BREEDING AND GENETIC IMPROVEMENT OF *G. HERBACEUM* DESI COTTON IN INDIA

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ABSTRACT

Desi diploid cotton (*Gossypium herbaceum* L.; 2n = 18) has inherent ability to adapt adverse climatic conditions and well known for resistant to pests and diseases. They are still under cultivation in some part of India as farmers believe the sustainability of the yield in marginal soil and less management practices. After the introduction of Bt cotton in India, there was significant decrease in area of *desi* cotton. But there is a big demand of short staple length for denim and surgical cotton. Efforts were made to improve the qualitative characters and yield potential from several years in India and changed the plant type through heterosis breeding. So far 22 varieties and 4 hybrids were released from inter specific breeding between *G. herbaceum* and *G. arboreum* for commercial cultivation in Gujarat, Karnataka and Maharashtra part of India and showed genetic improvement in *herbaceum* species. Germplasm consisting 582 accessions were raised in paper tubes tray nursery on 27th June and 28th July 2015 and 15 days old seedlings were transplanted in augmented design with three standard checks (Jayadhar, DDhC - 11 and GN. Cot - 25) at main research farm of ICAR – CICR, Nagpur, India. Further genotypes were screened for early maturity traits and initiated crossing programme. Six genotypes *viz.* IC - 371582, IC - 371575, IC - 371587, IC - 371560, IC - 371602 and IC - 371437 significantly outperformed for seed cotton yield from 160 to 180 g / plant. F_1 derived from introgress breeding between *G. arboreum* x *G. herbaceum* showed heterotic effect with respect to days to early flowering, days to harvest and seed cotton yield / plant. Few *G. arboreum* x *G. herbaceum* crosses recorded maturity of 150 - 160 days with improvement in fibre length. Wide range of segregating pattern was observed in F_2 populations of intra herbaceum crosses. Intra – specific herbaceum crosses between IC – 371437 x Baluchistan – 1 and IC – 371437 x Jayadhar showed better performance in boll numbers, boll weight and yield over the mid parent. These identified genotypes were used in genetic improvement of *herbaceum* race *Wightianum.*

Keywords: *Desi* cotton, *Gossypium herbaceum*, *Wightianum,* Heterosis

INTRODUCTION

Natural cotton fibre has vital role in Indian economy as well as other countries like USA, China, Pakistan, Uzbekistan and Australia. Out of four cotton species cultivated in India, *G. hirsutum* covers more than 90% of acreage. Due to introduction of Bt cotton in India, area under diploid cotton species *G. arboreum* and *G. herbaceum* declined drastically during the last fifty years. However these species had inherent ability to adapt adverse climatic conditions and well known for resistant to pests and diseases. These cultivated species embody considerable genetic diversity, but restricted cultivation only in the Indian subcontinent and are facing a threat of genetic erosion. Indian farmers considered them and still believe the sustainability of the yield in marginal soil and less management practices as compared to *G. hirsutum.*

During 2016 - 17 crop seasons Indian cotton occupied in 105.06 lakh hectares and produced 351 lakh bales of 170 kg with 568 kg per hectare productivity. Maharashtra state is top most in area (38.06 lakh hectare) with production (89 lakh bales of 170 kg) and productivity (398 kg per hectare). Gujarat ranked second in area (24.00 lakh hectare) but first in ranked for production (95 lakh bales of 170 kg) with productivity (673 kg per hectare) followed by Telangana and Rajasthan (CAB, 2016). Presently, area under herbaceum is negligible. But historical evidences showed that a popular cultivar Western of *herbaceum* cotton were grown on red and mixed soils of the Western part of Rayalseema track of Andhra Pradesh prior to 1910 (Vijayaraghavan *et al.,* 1936). However, there is a big demand of short staple cotton for denim and surgical cotton. Efforts were made to improve the qualitative characters and yield potential from several years in India and changed the plant type through breeding approaches. In India, the major area of cotton is in rainfed condition where water is limited and during sowing season rainfall pattern more frequently shift due to climate change. Due to dry spell during sowing period, sown seed often not germinate and active embryo dies for the want of required moisture. Farmers loose Bt based costly seeds resulted economic loss and go for re-sowing. Drought during flowering and boll development reduced yield drastically. As an environmental sensitive crop better growth and yield ensures with the appropriate coordination of different agronomic practices. To overcome biotic and abiotic stresses, *intra herbaceum* and inter specific breeding between *G. herbaceum* and *G. arboreum* were carried out and varieties were released for commercial cultivation in Gujarat, Karnataka and part of India showed genetic improvement in *herbaceum* species. Further improvement is in progress by evaluating larger number of *herbaceum race Wightianum* germplasm to develop drought tolerant and early matured cultures with adaptation to water stress so as to reap profitable yield in central zone of India and local cotton growing rainfed area of Maharashtra state.

MATERIALS AND METHODS

The experiment was conducted at ICAR – Central Institute for Cotton Research, Indian Council of Agricultural Research (ICAR – CICR), Nagpur (Latitude = 21° 09' 23.58"N; Longitude **=** 79° 05' 16.99" E; Altitude **=** 312.42m amsl. Annual Rainfall = 1082.1mm, Number of rainy days = 54.5**.** A paper tube seedling tray nursery of 582 G. *herbaceum* germplasm race *Wightianum* were raised on 27th June 2015 and 28th July 2015 and 15 days old seedlings were transplanted at ICAR - CICR research farm, Nagpur on 14th July 2015 and 12th August 2015 (Patil *et al*., 2017; Mahajan *et al*., 2017). Five seedlings of each genotype accordingly 5820 seedlings (5 x 582 x 2) were transplanted in two frame of sowing with the spacing of 60cm x 30cm in augmented design. Genotypes were distributed in twelve blocks with three standard checks (Jayadhar, DDhC-11 and GN.Cot-25). Recommended package of practices were followed. Fertilizer doses at seedling and 50:50:80NPK kg/ha were applied. In order to avoid fungal and soil born diseases spray of Carbendanzim @ 200g in 200litre of water was applied 3rd day of transplanting. After screening few genotypes were selected for early maturity traits and yield and *intra herbaceum* crossing programme was initiated in 2015 - 16. During 2016 - 17 crop season F_1 plants were raised. In 2017 - 18 crop season F_2 population was raised and developed the

segregating population. Back crossing was attempted in *intra herbaceum* F_1. In 2016 - 17 crop season inter species crossing programme was initiated with *G. herbaceum* x *G. arboreum* and F_1 plant were raised in 2017-18 crop season. Heterotic effect of F_1 was estimated (Shull, 1914; Shull, 1948) using relative heterosis (Mell, 1894), heterobeltiosis (Powers, 1944) and standard heterosis (Cook, 1913). Significance level of heterotic effect of F_1 and their parents were calculated at 5 % and 1 % and complied data was statically analyzed using on line OPSTAT programme (Sheoran *et al*., 1998).

RESULTS AND DISCUSSION

1.1. GENETIC IMPROVEMENT OF *G. HERBACEUM*

From ancient period *desi* cotton was existed in India and few popular local cultivars like Surti local, Broach Desi (BD), Broach local or Kanvi, Western local, Wagad local, Kumpta local, Jarilla cotton and Hyderabad Gaorani local were cultivated (Main, 1907; Gammie,1908; Gulati and Turnar, 1928; Mahta, 1938; Mahta, 1947; Khadilkar, 1947a; Bedekar,1955a;Pandya *et al.,* 1956). These genotypes had very high range of phenotypic variability and used further for genetic improvement in *G. herbaceum* race *Wightianum* using different breeding methods (Table I).

Table I. Local cultivars of *G. herbaceum* grown from ancient period in India

Local cultivars	Description
Surti Local	Originated from Surat as local cultivar. Seed cotton yield = 272 kg / ha. Ginning percentage = 34.8; Fibre length 21.25mm; Spinning Capacity = 20. Adapted to South Gujarat, Bombay state (Pandya *et al.,* 1956).
Broach Desi (BD)	Originated from Mid Gujarat as local cultivar. Seed cotton yield = 257 kg / ha. Ginning percentage = 37; Spinning capacity = 20. Fibre length = 20mm. Adapted to mid Gujarat, Bombay state (Mollison,1903; Patel and Patel, 1927).
Broach Local or Kanvi	Originated from Broach and popular as Kanvi. Seed cotton yield = 257 kg / ha. Ginning percentage = 37; Spinning capacity = 13. Fibre length = 18.75mm. Adapted to mid Gujarat, Bombay state (Patel, *et al.,* 1947).
Western Local	Local cultivar from Hagari area of Karnataka state. Seed cotton yield = 235.56kg / ha. Fibre length = 20mm. Ginning percentage = 25. Spinning capacity = 20. Suitable for Western tract of Mysore and Andhra Pradesh (Satynarayanas Murthy *et al.,* 1955a; Vijayaraghavan *et al.*, 1936).
Wagad Local	Local cultivar from Viramgam area of Gujarat. Seed cotton yield = 280.18kg / ha. Fibre length = 20 mm. Ginning percentage = 34.4, Spinning capacity = 17.5. Suitable for North Gujarat tract including Kutch, and Bombay state (Patel and Mankad, 1926; Patel, 1949).

Kumpta Local	Local cultivar from Kumpta area of Karnataka state. Seed cotton yield = 298.64 kg / ha. Ginning percentage = 24; Fibre length = 30mm, Spinning capacity = 22. Adapted to Kumpta tract, Mysore state (Tippannavar and Patil, 1952).

A typical *G. herbaceum* had phenotypic and distinguishable bracteole shape as they flare away from bolls. They differentiate easily from *G. arboreum* which are closed to the bolls (Figure 1). Other phenotypic variants are found in leaf (curly, crumpled, hairy, stellate hairs, glabrous, red), bolls (closed, big, opened), boll colour (red pigmented, green), seed (semi fuzzy, fuzzy), lint (white, coloured) and dwarf bushy early type (Venkoba Rao and Ramchandran, 1943).

Figure 1. *G. herbaceum* bracteole flare away from bolls and in *G. arboreum* bracteole closed to the bolls

The Genetic improvement of *G. herbaceum* was in progress even before independence so called pre-independence era. Research efforts of selection and introgressing were reported and documented when different cotton research stations established in India. University of Agricultural Sciences (UAS), Bangalore, Karnataka was established in 1899 and cotton improvement progressed continuously. Later in 1905 reorganised Madras Agricultural departments. Marathwada Agricultural University (MAU), Parbhani, Maharashtra established in 1918, ICAR - Central Institute for Research on Cotton Technology (ICAR - CIRCOT), Bombay in 1924, Agricultural Research Station, Raichur in 1935, Cotton Research Station, Nanded in 1941 and Cotton Research Station, Dharwad under UAS, Bangalore in 1948 worked on desi cotton. Regional Cotton Research Station, Viramgam, Gujarat existed with the establishment of Central Commodity Committee on Cotton in 1921 to cater the specific research and development of *G. herbaceum* cotton in North Gujarat and genetic improvement in diploid was initiated using different breeding methods (Table II).

Table II. Breeding methods applied in *G. herbaceum*

Breeding methods	Varieties
Pure line selection	Western -1, Selection - 69,Wagad - 8,
Backcross	Kalyan, Digvijay, Vijalpa,
Pedigree	Suyodhar, Sujay
Three way cross	Jayadhar, G.Cot. - 11, G.Cot. – 13
Mutation (Spontaneous)	DB - 3 -12
Heterosis breeding	DH - 7, DH - 9, DDH - 2 and Pha - 46

Single cross	Jayawant
Synthetic	Suyog, Sujay
Composite	Vijay

In Pre-independence era Hagari - 25 was released as first variety in 1917 from Karnataka region (MacKenna, 1918; Anon., 1919). The improvement of Wagad cotton started in the second decade of the 20th century, ever since the station has made a good contribution both the varietal and industry requirements of the state. This recorded an increase of 11% in yield and 4% in ginning percentage over the local (Patel, 1947; Patil, 1948; Patel, 1949). After independence Jayadhar was a first variety released in 1948 has wide adaptability and still it is more popular among the farmers of Karnataka state of India (Figure 2).

Figure 2. Jayadhar the most popular and adaptable *herbaceum* variety

After the inception of All India Coordinated Cotton Improvement Project (AICCIP) in 1967 and the establishment of the Central Institute for Cotton Research (CICR) at Nagpur in 1976, the infrastructure for cotton research was further strengthened and several improved varieties have been released. Altogether 22 varieties and 4 hybrids were developed through genetic improvement in *G. herbaceum* race *Wightianum* (Table III). Variety Renuka releazsed in 1983 matured in 170 days. Some of the notable of *G. herbaceum* varieties are Jayadhar, Renuka and G. Cot - 23 was released for Karnataka and Gujarat but became popular in Maharashtra, Madhya Pradesh and spread to Andhra Pradesh, Telanghana, Punjab, Haryana and Rajasthan indicated wide adaptability. Released *desi* hybrids like DH - 7, DH - 9, DDH - 2, Pha - 46 are drought tolerant spread to Madhya Pradesh and Karnataka states and adapted to rainfed conditions in India. Trend of increased seed cotton yield per hectare was in observed showed genetic improvement in *G. herbaceum* (Figure 3).

Table III. Varieties and hybrids released during pre and post independence in *G. herbaceum*

Varieties		**Year of release**	**Description**
Pre-independence era			
1.	Hagari - 25	1917	Originated from Hagari part of Karnataka state. Seed cotton yield = 269.53 kg / ha. Ginning percentage = 30; Fibre length = 20.92mm; Spinning capacity = 38.5. Adapted to mid Gujarat, Bombay

			state (Patel *et al.,* 1947; Patel, 1947) .
2.	Dharwad - 1	1918	Selection from Dharwad part of Karnataka state. Seed cotton yield = 339.75 kg / ha. Ginning percentage = 29; Fibre length = 21.97mm; Spinning capacity = 32.7. Adapted to Kumpta tract, Mysore state (Tippanavar and Patil, 1952) .
3.	1ALB	1920	Originated from Surat. Ginning percentage = 39; Fibre length 22mm. Adapted to south Gujarat, Bombay state (Patel *et al*., 1947).
4.	1027ALF	1924	Originated from Surat. Seed cotton yield = 576 kg / ha. Ginning percentage = 37; Fibre length = 23.8 mm; Spinning capacity = 32.5 Adapted to south Gujarat, Bombay state (Patel *et al.,* 1947).
5.	Western -1	1926	Originated from Hagari area of Karnataka state. Seed cotton yield = 261.60kg / ha. Fibre length = 21.47mm. Ginning percentage = 32; Spinning capacity = 29.8. Suitable for western tract of Mysore and Andhra Pradesh (Satyanarayana Murthy *et al.,* 1955b; Sethi *et al*., 1960).
6.	Jayawant	1928	A wilt – resistant. Seed cotton yield = 620.61 kg / ha; Staple length = 22.57mm. Ginning percentage = 31, Spinning capacity = 37.5. Blow room loss percentage = 12. Grown in Raichur district and Gulbarga districts of Mysore and Bombay state (Sethi *et al.,* 1960).
7.	Wagad - 8	1930	Selection from local Wagad of Kutch and Kathiawar area (Bombay state). It is a hardy variety. Seed cotton yield = 682.89kg / ha. Staple length = 19.72mm; Ginning percentage = 43. Grown in part of Ahmedabad district, Sabarmati river belt, Halar districts of Bombay state (Patel and Mankad, 1926; Patel, 1949; Sethi *et al.,* 1960).
8.	Wagotar	1934	Released from Viramgam station, Gujarat. Seed cotton yield = 498.30kg / ha. Fibre length 20.00mm. Ginning percentage = 41.5. Spinning capacity = 17.5. Suitable for North Gujarat tract including Kutch and Kathiawar (Patel and Patel, 1927; Mahta,1938; Patel, 1949).
9.	Selection - 69	1942	A unit plant selection from Kumpta cotton in Southern part of Mysore state grown purely as a rainfed crop. Seed cotton yield = 317 kg / ha; Staple length = 26 to 32mm; Ginning percentage = 30; Spinning capacity = 32, blow room loss percentage = 3. Suited to black cotton soil (Sethi *et al.,* 1960).
10.	Vijay (BG-1-2)	1946	A composite type from the backcross suitable for black clayey soil. Seed cotton yield = 432.04kg / ha. Staple length = 22.75mm. Ginning percentage = 41.2. Spinning capacity = 38; Blow room loss

			percentage = 5. Grown in Baroda, Kaira, and Sabarkantha and Dehgam taluka of Bombay province (Patel and Patel, 1927; Thakur, 1955).
11.	Suyog	1946	Originated from Surat. High degree resistant to wilt. Yield 656.39 kg/ha. Staple length = 24.27mm; Ginning percentage = 38; Spinning capacity = 32; Blow room loss percentage = 7. Grown in part of Nandod taluka lying south of river Narbada and Nawapur and akkalkuwa talukas of West Khandesh district of Bombay State (Patel and Bhat, 1953; Sethi *et al.,* 1960).
12.	Kalyan	1947	Derivative from the backcross. Seed cotton yield = 721.40kg/ha; Staple length = 21.25mm; Ginning percentage = 39.9; Spinning capacity = 27; Blow room loss percentage = 6. Released for the distribution in North Gujarat track of Bombay State (Patel and Mankad 1926; Mahta, 1947).
Post – independence era			
13.	Jayadhar	1948	Seed cotton yield = 737.25 kg / ha. Ginning percentage = 32; Fibre length = 22.95mm; Spinning capacity = 44; Blow room loss percentage 10. Wide adaptability and good general combine ability. Cultivated in Chitaldrug, Dharwad, Bijapur and Belgaum districts of Mysore State and South Satara and Kolhapur districts of Bombay State (Tappannavar and Patil, 1952; Sethi *et al.,* 1960).
14.	Vijalpa (2087)	1952	Highly resistant to wilt. Seed cotton yield 592.29kg / ha; Staple length = 24.27, Ginning percentage = 37; Spinning capacity = 37; blow room loss percentage = 4 Vijalpa, covered practically the whole area of South Gujarat zone of Bombay State (Patel and Bhat, 1953; Pandya and Patel, 1956)
15.	Digvijay (98 - 41)	1956	Highly resistant to wilt. Seed cotton yield = 618.34 kg / ha; Staple length = 22.75mm; Ginning percentage = 38.8; Spinning capacity = 43; Blow room loss percentage = 4. Recommended for mid Gujarat, Bombay state, Broach tract (Thakar, 1955; Anon., 1956a; Anon., 1957c).
16.	Raichur - 51	1968	Resistant to Fusarium wilt and sucking pests. Suitable to in Karnataka state (Ganga Prasad Rao, 1956).
17.	Sujay	1972	Tolerant to Jassids but late maturing variety released from GAU, Surat for Gujarat state (Basu and Narayanan, 1992).
18.	G. Cot.- 11	1979	High ginning percentage with resistance to fusarium wilt and tolerant to jassids, aphids, thrips and bollworms was developed at GAU, Surat. Adapted to south and middle Gujarat (Basu and Paroda, 1995).

19.	G. Cot.- 13	1981	High ginning percentage with resistant to Fusarium wilt and tolerant to jassids and bollworms.Variety developed from GAU, Surat and released for Wagad track of Gujarat state (Basu and Narayanan, 1992).
20.	Renuka (DB-3-12)	1983	This is an early maturing variety matured in 170 days. Higher yield (15 - 20%) and better plant type over parent variety. Released for *herbaceum* grown track of Karnataka state (Basu and Narayanan, 1992).
21.	GN Cot - 25	2010	Released by Navsari Agricultural University, Navasari, Gujarat. Seed cotton yield = 1500kg/ha. Fibre length 23.2mm. Ginning percentage = 39.3; Fibre fineness = 4.8. Fibre strength = 17.65g/tex (ICC mode). Suitable for Bhal & Coastal Zone - V & VIII, North West Agro climatic zone (Annual Report, 2012).
22.	Gvhv-655 (GADC - 2)	2015	Released as Gujarat Anand Desi Cotton – 2 was released from Anand Agricultural University, Anand, Cotton research station, Viramgam. Seed cotton yield = 1640kg / ha; Fibre length = 24.2mm. Ginning percentage = 45.4. Fibre fineness = 4.88; Fibre strength = 19.3g / tex (ICC mode). Suitable for Bhal & Coastal Zone - V & VIII, North West Agro climatic zone (Annual Report, 2016).
	Hrybrids		
1.	DDH - 7	1985	Hybrid was released from GAU, Surat for South and middle Gujarat. This is tolerant to Fusarium wilt. High ginning outturn and drought tolerant (Basu and Narayanan, 1992; Santhanam, 1997).
2.	DDH - 2	1986	Hybrid was released from USA, Dharwad for Karnataka state. This is resistant to Fusarium wilt and jassids. High ginning outturn and drought tolerant (Basu and Narayanan, 1992; Santhanam, 1997).
3.	DDH - 9	1988	Hybrid was released from GAU, Surat for south and middle Gujarat. High ginning outturn and drought tolerant (Basu and Narayanan, 1992; Santhanam, 1997).
4	Pha - 46	1996	Hybrid was released from Marathwada Agricultural University, Parbhani, Maharashtra for resistant to Fusarium wilt and jassids. High ginning outturn and drought tolerant (Santhanam, 1997)

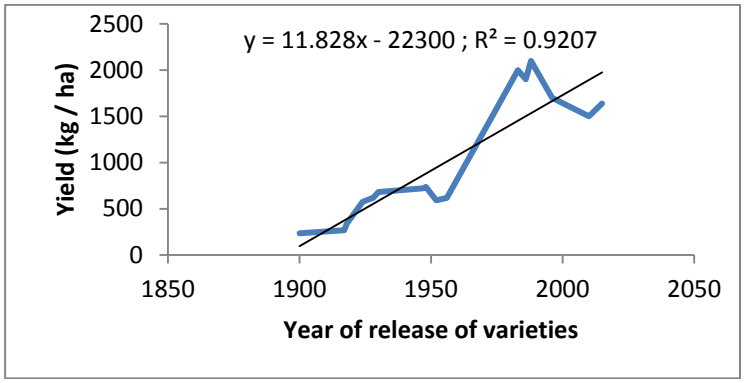

Figure 3. Trend of genetic improvement in *G. herbaceum* for seed cotton yield

1.2. HETEROSIS BREEDING IN *G. HERBACEUM*

Heterosis was studied for seed cotton yield and yield components from early fifties onwards in both intra and inter specific diploid hybrids (Anon.,1919; Zaitzev, 1923; Harland, 1923; Patel and Mankad, 1926; Desai, 1927). In the present study, 12 intra species *herbaceum* F_1 were developed. Baluchistan – 1, bushy, dwarf, early type crossed with IC – 371437 had more number of bolls and Jayadhar confined to drought tolerant traits. Crosses between IC – 371437 x Baluchistan – 1 and IC – 371437 x Jayadhar showed better performance in boll numbers, boll weight and seed cotton yield over the mid parent, better parent and standard check (Table IV).

Table IV. Heterosis in intra specific *G. herbaceum* x *G. herbaceum* F_1 hybrids

Phenotypic traits		F1 hybrids	
		IC - 371437 x Baluchistan – 1	IC – 371437 x Jayadhar
Number of bolls / plant	RH*	65.51	63.69
	HB	108.69	44.60
	SH	60.00	44.60
Boll weight	RH	19.58	15.22
	HB	69.82	65.68
	SH	93.91	89.18
Seed cotton yield / plant	RH	130.09	46.23
	HB	82.83	43.18
	SH	90.78	49.41

	Number of bolls / plant		Boll weight		Seed cotton yield / plant	
	CD = 0.05	CD = 0.01	CD = 0.05	CD = 0.01	CD = 0.05	CD = 0.01
RH	2.26	3.06	4.38	5.92	19.29	26.07
HB	16.86	22.80	4.28	5.76	13.26	17.93

SH	8.26	11.16	4.55	6.16	13.52	18.29
*RH = Relative heterosis; HB = Heterobeltiosis; SH = Standard heterosis						

The heterosis breeding in diploids has been considered as one of the potential way for improving productivity. In cotton, Mell (1894) who first observed an increase in fibre length and agronomic characters in the F1 hybrid of *G. hirsutum* with *G. barbadense* as compared to the parents. Cook (1909) was the first to utilize hybrid vigour in inter-specific hybrids (*G. barbadense* x *G. hirsutum*) and after that a number of workers all over the world suggested the possibility of economic exploitation for hybrid seeds production. Since then hybrid vigour in cotton has been observed by many workers in India (Patel and Mankad,1926; Patel and Patel, 1927; Koshal *et al*., 1940; Ramiah and Bholanath, 1943; Ramiah and Bholanath, 1944; Kelkar *et al*., 1947b; Patel *et al.,* 1947; Patel and Patel,1948; Santhanam, 1951; Patel and Bhat, 1953; Bhat and Kaiwar, 1955; Bhat and Desai, 1955; Bhat and Desai, 1956; Ganga Prasad Rao, 1956; Bederker, 1956; Bederker, 1958; Pandya and Patel,1958b). In intra specific crosses of *herbaceum* x *herbaceum*, the level of heterosis for seed cotton yield was reported upto 63 per cent over mid parent and 43 per cent over better parent (Basu and Paroda, 1995). In the present study maximum 130 per cent relative heterosis was estimated for seed cotton yield. Where as maximum 108 per cent heterobeltiosis was recorded for number of bolls / plant. In general herbeceum has lower boll weight (< 3g). Hence there is possibility for the improvement in boll weight using introgression and population improvemnent programme as highest 89.47 per cent standard hetrosis was recorded. Expression of negative heterosis were also observed for plant height, early and errect type against tall plant, late maturity and branched type traits.

1.3. INTROGRESSING OF *G. ARBOREUM* WITH *G. HERBACEUM*

India is the pioneer country for the commercial exploitation of heterosis in both tetraploid and diploid cottons. Development of inter specific hybrids is a significant milestone in the imrpvements of the native cotton species.The outstanding efforts were undertaken in Cotton Research Station, Surat, Dharwad and Parbhani between 1983 - 1996 in developing and releasing conventional inter-specific hybrids of *G. arboreum* x *G. herbaceum viz.* DH - 7 and DH - 9 (Surat), DDH - 2 (Dharwad) and Pha - 46 (Parbhani). High ginning outturn has been transferred from *G. arboreum* to *G. herbaceum*. The first two hybrids (DH - 7 and DDH - 9) are cultivated in Gujarat State, DDH - 2 in Karnataka and Pha - 46 in Marathwada region of Maharashtra state released for commercial cultivation in India. These hybrids matured early in 180 to 220 days after sowing (DAS), staple length ranged from 21.5mm to 28mm and high GOT (32 - 36). The heterosis of these hybrids was very impressive (200%). Their yield potential was reported to be 102 per cent higher than local cultivars (Basu and Paroda, 1995). These hybrids belong to medium (DH - 7 and DDH - 2) and long (DH - 9 and Pha - 46) staple group. The hybrid DDH - 2 has wide adaptability in Dharwad region of Karnataka state and high yield potential with average yield of 19 q / ha against 10 q / ha of cultivars of this species (Basu and Narayanan, 1992). It was reported that the F_1 obtained between *G. herbaceum* and *G. arboreum* had a higher

ginning percentage and fibre of better quality (Watt, 1907) indicated wide scope for further improvement.

During 2016 - 17, the efforts were made for introgressing of *G. arboreum* with *G. herbaceum* to improve the seed cotton yield and fibre traits like fibre length. Out of 27 inter specific crosses 7 showed higher heterosis for boll number, boll weight and seed cotton yield. Parents IC - 371437 and PA - 785 are the good general combiner. Cross PA – 785D x IC – 371437 showed high specific combining ability for boll number, boll weight and seed cotton yield (Table V).

Table V. Heterosis in inter specific *desi* F_1 hybrids

	G. herbaceum X *G. arboreum*		Number of bolls / plant	Boll weight	Seed cotton yield / plant
1.	GVHV – 655 X PA – 812	RH	35.06*	8.04	195.99**
		HB	0.84	6.01	176.43**
		SH	34.37*	25.89*	148.84**
2.	GVHV – 655 X PA – 785B	RH	112.29**	-11.92	39.76**
		HB	53.03**	-13.90	-4.83
		SH	126.20**	50.65**	105.56**
3.	PA – 785D X IC – 371437	RH	91.91**	32.40**	141.25**
		HB	47.82**	12.59	127.44**
		SH	90.36**	88.15**	110.59**
4.	IC – 371437 X PA – 785C	RH	78.88**	-25.46	43.78**
		HB	34.78**	-36.61	32.55**
		SH	73.57**	5.92	22.75
5.	Baluchistan – 1 X PA – 785C	RH	77.38**	16.05	26.30
		HB	72.00**	-0.39	-10.04
		SH	154.25**	6.64	94.30**
6.	G – 49 X PA – 785	RH	191.98**	8.67	32.35**
		HB	162.12**	3.97	-22.07
		SH	287.45**	89.47**	68.33**
7.	Jayadhar X PA – 740	RH	118.86**	3.91	83.39**
		HB	108.33**	3.54	58.52**
		SH	108.33**	3.54	58.52**

	RH		**HB**		**SH**	
	CD = 0.05	CD = 0.01	CD = 0.05	CD = 0.01	CD = 0.05	CD = 0.01
Number of bolls / plant	15.73	26.09	14.77	24.71	18.44	38.58
Boll weight	7.53	12.48	8.45	14.01	13.17	21.86
Seed cotton yield / plant	15.84	26.28	15.20	25.22	14.76	24.49

The inter specific crosses between *G. herbaceum* x *G. arboreum* exhibited higher level of heterosis than intra-*herabceum* crosses. (Patil, 1948; Santhanam, 1951; Loden and Richmond, 1951; Singh and Narayanan,1993). Basu and Paroda (1995), compared the level of heterosis in inter and intra desi *Gossypium* species. In inter

specific crosses boll number and boll weight are to be the major components of heterosis to improve the seed cotton yield. Similar results were obtained in the present study as heterosis was high (195.99%) for seed cotton yield and boll number (287.45%) and it is comparable significantly with intra specesis crossess developed between G. herbaceum x G. herbaceum (Table VI / Figure 4) . The heterosis for boll number, boll weight and seed cotton yield was not stable in different environments (Mehta *et al*., 1985). In the inter specific crosses between *G. arboreum* x *G. herbaceum*, heterosis was repoted upto 222.6 per cent over mid parent, 208.6 per cent over the better perent and 124.2 per cent over the commercial cultivar for the seed cotton yield (Basu and Narayanan, 1992). High level of heterosis in inter specific crosses resulted mainly due to vegetative superiority of such hybrids during initial growth period resulting in high fruiting potential (Patel, 1922; Sikka and Afzal, 1947; Singh and Narayanan, 1993). The new varieties developed are high yielding with medium and superior medium staple and resistance to Fusarium wilt and jassids (Basu and Paroda, 1995). Efforts showed that the improvements in seed cotton yield coupled with tolerent to post seasonal moisture stress can be achieved by implementing *G. herbaceum* and *G. arboreum* breeding programme.

Table VI. Comparism of the level of heterosis in inter and intra *desi Gossypium* species

	G. herbaceum x *G. herbaceum*			*G. herbaceum* x *G. arboreum*		
	MP	BP	SP	MP	BP	SP
Number of bolls / plant	65.51	108.69	60.00	191.98	162.12	287.45
Seed cotton yield / plant	130.09	82.53	90.78	195.99	176.43	148.84

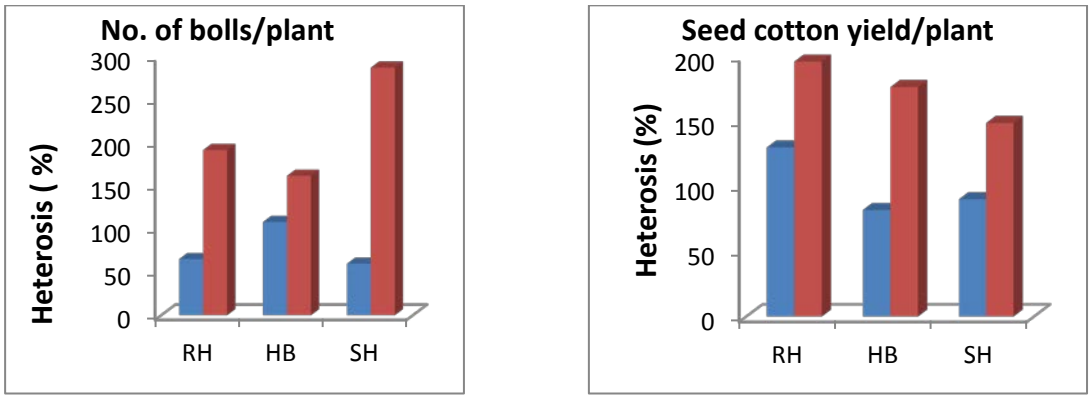

Figure. 4. Comparison of heterosis level between inter and intra diploid crosses

1.4. ACHIEVABLE PROPERTIES

Desi cotton species survived in Indian sub-continent for millions of years thus evolved to tolerate and resist a wide range of diseases, insect pests, drought, water-logging, salinity and many adverse environment conditions. *Desi* species are immune to many diseases and donor of cotton leaf curl virus. They grow well in marginal soils

and sub-optimal regions. However the American cotton species *G. hirsutum* and the Egyptian species *G. barbadense* which struggle for years to adapt to new environment and are highly susceptible to many insect pests, diseases and drought. Desi species are good yielders and require least chemical inputs such as fertilizers and pesticides to obtain similar or better yields as compared to the American cotton. From 1946 onwards research efforts were on development *Fusarium* wilt resistant varieties. Further research focused on high ginning percentage and jassid tolerant varieties. Archaeological evidence indicates that cotton has been in use in India for more than 5000 years. Excavations carried out during the 1920's at Mohenjodaro in the Indus valley revealed silver vessels of 3000 BC containing well preserved cotton fabrics made from *G. arboreum*, thus providing evidence of highly sophisticated textile craftsmanship with fine and delicate Rahmi fabrics. The British introduced American cotton species *G. hirsutum* into India in 1790 and tried hard for 150 years to replace the Indian *desi* cotton species with American cotton. In 1947, when the British left India, at least 97.0% of India's cotton area was under *desi* cotton varieties. Now, 69 years after independence, in 2016 less than 3% area is under *desi* cotton varieties. Today may be less than 1.0% of India's area under *desi* species. The fibre generally produced by many *desi* cotton varieties was short and coarse and was not considered ideal for the mechanized spinning industry. Early maturing varieties and hybrids permit farmers to take more than one crop in a year, suited to multiple cropping systems, crop escape from late season pests, reduce costs on pesticide sprays and crop management resulting in reduction in the cost of cultivation. The crop duration, which ranged from 250 - 270 days, has been reduced to 150 -190 days. Because of the robust nature, *desi* cottons can be easily adapted to organic conditions. Early and rapid flowering coupled with shorter boll maturity period offers selection criteria for early crop maturity. Continuous research efforts showed that there is breakthrough against conventional *Desi* cotton cultivation and opened new avenues for newly developed *desi* varieties (Table VII). The improvements made in Desi sustainable cotton is an alternatives for high yields with low cost of production. This assumes significance in light of the significant increase in cost of cotton production over the past 10 years, when the yields also became stagnant. The main reasons for the preference are *desi* cotton varieties are deep rooted and overcome drought (Figure 5). Whiteflies have been causing immense damage to almost all the Bt cotton hybrids in North India, whereas *desi* cotton varieties are resistant to whiteflies, leaf hoppers and cotton leaf curl virus disease. *Desi* varieties hardly need any chemical inputs such as fertilizers or insecticides for higher yields, thus the cost of production is less than half of Bt-cotton hybrids. Even with moderate care, the yields of *desi* cotton varieties can easily exceed the yields of Bt cotton in rainfed and irrigated regions.

Table VII. Conventional Vs Breakthrough in *desi* diploid cotton cultivation

Conventional		Breakthrough	
Long duration	180 - 240 days	Short duration	140 - 160 days
Short staple *desi*	22 mm	Long staple *desi*	30 mm
Low density crop	16,000 plants / ha	High density planting	168,000 plants / ha

High cultivation cost	Rs 75,000/ha	Low cultivation cost	Rs 30,000 / ha
Moderate net returns	Rs 10,000 / ha	High net returns	Rs.45,000 / ha
High chemical inputs		Low chemical inputs	
Source: Ministry of Agriculture, 2011; Kranthi, 2015			

Figure 5. Field view of *G. herbaceum* genotypes survived in moisture stress condition

1.5 POSSIBLE USES OF THE COTTON

India was the world's largest exporter of cotton textiles. The Dhaka Muslins were famous all over the world. The East India Company traded the beautiful cotton 'Calico' from 1640 and 'Dacca' muslin cloth from 1666 to Britain and all parts of the globe. But the domestic Indian craftsmanship is now on the verge of extinction. An amazing fact is that, even now Andhra Khadi worker women spin 100 counts yarn with *G. arboreum* coarse fibre of 15 mm length, which would otherwise yield only 12s counts yarn in machine spinning. As a natural fibre crop other than textiles, *Desi* cottons can be an ideal and excellent source for other purposes. Jayadhar is an excellent example of a *G. herbaceum* variety released in 1948 that withstood at least six decades of commercial cultivation. There are several other varieties all of which can provide fibre for cushions, mattresses etc. Renuka (DB - 3 - 12) released during 1983 is early maturing variety escaped from late moisture stress. One application that perfectly suits *G. arboreum* cotton is the manufacture of **absorbent cotton**. Inherently many *G. arboreum* varieties naturally produce high yields of non-spinnable short staple, coarse, high water absorbing fibre with low ash content. These traits comprise ideal requirements for the manufacture of absorbent cotton. Absorbent cotton, which in all likelihood would be ideally suited for medical purposes and would have great prospects for domestic markets and also huge demand for exports.

Currently, **comber noil** (short fibres waste of spinning mills) is generally utilized for **absorbent cotton** all over the world. However this is significantly inferior to *desi* short staple cotton for absorbent purposes. If *desi* cotton is used, the domestic demand in India itself is estimated to be at least 3.4 lakh million tonnes (20 lakh bales) per year. Besides the Indian market, there is enormous export potential too. Japan, USA and EU countries import absorbent cotton from India with specific standards. It is estimated that the demand for absorbent cotton is growing at the rate of 10 percent per annum across the world. Based on the growth rate, it is estimated that within the next 5 years, 30 - 35 lakh bales will be required to fulfil the domestic

market and more would be needed to plan for the export market. Several Desi varieties such as Lohit, LD -133, RG - 8, LD - 327, DS - 21, LD - 491, HD - 107 and HD - 11 have fibre quality parameters ideally suited for absorbent surgical cotton. Recently, *G. arboreum* based variety; Phule Dhanwantary was developed by MPKV Rahuri, which has good yield along with excellent fibre properties used for absorbent cotton. Regional Cotton Research Station, Nanded (Marathwada Agricultural University), Maharashtra has developed PA - 740, PA – 785, PA - 812 cultures for high staple length (> 28mm) are the sources for introgression with *G. herbaceum* showed high heterotic effect in F1 population.

1.6. POSSIBLE DEVELOPMENT OF THE HARVESTED AMOUNT

Possible development of the harvested amount can make a huge difference for cotton industry. *Desi* cotton varieties can be categorized into two groups like **spinnable** and **non-spinnable** fibres that comprise 60% rainfed tracts of the cotton area of India. One type is the **short** and **coarse fibre varieties** that are suitable for absorbent cotton, surgical, denims, mattresses, technical textiles etc., whose demand is growing and the market is very high. Few *G. herbaceum* genotypes were identified in this category like seed index and lint index (SLG - 21, G - 6057, KAP - 01/1, DCB – 320 - 2), Boll weight (SM - 61) and Bundle strength (SLG - 25, KAP - 01/26, SLG - 2).

In order to double the farmer's income, erect, compact plant type and suited to high density planting system are needed. Yields are high with high density planting because of the compact nature of varieties. For example, Phule Dhanwantary from MPKV Rahuri is one outstanding desi variety which gives high yields of 25 - 30 q / ha or more under high density planting in rainfed conditions with less than half of the production cost compared to any Bt cotton hybrid (Venugopal *et al.,* 2013). Ginning out-turn is very high. Other category pertains to *desi* varieties that produce good **quality spinnable fibres**. There are some newly improved varieties with very good fibre traits that are equivalent to American cotton varieties. Comparison of four improved new desi cotton G. arboreum varieties (PA - 255, DLSA - 17, MDL - 2463 and Jawahar Tapti) with two American cotton *G. hirsutum* varieties (Bikaneri Narma and LRA - 5166) reported that *G. arboreum* strains perform better than that of *G. hirsutum* strain LRA – 5166. The strain PA - 255 possesses best fibre quality traits, especially fibre length and fineness (Chandra and Srinivasan, 2011). The improved *G. arboreum* cotton fabric records markedly higher values for dye uptake and air permeability as compared to *G. hirsutum* cotton fabric. These fabrics are suitable for men's winter wear. Few newly developed cultures like, PA – 740, PA – 785 and PA – 812 are in pipe lines alternative to the medium long staple *G. hirsutum* cotton particularly with regard to the yarn count range 8 - 25s and for specific end uses like denims and twills. AKA - 8401, PA -183, PA - 255 are some of the prominent varieties with superior medium staple of 27mm - 28 mm. In South Zone, K - 8, K - 9, K -10 and K - 11 expressed 24mm - 25 mm staple length. Improvement in North Zone was focused mainly on yield with LD - 230, DS - 5, LD - 123, RG - 18 and HD - 107 yielding 20 - 26 q / ha and LD - 327 with higher yield of 29 - 30 q / ha at significantly low cost of production. The fibre of these varieties can spin up to 30 - 40 counts, which is equivalent to the American cottons.

The recent challenges of ever-increasing cost of chemical inputs and labour scarcity have been pushing cotton cultivation towards unsustainability and marginalized

profits. The current American cotton hybrid are expensive to cultivate input intensive and run the constant risks of collapsing under high sensitivity to biotic and abiotic stresses. What is imminently needed for India is a vision based policy to plan towards sustainable profits through *desi* cotton only.
Two aspects strengthen *desi* cotton. One is improvement of fibre traits. The second aspect relates to the exploitation of the existing traits for specialized purposes such as **absorbent cotton** and ancillary uses for which desi cotton is the best and other species cannot serve the purpose. As per the data available with the Ministry of Agriculture, the average cost of cultivation was Rs. 15,961 per hectare in 2002, which increased to an average of Rs. 71,115 per hectare in 2011. The yields may have increased, but fertilizer usage per hectare increased by 3.6 times from an average of 74.1 kg per hectare in 2002 to 267 kg per hectare in 2011. With the increase in fertilizer usage, predominantly urea on hybrid cotton, insect pest infestation increased. The average expenditure on insecticides was Rs. 1073 per hectare in 2001, which increased to Rs. 2925 per hectare in 2011. Thus, India's cotton is now characterised with a constant increase in chemical fertilizers and insecticide usage, to move away from sustainability. This shift towards unsustainable cotton production systems makes farmers highly vulnerable to economic risks. Need envisaged to move towards robust and sturdy climate resilient cotton production methods where *desi* cotton provides exciting prospects towards sustainability (Kranthi, 2015).

One more aspect is that the development of **spinning units for Desi cotton fibres**. Micro spinning machinery should be developed to suit *desi* cotton fibre traits, so that even short fibres can result in yarn that is of equivalent quality of the high count hand-spun yarn. Hence concept of spinning of ***desi* fibres on *desi* machines is to be generated.** Micro spinning for making crafted yarn adds values for export purpose. The scale of Micro spin makes integration possible from farm-to-fashion and imparts a distinct look and rare comfort to textiles. It is often compared to linen, an imported fibre which is six-times more expensive than that of crafted yarn manufactured from desi cotton (Kranthi, 2015). With over 1500 textile mill units, about 4 million hand looms, 1.7 million power looms and thousands of garments, hosiery and processing units, the textile industry in India has grown to be the single largest agro-based industry in the last decade of the 20th century. The industry is predominantly cotton based with the fibre consumption ratio being nearly 70% cotton and 30% non-cotton. Indians were known for their supreme mastery over spinning and weaving to produce the finest cotton fabrics ever known to mankind. The yarn spun from fibre of *G. arboreum* was the finest of 345 - 356 counts. In the 1st century AD, the Roman historian calculated that the annual cotton fabric trade between India and Rome was worth 100 million sesterces (equal then to Rs 1.5 crores) indicated to look backward to look the golden era of *desi* cotton.

CONCLUSION

India has the advantage of having the world's highest number of assemblage of both the *desi* species in the ICAR - CICR germplasm bank. Since India is the centre of origin for the species, the prospects of cultivation is high in any part of the country under any adverse condition. Because of the low cost of production, suitability for marginal soils and the possibility of obtaining high yields through sound technological

backup, there is immense scope for the promotion of *desi* cotton varieties for sustainable cotton farming in the country. Study shows high range of variability exists in *G. herbaceum* cotton germplasm for partitioning of total biomass into yield and yield contributing traits as cotton plants grown in different environments. To improve the native cotton varieties there is considerable scope for altering the capability of boll numbers, boll weight and fibre quality traits for the development of superior cotton lines and hybrids with higher yield potential. Whereas to improve introduced varieties approaches should be to improve tolerance to pests and diseases and adaption to climate change. Genetically distinct diploid genotypes and inter specific crosses between *G. herbaceum* x *G. arboreum* exhibited higher level of heterosis can be used for hybrid development and population improvement programme. Further study is imperative to find out relationship and study the inheritance pattern that enable to break the linkages of the qualitative traits. Large number of crosses to be attempted in diploid x diploid that are more easier in conventional breeding than that of introgressing between diploid x tetraploids species which will enable to sustain *desi* cotton improvement. *Desi* cotton can be as profitable as Bt-cotton in rainfed cotton growing area of Maharashtra. India has to move towards sustainable cotton cultivation, *desi* cotton provides the answers not just for sustainability but for a vision towards India's global leadership that can happen through focused efforts and sound planning. It is not easy to accept the opinion instantly, but with noble thoughts it is not difficult to put forth vision that India's cotton future lies in *desi* cotton.

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REFERENCES

Annual Report. 2012. Navasari Agricultural University, Navasari, Gujarat, India

Annual Report. 2016. Anand Agricultural University, Anand, Gujarat, India

Anonymous. 1956b. Annu. Rep. Indian Central Cotton Committee, Bombay, (1954 - 55) : 106

Anonymous. 1957c. What the scientist are doing? II. Digvijay the superior new cotton strain for middle Gujarat., I.C.C.C., 11: 396

Anonymous.1919. Report of the Indian cotton Committee. Government printing, Calcutta, India, 264pp.

Anonymous.1956a. A guide to Indian cotton (Revised). Indian Central Cotton Committee, Bombay, 74

Basu, A.K. and Paroda, R.S. 1995. Hybrid Cotton in India – A Success Story. Asia - Pacific Association of Agricultural Research Institutions, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. 38 pp

Basu, A.K. and S.S.Narayanan. 1992. All India Coordinated Cotton Improvement Project – Achievements 1967-1992, Central Institute for Cotton Research, Nagpur

Bederker, V. K. 1958. Preliminary study of heterosis in Gaorani cotton. 8th Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay.

Bederker, V. K. 1956. A scope for further improvements of Hyderabad Gaorani cotton. 7th Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay. 1 – 5

Bederker, V.K. 1955a. Future improvements of Hyderabad Gaorani cotton. I.C.G.R., 9 : 1- 23

Bhat, N. R. and N. D. Desai. 1955. Linkage for pale green leaf with curled in *G. herbaceum*. Curr. Sci. 24 : 170 – 171

Bhat, N. R. and N. D. Desai. 1956. Genetic investigation on the whorled mutant in *G. herbaceum*. Genetics. 41 : 915 – 929

Bhat, N. R. and S. R. Kaiwar. 1955. Some new hybrid cotton of economic importance. 6th Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay, 1 - 4

CAB. 2016. Cotton Advisory Board Report, Cotton Corporation of India, Bombay, India

Chandra, M. and S. Sreenivasan. 2011. Studies on improved *Gossypium arboreum* cotton : Part – I- Fibre quality parameters. Indian J. of Fibre and Textile Res., 36 : 24 – 34.

Cook, O.F. 1909. Suppressed and intensified characters in cotton hybrids. Bull. U.S. Bur. Pl. Ind. no. 147 : 27

Cook, O.F. 1913.Heredity and cotton breeding. Bull. U.S. Bur. Pl. Ind. 256 : 113
Desai, B. B. 1927. A cross between Indian and American cottons. Agric. J. India, 22 : 351 - 352

Gammie, G. A. 1908. Work done towards improvements of cotton in Bombay Presidency. Agric. J. India, 3 : 135 - 143

Ganga Prasad Rao, N. 1956. Some perennial cottons of Raichur and their utilization in cotton breeding under the Tungabhadra project. 7th Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay, 14 - 16

Gulati, A. N. and A. J. Turnar.1928. A note on the early history of cotton. Technol. Bull., I.C.C.C., Bombay, 17 : No. 12 : 10

Harland, S. C. 1923. Inbreeding in cotton and its importance to the plant breeder. Agric. J. India. 18 : 465 - 473

Kelkar, S. G., S. P. Choudhari, and N. B. Hiremath, 1947b. Paths and bypaths to the improvement of *G. herbaceum* cotton. 3rd Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay, 110 -119

Khadilkar, T. R. 1947a. Breeding of high ginning Jarila cotton. I.C.G.R., 1: 64

Koshal, R. S., A. N. Gulati, and N. Ahmad. 1940. The inheritance of mean fibre length, fibre weight per unit length and fibre maturity of cotton. Indian J. Agric. Sci., 10: 975 - 989

Kranthi K. R. 2015. Desi cotton – Returns?. Cotton Statistics and News., Cotton Association of India, Mumbai., 15 : 7, 1 – 4.

Loden, H. D. and T. R. Richmond. 1951. Hybrid vigour in cotton - Cytogenetic aspects and practical applications. Econ. Bot., 5 : 387- 408

MacKenna, J. 1918. The early history of cotton in Bombay. Agric. J. India, 13 : 289 - 404

Mahajan. S. S., D.V. Patil, Punit Mohan and V. N. Waghmare. 2017. Evaluation of viability and germination potential of Gossypium *herbaceum* germplasm stored under MTS by paper tube technique. Ab : Seventh Asian Cotton Research and Development Network Meeting, Nagpur, September 15 - 17, 2017, ISCI, Mumbai, India., pp. 77

Mahta, D. N. 1938. Cotton breeding in the Central Provinces and Berar. 1st. Conf. Sci. Res. Workrs. Cott. India, I.C.C.C., Bombay, 401 - 409

Mahta, D. N., 1947. Cotton growing in India. I.C.G.R., 1: 1 - 9

Main, T. F. 1907. Improvement of cotton in India. Agric. J. India, 2: 349 - 355

Mehta, N.P., A.K. Basu and K.C. Mandloi. 1985. Rainfed cotton production technology - Crop Improvement. In: Proc. National Seminar on rainfed cotton production Tech, May 24, 1985, MAU, Parbhani. pp. 9 - 24

Mell, P.H. 1894. Experiment in crossing for the purpose of improving the cotton fibre. Alabama Agric. Expt. Sta. Bull. 56

Mollison, J. W. 1903. The improvement of Indian cotton, 1902 - 1903 and note on the improvement of Indian cotton. Secretariat Press, Nagpur, India

Pandya, P. S. and C. T. Patel. 1958b. Heterosis and its exploitation in cotton improvement. 8th Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay

Pandya, P.S. and C. T. Patel, 1956. Review of further progress in inter specific hybridization work at Surat. 7th Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay, 9 - 14

Pandya, P.S., P. N. Majumdar, and K. B. Desai. 1956. Breeding for fibre length in *herbaceum* cottons. 7th Conf. Cott. Gr. Probl. India, I.C.C.C., Bomaby, 25 - 26

Patel, A. F. and S. J. Patel. 1948. 'Pratap' cotton of the Motheo track. I.C.G.R., 2: 140 - 144

Patel, C.B.1947. Cotton improvement in South Gujarat (Bombay Province). I.C.G.R., 1: 19 - 21

Patel, G.B. and N. R. Bhatt. 1953. Strains 2087, a new wilt resistant cotton for the Surat track. I.C.G.R., 7: 230 - 232

Patel, G.B., Z.A. Munshi, and G. T. Patel. 1947. Genetics of some mutations in *herbaceum* cottons of Gujarat (Bombay province). 3rd Conf. Cott. Gr. Probl. India. I.C.C.C., Bombay, 87 – 97

Patel, M. L. and Patel, S. J. 1927. Studies in Gujarat cotton. IV. Hybrids between Broach Desi and Goghari varieties of *Gossypium herbaceum*. Mem. Dept. Agric. India Bot., 14: 131-176

Patel, M. L.1922. The connection between seed weight and lint weight in cotton. Agric. J. India, 17 : 204 - 205

Patel, M.L. and D.P. Mankad. 1926. Studies in Gujarat cottons. Part III. The Wagad cotton of upper Gujarat, Kathiawar and Kutch. Mem. Dept. Agric. India., Bot., 14 : 59 -112

Patel, P. L. 1947. Improvement of cotton in middle Gujarat. I.C.G.R., 1: 184 -189

Patel, S. J., 1949. Improvement of Wagad cotton in North Gujarat. I.C.G.R., 3: 84 - 91

Patil, A. S. 1948. Cotton improvement in the Bombay Karnataka. I.C.G.R., 2: 31 - 34

Patil, D.V., Punit Mohan and V. N. Waghmare. 2017. Evaluation of *Gossypium herbaceum* germplasm race *Wightianum* under different sowing dates in the central cotton zone of India. Ab: Seventh Asian Cotton Research and Development Network Meeting, Nagpur, September 15 -17, 2017, ISCI, Mumbai, India. pp. 59

Powers L. 1944. An expansion of Jones's theory for the explanation of heterosis. Am. Nat. 78: 275 – 280

Ramiah, K. and Bholanath. 1943. Genetics of single lobe leaf mutant in cotton. Indian J. Genet. 3 : 89 - 98.

Ramiah, K. and Bholanath. 1944. Genetics of two new anthocyanin patterns in Asiatic cottons. Indian J. Genet. 4 : 23 – 42

Santhanam, V. 1951. The role of heterosis in crop breeding with special reference to hybrid cotton. Madras Agric. J., 38 : 431- 441

Santhanam. V. 1997. Significant milestones in cotton research in India and future scenario for technology development. J. Indian Soc. Cotton. Improv. 22(2) : 67 - 79

Satyanarayana Murthy, K., M. Venkoba Rao, and C. Jagannatha Rao, 1955a. A review of recent cotton improvement work under the Mungari scheme in Andhra State. 6th Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay, 47- 48

Satyanarayana Murthy, K., M. Venkoba Rao, and C. Jagannatha Rao, 1955b. A brief resume of progress made in the improvement of Western cotton. 6th Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay, 45 - 47

Sethi, B.L., S.M. Sikka, R.H. Dastur, P. D. Gadkari, R. Balasubrahmamanyan, P. Maheshwari, N.S. Ranga Reddy and A.B. Joshi.1960. Cotton in India – A Monograph. Indian Central Cotton Committee, Bombay. 336 – 446

Sheoran, O.P., D.S, Tonk, L.S. Kaushik, R.C. Hasija, and R.S. Pannu. 1998. Statistical Software Package for Agricultural Research Workers. Recent Advances in information theory, Statistics & Computer Applications by D.S. Hooda & R.C. Hasija Department of Mathematics Statistics, CCS HAU, Hisar. 139 -143.
Shull. G. H.1914. Duplicate genes for capsules form in bursapastoris Z. Indukt. Abstammungs u. Vererbungsl. 12 : 97 – 149

Shull. G.H. 1948. What is heterosis? Genetics, 33 : 439 – 446

Sikka, S. M. and M. Afzal. 1947. A note on the correlation between lint weight, fibre weight and ginning outturn in some *arboreum* crosses. 3rd Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay, 210 - 216

Singh, P. and S.S. Narayanan. 1993. A brief review on breeding aspects of plant type in cotton. ISCI J.18 (1): 1 – 4.

Thakar, B. J. 1955. Cotton improvement after Vijay in Middle Gujarat. 6th Conf. Cott. Gr. Probl. India, I.C.C.C., Bombay, 35 - 37.

Tippannavar, M. B. and S. V. Patil.1952. Retrospect and prospect of cotton cultivation in Bombay – Karnatak. Indian Cott. Grow. Rev.6 : 26 – 34

Venkoba Rao, M. and C. K. Ramachandran.1943. The mode of inheritance of dwarf bushy type in *G. herbaceum*. Madras Agric,. J. 31: 28 – 29

Venugopalan, M. V., K. R. Kranthi, D. Blaise, Shubhangi Lakde and K. Shankaranarayanan. 2013. High density planting system in cotton - The Brazil Experience and Indian Initiatives. *Cotton Res. J*. 5 : 2, 172 - 185

Vijayaraghavan, C., N. K. Iyenger and M. Venkoba Rao.1936. A heritable case of female sterility in *herbaceum cotton.* Madras Agric. J. 24 : 365 – 368

Watt, G., 1907. The wild and cultivated cotton plants of the world. Longmans, Green and Co.London, 406

Zaitzev, G. S. 1923. A hybrid between Asiatic and American cotton plants – *Gossypium herbaceum* L. and *Gossypium hirsutum* L. Bull Appl. Bot. Plant Breed. 13 : 117 – 134