

# Biology of *Gossypium spp.* (Cotton)



Ministry of  
Environment and Forests  
Government of India

Department of Biotechnology  
Ministry of Science & Technology  
Government of India

Series of Crop Specific Biology Documents

**Biology of**  
*Gossypium spp.*  
**(Cotton)**



Ministry of  
Environment and Forests  
Government of India

Department of Biotechnology  
Ministry of Science & Technology  
Government of India

## **Biology of *Gossypium spp.* (Cotton)**

© Department of Biotechnology  
Ministry of Science & Technology

&

Ministry of Environment and Forests  
Govt. of India, 2011

Material from this publication may be used for  
educational purpose provided due credit is given.

### **Compiled by:**

Dr. K.K. Tripathi  
Advisor  
Department of Biotechnology  
Government of India

Dr. Ranjini Warriar  
Director  
Ministry of Environment & Forests  
Government of India

Dr. O.P. Govila  
Former Professor of Genetics  
IARI

Dr. Vibha Ahuja  
General Manager  
Biotech Consortium India Limited

### **Assisted by**

Pragati Mehra, Tarak Nath Chakraborty and Simple Kumari, Project Executives, and Hira Lal, PA, BCIL

### **Consultation process:**

Circulated to concerned state agricultural universities, research institutions and industry and placed at websites viz. <http://www.igmoris.nic.in> and <http://dbtbiosafety.nic.in>. The inputs and comments provided by the following are gratefully acknowledged.

- Acharya N.G. Ranga Agricultural University, Hyderabad
- Anand Agricultural University, Anand
- CCS Haryana Agricultural University, Hisar
- Central Institute for Cotton Research, Nagpur
- Dow Agrosiences Pvt. Ltd., New Delhi
- Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
- JK Seeds, Hyderabad
- Junagadh Agricultural University, Junagarh, Gujarat
- Krishidhan Seeds Pvt. Ltd., Jalna
- Maharashtra Hybrid Seeds Company Limited, Mumbai
- National Centre for Integrated Pest Management, N.Delhi
- Navsari Agricultural University, Navasari, Gujarat
- Punjab Agricultural University, Ludhiana
- Tamil Nadu Agricultural University, Coimbatore
- University of Agricultural Sciences, Dharwad

### **For further information, please contact:**

Department of Biotechnology  
Government of India  
Block-II, 7th Floor,  
CGO Complex, Lodhi Road  
New Delhi - 110003  
Email: [kkt@dbt.nic.in](mailto:kkt@dbt.nic.in)

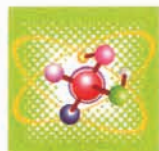
Ministry of Environment & Forests  
Government of India  
Paryavaran Bhawan  
CGO Complex, Lodhi Road  
New Delhi-110003  
Email: [warrier@nic.in](mailto:warrier@nic.in)



सत्यमेव जयते



अस्य हिन्द



MINISTRY OF  
SCIENCE & TECHNOLOGY

डा० एम० के० भान  
Dr. M. K. Bhan

सचिव  
भारत सरकार  
विज्ञान और प्रौद्योगिकी मंत्रालय  
बायोटेक्नोलॉजी विभाग  
ब्लॉक-2, 7 वां तल, सी० जी० ओ० कम्प्लेक्स  
लोदी रोड, नई दिल्ली-110003

SECRETARY  
GOVERNMENT OF INDIA  
MINISTRY OF SCIENCE & TECHNOLOGY  
DEPARTMENT OF BIOTECHNOLOGY  
Block-2, (7th Floor) C.G.O. Complex  
Lodi Road, New Delhi-110003

## FOREWORD

India is one of the leading countries having an active agricultural biotechnology research and development programmes in diverse crops including cereals, vegetables, oilseeds etc. and traits such as insect, disease, and virus resistance, herbicide tolerance, stress tolerance etc. The successful development and commercialization of biotech derived crops also referred as genetically engineered (GE) or genetically modified (GM) crops requires a science based regulatory process to address the concerns arising out of genetic manipulation to human health and environment.

The Department of Biotechnology (DBT), as one of the implementing agencies for biosafety regulations in India has been providing science based support for evaluating the GM crops by preparing various guidance documents and disseminating information through websites. In continuation with the above efforts, a need was felt to prepare crop specific biology documents to provide relevant baseline information about various crops in a readily accessible format.

I am pleased to note that Dr. K.K. Tripathi, Advisor, DBT and Member Secretary, RCGM has put in considerable efforts in putting together a series of five crops specific biology documents on cotton, brinjal, okra, maize and rice, in association with the Ministry of Environment and Forests (MoEF). The biology documents have been put through a consultative process with various stakeholder viz. agriculture research institutions, state agricultural universities, industry etc. The views have been taken by circulating the documents to relevant institutions as well as by placing them on websites. The documents have also been reviewed by the members of RCGM and GEAC. Biotech Consortium India Limited (BCIL) provided support in compiling the baseline information, as well as the consultative process.

I believe that these crop specific biology documents would be of immense value for both the developers in planning the safety assessment of their products as also the regulators for evaluating the data submitted to them. Scientific developments being advancing at a rapid rate, I hope that these biology documents would be continuously updated from time to time.

  
(M.K. Bhan)



सत्यमेव जयते

मु. फ़ै. फारूकी

अपर सचिव

M.F. Farooqui

Additional Secretary

पर्यावरण एवं वन मंत्रालय  
MINISTRY OF ENVIRONMENT & FORESTS  
भारत सरकार  
GOVERNMENT OF INDIA  
नई दिल्ली-110 003  
NEW DELHI-110 003

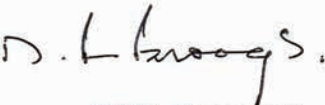
## PREFACE

Genetically engineered (GE) crops are regulated products in view of various concerns for human and animal health and environment. Extensive evaluation and regulatory approval process take place before any GE crop is introduced for cultivation. The approval for release of a GE crop is given by the Genetic Engineering Approval Committee (GEAC) functioning in the Ministry of Environment and Forests (MoEF) as per "Rules for the manufacture, use, import, export & storage of hazardous microorganisms, genetically engineered organisms or cells, 1989" notified under the Environment (Protection) Act, 1986.

So far, Bt cotton, is the only GE crop approved for commercial cultivation in India. There are several crops under various stages of research, development and field trials. The present set of crop specific biology documents has been prepared jointly by MoEF and the Department of Biotechnology (DBT) to provide scientific baseline information used for safety assessment of GE crops. These biology documents have sections on taxonomy, economic importance, centre of origin, growth and development (vegetative and reproduction biology), ecological interactions, distribution pattern in India etc.

I wish to put on record my appreciation of the sincere efforts put in by Dr. Ranjini Warriar, Director, MoEF who has worked closely with DBT and other stakeholders for this initiative and the consultative approach adopted in finalizing these documents. I also acknowledge the support of members of both GEAC and RCGM for their useful inputs during the review process. The inputs and support provided by Dr O.P. Govila, Former Professor of Genetics, Indian Agricultural Research Institute (IARI) and Dr. Vibha Ahuja, General Manager, Biotech Consortium India Limited (BCIL) has also been extremely valuable.

I am sure that these crop specific biology documents would serve as practical tools for researchers, regulators and industry.

  
(M.F. Farooqui)

---

पर्यावरण भवन, सी.जी.ओ. कॉम्प्लैक्स, लोदी रोड, नई दिल्ली-110 003  
Paryavaran Bhawan, C.G.O. Complex, Lodhi Road, New Delhi-110 003  
Telephone : 24361308 Fax : (91) 011-24363967  
E-mail : mffarooqui@nic.in Website : www.envfor.nic.in



## PROLOGUE

Modern biotechnology like any new technology has its associated benefits and risks. Accordingly products of modern biotechnology like biopharma, genetically engineered (GE) crops etc. are regulated for ensuring safety to human and animal health and environment. In case of GE crops, scientific assessments ensure food safety and environmental safety, an integral part of approval process. The whole process of safety assessment is based upon comparison between genetically engineered crop and its unmodified counterpart and thus requires a broad understanding and knowledge of various features of the crop plants. This familiarity with the crops allows both the developers and regulators to draw on previous knowledge and experience to ensure safety of the GE crops.

Keeping in view the above, the Department of Biotechnology (DBT) and the Ministry of Environment and Forests initiated the preparation of a "Series of Crop Specific Biology Documents" to provide information directly relevant to safety assessment in a readily accessible format. The objective of these documents is to make available the information about biology of the crops to applicants as information in applications to regulatory authorities; to regulators as a guide and reference source in their regulatory reviews; and for information sharing, research reference and public information. To start with, crop specific documents for five crops viz. cotton, brinjal, maize, okra and rice have been prepared. In addition to the scientific literature and references, the documents have also taken into account the information available in Consensus documents published by OECD as well as biology documents by other countries. The documents have been finalized through a consultative process with the concerned research institutions, state agricultural universities and subject experts. The documents were also placed on DBT's biosafety website for public review.

It is proposed to continue this exercise for more crops such as mustard, potato, tomato etc. that are under development. The support from various technology developers from both public and private sector, state agricultural universities, agricultural research institutions and other subject experts in providing information as well as reviewing these documents is acknowledged. We also appreciate the assistance provided by Dr. Vibha Ahuja, General Manager, Biotech Consortium India Limited, Dr. O.P. Govila, Former Professor of Genetics, Indian Agricultural Research Institute and other team members at BCIL for backend support in finalizing these documents.

**Dr. Ranjini Warriar**

**Dr. K.K. Tripathi**

# CONTENTS

	<b>Foreword</b>	
	<b>Preface</b>	
	<b>Prologue</b>	
<b>1.</b>	<b>General Description .....</b>	<b>01</b>
<b>2.</b>	<b>Taxonomy, Geographic Origin and Distribution .....</b>	<b>01</b>
	2.1 Taxonomy .....	01
	2.2 Geographic origin .....	02
	2.3 Genomic evolution and geographic distribution .....	02
	2.4 Cotton gene pool .....	04
<b>3.</b>	<b>Reproductive Biology .....</b>	<b>06</b>
	3.1 Growth and development .....	06
	3.2 Floral biology .....	06
	3.3 Pollination and fertilization .....	07
	3.4 Pollen dispersal .....	08
	3.5 Seed dispersal .....	08
	3.6 Mating systems .....	08
	3.7 Methods of reproductive isolation .....	09
<b>4.</b>	<b>Ecological Interactions .....</b>	<b>09</b>
	4.1 Potential for gene transfer from cotton .....	09
	4.2 Free living populations of cotton .....	10
	4.3 Weediness of cotton .....	10
<b>5.</b>	<b>Health Considerations .....</b>	<b>10</b>

<b>6.</b>	<b>Cotton Cultivation in India .....</b>	<b>11</b>
6.1	Climatic and soil requirements .....	11
6.2	Zonal distribution .....	12
6.3	Pests and diseases of cotton .....	13
6.4	Breeding objectives and varietal testing system .....	13
6.5	Germplasm maintenance and its evaluation .....	14
6.6	Status of cotton cultivation .....	15
<b>7.</b>	<b>Annexes .....</b>	<b>17</b>
1.	Botanical features .....	17
2.	Key insect pests of cotton .....	23
3.	Major diseases of cotton .....	29
4.	Major predators of cotton .....	32
5.	Biotech interventions in cotton .....	35
<b>8.</b>	<b>References .....</b>	<b>38</b>



# BIOLOGY OF *GOSSYPIMUM SPP.* (COTTON)

## 1. GENERAL DESCRIPTION

Cotton is a major fibre crop of global importance and has high commercial value. It is grown commercially in the temperate and tropical regions of more than 70 countries. Specific areas of production include countries such as China, USA, India, Pakistan, Uzbekistan, Turkey, Australia, Greece, Brazil, Egypt etc., where climatic conditions suit the natural growth requirements of cotton. These include periods of hot and dry weather and adequate moisture obtained through irrigation. Cotton is harvested as 'seed cotton' which is then 'ginned' to separate the seed and lint. The long 'lint' fibres are further processed by spinning to produce yarn which is knitted or woven into fabrics.

India has the largest cotton growing area in the world with about 96 lakh hectares under cultivation accounting for one-fourth of the global cotton area. It contributes to 16% of the global cotton produce and has emerged as the world's second largest cotton producer in 2006-07, edging past the USA, which held the second rank until recent past. China is the world's leading cotton producer. It has been estimated that cotton contributes to approximately 30% of the Indian agricultural gross domestic product and considerable export earnings. The organized sector of the Indian textile industry constitutes the largest single industrial segment in the country in terms of annual value of output and labour employed, both direct and indirect. There are more than 1,500 spinning mills, 250 composite mills in India having an installed capacity of approximately 35 million spindles and more than 1 lakh handlooms. The decentralized sector comprising power looms and handlooms, provide employment to over 2.5 million people (ICAR, 2006). The fabric quality of handlooms has been widely acclaimed for fitness and comfort. Thus, cotton is an immensely important crop for the sustainable economy of the country and livelihood of the Indian farming community.

## 2. TAXONOMY, GEOGRAPHIC ORIGIN AND DISTRIBUTION

### 2.1 Taxonomy

The word 'cotton' refers to four species in the genus *Gossypium* (family Malvaceae), namely *G.hirsutum* L., *G.barbadense* L., *G.arboreum* L., and *G.herbaceum* L., that were domesticated independently as sources of textile fibre. Globally, the *Gossypium* genus comprises about 50 species (Fryxell, 1992).

Name	Cotton
Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Malvales
Family	Malvaceae
Genus	<i>Gossypium</i>

## 2.2 Geographic Origin

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). DNA sequence data from the existing *Gossypium spp.* suggests that the genus arose about 10-20 million years ago (Wendel & Albert, 1992; Seelanan *et al.*, 1997).

The antiquity of cotton in the Indian subcontinent has been traced to the 4<sup>th</sup> millennium BC (Santhanam and Sundaran, 1997). The first reference to cotton is found in Rig Veda hymn (Khadi and Kulkarni, 2001). The stages of seed cotton, spinning the lint and weaving the yarn are covered in various religious texts, and thus suggesting the implicit use of cotton in India by 1000 BC (Sundaram, 1974). The fabrics dated approximately 3000 BC recovered from Mohenjodaro excavated in Sind were identified to have originated from cotton plants, closely link to *Gossypium arboreum* species (Gulati and Turner, 1929), thereby confirming that cotton lint was spun and woven into cloth even before 3000 B. C.

## 2.3 Genomic Evolution and Geographic Distribution

Most commercially cultivated cotton is derived from two species, *G.hirsutum* (Upland cotton, 90% of world plantings) and *G.barbadense* (Pima, or Long-staple cotton). Two other species, *G.arboreum* and *G.herbaceum*, are indigenous to Asia and Africa and are popularly referred as desi cottons in India. The new world cottons, i.e., the tetraploid (2n=52) species of *G.hirsutum* L. and *G. barbadense* L. were initially introduced into India during the 17<sup>th</sup> and 18<sup>th</sup> centuries A.D. (Hutchinson, 1959). It has been shown that the new world cottons are natural amphidiploids containing A genome from a taxon of the Asiatic diploid group and a D genome from a taxon of the American diploid group. The new world cottons in India are popularly known as American (*G.hirsutum*) and Egyptian (*G.barbadense*) cottons. How and when the original crosses occurred is a matter of speculation. Allotetraploids of these plants have 52 somatic chromosomes, and are designated as AADD genomes. Four additional new world allotetraploids occur in the genus, including *G.tomentosum*, native of Hawaii, which have been utilized in the improvement of *G.hirsutum* in breeding programs.

As regards the concept of organismal and genome relationships of diploid and cultivated allopolyploid species in the genus *Gossypium*, the diploid ancestral A and D genomes of extant allotetraploid are thought to have diverged from a common ancestor about 6 to 11 million years ago giving rise to two lineages as illustrated in Figure 1 (Wendel, 1989; Cronn and Wendel, 1998). The five polyploid *Gossypium spp.* recognized today, including cultivated cottons of *G.hirsutum* and *G.barbadense*, are thought to have originated 1 to 2 million years ago by transoceanic migration of Old World A genome progenitor, followed by hybridization with New World D genome progenitor (Endrizzi *et al.*, 1985; Wendel, 1989; Cronn and Wendel, 1998). This hypothesis is a revised version of simple origin of Old World and New World diploids and their hybridization in the new world 1-2 million years ago. Despite intensive study, the identity of the parental diploids and the antiquity of polyploidisation remain unresolved.

Some of the established and accepted facts about genomic evolution and geographic distribution of

*Gossypium* are as follows:

- The cultivated *G. herbaceum* was derived from the truly wild form of the diploid, *G. herbaceum* race *africanum* which has distribution in South Africa. It has been assumed that traders sailing between Mozambique and Western India introduced this wild form of *G. herbaceum* into Southern Arabia, where the first domestication in the Old World cotton took place. From here, the spread of the species led to the development of new races. *G. herbaceum* consists of five races: 1. *africanum* 2. *acerifolium* 3. *persicum* 4. *kuljianum* and 5. *wightianum*.
- The genome of *G. arboreum* is derived from that of *G. herbaceum* and these two species are set apart by a reciprocal translocation (Gerstel, 1953). Genetically both species are closely related and are good functional diploids. *G. arboreum* arose as an incipient species with the origin and fixation of the translocation. The accumulation of genes due to consistent isolation and selection supported by hybridization resulted into eventual re-emergence of *G. arboreum* as a full fledged species (Fryxell, 1984). The races evolved from *G. arboreum* are 1. *indicum* 2. *burmanicum* 3. *sinense* 4. *sudanense* 5. *cernum*.
- At least eight genomes designated A, B, C, D, E, F, G and K, are found in the genus. The A genome is restricted in diploids of two species (*G. arboreum* and *G. herbaceum*) of the Old World. The wild diploid species belonging to B, E and F genome have distribution in Africa and Arabia and the entire D genome has distribution in South and Central America (Fryxell, 1992). Kimberly cottons belonging to Grandicalyx (K) and other diploids belonging to Sturtia (C) and Hibiscoidea (G) have been found distributed in Australian continent (Craven *et al.*, 1995). The AD genome group diverged into these distinct lineages is presently represented by five species including economically important cottons of *G. hirsutum* and *G. barbadense*.
- The New World allotetraploids are peculiar in the genus, because the species, atleast in their wild forms, grow near the ocean, as invaders in the constantly disturbed habitats of strand and associated environments. It is from these “weedy” or invader species that the cultivated cottons developed (Fryxell, 1979).

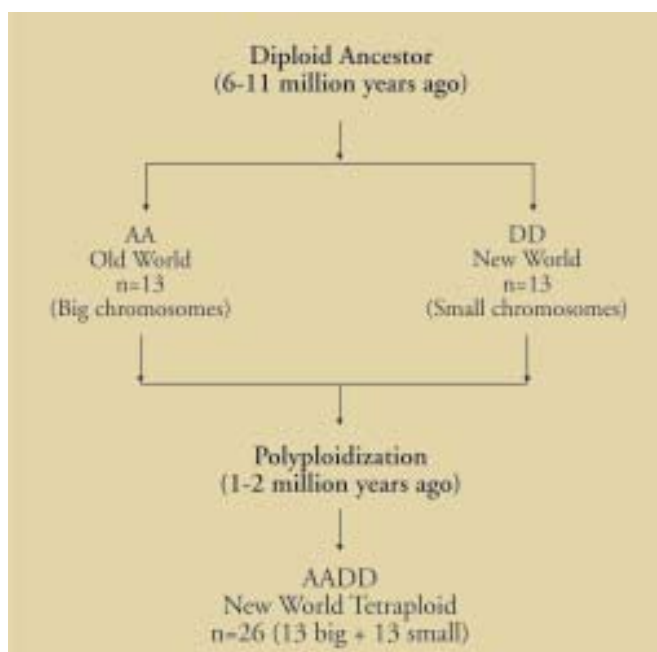


Figure 1: Evolution and Phylogenetic relationships among *Gossypium* Genus (Endrizzi *et al.*, 1985; Wendel, 1989)

## 2.4 Cotton Gene Pool

Cotton gene pool has been classified as primary, secondary and tertiary according to ease with which genes could be transferred from source to tetraploid cultivated cotton (Stewart, 1995) as under:

- **Primary gene pool:** The primary pool of cotton germplasm consists of all natural *Gossypium* allotetraploids (2AD) which cross with *G. hirsutum* lines resulting in direct genetic recombination between the parental genomes. Production of sexual hybrids requires no special technique in this pool other than synchronized flowering.
- **Secondary gene pool:** The secondary pool consists of mainly A and D diploid genomes because of their affinity towards corresponding A and D of tetraploid. It also comprise species of B and F genomes because of their affinity to A genome. Here production of fertile hybrids, between *G. hirsutum* and secondary pool require some degree of manipulation and some times special techniques. However, recombination potential of secondary pool is high in the hybrids with tetraploid gene pool.
- **Tertiary gene pool:** The tertiary germplasm pools comprise of all *Gossypium spp.* indigenous to Australia and a few from Africa belonging to C,G,K and E genomes that have reduced homology to the chromosomes of cultivated tetraploid cotton. The gene pools may or may not hybridize easily with tetraploid cotton and produce very low level of genetic recombination.

List of *Gossypium spp.* according to germplasm pool is given in Table 1.

Table 1: List of *Gossypium spp.* according to germplasm pool

Species	Genome	Notes
<b>Primary Germplasm Pool</b>		
<i>G.hirsutum</i>	AD <sub>1</sub>	Current & obsolete cultivars, breeding stocks, primitive and wild accessions.
<i>G.barbadense</i>	AD <sub>2</sub>	Current & obsolete cultivars, breeding stocks, primitive and wild accessions.
<i>G.tomentosum</i>	AD <sub>3</sub>	Wild, Hawaiian Islands.
<i>G.mustelinum</i>	AD <sub>4</sub>	Wild, NE Brazil
<i>G.darwinii</i>	AD <sub>5</sub>	Wild, Galapagos Islands
<b>Secondary Germplasm Pool</b>		
<i>G.herbaceum</i>	A <sub>1</sub>	Cultivars and land races of Africa and Asia Minor, one wild from Southern African.
<i>G.arboreum</i>	A <sub>2</sub>	Cultivars and land races of Asia Minor to SE Asia, &China , some African.
<i>G.anomalum</i>	B <sub>1</sub>	Wild, two subspecies from Sahel and SW Africa
<i>G.triphyllum</i>	B <sub>2</sub>	Wild, Cape Verde Islands
<i>G.capitis-viridis</i>	B <sub>3</sub>	Wild, Cape Verde Islands
<i>G.trifurcatum</i>	(B)	Wild, Somalia
<i>G.longicalyx</i>	F <sub>1</sub>	Wild, trailing shrub, East Central Africa
<i>G.thurberi</i>	D <sub>1</sub>	Wild, Sonora Desert
<i>G.armourianum</i>	D <sub>2-1</sub>	Wild Baja California
<i>G.harknessii</i>	D <sub>2-2</sub>	Wild, Baja California

Species	Genome	Notes
<i>G. davidsonii</i>	D <sub>3-d</sub>	Wild, Baja California
<i>G. klotzschianum</i>	D <sub>3-k</sub>	Wild, Galapagos Islands
<i>G. aridum</i>	D <sub>4</sub>	Wild, arborescent, Pacific slopes of Mexico
<i>G. raimondii</i>	D <sub>5</sub>	Wild, Pacific slopes of Peru
<i>G. gossypioides</i>	D <sub>6</sub>	Wild, South central Mexico
<i>G. lobatum</i>	D <sub>7</sub>	Wild, arborescent, SW Mexico
<i>G. trilobum</i>	D <sub>8</sub>	Wild, West central Mexico
<i>G. laxum</i>	D <sub>9</sub>	Wild arborescent, SW Mexico
<i>G. turneri</i>	D <sub>10</sub>	Wild, NW Mexico
<i>G. schwendimanii</i>	D <sub>11</sub>	Wild, arborescent, SW Mexico
<b>Tertiary Germplasm Pool</b>		
<i>G. sturtianum</i>	C <sub>1</sub>	Wild, Ornamental, Central Australia
<i>G. robinsonii</i>	C <sub>2</sub>	Wild, Western Australia
<i>G. bickii</i>	G <sub>1</sub>	Wild, Central Australia
<i>G. australe</i>	(G)	Wild, North Transaustralia
<i>G. nelsonii</i>	(G)	Wild, Central Australia
<i>G. costulatum</i>	(K)	Wild, decumbent, North Kimberleys of W Australia
<i>G. cunninghamii</i>	(K)	Wild, ascending, Northern tip of NT, Australia
<i>G. enthyle</i>	(K)	Wild, erect, N Kimberleys, Australia
<i>G. exgiuum</i>	(K)	Wild, prostrate, N Kimberleys, Australia
<i>G. londonderriense</i>	(K)	Wild, ascending, N Kimberleys, Australia
<i>G. merchantii</i>	(K)	Wild, decumbent, Australia
<i>G. nobile</i>	(K)	Wild, erect, N Kimberleys, Australia
<i>G. pilosum</i>	(K)	Wild, ascending N Kimberleys, Australia
<i>G. populifolium</i>	(K)	Wild, ascending N Kimberleys, Australia
<i>G. pulchellum</i>	(K)	Wild erect, N Kimberleys, Australia
<i>G. rotundifolium</i>	(K)	Wild, prostrate, N Kimberleys, Australia
<i>G. anapoides</i>	(K)	Wild, erect, N Kimberleys, Australia
<i>G. stocksii</i>	E <sub>1</sub>	Wild, Arabian Peninsula and Horn of Africa
<i>G. somalense</i>	E <sub>2</sub>	Horn of Africa and Sudan
<i>G. areysianum</i>	E <sub>3</sub>	Arabian Peninsula
<i>G. incanum</i>	E <sub>4</sub>	Arabian Peninsula
<i>G. bricchettii</i>	(E)	Somalia
<i>G. benadirensis</i>	(E)	Somalia, Ethiopia, Kenya
<i>G. vollensii</i>	(E)	Somalia

Source: Adopted from Stewart, 1995, cited in Khadi and Kulkarni, 2001 and Khadi et al., 2003.

Several centers across the world maintain large collections of cotton germplasm. The major ones are United States Department of Agriculture (USDA), Central Institute of Cotton Research (CICR), Nagpur, Tashkent and germplasm in China (Khadi and Kulkarni, 2001).

### 3. REPRODUCTIVE BIOLOGY

#### 3.1 Growth and Development

The growth of cotton plant starts with germination of seed and it depends on the availability of soil moisture, temperature and oxygen. Germination begins with the entry of moisture into the seed and embryo via the chalazal aperture at the seeds' apex (Christiansen and Moore, 1959). The seed/embryo then begins to swell as it absorbs moisture. Under favorable conditions, the radicle (root tip) emerges within 2-3 days from the seed and newly germinated seedlings emerge above the soil 5-6 days after emergence of the radicle (Oosterhuis and Jernstedt, 1999). The first cotton leaf appears 10-12 days after emergence and leaf development reaches its peak about three weeks after the first buds are formed. The first flower-bud appears on the lowest fruiting branch 35-45 days after emergence, depending upon prevailing temperatures. The other flower buds follow at regular intervals until shortly before flowering ceases. The time taken between the appearance of first flower bud and opening of the flower may be between 25-30 days. Emergence of large number of flowers is seen for certain period and thereafter it declines. During the peak period of flowering the vegetative growth is almost negligible and once the rate of flowering declines the vegetative growth restarts. Period of flowering is reduced by late sowing, strong plant competition and moisture stress. The botanical features of the cotton plant are detailed in Annexure-I.

The duration of annual cultivated cotton varieties/hybrids is around 140 days. In most varieties the boll bursting begins 120 days after the shoot emergence. From the time of sowing until boll bursting of the cotton plant, the following five basic and phenological phases are distinguished:

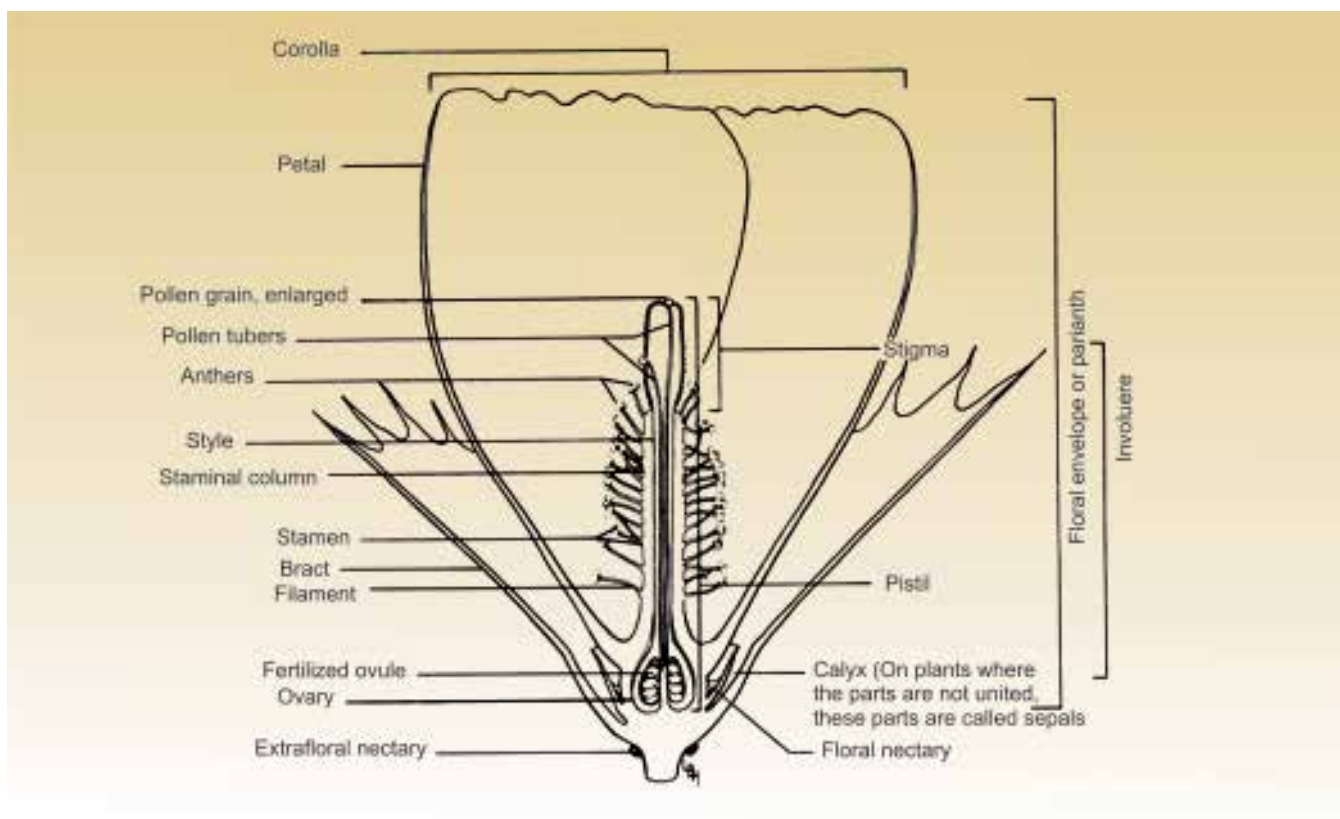
- 1) Germination and emergence of shoot – the phase of cotyledon
- 2) True leaf formation
- 3) Formation of sympodial shoot and square formation (flower bud)
- 4) Peak flowering
- 5) Boll development and boll bursting

The length of each phase differs depending upon the species, varieties and weather conditions as well as the cultivation techniques followed. The flowering phase is greatly influenced by the environmental factors. Flowering in cotton is sensitive to both thermo and photoperiods. For example, varieties developed under short-day condition of southern cotton growing zone in the country may not flower in the northern zone at a particular period of time when long day conditions prevails. The day length alone or in combination with temperature determines the formation of flowering buds.

#### 3.2 Floral Biology

Cotton flowers are extra-axillary, terminal and solitary and are borne on the sympodial branches. The

flower is subtended by an involucre of usually three unequal leaf like bracts. Bracteoles, alternating with the bracts on the inside of the involucre or standing on either side of the small bract, may be present. The calyx, consisting of five undiverged sepals, is persistent and shaped as a shallow cup. The calyx adheres tightly to the base of the boll as it develops. The corolla is tubular, consisting of five obcordate petals alternating with calyx lobes and overlapping the next one in the series in a convolute manner. In some species, a spot of purple, sometimes called 'petal spot', is found on the claw (base) of the petals. On the first day after anthesis, the corolla changes into pinkish blue and then into red during succeeding days. It withers and falls off on the third day, together with the staminal column and stigma leaving the ovary, calyx and involucre intact. Various components of cotton flower are illustrated in Figure 2.



*Figure 2: Longitudinal Section of a cotton flower*  
 Source: <http://gears.tucson.ars.ag.gov/>

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.

### 3.3 Pollination and Fertilization

Cotton pollen is relatively large, heavy, sticky and watery and thus wind is not a factor in the pollination of cotton. Cross-pollination in cotton may vary from zero to more than 20 percent. Many insects especially honey bees are attracted to the cotton flowers and they are active in 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 (Govila, 1969). Corolla along with anthers and filament, drop from the fertilized ovary. Initially 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 fibres and seed formation.

### 3.4 Pollen Dispersal

The pollen dispersal depends upon the insect activity and environment in which the parents are grown. The amount of cross pollination depends upon the relative abundance of pollen-carrying insects than any other factor. Generally cross pollination occurs in close vicinity; however insects may carry the pollen upto several hundred meters. In case of cotton, dispersal studies have consistently demonstrated that when outcrossing occurs, it is localized around the pollen source and decreases significantly with the distance (Thomson, 1966; Galal *et al.*, 1972; Theron & van Staden, 1975; Elfawal *et al.*, 1976; Chauhan *et al.*, 1983; Umbeck *et al.*, 1991; Llewellyn & Fitt, 1996).

There are approximately 10,000 pollen grains in a flower. Under normal conditions, the pollen grains are viable upto 24 hours and thereafter lose potency and fail to effect fertilization (Govila and Rao, 1969).

Honey bee (*Apis mellifera* L.) is the main vector for pollination in cotton, apart from these honey bees (*A. dorsata*, *A. florea*, *A. indica*), bumble bees (*Bombus* sp.), leaf cutting bees (*Hymenoptera megachilidae*) and a few dipterans help in pollination. The main pollinating insects differ due to distribution of insects and ecological conditions and their capability also differs on account of their visiting behaviour and body size. Fully pubescent insects such as yellow breast wood bee, heavy flower wasp and black spinytibial bee are also highly efficient for cross - pollination.

### 3.5 Seed Dispersal

As cotton does not generally reproduce vegetatively (Serdy *et al.*, 1995), spread within the environment occurs by seed dispersal. Dispersal of cotton seeds is a physical process. Observations of dispersed seeds and the occurrence of volunteer plants in northern Australian cotton trials indicated that delinted black seed has the lowest risk of unintentional spread within the environment (OGTR, 2002). When dispersal of black seed occurs, it is associated with spillage at sowing in cotton production areas.

Fuzzy seed is commonly used as livestock feed and therefore has a high potential for dispersal to non-cotton production habitats. Unprocessed 'seed cotton' that retains all of the fibres attached to the seed coat, also has a high potential for dispersal within the environment. Volunteers from dispersed seed cotton are relatively common in irrigated channels and drains and along roadsides. Seed cotton spillage during transport of cotton modules also leads to establishment of roadside volunteers.

However, following dispersal, seeds that do not germinate are removed by seed predators or by rotting.

### 3.6 Mating Systems

Cotton is predominately a self-pollinated crop though varying degree of cross-pollination has been reported.



Many field based assessments have estimated out-crossing at 10% or less (Meredith & Bridge, 1973; Gridley, 1974; Theron & van Staden, 1975; Elfwal *et al.*, 1976; Umbeck *et al.*, 1991; Llewellyn & Fitt, 1996). Higher estimates (16.5% to 25%) have been reported in few cases (Smith, 1976; Moresco *et al.*, 1999). However, in certain conditions, out-crossing upto 80% have also been observed (Richmard, 1951; Oosterhuis & Jernstedt, 1999). In India natural outcrossing has been observed only upto 2 percent (Khadi and Kulkarni, 2001). Hence, breeding methods employed for cotton involve procedures for both self and cross-pollinated crops. The hybridization and hybrid seed production is being done by following Doak's Method (Doak, 1934) of hand emasculation and pollination. The genetic and cytoplasmic male sterility systems are also available.

### 3.7 Methods of Reproductive Isolation

The commonly used method of reproductive isolation in case of cotton is spatial isolation. As per the Indian Minimum Seed Certification Standards, an isolation distance of 50 meters is required for production of foundation seed of varieties/hybrids (Tunwar and Singh, 1998). Accordingly, requirement of 50 meters as the isolation distance has been adopted for conducting various field trials of genetically modified cotton.

## 4. ECOLOGICAL INTERACTIONS

### 4.1 Potential for Gene Transfer from Cotton

The possibility of gene transfer between different *Gossypium spp.* and to other plant genera is addressed below:

\* **Gene Transfer between different Cotton Species:** As mentioned above, genetic material of *G.hirsutum* may escape from a test area by seed, or by pollen. Whereas movement of seed from the test area can be inhibited by adequate physical safeguards, movement of genetic material by pollen is possible only to compatible varieties and related species. Movement of *G.hirsutum* to *G.barbadense* and *vice versa* is possible in India if suitable insect pollinators are present. Physical barriers, intermediate pollinator-attractive plants, and other temporal or biological impediments could be used to reduce the potential for pollen movement, if required. The native Indian cottons *G.arboreum* and *G.herbaceum* are diploids and are not crossable to tetraploids (*G.hirsutum* and *G.barbadense*) in nature. Also the wild species are neither found and nor are under commercial cultivation in India.

- **Gene Transfer to Other Plants:** As mentioned earlier, gene transfer to unrelated plant species is highly improbable because of pre-and post-zygotic genetic incompatibility barriers that are well documented for distantly related plant groups. No evidence for horizontal gene transfer from cotton to other plant taxa has been identified.
- **Gene Transfer to Other Organisms:** Horizontal gene transfer from plants to animals (including humans) or microorganisms is extremely unlikely. No evidence has been identified for any mechanism by which cotton genes could be transferred to humans or animals, nor any evidence that such gene transfer has occurred for any plant species during evolutionary history, despite animals and humans eating large quantities of plant DNA. The likelihood of cotton genes transferring to humans and

other animals is therefore effectively zero. Similarly gene transfer from cotton, or any other plant, to microorganisms is extremely unlikely. Horizontal gene transfer from plants to bacteria has not been demonstrated experimentally under natural conditions (Nielsen *et al.*, 1997; Nielsen *et al.*, 1998; Syvanen, 1999) and deliberate attempts to induce such transfers have so far failed (Schlüter *et al.*, 1995; Coghlan, 2000).

- **Seed Dormancy:** Cotton seeds in general do not possess seed dormancy. Very few lines have dormancy and it breaks by the time it undergoes grow out test (GOT) and other processing schedules. It is widely accepted that dormancy in case of cotton seeds gets induced by low soil temperature and/or soil moisture (OGTR, 2002). Additionally, some forms of cotton may produce 'hard seeds' that, upon *drying*, become impermeable to water and suffer delayed germination (Christiansen and Moore, 1959). This 'induced dormancy' can be overcome by various treatments.

#### 4.2 Free Living Populations of Cotton

The term "free living" is assigned to plant populations that are able to survive, without direct human assistance, over the long term in competition with the native flora. This is a general ecological category that includes plants that colonize in open, disturbed prime habitat that is either under human control (weedy populations) or natural disturbed areas such as river banks and sand bars (wild populations). There are no such free living populations of cotton in India.

#### 4.3 Weediness of Cotton

Cotton has been grown for centuries throughout the world without any reports that it is a serious weed pest. No *Gossypium spp.* are recognised as problematic weeds, either agriculturally or environmentally (Tothill *et al.*, 1982; Lazarides *et al.*, 1997). Cotton has no relatives that are problematic weeds (Keeler *et al.*, 1996).

### 5. HEALTH CONSIDERATIONS

Cotton is not a pathogen and not capable of causing any disease in humans, animals or plants. Cotton pollen is neither allergenic nor has potential to act as an airborne allergen as it is relatively large and heavy and is not easily dispersed by wind (OGTR, 2002).

Although, cotton is mainly cultivated for its lint, the cotton seed is one of the important byproducts. Processed cotton fibre consists of more than 99% cellulose, after the refining and processing of cotton lint through chemical and thermal means. Cotton lint contains no detectable nitrogen, and hence no DNA or protein. In fact, because of its very low allergenicity, it is widely used in pharmaceutical and medical applications as well (OGTR, 2002). On the other hand, cotton seeds can be toxic if ingested in excessive quantities because of the presence of anti-nutritional and toxic factors including gossypol and cyclopropenoid fatty acids (including dihydrosterculic, sterculic and malvalic acids). Cotton seed is processed into four major products: oil, meal, hulls and linters. After extensive processing to remove

toxicants, especially gossypol and its derivatives, the oil and linters are used as premium vegetable oils and as cellulose dietary additives for human consumption, respectively. Traditionally, whole cotton seed is used as cattle feed in India. However, the increase in demand of edible oils has necessitated processing of cotton seed for its oil. Therefore, cotton seed oilcake/meal after extraction is now used as cattle feed. The extraction process also help in removing gossypol to a large extent.

## 6 COTTON CULTIVATION IN INDIA

India is the only country in the world where all the four cultivated species of cotton, viz. *G.hirsutum*, *G.arboreum*, *G.herbaceum* and *G.barbadense*, are cultivated on commercial scale, besides their hybrid combinations. The diversity of cotton cultivars and cotton agro-climatic zones in India is considerably larger as compared to other major cotton growing countries in the world. The climatic and soil requirements and production status are given as under:

### 6.1 Climatic and Soil Requirements

Cotton requires a daily minimum temperature of 16°C for germination and 21°C to 27°C for proper crop growth. During the fruiting phase, the day temperature ranging from 27°C to 32°C and cool nights are needed. The sowing season of cotton varies considerably from tract to tract and is generally early (April-May) in northern India where it is mostly irrigated. It is delayed on proceeding to down south. It is cultivated largely under rainfed or dryland conditions. An annual rainfall of atleast 50 centimetre distributed through-out the growing season is required for good yield. It is mainly raised during tropical monsoon season, although in southern India it is cultivated during late-monsoon season in winter. The cotton picking period from mid September to November must have bright sunny days to ensure a good quality (Table 2).

Cotton is successfully grown on all soils except sandy, saline or water logged types. It is grown in well

**Table 2: Climatic and soil requirements for cotton cultivation in various zones**

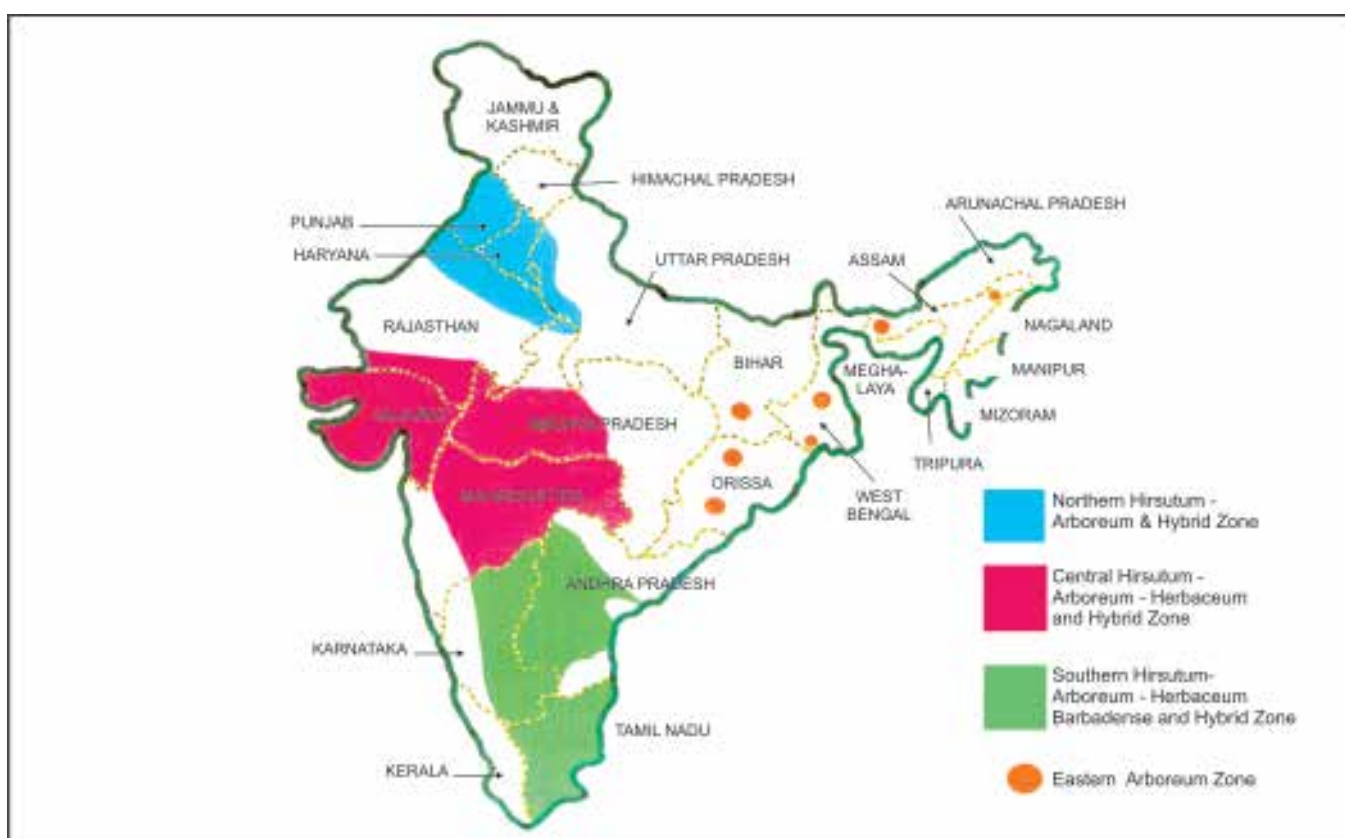
Zone	Soil	Climate	Optimal sowing time	
			Irrigated	Rainfed
North	Indo-Gangetic alluvial soils	Arid and semi arid	April-May	-
Central	Shallow to medium and deep black soils (sandy coastal alluviums, saline-alkali soils and desert sands in Gujarat)	Hot semi arid	Mid May	With onset of monsoon (third week of June in Vidarbha and South Gujarat, 16-30 June in Marathwada region of Maharashtra)
South	Medium black soil, red and black soil and coastal alluviums	Hot semi arid	April 15 – May 15 in Ghataprabha and July 15–Aug 15 in Tungabadhra canal areas, August in Karnataka, Winter-irrigated tract of Tamil Nadu; January – February in rice fallows of Andhra Pradesh and Tamil Nadu	With the onset of monsoon, June in Karnataka, July 15 – Aug 15 in Guntur and Prabhushan Krishna districts (Andhra Pradesh); mid-September to first week of October in black soil area of Tamil Nadu

Source : Handbook of Agriculture, ICAR, 2006

drained deep alluvial soils in the north to black clayey soils of varying depth in central zone and in the black and mixed black and red soils in south zone. It is moderately tolerant to salinity and is sensitive to water logging as well as frost and chilling temperature in winter.

## 6.2 Zonal Distribution

Cotton is grown in India in three distinct agro-ecological zones *viz.*, north zone (Punjab, Haryana, Rajasthan and Western Uttar Pradesh), central zone (Gujarat, Madhya Pradesh, Maharashtra and Orissa) and south zone (Karnataka, Andhra Pradesh and Tamil Nadu). The northern zone is totally irrigated, while the percentage of irrigated area in the central and southern zones is much lower, the lowest being in the central zone which has nearly 60% of cotton area. It is also grown in small area in the eastern region in Sundarbans of West Bengal and in north-eastern states. An overview of zone wise distribution of cotton area is illustrated in Figure 3.



*Figure 3: Cotton growing zones in India*  
*Source: Central Institute for Cotton Research*

An overview of important features of cotton cultivation in different zones based on information provided by Central Institution for Cotton Research (CICR) is as under:

- **North Zone:** In this zone, cotton cultivation is beset with threat from cotton leaf curl virus (CLCuV) disease, bollworms and waterlogging stress. Efforts are underway for release of high yielding CLCuV disease resistant cultivars. In spite of the fact that cotton in north zone is fully irrigated, the average yield levels stagnate around 400 to 700 kg lint/hectares, whereas the potential is around 800 kg lint/

ha under ideal irrigation and management conditions. North zone witnesses a harsh climate with high temperature (40-45°C), aridity and has a limitation in canal water irrigation.

- **Central Zone:** Nearly 60% of cotton area is accounted by this zone and Maharashtra alone accounts for nearly 30% of the cotton area. Even though the irrigation source and potential are very much limited in central zone, ideal temperatures and ample sunshine during growth and maturity periods and the extended moderately cool, rain free dry weather prevailing during October to February are favourable for obtaining higher yields.
- **South Zone:** In south zone states, irrigated tracts around Dharwad, Siruguppa and Raichur in Karnataka, irrigated tracts of Guntur, Adilabad, Warangal and Karimnagar of Andhra Pradesh, winter irrigated tracts of Coimbatore, Erode, Salem, Dindugul and Madurai of Tamil Nadu offer good scope for high yielding packages. South zone states are also ideal for cultivation of extra long staple varieties of cotton, but the quality is assured only under irrigated conditions.

### 6.3 Pests and Diseases of Cotton

Insect pests are one of the major limiting factors in cotton production. About, 1300 species of insects have been reported on cotton worldwide (Matthews and Tunstall, 1994), out of which caterpillars of six lepidopteran species are of great economic importance. Out of these nearly 130 species occur in India. About a dozen of these arthropods are commonly present in sufficient numbers requiring their management for better cotton yields. The major pests, diseases and predators of the cotton in India based on the information provided by CICR are detailed in Annexure-II to IV.

### 6.4 Breeding Objectives and Varietal Testing System

The varietal testing of cotton is undertaken through All India Coordinated Cotton Improvement Project (AICCIP), which was launched in 1967 with its headquarter at Coimbatore, Tamil Nadu under the aegis of Indian Council for Agricultural Research (ICAR). The AICCIP has 21 participating centers involving 15 State Agricultural Universities (SAUs) involved in cotton research.

The Central Institute for Cotton Research (CICR), Nagpur and its regional stations at Coimbatore and Sirsa provide basic research support and also take part in certain research activities of the AICCIP on cotton. The Central Institute for Research on Cotton Technology (CIRCOT, ICAR), Mumbai and its regional units located at Sirsa, Surat, Nagpur, Dharwad, Guntur and Coimbatore are closely associated with AICCIP in assessing the quality parameters of cotton besides ensuring value addition to cotton.

Breeding objectives are formulated by taking into consideration the species in which improvement is sought. However, in India all four species have equal importance in judging their genetic improvement programmes. By and large breeding objectives in India vary according to the cotton growing zones generally and different regions specifically. Nevertheless, increased per day productivity and fibre quality along with resistance to biotic and abiotic stresses assumes general importance in most situations. Genetic modification of seed oil content and gossypol free oil are also important.

In India heterosis has been exploited extensively to improve the yield. Several factors like geographical and genetic diversity, agronomic performance, adaptability and genetic base of parental lines are reported to play an important role in the manifestation of heterosis in cotton. Though, heterosis in cotton was known by the end of nineteenth century, the first commercial hybrid of the world “Hybrid 4 (HXH)” was developed in India in 1971 by using hand emasculation method (Patel, 1971). In the same year first inter-specific hybrid HXB was also developed (Katarki, 1971). The two events transformed the entire cotton scenario of India. Since then heterosis has been exploited in several combinations for economical use in H X H, H X B, a x a and h x a [(*Gossypium hirsutum* (H); *G. barbadense* (B); *G. herbaceum* (h) and *G. arboreum* (a)]. Hybrid seed production has also been achieved through genetic male sterility and ABR system as indicated below:

- i. **Genetic Male Sterility (GMS):** In Genetic Male Sterility, the hybrid seed production plot consists of sterile and fertile plants in the ratio of 50% each. Once the flowering starts the fertile population from the female will be rogued out. After confirming the total female population, sterile pollinations as in conventional method are attempted.
- ii. **Cytoplasmic Genetic Male Sterility (CGMS) or ABR system:** *G. harkensii* is used as a source of cytoplasmic genetic male sterility for hybrid seed production (Weaver and Weaver, 1977). The male sterility is transferred to the female parent (A line) and restorer gene (R) to the male parent by back crossing technique. A line is maintained by isogenic fertile B line. The male sterile and restorer line are planted in same field in a ratio of 4:1 or 3:1. The crop is grown at wider spacing under irrigated conditions to get continuous flush of flowers for seed production. The male sterile female parent is pollinated with pollen from restorer male parent. There is no need for emasculation unlike conventional system. This system commonly referred as “ABR system” is an ideal system of producing hybrids without utilizing labour. However, in *G. hirsutum*, there are not many restorer lines, hence exploitation of heterosis becomes difficult. Moreover, cross-pollination is also a problem if pollinating agents such as bees are not in abundance.

## 6.5 Germplasm Maintenance and its Evaluation

CICR was given the mandate of maintenance and management of cotton germplasm of the country by establishing National Centre for Cotton Genetic Resources, which was re-designated as National Cotton Gene Bank. The Bank contains 7484 accessions of *G. hirsutum*, 263 *G. barbadense*, 1877 *G. arboreum*, 530 *G. herbaceum*, 26 wild species, 32 perennials and 15 races of cultivated species totaling 10227 accessions.

Some of the important characters/traits maintained in the germplasm of different species are listed in Table 3.

Most of the germplasm accessions available in the gene bank have been evaluated for major economic characters viz. high yield, high boll weight, high Ginning Out Turn (GOT) and maturity besides their

reaction to major pests and diseases. The new germplasm lines received every year are evaluated for 10-12 characters. The superior accessions are evaluated for agronomical traits. Simultaneously, fibre quality analysis is also done.

**Table 3: Important characters/traits maintained in the germplasm**

Species	No. of accessions	Characteristics in elite type
<i>G. hirsutum</i>	7484	Early maturity (140-150 days)
		Dwarf (below 80cm)
		Compact plant
		Bacterial blight resistant
		High boll weight
		High boll No.
		High ginning out turn or ginning %
		Marker types (Okra glandless, pigmented, etc)
		Yield
<i>G. barbadense</i>	263	High yield
		Extra-long staple
		High seed oil (above 25%)
		High biomass
<i>G. arboreum</i>	1877	Red plant body
		Brown linted·Nectariless
		Spotless
		Low shedding
		Big boll
		High Ginning Out Turn
		Early maturity
		High seed oil (above 20%)
		Long staple
		High yield
<i>G. herbaceum</i>	530	General
Wild species and perennials	2632	
<b>Total</b>	<b>10180</b>	

Source: Central Institute for Cotton Research, Nagpur

## 6.6 Status of Cotton Cultivation

Cotton is the major cash crop of India with about 9.6 million hectares area under cultivation where as India's cotton area represents 25% of the global area of cotton. However, the Indian cotton yields were some of the lowest in the world. With the introduction of Bt cotton, which confers resistance to important insect pests of cotton in 2002, there has been a significant increase in the cotton production in the country as may be seen in Figure 4. The advent of Bt cotton over the last seven years has coincided with more than doubling of yield (James, 2008). Within a period of seven years after the approval of Bt cotton with *cry1Ac* (MON 531) the area under Bt cotton has increased from 50,000 hectares to 7.6million hectares in 2008.

The number of events, as well as the number of Bt cotton hybrids have increased significantly since 2002, when Bt cotton containing *cry1Ac* gene (MON 531 event) developed by M/s Maharashtra Hybrid Seeds Company Ltd. was first approved. The other genes/ events approved for commercial use are fusion genes (*cry1Ab+cry1Ac*) “GFM *cry1A*” developed by M/s Nath seeds, *cry1Ac* gene (Event-1) by M/s JK Seeds Ltd. stacked genes *cry1Ac* and *cry2Ab* (MON 15985)-BG II by M/s Mahyco, *cry1Ac* gene (Event 1) by Central Institute of Cotton Research and *cry1C* gene (Event MLS 9124) by M/s Metahelix Life Sciences.

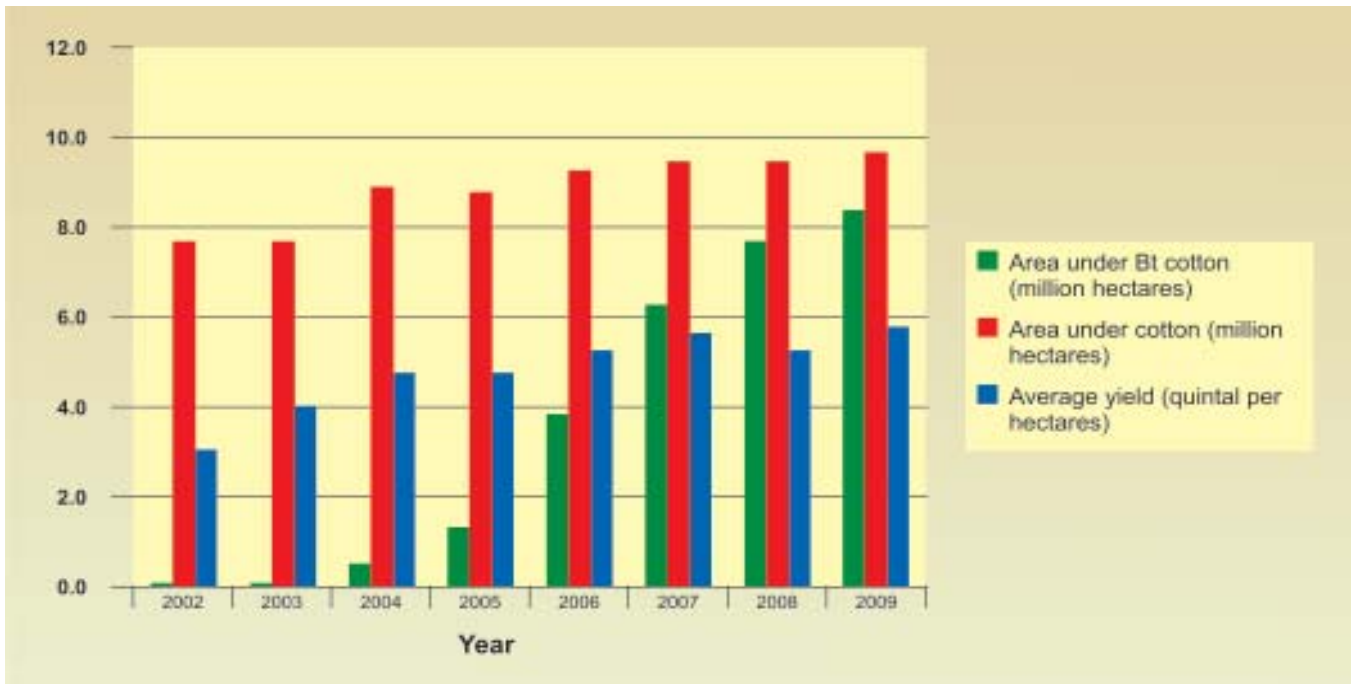


Figure 4: Adoption of Bt cotton in India

Source: Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India (<http://agricoop.nic.in/Agristatistic.htm>).

By 2010 more than 600 hybrids with diverse parents have been approved and introduced into Indian cotton cultivation.



## BOTANICAL FEATURES

The botanical features of cotton plant are as follows:

**Root:** Cotton plant has a taproot system that grows quickly and it can reach a depth of 20-25cm before the seedling has even emerged above ground. After emergence and unfolding of cotyledons, lateral roots begin to develop; they first grow side ways and then downwards. The taproot continues to grow rapidly. Final depth of root system depends on soil moisture, aeration, temperature and variety but is usually about 180-200 cm. Under dry growing conditions, cotton roots have been known to reach a depth of 3-4m. The growth of tap root as well as lateral root is affected by excessive moisture, hard dry soil layer and degree of soil alkalinity. Lateral roots adjust their quantum to the plant spacing and soil moisture regimes.

**Stem:** Cotton plant consists of an erect main stem and a number of lateral branches. The stem has a growing point at its apex, with an apical bud. As long as this bud remains active, lateral buds situated below it remain dormant. The main stem carries branches and leaves but no flowers. Length and number of internodes determine the final height of the plant. As a rule plant with short internodes is early maturing. Length of internodes is determined mainly by the moisture supply while the number of internodes is usually a function of nitrogen supply to the plant. At the axil of each leaf there are two buds, the axillary bud from which most vegetative and fruiting branches (sympodia) develop and a lateral bud on one side of axillary bud. The lateral bud normally remains dormant; but if the axillary bud aborts, it may develop into a branch. Vegetative branches (monopodia) are morphologically similar to the main stem. They do not bear flowers or fruits directly, but carry secondary branches (fruiting branches), that are characterized by their sympodial growth habit.

**Leaves:** Leaves of cotton are generally hairy and some varieties have glabrous leaves. Hairy leaves cause fewer difficulties in mechanical harvesting and are more tolerant to jassids, but bear larger proportions of white fly which apparently finds more sheltered conditions among the leaf hairs. The leaves have variable lobes. Size, texture, shape and hairiness of leaves vary a great deal. Nectaries are present on leaf calyx and bracts. Each leaf has two buds at its axis. Different shapes of leaves of diploid and tetraploid cotton used for varietal classification are indicated in Figure 5.

## A. Diploid Cotton



## B. Tetraploid cotton



*Figure 5: Various shapes of leaves in diploid and tetraploid cotton*

*Source: Guidelines for the conduct of tests for Distinctiveness, Uniformity and Stability. Protection of Plant Varieties & Farmer's Rights Authority, India. <http://plantaauthority.gov.in/>*

**Branching:** Lateral branches arise from the axils of the leaves of main stem and consist of two types *viz.*, vegetative and fruiting. Vegetative branches are more vertical and ascending. Fruiting branches are nearly horizontal. The internodes on the fruiting branches, referred to as sympodial branches are not straight as in main stem but have a zig zag appearance with the leaves alternately placed. The flowering and fruiting are dependent on the initiation of sympodial branches. The timing of the crop for harvest is also determined by the early or late production of such sympodial branches on the plant body. Very early varieties have their fruiting branches even at first or second node to the total exclusion of vegetative branching from leaf axils. Similarly, very late varieties go on producing a very large number of monopodial before sympodial divergence appear. Relative proportion of vegetative and fruiting branches is dependent on temperature, day-length, plant density and the rate of boll shedding.

**Floral bud:** Floral bud is enclosed in and protected by, three triangular bracts. The whole structure is called a “square”. The five petals of the corolla are wrapped tightly around one another (Figure 6). Within the corolla is a tube formed of numerous stamen filaments, surrounding the pistil. The ovary at the base of the pistil consists of generally three to five carpels, containing as many locules. Each locule contains 8-12 ovules.



Figure 6: Cotton floral bud  
Source: <http://ikisan.com>

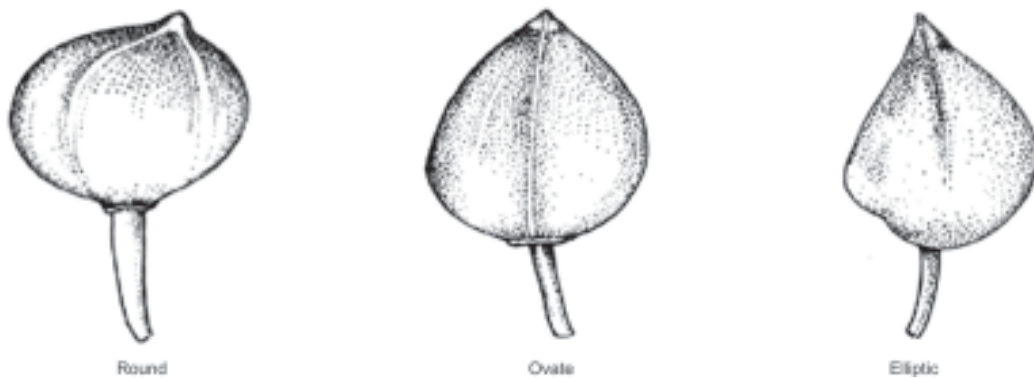
**Flower:** Flower is large, axillary, terminal and solitary. On account of the sympodial development of fruiting branches, the flower opening follows a spiral course in acropetal and centrifugal succession (Figure 7). The innermost bud of the lowest and oldest branch is the first to open while the outermost bud of the highest and youngest branch is the last to do so. When the flower opens it is white or creamy white or yellow in the American varieties, changing to pink towards the end of the day and becoming red the following morning; on the third day the petals wither and fall.



Figure 7: Cotton flower  
Source: <http://ikisan.com>

**Bolls:** In *G. hirsutum* bolls are large, generally ranging from 4-5 grams. The general variation in boll weight is 3-5 g, however in some varieties it can weigh upto 8g. The bolls are pale green, smooth-skinned and with few oil glands. In contrast, bolls of *G. arboreum* are smaller (1.5 - 3g), dark green and covered with numerous glands. Cotton plants by its remarkable auto-regulatory mechanism shed the bolls that are in excess of the load capacity of the plant under given environmental conditions. As a result, the ratio of bolls to total vegetative growth is fairly constant. In general, varieties or strains with large bolls do not adjust so well to change in environment and to stress as do types with smaller bolls. Hence, shedding occurs more readily and to a large extent in the former than in the latter case. Bolls developing under falling temperature need more days to mature than those growing under rising temperature. The big-bolled American types in India take about 40-50 days while the Asiatic cottons require 35 days. In *G. hirsutum* the boll consists of four to five locules each of which contains about 7 mature seeds. A fair percentage of the ovules remain undeveloped due to non-fertilization, heredity and environment. These are called “motes”. The size and shape of the bolls differ in diploid and tetraploid cotton (Figure 8).

## A. Diploid cotton



## B. Tetraploid cotton



*Figure 8: Various shapes of bolls in diploid and tetraploid cotton*

*Source: Guidelines for the conduct of tests for Distinctiveness, Uniformity and Stability. Protection of Plant Varieties & Farmer's Rights Authority, India. <http://plantaauthority.gov.in/>*

**Seed:** The full-grown seed of cotton is irregularly pear-shaped, varying in size depending on the variety and conditions of growing. It may be naked or bear short hairs called “fuzz”. All cultivated cotton seeds bear long fibres named “lint” and a majority of them also have fuzz on the same seed. The lint is removed by gins while the fuzz remains attached. The colour of fibres is generally white, but may also be brown or green and that of the seed is usually grey, brownish or black. The mature seed has two cotyledons folded up that occupy the entire portion of its cavity. The cotyledons are broad and kidney shaped. Delayed germination in some of the species and varieties may be due to hard seed coat, closed micropyle and partially filled cotyledonary-cum-embryonic contents. The germination increases when the seed coat thickness is reduced by various methods of delinting. The seeds account for about 65 to 70 per cent of the total yield by weight. The seeds are rich in protein (10-20%) and oil (up to 25%). The oil content in *G. barbadense* is higher than *G. hirsutum*.

**Seed hairs/Lint:** As mentioned above, lint and fuzz represent the outgrowths of epidermal cells on seeds. Some cells continue to lengthen while others stop growing after a time. The former is known as

the lint and the latter is the fuzz. The lint hair is unicellular and its development is phased in two stages, the first phase is a period of elongation and the second phase is increase in thickness. A lint cell bulges first, the protoplasm inside turns granular, and the nucleus moves towards the bulge. The swelling enlarges until it is twice the diameter of the original cell and the nucleus moves to or near the tip. The elongation of cell may take upto 40 days. There is no change in thickness. The growth is not regular; slow at first but fast from about the 15th day. The rate slackens during days and quickens during nights. The cell wall thickens in the second half of boll maturation. Deposits of cellulose are formed on the inside of primary wall. They are laid in layers as seen from some fibres showing as many as 25 concentric layers. As soon as the boll dehisces, the hairs dry, collapse and flatten the cylindrical form, assuming ribbon like shape and go into spirals. The mature hair is uniform in diameter up to 3/4th length and then gradually tapers to a point. The length of lint is a varietal character and varies from 15-50mm in different varieties. Fibre quality traits such as length, fineness and strength are important as spinning are dependent on these characteristics.

**Glands:** On all aerial parts of cotton plants are found internal glands which in different species vary in size, number, distribution and pigmentation. These glands secrete a volatile oil i.e. gossypol and related compounds. Gossypol is a polyphenolic yellow pigment and is toxic to non-ruminants. The presence of gossypol makes cotton seed cake toxic and hence, glandless varieties have been bred in recent years. However, it has been found that glandless varieties are susceptible to a wide range of pests over the glanded varieties.

The distinguishing features of all four cultivated species of *Gossypium* in the country are given in Table 4.

**Table 4: Distinguishing features of cultivated species of *Gossypium***

S.No	Feature	<i>G. hirsutum</i>	<i>G. barbadense</i>	<i>G. arboreum</i>	<i>G. herbaceum.</i>
1.	Chromosome number	2n=52	2n=52	2n=26	2n=26
2.	Ploidy	Tetraploid	Tetraploid	Diploid	Diploid
3.	Origin	Central America, Mexico (New World)	South America (New World)	Africa (Old World)	India and East Asia (Old World)
4.	Popular names	American cotton, Upland cotton, Cambodia cotton, Dharwad American	Egyptian cotton, Sea Island cotton, Pima cotton.	Asiatic cotton, <i>Desi</i> cotton	Asiatic, <i>Desi</i> cotton.
5.	Habit	Small, Annual, sub-shrub 1.5m tall	Perennial, shrub/ annual, sub-shrub. 1-3m tall	Perennial, branched, shrub/annual, sub-shrub 1.5-2m Tall	Sub-shrubs 1-1.5 m tall.
6.	Stem	Green or brown sparsely hairy or glabrous, fruiting branches many jointed.	Green glabrous and rarely hairy, fruiting branches many jointed.	Green, brown, hairy, fruiting branches two jointed.	Green, rarely pigmented, hairy, rarely glabrous and fruiting branches many jointed.
7.	Leaves	Large cordate, 1/2 cut or less, 3-5 lobes not constricted, also overlapping lobes.	2/3 cut into 3-5 lobes, sinuses thrown into folds, lobes long and tapering.	2/3 to 4/5 cut into 5-7 lobes long and narrow	1/2 cut or less, 3-7 lobes only slightly constricted at the base.
8.	Bracteole	Triangular, 4-12 long teeth, longer than broad.	10-15 acuminate teeth, as long as broad	3-4 teeth closely invested to bud flower, longer than broad.	6-8 teeth, flaring widely from the buds, flower and capsule.
9.	Petal	Cream, light, yellow to yellow	Sulphur yellow, deep	White to yellow red	Medium yellow
10.	Petal spot	Absent	Prominent, large dark	Present, prominent	Present, dark
11.	Stamen/ Anthers stigma	Staminal column short, Anthers closely arranged, stigma united throughout, rarely divided at tip.	Staminal column long, antheriferous, closely packed, filaments short.	Staminal column long, antheriferous, short anthers, short style, united stigma.	Staminal column throughout antheriferous, filament short style short, united top.
12.	Boll (capsules).	Rounded to mod, tapering 3-5 locular, 4 common smooth to mod pitted.	Tapering longer than broad 3-4 but usually 3 loculi, deeply pitted and glanded often rough.	Moderately rounded to tapering, 3 to 4 loculi (3 common), smooth to deeply pitted, rough.	Rounded, smaller 3-5 loculi smooth to moderately pitted.
13.	Seeds	5-11 Large size seeds/ loculus, mod, large, Fuzzy to rarely naked	5-8 long size seeds/ loculus, tuft of frizz on seeds, seeds often without coat of fuzz. very long fibre.	6-17, medium seeds/ locule rarely naked, Fuzzy.	8-11 medium size seeds/ locules Fuzzy.
14.	Fibres	Moderate to long fibre	Very long fibre	Short to medium fibre	Short to medium fibres.
15.	Gining out time	More	Less	More	Less

Source: Khadi and Kulkarni (2001)

## ANNEXURE - II

### KEY INSECT PESTS OF COTTON

The key insect pests affecting cotton plant could be divided into three categories viz. boll worms, sap sucking pests and stem, leaf and foliar feeders depending on the type of damage caused. Major yield loss to the Indian cotton (even up to 60%) is due to bollworm complex consisting of three genera of bollworms viz. *Helicoverpa*, *Earias*, and *Pectinophora*, commonly referred to as American bollworm, Spotted bollworm and Pink bollworm respectively. Sucking pests i.e. jassids, aphids, whiteflies and thrips are deleterious during early season of the cotton plant growth and development and have the ability to build up to serious proportions as a result of rapid breeding. The important foliage feeders includes semilooper, spodoptera, leaf roller, ash weevil and grass hoppers. The variations are observed on geographical basis regarding occurrence of insect pests. Further, the pest occurrence is affected by the weather, cropping system and insecticide use pattern. The major cotton pests among cotton growing zones of India with their damage symptoms and seasonal occurrence are given in following Table 5.

Table 5: Major cotton insects pests and their symptoms of damage

Insect pest	Scientific name	Symptoms of damage
<b>Bollworms</b>		
American Bollworm	<i>Helicoverpa armigera</i>	Small amount of webbing on small squares injured by young larvae, squares have a round hole near the base, larval frass and flaring of bracts on large squares, clean feeding of internal contents of bolls, excessive shedding of buds and bolls
Spotted and spiny bollworms	<i>Earias vittella</i> and <i>E. insulana</i>	Boremark in main shoot, dried and withered away shoot, twining of main stem due to axillary monopodia, feeding holes in flower buds and bolls blocked by excrement
Pink bollworm	<i>Pectinophora gossypiella</i>	“Rosetted” bloom, pink larvae inside developing bolls with interloculi movement
<b>Sucking pests</b>		
Jassids	<i>Amrasca biguttula biguttula</i>	Affected leaves curl downwards, turn yellowish, then to brownish before drying and shedding, “hopper burn” stunts young plants
Aphids	<i>Aphis gossypii</i>	Leaf crumpling and downward curling of leaves, sticky cotton due to deposits of honey dew on open bolls
Thrips	<i>Thrips tabaci</i>	Leaves of seedlings become wrinkled and distorted with white shiny patches, older crop presents rusty appearance from a distance
Whiteflies	<i>Bemisia tabaci</i>	Upward curling of leaves, reduced plant vigour, lint contamination with honey dew and associated fungi, transmission of leaf curl virus disease

Insect pest	Scientific name	Symptoms of damage
Mealy bug	<i>Phenacoccus solenopsis</i>	Feed on plant sap, normally in roots or other crevices. Attach themselves to the plant and secrete a powdery wax layer. Moves from plant to plant and row-to-row causing severe damage to crop
<b>Stem, leaf and foliar feeders</b>		
Semi-looper	<i>Anomis flava</i>	Causes significant loss of leaf area to young plants, larvae with looping action are seen on plant parts
Leaf roller	<i>Sylepta derogata</i>	Leaves are folded and larvae are seen in groups amidst fecal materials, commonly seen on leaves at the bottom of crop canopy at low infestation levels, severe infestation defoliates the whole plant
Cotton leafworm / Tobacco caterpillar	<i>Spodoptera litura</i>	Young larvae in groups skeletonise leaves and older larvae voraciously defoliate leaves
Grey weevil	<i>Myllocerus subfasciatus</i>	Marginal notching of leaves by adults. Both grubs and adults feed on roots of cotton seedlings
Hairy caterpillar	<i>Amsacta albistriga</i>	Defoliates the crop, attacks in large group.
Stem weevil	<i>Pempherulus affinis</i>	Root damage by grubs kills young seedlings, gall like swelling seen on lower stem, wilting of seedlings
Shoot/Stem Weevil	<i>Alcidodes fabrici.</i>	Lay eggs at the node axil and the grubs feed on the tissue at the axil. The affected leaves wilt and droop.
Sesabnia stem borer	<i>Azygophleps scalaris</i>	Lay eggs in the bark of young plants, caterpillars bore into stem and form galleries.
Cotton stem borer	<i>Sphenoptera gossypii</i>	Lay eggs on young plants at collar. Grubs bore into stem and form galleries.
<b>Stainers</b>		
Red cotton bug	<i>Dysdercus cingulatus</i>	Feed on developing and mature seeds, stain the lint to typical yellow colour, reddish nymphs seen in aggregations around developing and open bolls, affected seed yield low oil.
Dusky cotton bug	<i>Oxycarenus hyalipennis</i>	Associated with ripe seeds, all stages characterized by a powerful smell, discolour the lint if crushed, affected seed yield low oil

Source: Technical Bulletin No. 8, CICR (Vennila et al., 2000).

To assist in the identification of major insects/pests, the morphological features of a few important pests along with their pictures provided by Central Institute for Cotton Research are given below :

i) **American Bollworm (*Helicoverpa* sp.)**

Eggs of *Helicoverpa* are spherical with a flattened base laid on the tender foliage and calyx of squares of the cotton plant (Figure 9). Surface is sculptured with longitudinal ribs and colour is white to creamy white after oviposition. As the embryo develops, reddish brown band is seen centrally which gradually darkens and together with rest of egg becomes brown before hatching. Newly hatched larvae are translucent yellowish white with brown to black head capsules. The thoracic and anal shields, spiracles, thoracic legs, setae and their tubercle bases are also brown to black, giving the larvae a spotted appearance (Figure 10).



Figure 9: American Bollworm (*H.armigera*) larva feeding cotton square  
Source: <http://cicr.org.in/>



Second instar is essentially similar but with darkened ground colour and lightened sclerotized head capsule, thoracic and anal shields and thoracic legs. The third instar has a predominantly brown ground colour. The characteristic patterning becomes more prominent and colouring generally darker in later instars, although host diet plays a role to an extent. Larva is about 35mm long, greenish brown with dark grey yellow strips along the sides of the body.



Figure 10: Larva of American Bollworm (*Helicoverpa* sp.)  
Source: <http://cicr.org.in/>

ii) **Spotted Bollworm** (*Earias vitella*)

Adult moths differ with species. In *E. insulana*, the head, the thorax, and forewing colour varies from silver green to straw yellow; the distal fringe of wing is of the same colour. There are three distinct transverse lines of darker shade and traces of the fourth at times. Green forms are common during summer, while yellow/brown forms occur toward the end of season. Eggs are spherical, with less than 0.5 mm diameter and have light blue-green colour with longitudinal ridges resembling the fruit of a poppy. Eggs are laid singly on most parts of the cotton plant (flower buds, bolls, peduncles and bracteoles), the favoured one being young shoots. Full grown larva is about 1.3-1.8 cm long, stout and spindle shaped bearing a number of long setae on each segment. Last two thoracic and all abdominal segments bear two pairs of fleshy tubercles, one of which is dorsal and the other lateral. Larva is light brown, tinged with grey to green, paler along the mid dorsal line with dark spots at the base of the setae, more pronounced on the second and fifth abdominal segments. Yellowish spots are seen at the base of tubercles of thoracic segments (Figure 11). Larvae of *E. insulana* are generally lighter in colour, the pattern being grey and yellow than brown and deep orange. In *E. vitella* larval tubercles are much less prominent especially in the abdomen.



Figure 11: Larva of Spotted Bollworm (*Earias vitella*)  
Source: <http://cicr.org.in/>

iii) **Pink Bollworm** (*Pectinophora gossypiella*)

Eggs are pearly iridescent white, flattened, oval measuring approximately 0.5 mm long, 0.25 mm wide and sculptured with longitudinal lines. They are laid singly or in small groups of four to five. Early in the season, eggs are laid in any of the sheltered places of the plant axis of petioles or peduncles, the underside of young leaves, on buds or flowers. Once the bolls are 15 days old, these become favoured sites for oviposition. Incubation period is 3-6 days. First two instars are white, while from third instar pink colour develops. Larva when attacks bud of less than 10 days old, shedding of bud occurs and larva dies. With older bud larva can complete development. Larva in flower bud spins webbing that prevents proper flower opening leading to “rosetted-bloom”. Ten to twenty days old bolls are attacked from under bracteoles. Larvae feed on the developing seeds. While in younger bolls entire content may be destroyed, in older bolls development could be completed on three four seeds (Figure 12).



Figure 12: Larva of Pink Bollworm (*Pectinophora gossypiella*)  
Rosetted flower found due to Pink Bollworm infestation  
Source: <http://cicr.org.in/>

iv) **Jassids** (*Amrasca biguttula biguttula*)

Adults are elongate and wedge shaped with pale green body; very active with sideways walk but quick to hop and fly when disturbed (Figure 13). Eggs are curved and deeply embedded in the midribs of large veins on



Figure 13: Adults of Jassids (*Amrasca devastans*)

Source: <http://cicr.org.in/>



Figure 14: Cotton plant affected with jassids

Source: <http://cicr.org.in/>

the under surface of the leaves. Nymphs are flattened, pale yellowish green with sideway movements and remain confined to the lower surface of leaves during day time (Figure 14).

v) **Aphids** (*Aphis gossypii*)

*Aphis gossypii* is extremely variable in colour (dirty green, dark green, blackish brown, orange/dirty yellow). Aggregating populations are seen at the terminal buds and largest populations are found below the leaves of the lower third of plants, where they are partially protected from high temperature (Figure 15).



Figure 15: Aphids (*Aphis gossypii*)

Source: <http://cicr.org.in/>

vi) **Thrips** (*Thrips tabaci*)

Thrips are slender and the colour of macropterous adults varies from pale yellow to dark brown. Antennae have seven segments with the first segment always paler than second segment which is usually dark. Anterior edge



Figure 16: Thrips (*Thrips tabaci*)

Source: <http://cicr.org.in/>



Figure 17: Damaged caused by thrips

Source: <http://cicr.org.in/>

of the abdominal tergites is marked by a brown band. There is a single pair of pores on tergite (Figure 16). Damage caused by thrips to cotton plants is shown in Figure 17.

vii) **Whiteflies** (*Bemisia tabaci*)

Adults are white and small; females are 1.1 -1.2 mm long; the males are slightly smaller (Figure 18). Antennae of females are longer than males. Genitalia of female consists outer and inner vulvulae and rounded, whereas paramors of males are extended, narrow and pointed. Parthenogenetic reproduction is also seen.



Figure 18: Whiteflies (*Bemisia tabaci*)

Source: <http://cicr.org.in/>

viii) **Mealy Bug** (Family *Pseudococcidae*): Mealy bugs are cottony white, fluffy, scale like insect, known to damage the plants by sucking cell sap (Figure 19). Severe infestation resulted in stunted growth, premature leaf fall, incomplete opening of bolls and reduction in fibre quality. Honey dew secreted by nymphs and adults support growth of sooty mould on the plant.



Figure 19: Mealy bug  
Source: <http://cicr.org.in/>

ix) **Cotton Semilooper** (*Anomis flava*)

Larvae are long, slender and green with faint whitish longitudinal lines on the sides and can be distinguished by their looping action (Figure 20). Looper eggs may be deposited anywhere on the cotton plant, but larvae are usually found on the lower leaf surface and are most likely to be observed on the upper third of the plant.



Figure 20: Cotton semilooper  
(*Anomis flava*)  
Source: <http://cicr.org.in/>

x) **Cotton Leaf Roller** (*Sylepta derogata*)

Larvae seen in groups during initial stages in folded leaves amidst fecal material. Late/last instar larvae move out and pupate individually. The larvae are greenish white and semi translucent, roll up leaves to protect while feeding. Brown pupae are typical in having 8 short spines with hooked tips at their extremity. Moth is light cream with wings transversed with brown/black wavy lines and a black border with greyish fringe. Head and thorax are dotted black and abdomen has brown rings.

xi) **Cotton leafworm/Tobacco caterpillar** (*Spodoptera litura*)

Pest in polyphagous and is occasionally a serious pest of cotton. Eggs are laid in clusters and are covered with scales and hairs. The young larvae are gregarious and are solitary in nature. The colour of the small larvae is black whereas grown up are dark green in colour with black triangular spots on the body (Figure 21).



Figure 21: Cotton leafworm/Tobacco caterpillar (*Spodoptera litura*) larva  
Source: <http://cicr.org.in/>

xii) **Red cotton bug** (*Dysdercus cingulatus*)

Nymphs and adults are brightly coloured with red head with a white prothoracic collar. Eggs are laid in shallow depression in soil or under debris in batches. The nymphal instars are gregarious and feeding is in congregation. Both nymphs and adults suck sap from leaves and green bolls (Figure 22).



Figure 22: Colony of young red cotton bug  
(*Dysdercus cingulatus*)  
Source: <http://cicr.org.in/>

**xiii) Dusky Cotton Bug (*Oxycarenus hyalipennis*)**

Adults are small-elongated bugs with pointed heads, dull black to very dark brown (Figure 23). The hemielytra has a translucent dusky appearance. Eggs are laid in moist soil or soil crevices. The nymphs and adults suck sap from immature seeds which don't ripen, remain light weight. All stages are characterized by a powerful smell when crushed.



*Figure 23: Dusky cotton bug  
(Oxycarenus hyalipennis)  
Source: <http://cicr.org.in/>*

**xiv) Mirid Bug (*Creontiodes biseratense*)**

The eggs are laid either singly or in groups on ventral surface of leaf and on petiole. Freshly hatched nymphs are light transparent yellow in colour with tip of antennae having reddish tinge and thorax brownish or reddish in colour, while the adults are swift fliers and brown in colour (Figure 24). The nymphs and adults both damage developing flower buds and tender bolls. The characteristic symptoms of feeding on the flower bud shows oozing out of yellow fluid from the buds and staining of this yellow fluid on the inner surface of the bracts. Infested tender bolls have number of black patches on all sides of the outer surface.



*Figure 24: Mirid Bug  
(Creontiodes biseratense)  
Source: <http://cicr.org.in/>*

## MAJOR DISEASES OF COTTON

Various bacterial, fungal and viral diseases affecting the cotton crop in India are as follows:

i) **Root rot** (*Rhizoctonia bataticola* and *R. solani*)

This disease is caused by soil-borne fungi *Rhizoctonia bataticola* and *R.solani*. The loss in yield results due to reduction in plant stand by way of sudden death of plants (Figure 25). The disease appears in patches. Due to this disease perfectly healthy plants may wilt within 24 hours with leaves drooping without showing any discoloration. Roots of affected plants becomes brown to dark and the bark of the affected roots shred.



Figure 25: Root rot (*Rhizoctonia solani*)  
Source: <http://lipmimages.org/>

ii) **Cotton Bacterial blight** (*Xanthomonas axanopodis*)

This disease is caused by a bacterium *Xanthomonas axanopodis* pv. *malvacearum*. In northern region infected seeds are the primary source of infection while in southern region plant debris is the main source of infection. The disease attacks at all stages of the crop growth. The losses in yield and quality of lint result due to heavy drop of leaves, young bolls and squares, and rotting of bolls. Defoliation causes shedding of young bolls and thus leads to reduction in yield (Figure 26).



Figure 26: Bacterial blight (angular leaf spot) caused by (*Xanthomonas campestris* pv. *malvacearum*)  
Source: <http://ces.ncsu.edu/>

iii) **Alternaria leaf blight** (*Alternaria macrospora*)

It is caused by *Alternaria macrospora*, a fungus that infects the leaves, bracts and bolls. Pima cotton (*G.barbadense*) is very susceptible, while upland cotton (*G.hirsutum*) is fairly tolerant under normal dry weather conditions. *A. macrospora* survives in cotton debris and on weeds. Under high humidity or rainfall, spores are produced that are wind blown ,or splashed on cotton plants. Red concentric lesions appear where spores have germinated and grown into the host tissue (Figure 27). Infections late in the season are not considered a problem, but early infections during summer rains in July and August can cause severe defoliation.



Figure 27: *Alternaria* leaf blight  
Source: <http://cicr.org.in/>

iv) **Grey mildew** (*Ramularia areola*)

Grey mildew in cotton usually appears first on the lower canopy leaves after first boll set. Lesions are 3-4 mm in width bounded by the veinlets, giving an irregular or angular outline to the appearance of the lesions (Figure 28).



Figure 28: Grey mildew (*Ramularia areola*)  
Source: <http://cicr.org.in/>

The conidial stage of the causal organism is known as *Ramularia areola*. The fungus has an ascomycete sexual stage known as *Mycosphaerella areola*. Conidiophores bear one or two septate, hyaline conidia. Spermogonia appear as raised black dots in lesions on the lower surface of fallen leaves.

When mature, rod shaped spermatia ooze out through an apical opening in viscous mucilage. Perithecia later replace the spermogonia and are brown in colour producing eight, two celled ascospores. Conidia and ascospores produced on fallen leaves or volunteer plants provide the primary inoculum, which is disseminated by wind and water.

v) **Powdery mildew** (*Leveillula taurica*)

The disease is confined mainly to young cotton plants. The symptoms are angular or rounded, powdery, white patches on the underside of the leaf. The patches later coalesce to cover the entire underside of the leaf (Figure 29). Sometimes no external symptoms occur until leaves become chlorotic and defoliate.



Figure 29: Powdery mildew (*Leveillula taurica*)  
Source: <http://agroAtlas.ru/en/>

vi) **Cotton Leaf curl virus** (*Bemisia tabaci*)

It is major disease of cotton caused by the cotton leaf curl geminivirus (CLCuV) transmitted through *Bemisia tabaci*. Leaves of infected cotton curl upward and bear leaf-like enations on the underside along with vein thickening (Figure 30). Plants infected early in the season are stunted and yield is reduced drastically.



Figure 30: Cotton leaf curl virus (*Bemisia tabaci*)  
Source: <http://cicr.org.in/>

vii) **Verticillium wilt** (*Verticillium dahliae*)

This disease is caused by *Verticillium dahliae*, a soil borne fungus that enters the roots and grows into the vascular system of the plant. Symptoms of infection appear as necrotic areas on leaves, wilting and usually discoloration of the vascular tissue (Figure 31). Plants may lose their leaves if infected with a defoliating strain of the fungus. *V.dahliae* survives in the soil for long periods of time as microsclerotia, tiny structures produced in the plant tissue.



Figure 31: Verticillium wilt (*Verticillium dahliae*)  
Source: <http://ag.arizona.edu/>

viii) **Fusarium wilt** (*Fusarium oxysporum f.sp. vasinfectum*)

It affects diploid cotton in north India, parts of Gujarat, Maharashtra and Karnataka. This disease is caused by a soil-borne fungus *Fusarium moniliform f.sp vasinfectum*. The disease causes considerable reduction in yield. In young as well as old plants the initial symptoms are stunting followed by yellowing, wilting and drooping of most of the leaves (Figure 32). In old plants, lower leaves towards the base are affected first followed by younger ones towards the tips. Leaf discolouration appears around the edges and progresses towards the midrib and leaves gradually drop.



Figure 32: *Fusarium wilt affects young cotton plant*  
Source: <http://cicr.org.in/>

Diseases such as Bacterial blight and *Alternaria* leaf spot have been found to be internally seed borne and hence could become a source of inoculum if fuzzy seeds are cultivated without recommended seed treatment. Besides the above mentioned diseases of known origin, a wilt syndrome of unknown etiology known with widely varying names such as: Adilabad wilt, Para wilt, Sudan Wilt, New Wilt etc. had obsessed the farmers during the seventies and early eighties in all the states of central and south India attacking all cultivated *Gossypium spp.*, more vigorously on tetraploid varieties/hybrids.

Sporadic incidence of *Myrothecium*, caused by *Myrothecium roridum*, Helminthosporium leaf spot by *Helminthosporium sp.* Helminthosporium collar rot (*Sclerotium rolfsii*) and rust by *Phakospora gossypii* were reported. Change over of major cotton area from diploid to high yielding tetraploid cotton has also led to change in the disease such as *Fusarium* wilt, *Cercospora* leaf spot which existed among diploids have either reduced or totally eliminated from scenario. But diseases such as Grey mildew, a problem of Asiatic cotton has turned out to be a major potential threat to tetraploid cotton in central and south zones.

The fragment and indiscriminate use of many rounds of spray of synthetic pyrethroids led to the resurgence and aggravation of foliar diseases due to *A. macrospora* and *R. areola* in all cotton areas of the country. Fungal boll rot due to *Rhizopus sp.*, *Chaetomium sp.*, *Aspergillus sp.*, *Fusarium sp.* *Nematospora sp.*, etc. after bollworm damage is also substantial in rainfed cotton growing states as well as in northern irrigated areas.

The last three decades have witnessed no incidence of *Verticillium* wilt although in seventies and eighties, it used to occur in Tamil Nadu and Karnataka. Recent increase incidence of Grey mildew in Peninsular India, wilts of unknown etiology in the central Indian cotton tracts, Bacterial blight in Sriganganagar area of Rajasthan and Andhra Pradesh, Cotton leaf curl virus disease in north Indian cotton tracts are significant to reduce crop yield.

## MAJOR PREDATORS OF COTTON

Large numbers of natural enemies are known to attack insect pests of cotton in different agro-climatic zones but only a few species are economically important for reducing the population of insect pests. Natural enemies of cotton insect pests have been compiled by Central Institute of Cotton Research under the category of predators, parasitoids, and pathogens based on the readily available reports of the past as detailed below:

### I. PREDATORS

1. *Chrysopa* and *Chrysoperla*: The two lacewings species i.e. *Chrysopa* and *Chrysoperla* offer important control of sucking pests and bollworm in the field (Figure 33, 34). Their larvae are voracious predators of sucking pests and bollworms attacking them at various stages of their life cycle including egg, nymph, adult.



Figure 33 : *Chrysoperla camea* (grubs and adults)



Figure 34: *Chrysopa* (grubs and adults)

Source: <http://cicr.org.in/>



2. **Coccinellids:** Many species of ladybird beetle belonging to family *Coccinellids* can be found on cotton fields. Both larval and adult stages of ladybird beetles are beneficial as they prey upon aphids, mealy bugs and whitefly (Figure 35). The eggs and nymphs of aphids are attacked whereas nymphs and adults of mealy bugs are targeted. In case of whitefly only nymphs are attacked.



Figure 35: *Coccinellids* (grubs and adults)  
Source: <http://cicr.org.in/>

3. **Syrphid:** The larvae of syrphid flies prey primarily on aphids. They attack eggs or nymph of their prey. One larvae may destroy hundreds of aphids before reaching maturity (Figure 36).



Figure 36: *Syrphid*  
Source: <http://cicr.org.in/>

4. **Spiders:** Many species of spiders are found in cotton fields. Since spiders will eat most insects injurious to cotton, they are extremely beneficial. They catch their prey in webs or spread themselves out on the upper surface of a leaf (Figure 37).



Figure 37: *Spider*  
Source: <http://cicr.org.in/>

5. ***Geocoris*:** *Geocoris* sp. or big eyed bugs are piercing-sucking predators and attack nymph of jassids and whiteflies (Figure 38).



Figure 38: *Geocoris*  
Source: <http://cicr.org.in/>

## 6. Canthocorid sp.



*Figure 39: Canthocorid*  
*Source: <http://cicr.org.in/>*

## II. PARASITOIDS

Several parasitoids species of flies and wasps also attack cotton pests, especially larvae of lepidopteran pests. Some of the commonly found parasitoids in India are as follows (Figure 40 - 44).



*Figure 40: Apanteles*



*Figure 41: Campoletis*



*Figure 42: Rogas*



*Figure 43: Aphelinus*



*Figure 44: Tachinid*

*Source: <http://cicr.org.in/>*

# ANNEXURE - V

## BIOTECH INTERVENTIONS IN COTTON

Genetic engineering has been used to insert specific genes into cotton plants for transfer of specific characters. The cotton plant has been transformed with variety of genes expressing different traits such as insect resistance, herbicide tolerance, drought tolerance, improved fibre quality etc. However, only insect resistance and herbicide tolerance genes have been approved individually as well as stacked in various combinations for commercial cultivation in cotton in various countries as may be seen in the Table 6.

**Table 6: Year wise list of commercially cultivated Bt cotton in various countries**

Biotech Cotton	Active Gene(s)	Argentina	Australia	Brazil	China (Mainland)	Colombia	India	Indonesia	Mexico	South Africa	USA
BXN <sup>TH</sup>	Nitrolase										1995/96
Round Ready*	cp4 epsps (Mon 1445/1698)	1999/00	2001/02			2004/05			2000/01	2001/02	1997/98
Round Ready* Flex	cp4 epsps (Mon 88913)		2006/07							2008/02	1997/98
Liberty Link*	bar (LL Cotton 25)		2006/07								2004/05
Bollgard*	cry 1 Ac (Mon 531)	1998/99	1996/97 (Ingard)	2005/06	1997/98	2003/04	2002/03	2002/03	1996/97	1998/99	1996/97
Bollgard* II	cry 1 Ba (Mon 531)+ cry 2 Ab (Mon 15985)15		2003/04			2007/08	2006/07			2006/07	2003/04
Wide Strike <sup>TH</sup>	cry 1 Ac + cry 1F (Event 3006-210-23 + Event 281-24-236)										2005/06
Guokang	cry 1A + CpTI				1997/98		2006/07 (GFM Event)				
Round Ready* + Bollgard*	cp4 epsps (Mon 1445/1698) + cry 1Ac (Mon 531)		2001/02			2007/08			2000/01	2005/06	1997/98
Round Ready* Flex + Bollgard* II	cp4 epsps (Mon 88913) + cry 1Ac (Mon 531) + cry 2Ab (Mon 15985) 15		2006/07			2007/08				2008/09	2006/07
Event 1	cry 1Ac						2006/07 (Event 1)				
Wide Strike <sup>TH</sup> + Round Ready*	cry 1Ac + cry 1F (Event 3006-210-23 + Event 281-24-236) + cp4 epsps (Mon 1445/1698)										2006/07

Biotech Cotton	Active Gene(s)	Argentina	Australia	Brazil	China (Mainland)	Colombia	India	Indonesia	Mexico	South Africa	USA
Wide Strike <sup>TH</sup> + Roundup Ready* Flex	cry 1Ac + cry 1F (Event 3006-210-23 + Event 281-24-236) + cp4 epsps (Mon 88913)										2007/08
Liberty Link* + Bollgard* II	bar + cry 1Ac (Mon 531 + cry 2Ab (Mon 15985) 15										2006/07

As per estimates of the International Cotton Advisory Committee (ICAC) various types of biotech cotton were planted on 44% of world area in 2007/08, accounting for 51% of production and 48% of cotton traded internationally (Figure 45). The confined field trials of biotech cotton varieties resistant to lepidopteron pests are underway in several countries such as Burkino Faso, Egypt, Kenya, Tanzania, Zimbabwe, Uganda etc.

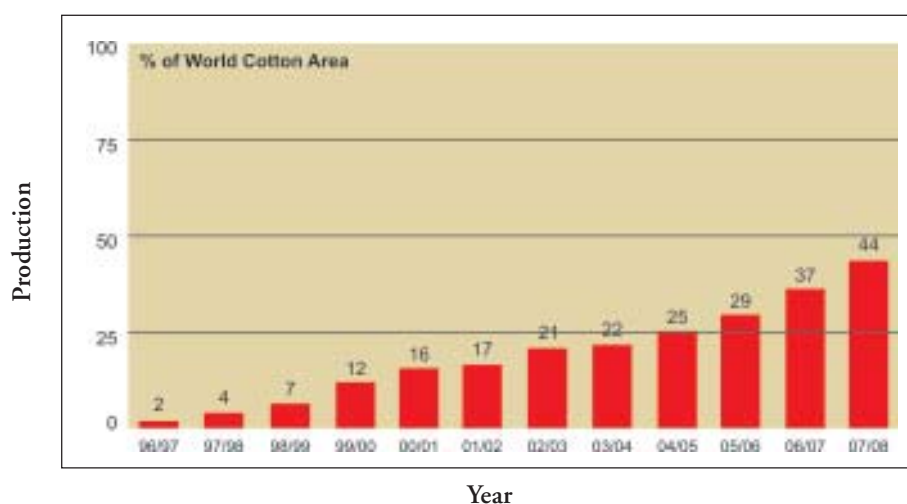


Figure 45: An increase in cotton production from 1996 - 2008

Source: International Cotton Advisory Committee (ICAC)

As mentioned above, extensive research efforts are underway for incorporation of genes for traits such as drought tolerance, disease resistance including viral and fungal diseases, insect resistance, herbicide tolerance and improved fibre quality. Some of the above are already under various stages of field trials in USA, Canada and Australia.

In India, five genes/events for insect resistance have been approved so far. These include:

- i. *cry1Ac* (MON 531) by Mahyco-Monsanto
- ii. *cry1Ac* + *cry2Ab* (MON 15985) by Mahyco-Monsanto
- iii. *cry 1Ab+cry 1Ac* “ (GFM event) by Nath Seeds

- iv. *cry1 Ac gene* (Event-1) by J.K. Agri Genetics
- v. *cry1Ac gene (CICR)* by Central Institute of Cotton Research
- vi. *cry1 C* by Meta-Helix Life Sciences

In addition, research and field trials have been undertaken/are underway for the following insect resistance and herbicide tolerant genes:

- i. *vip3A+cry1 Ab* by Syngenta
- ii. *cry1 Ac+ cry 1F* by Dow Agrosiences
- iii. *cry1 Aa3, cry1 F, cry1 Ia5, cry1 Ab* by ICAR institutions
- iv. *cry1 Ec* by J.K. Agri Genetics
- v. *cp4epsps* gene by MAHYCO

# REFERENCES

- Chauhan, D.S., Singh, P., Singh, P. 1983. Isolation distance in upland cotton under Nagpur conditions. *Cotton Development*.13: 23.
- Christiansen, M.N., Moore, R.P. 1959. Seed coat structural differences that influence water uptake and seed quality in hard seed cotton. *Agronomy Journal*. 51: 582-584.
- Coghlan, A. 2000. For the moment, the gene genie is staying in its bottle. *New Scientist*. 25.
- Craven, L.A., Steward, J.McD., Brown, A.H.D. and Grace, J.P. 1995. The Australian wild species of *Gossypium*. In: Challenging the Future: Proceeding of the World Cotton Research Conference- I. Constable, G.A. and Forrester, N.W. (Eds.). Brisbane Australia. February 14-17, 1994. CSIRO. Melbourne. pp. 278-281.
- Cronn, R. and Wendel, J.F. 1998. Simple methods for isolating homologous loci from allopolyploid genomes. *Genomes*. 41:756-762.
- Doak, C.C. 1934. A new technique in cotton hybridizing suggested changes in existing methods of emasculation and bagging of cotton flowers. *J. heredity*. 25: 201-204.
- Elfawal, M.A., Bishr, M.A. and Hassoub, E.K. 1976. Natural cross pollination in Egyptian cotton (*Gossypium barbadense* L.). *Journal of Agricultural Science*. 86: 205-209.
- Endrizzzi, J.E., Turcotte, E.L. and Kohel, R.J. 1985 Genetics, cytology and evolution of *Gossypium*. *Adv. Genet.* 23:271-327.
- Fryxell, P.A. 1979. The Natural History of the Cotton Tribe (Malvaceae, Tribe Gossypieae). pp 245. Texas A&M University Press. College Station and London.
- Fryxell, P.A. 1984. Taxonomy and Germplasm resources in Cotton. Agronomy monograph ASA-CSSA-SSSA. pp 27-29. 677 South Segoe, Road Madison, WI 53711, USA.
- Fryxell, P.A. 1992. A revised taxonomic interpretation of *Gossypium* L.(Malvaceae.) *Rheedea*. 2:108-165.
- Galal, H.E. , Abou-el-fittouh, H.A. and Morshed, G. 1972. Effect of direction and distance on cross pollination in Egyptian cotton (*Gossypium barbadense* L.). *Experimental Agriculture*. 8: 67-71.
- Gerstel, D.U. 1953. Chromosome translocations in interspecific hybridization of genus *Gossypium*. *Evolution*. 7: 234-244.

- Govila, O.P. and Rao, C.H. 1969. Studies on the in vitro germination and storage of cotton pollen. *Journal of Palynology*. 5: 37-41.
- Govila, O.P. 1969. Fertilization and seed development in crosses between *G. arboreum* and *G. hirsutum*. *Indian J. Genetics*. 29: 407-417.
- Gridley, H.E. 1974. Natural and artificial crossing in upland cotton at Namulongu, Uganda. *Cotton Growing Review*. 51: 149-152.
- Gulati, A.N. and Turner, A. J. 1929. A note on early history of cotton. *Journal of the Textile Institute, Transactions*. 20: 1-9.
- Hutchinson, J.B. 1959. *The Application of Genetics of Cotton Improvement*. Cambridge University Press London, New York.
- Handbook of Agriculture. 2006. pp 1018-1036. ICAR, New Delhi.
- James, C. 2008. Global status of commercialized biotech/GM crops. ISAAA Brief No. 39. ISAAA. Ithaca. New York.
- Katarki, B.H. 1971. Varalaxmi: A high yielding hybrid cotton of quality. *Indian Farm*. 21:35-36.
- Khadi, B.M., Kulkarni, V.N., Ansingkar, A.S., Singh, V.V. and Gotmare, V. 2003. Gene pool concept in diploid cotton. In proceedings of World Cotton Conference -3, Cape Town, South Africa.
- Khadi, B.M. and Kulkarni, V.N. 2001. In: Chopra, V.L. *Breeding Field Crops. Theory and Practice*. Chapter 14. Oxford & IBH Publishing Co. Pvt. Ltd. Delhi and Calcutta. pp 531-575.
- Keeler, K.H., Turner, C.E. and Bolick, M.R. 1996. Movement of crop transgenes into wild plants. In *Herbicide resistant plants*. CRC Press Inc.,
- Lazarides, M., Cowley, K., Hohnen, P. 1997. *CSIRO Handbook of Australian Weeds*. Canberra, ACT.
- Llewellyn, D. and Fitt, G. 1996. Pollen dispersal from two field trials of transgenic cotton in the Namoi valley, Australia. *Molecular Breeding*. 2: 157-166.
- Mathews, G.A. and Tunstall, J.P.(eds.). 1994. *Insect pests of cotton*. CAB International. pp. 393.
- Meredith, W.R.J. and Bridge, R.R. 1973. Natural crossing in cotton (*Gossypium hirsutum* L.). *Crop Science*. 13: 551-552.
- Moresco, E. R., Farias, F. J. C., Aguiar, P. H., Griodi-Papp, I. I., Freire, E. C., Marques, M. F., and de Souza, M. C. 1999. Determination of the rate of allogamy in herbaceous cotton in the cerrado of Mato Grosso, In *Anais II Congresso brasileiro de Algodao: O algodao no seculo XX perspectivas para o seculo XXI*, Ribeirao Preto, SP.

- Nielsen, K.M., Bones, A.M., Smalla, K. and van Elsas, J.D. 1998. Horizontal gene transfer from transgenic plants to terrestrial bacteria - a rare event? *FEMS Microbiology Reviews*. 22: 79-103.
- Nielsen, K.M., Gebhard, F., Smalla, K., Bones, A.M. and van Elsas, J.D. 1997. Evaluation of possible horizontal gene transfer from transgenic plants to the soil bacterium *Acinobactor calcoaceticus* BD 413. *Theoretical and Applied Genetics*. 95: 815-821.
- OGTR. 2002. The Biology and Ecology of Cotton (*Gossypium hirsutum*) in Australia. Office of the Gene Technology Regulator (OGTR), Canberra, Australia. <<http://www.ogtr.gov.au/pdf/ir/biologycotton.pdf>>
- Oosterhuis, D.M. and Jernstedt, J. 1999. Morphology and anatomy of the cotton plant. In Smith, W. C., Cothren, J. T., eds Cotton: Origin, History, Technology and Production. pp 175-206. John Wiley and Sons, Inc., New York.
- Patel, C.T. 1971. Hybrid 4 - A new hope towards self sufficiency in cotton in India. *Cotton Development*. 1(2):1-6.
- Richmond, T.R. 1951. Procedures and methods of cotton breeding with special reference to American cultivated species. *Advances in Genetics*. 4: 213-245.
- Santhanam, V. and Sundaram, V. 1997. Agri history of cotton India - An overview. *Asian Agri-History*. 1, 4: 235-251.
- Seelanan, T., Sch nabel, A. and Wendel, J.F. 1997. Congruence and consensus in the cotton tribe (Malvaceae). *Systematic Botany*. 22: 259-290.
- Schlüter, K., Fütterer, J. and Potrykus, I. 1995 Horizontal gene transfer from a transgenic potato line to a bacterial pathogen (*Erwinia chrysanthemi*) occurs- if at all- at an extremely low frequency. *Bio/Technology*. 13: 1094-1098.
- Serdy, F. S., Berberich, S., and Sharota, E. 1995. Petition for determination of nonregulated status Bollgard® cotton lines 757 and 7076 (*Gossypium hirsutum* L.) with the gene from *Bacillus thuringiensis* subsp. *kurstaki*. Monsanto Company, St. Louis, Mo.
- Smith, W.C. 1976. Natural cross-pollination of cotton. *Arkansas Farm Research*. 25: 6.
- Stewart, J: Mc D. 1995. Potential for crop improvement with exotic germplasm and genetic engineering. In challenging the future: Proceedings of the World Cotton Research Conference-I. Brisbane Australia Feb. 14-17, 1994. G.A., pp 313-312. Constable and N.W. Forrester (Eds), LSIRO, Melbourne.
- Sundaram, V. 1974. Antiquity of Cotton. In: 50 years of research at Cotton Technological Research Laboratory, pp 212. Indian Council of Agricultural Research, New Delhi, India,
- Syvanen, M. 1999. In search of horizontal gene transfer. *Nature Biotechnology*. 17: 833.
- Theron, C. C. and van Staden, W.H. 1975. Natural cross pollination of cotton at Uptington (Natuurlike kruisbestuiwing van katoen te Upington). *Agroplanta*. 7: 91-92.



- Thomson, N. J. 1966. Cotton variety trials in the Ord valley, North Western Australia 4. Natural crossing of cotton. *Empire Cotton Growing Review*. 43: 18-21.
- Tohill, J. C., Mott, J. J. and Gillard, P. 1982. Pasture weeds of the tropics and subtropics with special reference to Australia. In *Biology and Ecology of Weeds*. pp 403-427. Dr W. Junk Publishers. The Hague.
- Tunwar, N.S. and Singh, S.V. 1988. Indian Minimum Seed Certification Standards published by The Central Seed Certification Board, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India.
- Umbeck, P., Barton, K. A., Norheim, E. V., McCarty, J. C., Parrot, W. L., Jennings, J. C. 1991. Degree of pollen dispersal by insects from a field test of genetically engineered cotton. *Journal of Economic Entomology*. 84: 1943-1950.
- Vennila, S., Ramasundaram, P., Raj, S. and Kairon, M.S. 2000. Cotton IPM and its Current Status. Technical Bulletin No. 8. Central Institute for Cotton Research, Nagpur.
- Weaver, D.B. and J.B. Weaver Jr. 1977. Inheritance of pollen fertility restoration in cytoplasmic male-sterile cotton. *Crop Sci*. 17: 497-449.
- Wendel, J. F. and Albert, V. A. 1992. Phylogenetics of the cotton genus (*Gossypium*): Character-State Weighted Parsimony Analysis of chloroplast DNA restriction site data and its systematic and biogeographic implications. *Systematic Botany*. 17: 115-143.
- Wendel, J. F. 1989. New World Tetraploid cottons contain Old World cytoplasm. *Proc. Natl Acad. Sci. USA*. 86: 4132-4136.



सत्यमेव जयते

Ministry of Environment and Forests  
Government of India

Department of Biotechnology  
Ministry of Science & Technology  
Government of India