed lot is 100%. Moreover, seed grower saves half of his labour cost required in emasculation thus saving on the cost of production.

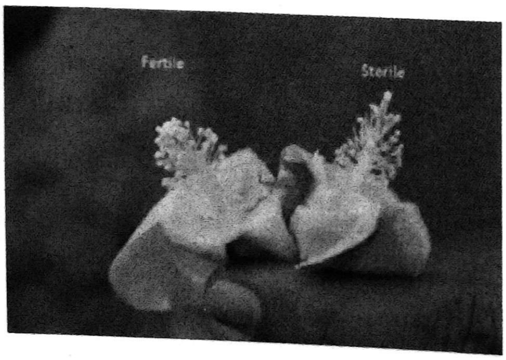

Fig. 3. Genetically male sterile & a normal flower

Another type of male sterility available in cotton is cytoplasmic genetic male sterility. This is a three line system available in cotton denoted by A, B and R lines. A line is fully male sterile. B line works as maintainer of male sterility whereas the R line is a line that restores fertility of A line. First CGMS system in cotton was developed in 1977 by Weaver. This male sterility system was based on D_2 cytoplasm from *G. harknessii* and restored by *Rf1* factor. Couple of hybrids were developed using this system in India e.g. MECH4, CAHH 468. Another system of cytoplasmic genetic male sterility was developed by Stewart using D_8 cytoplasm from *G. trilobum* in 1992 but has not been exploited commercially in India. This male sterility system is restored by *Rf2* factor. Cytoplasmic system has an advantage that the female parent is fully male

Table 2. Genetic male sterility genes identified in cotton

S. No.	Gene	Species	Inheritance	Identified By
1	ms_1	*G. hirsutum*	Recessive (Partial)	Justus and Leinweber, 1960
2	ms_2	*G. hirsutum*	Recessive	Richmond and Kohel, 1961
3	ms_3	*G. hirsutum*	Recessive	Justus *et al.*, 1963
4	Ms_4	*G. hirsutum*	Dominant	Allison and Fisher, 1964
5	ms_5ms_6	*G. hirsutum*	Recessive	Weaver, 1968
6	MS_7	*G. hirsutum*	Dominant	Weaver and Ashley, 1971
7	ms_8ms_9	*G. hirsutum*	Recessive	Rhyne, 1971
8	MS_{10}	*G. hirsutum*	Dominant	Bowman and Weaver, 1979
9	MS_{11}	*G. barbadense*	Dominant	Turcotte and Feaster, 1979
10	MS_{12}	*G. barbadense*	Dominant	Turcotte and Feaster, 1985
11	ms_{13}	*G. barbadense*	Recessive	Percy and Turcotte, 1991
12	ms_{14}(Dong A)	*G. hirsutum*	Recessive	Tianzhen *et al.*, 1994
13	ms15 (Lang A)	*G. hirsutum*	Recessive	Tianzhen *et al.*, 1994
14	ms16 (81 A)	*G. hirsutum*	Recessive	Tianzhen *et al.*, 1994

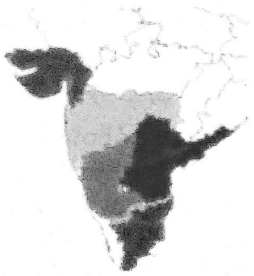

Fig. 4. Seed producing states in India

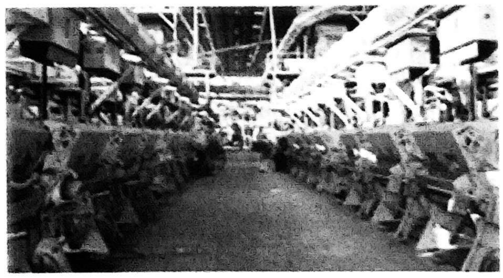

Fig. 5. View of a commercial DR gin. (Source: Bajaj Gins, Nagpur

sterile. Disadvantage with using this system is that *hirsutum* germplasm works as maintainer for sterility and hence *Rf* factor has to be separately introgressed in the male parent. This limits the use of this system in hybrid development. Another limitation of using this system is yield drag occurring in the hybrids because of the effect of cytoplasm.

Seed production landscape

Hybrid cotton business in India has also given platform to organized hybrid seed production mechanism in the country. India produces estimated 25000 ton of processed seed annually. Although hybrid seed production activity mainly coincides with the commercial cultivation calendar, certain regions in southern Karnataka take up hybrid seed production in the counter season as well. Cotton hybrid seed production activity is nearly 180 days activity, upto handing over of the lots for further processing. Seed production is restricted to the six major cotton growing states of

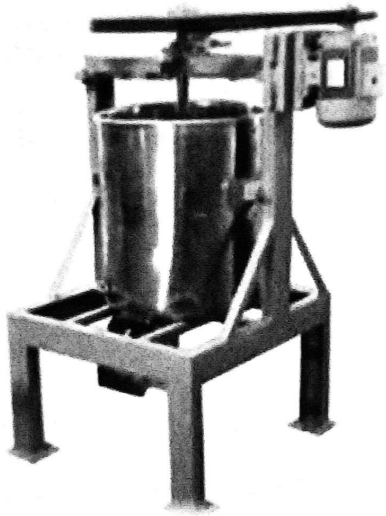

Fig. 6. Acid delinting machine

Gujarat, Maharashtra, Telangana, Andhra Pradesh, Karnataka and Tamilnadu. Of these states, Gujarat has the highest acreage under hybrid seed production followed by Telangana, AP, Karnataka and Tamilnadu. There are reports of seed production activities near Khandwa in Madya Pradesh. Gujarat produces the best quality hybrid seed in the country. It is estimated that seed production is annually organized on 125000 acres. Of this, 95% of the hybrid seed production is done by conventional emasculation and pollination technique. Rest of the production is done using genetic male sterility. Crossing in a hybrid seed production plot normally continues for about 45 days. There's a well organized network of seed production organizers and growers in the seed production areas. Seed companies distribute the target hybrid seed production programs well ahead of the season. Organizers mostly complete post harvest processing activities that include ginning, delinting and grading. Ginning is the process of separating seed from the fibers and is done with a machine called gin. There are two types of gins based on its principle of separating the fibers i) saw gin and ii) roller gin. In India, ginning is majorly done with roller gins (Fig. 4). In seed production, the next important step is delinting. Delinting is a process in which the short fibers on the surface of the seed coat called fuzz are removed by burning. This is either done with the help of conc. Sulphuric acid or by gas delinting using HCL. Gas delinting is helpful for processing large lot sizes and is relatively safe, whereas for the smaller lot sizes, acid delinting is practiced (Fig. 5). Delinted seed goes for further processing where the seeds are first graded on the basis of their size using Air Screen cleaner and then based on specific gravity on Gravity separator. Industry is also using needle sortex machine to separate physically damaged seeds from the lots. Such lots are then bulked based on their germination, genetic purity and trait purity into a bulk seed lot which further goes for seed treatment and packing. Typically, recovery of clean good seed is between 45-48 Kg from one quintal of seed cotton. Seed certification standards for hybrid cotton set by Govt. of India are as under:

1.	Pure seed (min.)	–98%
2.	Inert matter (max.)	–2%
3.	Other crop seeds (max.)	–10/Kg
4.	Weed seeds (max.)	–10/Kg
5.	Germination (min.)	–75%
6.	Moisture (max.)	–10%
7.	Moisture (vapour proof containers) max.	–6%
8.	Genetic purity (min.)	–90%
9.	Bt protein content (min.)	–90%

The seed companies however are maintaining higher than the prescribed standards for germination and trait purity for Bt cotton hybrids. Along with hybrids, a separate pack of 120 g is also to be inserted in the pack along with Bt cotton which is called refuge seed. Refuge is seed of non-Bt cotton of similar maturity and fiber character. This is to be planted surrounding the Bt cotton crop as insect resistance management strategy. Due to lack of awareness of the purpose of refuge, there have been issues with its implementation at ground level. A strategy to introduce built in refuge in Bt cotton is also discussed to ensure natural planting of refuge interspersed with the Bt crop.

To take up hybrid seed production, foundation seed multiplication and breeder seed production have to be planned two years ahead of actual hybrid seed production. The whole system is dependent on weather conditions during the cropping season which can play spoil sport at any stage of seed multiplication. One can therefore understand the complexity of hybrid cotton seed production business and series of factors involved in the process.

Crop improvement is a continuous process and researchers are working on different approaches for improving production and productivityof cotton. Experiments examining effect of higher plant population per acre is one such approach. At present, average seed rate for planting hybrid cotton is 1.72 packets per acre. Seed companies are experimenting with higher seed rate to improve production of hybrid cotton. This is particularly useful in dryland cotton growing areas where, by reducing the plant to plant distance, attempts are being made to accommodate more population per acre and increase production. Another approach is being attempted with high density planting and mechanized picking. Experiments on maintaining around 30,000 plants per acre, controlling excess vegetative growth with use of plant growth regulators and forced termination of the crop using defoliants are being attempted. Such plots are then harvested with customized cotton pickers. Companies like Bayer and Monsanto are taking these experiments on farmers' fields using hybrids. Initial results are encouraging. Although proof of concept has been established, there's a long way to go before it reaches a commercial stage. There are a few unanswered questions in adopting this technique e.g. approach for hybrids and varieties, standardizing dose of plant growth regulators and harvest aid chemicals, fitment for smaller holdings etc. Benefits arising out of these practices and ease of operation will be the key to adoption of these agronomic techniques.

CONCLUSION

Indian seed industry has to shoulder responsibility along with the public sector in meeting the growing needs of the country. It will have a major responsibility of maintaining seed quality, as larger area is expected to remain under hybrids. Industry also has a major role to play in responsible handling of the transgenic technologies. Future yield gains are expected through agronomic interventions followed by genetics and transgenic technology. Native traits of resistance are expected to provide value addition to the germplasm. No major technology changes are expected in the coming decade except the transgenic traits for herbicide tolerance and insect resistance. Focus will also be on integrated pest management, integrated nutrient management and integrated resistance management for overall benefits in cotton.

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