

For Official Use

ENV/JM/MONO(2008)33



Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

05-Dec-2008

English - Or. English

ENVIRONMENT DIRECTORATE
JOINT MEETING OF THE CHEMICALS COMMITTEE AND
THE WORKING PARTY ON CHEMICALS, PESTICIDES AND BIOTECHNOLOGY

Cancels & replaces the same document of 04 December 2008

Series on Harmonisation of Regulatory Oversight in Biotechnology No. 45

CONSENSUS DOCUMENT ON THE BIOLOGY OF COTTON
(Gossypium spp.)

JT03257047

Document complet disponible sur OLIS dans son format d'origine
Complete document available on OLIS in its original format

ENV/JM/MONO(2008)33
For Official Use

English - Or. English

Also published in the Series on Harmonisation of Regulatory Oversight in Biotechnology:

- No. 1, *Commercialisation of Agricultural Products Derived through Modern Biotechnology: Survey Results (1995)*
- No. 2, *Analysis of Information Elements Used in the Assessment of Certain Products of Modern Biotechnology (1995)*
- No. 3, *Report of the OECD Workshop on the Commercialisation of Agricultural Products Derived through Modern Biotechnology (1995)*
- No. 4, *Industrial Products of Modern Biotechnology Intended for Release to the Environment: The Proceedings of the Fribourg Workshop (1996)*
- No. 5, *Consensus Document on General Information concerning the Biosafety of Crop Plants Made Virus Resistant through Coat Protein Gene-Mediated Protection (1996)*
- No. 6, *Consensus Document on Information Used in the Assessment of Environmental Applications Involving Pseudomonas (1997)*
- No. 7, *Consensus Document on the Biology of Brassica napus L. (Oilseed Rape) (1997)*
- No. 8, *Consensus Document on the Biology of Solanum tuberosum subsp. tuberosum (Potato) (1997)*
- No. 9, *Consensus Document on the Biology of Triticum aestivum (Bread Wheat) (1999)*
- No. 10, *Consensus Document on General Information Concerning the Genes and Their Enzymes that Confer Tolerance to Glyphosate Herbicide (1999)*
- No. 11, *Consensus Document on General Information Concerning the Genes and Their Enzymes that Confer Tolerance to Phosphinothricin Herbicide (1999)*
- No. 12, *Consensus Document on the Biology of Picea abies (L.) Karst (Norway Spruce) (1999)*
- No. 13, *Consensus Document on the Biology of Picea glauca (Moench) Voss (White Spruce) (1999)*
- No. 14, *Consensus Document on the Biology of Oryza sativa (Rice) (1999)*
- No. 15, *Consensus Document on the Biology of Glycine max (L.) Merr. (Soybean) (2000)*
- No. 16, *Consensus Document on the Biology of Populus L. (Poplars) (2000)*
- No. 17, *Report of the OECD Workshop on Unique Identification Systems for Transgenic Plants, Charmey, Switzerland, 2-4 October 2000 (2001)*
- No. 18, *Consensus Document on the Biology of Beta vulgaris L. (Sugar Beet) (2001)*
- No. 19, *Report of the Workshop on the Environmental Considerations of Genetically Modified Trees, Norway, September 1999. (2001)*
- No. 20, *Consensus Document on Information Used in the Assessment of Environmental Applications Involving Baculoviruses (2002)*
- No. 21, *Consensus Document on the Biology of Picea sitchensis (Bong.) Carr. (Sitka Spruce) (2002)*
- No. 22, *Consensus Document on the Biology of Pinus strobus L. (Eastern White Pine) (2002)*
- No. 23, *Revised 2006: OECD Guidance for the Designation of a Unique Identifier for Transgenic Plants (2006)*
- No. 24, *Consensus Document on the Biology of Prunus spp. (Stone Fruits) (2002)*

- No. 25, *Module II: Herbicide Biochemistry, Herbicide Metabolism and the Residues in Glufosinate-Ammonium (Phosphinothricin)-Tolerant Transgenic Plants* (2002)
- No. 26, *Output on the Questionnaire on National Approaches to Monitoring/Detection/Identification of Transgenic Products* (2003)
- No. 27, *Consensus Document on the Biology of Zea mays subsp. mays (Maize)* (2003)
- No. 28, *Consensus Document on the Biology of European White Birch (Betula pendula Roth)* (2003)
- No. 29, *Guidance Document on the Use of Taxonomy in Risk Assessment of Micro-organisms: Bacteria* (2003)
- No. 30, *Guidance Document on Methods for Detection of Micro-organisms Introduced into the Environment: Bacteria* (2004)
- No. 31, *Consensus Document on the Biology of Helianthus annuus L. (Sunflower)* (2004)
- No. 32, *An Introduction to the Biosafety Consensus Documents of OECD's Working Group for Harmonisation in Biotechnology* (2005)
- No. 33, *Consensus Document on the Biology of Papaya (Carica papaya)* (2005)
- No. 34, *Consensus Document on the Biology of Pleurotus spp. (Oyster Mushroom)* (2005)
- No. 35, *Points to Consider for Consensus Documents on the Biology of Cultivated Plants* (2006)
- No. 36, *Consensus Document on the Biology of Capsicum annum Complex (Chili peppers, Hot peppers and Sweet peppers)* (2006)
- No. 37, *Consensus Document on Information Used in the Assessment of Environmental Application involving Acidithiobacillus* (2006)
- No. 38, *Consensus Document on the Biology of Western White Pine (Pinus monticola Dougl. ex D. Don)* (2008)
- No. 39, *Abstracts of the OECD Expert Workshop on the Biology of Atlantic Salmon* (2006)
- No. 40, *Consensus Document on the Biology of Pinus banksiana (Jack Pine)* (2006)
- No. 41, *Consensus Document on the Biology of the Native North American Larches: Subalpine Larch (Larix lyallii), Western Larch (Larix occidentalis), and Tamarack (Larix laricina)* (2007)
- No. 42, *Consensus Document on the Safety Information on Transgenic Plants Expressing Bacillus thuringiensis – Derived Insect Control Protein* (2007)
- No. 43, *Consensus Document on the Biology of Douglas-Fir (Pseudotsuga Menziesii (Mirb.) Franco)* (2008)
- No. 44, *Consensus Document on the Biology of Lodgepole Pine (Pinus contorta Dougl. ex. Loud.)* (2008)

© OECD 2008

Applications for permission to reproduce or translate all or part of this material should be made to: RIGHTS@oecd.org, Head of Publications Service, OECD, 2 rue André-Pascal, 75775 Paris Cedex 16, France.

OECD Environment, Health and Safety Publications

Series on Harmonisation of Regulatory Oversight in Biotechnology

No. 45

Consensus Document on the Biology of Cotton (*Gossypium* spp.)

Environment Directorate

Organisation for Economic Co-operation and Development

Paris 2008

ABOUT THE OECD

The Organisation for Economic Co-operation and Development (OECD) is an intergovernmental organisation in which representatives of 30 industrialised countries in North America, Europe and the Asia and Pacific region, as well as the European Commission, meet to co-ordinate and harmonise policies, discuss issues of mutual concern, and work together to respond to international problems. Most of the OECD's work is carried out by more than 200 specialised committees and working groups composed of member country delegates. Observers from several countries with special status at the OECD, and from interested international organisations, attend many of the OECD's workshops and other meetings. Committees and working groups are served by the OECD Secretariat, located in Paris, France, which is organised into directorates and divisions.

The Environment, Health and Safety Division publishes free-of-charge documents in ten different series: **Testing and Assessment; Good Laboratory Practice and Compliance Monitoring; Pesticides and Biocides; Risk Management; Harmonisation of Regulatory Oversight in Biotechnology; Safety of Novel Foods and Feeds; Chemical Accidents; Pollutant Release and Transfer Registers; Emission Scenario Documents; and the Safety of Manufactured Nanomaterials.** More information about the Environment, Health and Safety Programme and EHS publications is available on the OECD's World Wide Web site (<http://www.oecd.org/ehs/>).

This publication is available electronically, at no charge.

For the complete text of this and many other Biosafety publications, consult the OECD's World Wide Web site (<http://www.oecd.org/biotrack>)

or contact:

**OECD Environment Directorate,
Environment, Health and Safety Division**

**2 rue André-Pascal
75775 Paris Cedex 16
France**

Fax: (33-1) 45 24 16 75

E-mail: ehscont@oecd.org

FOREWORD

Consensus Documents contain information for use during the regulatory assessment of a particular product. In the area of plant biosafety, these are being published on information on the biology of certain plant species, selected traits that may be introduced into plant species, and biosafety issues arising from certain general types of modifications made to plants.

This document addresses the biology of cotton (*Gossypium* spp.). Spain served as the lead country in the preparation of this document. The draft was revised on a number of occasions based on the inputs from other member countries. This document is published on the responsibility of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology of the OECD.

TABLE OF CONTENTS

ABOUT THE OECD.....	6
FOREWORD.....	7
PREAMBLE.....	10
SECTION I. INTRODUCTION: DESCRIPTION AND USES.....	11
1.1. Description.....	11
1.2. Uses.....	13
SECTION II. TAXONOMY AND CENTRES OF ORIGIN, DIVERSITY AND DOMESTICATION.....	14
2.1. Taxonomy.....	14
2.2. Major evolutionary events.....	15
2.3. Domestication and early cultivation.....	16
2.3.1. Old World diploids.....	16
2.3.2. New World tetraploids.....	17
SECTION III. AGRONOMIC REQUIREMENTS AND PRACTICES.....	19
3.1. Abiotic environment.....	19
3.2. Cultivation.....	20
3.3. Biotic environment.....	21
3.4. Harvest and processing (ginning, crushing).....	23
3.5. Crop rotation.....	23
SECTION IV. REPRODUCTIVE BIOLOGY, DISPERSAL AND ESTABLISHMENT.....	24
4.1. Floral biology, pollination and development of seeds.....	24
4.2. Dispersal.....	25
4.3. Seed dormancy and germination.....	26
4.4. Weediness and naturalisation.....	26
SECTION V. GENETICS AND HYBRIDISATION.....	28
5.1. Genomes.....	28
5.2. Intraspecific crossing.....	29
5.3. Interspecific crossing.....	29
5.3.1. Primary gene pool — the tetraploids.....	30
5.3.2. Secondary and tertiary gene pools — the diploids.....	31
SECTION VI. BIOTECHNOLOGY AND GENETIC TRANSFORMATION.....	33
SECTION VII. HUMAN HEALTH AND BIOSAFETY.....	34
7.1. Toxins.....	34
7.2. Allergens.....	35
APPENDIX 1. <i>GOSSYPIUM</i> SPECIES.....	36

APPENDIX 2. GENERA OF WEEDS REGIONALLY COMMON IN COTTON	38
REFERENCES	39
QUESTIONNAIRE TO RETURN TO THE OECD	63

PREAMBLE

The environmental safety/risks of transgenic organisms are normally based on the information on the characteristics of the host organism, the introduced traits, the environment into which the organism is introduced, the interaction between these, and the intended application. The OECD's Working Group on Harmonisation of Regulatory Oversight in Biotechnology decided at its first session, in June 1995, to focus its work on identifying parts of this information, which could be commonly used in countries for environmental safety/risk assessment to encourage information sharing and prevent duplication of effort among countries. Biosafety Consensus Documents are one of the major outputs of its work.

Biosafety Consensus Documents are intended to be a "snapshot" of current information on a specific host organism or trait, for use during regulatory assessments. They are not intended to be a comprehensive source of information on everything that is known about a specific host or trait; but they do address the key or core set of issues that member countries believe are relevant to risk/safety assessment. This information is said to be mutually acceptable among member countries. To date, 31 Biosafety Consensus Documents have been published. They include documents which address the biology of crops, trees and micro-organisms as well as those which address specific traits which are used in transgenic crops.

In reading the Consensus Documents, it is useful to consult two additional texts. The first, entitled *An Introduction to the Biosafety Consensus Document of OECD's Working Group for Harmonisation in Biotechnology* explains the purpose of the Consensus Documents and how they are relevant to risk/safety assessment. It also describes the process by which the documents are drafted using a "lead country" approach. The second text is *Points to Consider for Consensus Documents on the Biology of Cultivated Plants*. This is a structured checklist of "points to consider" for authors when drafting or for those evaluating a Consensus Document. Amongst other things, this text describes how each point is relevant to risk/safety assessment.

The Consensus Documents are of value to applicants for commercial uses of transgenic organisms, regulators in national authorities as well as the wider scientific community. As each of the documents may be updated in the future as new knowledge becomes available, users of Consensus Documents are encouraged to provide any information or opinions regarding the contents of this document or indeed, OECD's other harmonisation activities. If needed, a short pre-addressed questionnaire is attached at the end of this document that can be used to provide such comments.

The published Consensus Documents are also available individually from OECD's website (<http://www.oecd.org/biotrack>) at no cost.

SECTION I. INTRODUCTION: DESCRIPTION AND USES

1. Generally cotton refers to four species of the genus *Gossypium* L. apparently domesticated independently in four separate regions, in both the Old World and the New World (Sauer, 1993; Brubaker *et al.*, 1999c). The word is derived from the Arabic “quotr”, “kutum” or “gutum” and refers to the crop that produces spinnable fibres on the seed coat (Lee, 1984; Smith, 1995). *Gossypium* (cotton) comprises approximately 50 species worldwide in the arid to semi-arid tropics and subtropics (Fryxell, 1992; Wendel and Cronn, 2003) (Appendix 1). The cultivated species are grouped according to their level of ploidy:

- Diploids (AA) ($2n = 2x = 26$): *Gossypium herbaceum* L. and *Gossypium arboreum* L.;
- Tetraploids (AADD) ($2n = 4x = 52$): *Gossypium barbadense* L. and *Gossypium hirsutum* L.

2. Of these four cultivated species, *Gossypium hirsutum* and *G. barbadense* account for 95% or more of world cotton production (Jenkins, 1993; May and Lege, 1999; Zhang *et al.*, 2008). Throughout this document the word cotton often is used to include both of these dominant crop species, but where the differences are significant and relevant, individual species are differentiated. *Gossypium hirsutum*, widely known as upland cotton or sometimes American, Mexican or Acala cotton, accounts for over 90% of the production. *Gossypium barbadense*, which accounts for some 5%, is commonly known as extra long-staple cotton or Pima or Egyptian cotton.

1.1. Description

3. A full description of the cotton plant is provided by Oosterhuis and Jernstedt (1999). Potentially perennial but typically grown commercially as annual crops, both species include plants that can grow into a bush or small tree. *Gossypium hirsutum* grows to 1.5-2 (-5) m tall and *G. barbadense* to 3 m. However, both are typically cultivated as plants approximately 1-1.5 m high, with destruction after harvesting the fruits for lint and seed. The plants have a taproot which can reach a depth of 1-3 m depending on the variety's age, soil characteristics and the management regime, and many lateral roots. Cotton plants have a prominent upright main stem, monopodial and indeterminate in growth, which bears the branches and leaves (Hanan and Hearn, 2003; Marur and Ruano, 2001, 2004; Ritchie *et al.*, 2007). The number and length of axillary branches vary depending on the variety and environmental conditions.

4. The leaves are arranged alternately in a spiral around the axis of the main stem or branch. Phyllotaxis is 3/8 back over the last leaf. Leaves vary in size, shape, texture and hairiness. Most lamina are palmate, with several sinuses and lobes more or less defined, varying in shape from rounded to acute. The leaves are usually large and relatively hairy (Hu and Zhao, 1992; Susin *et al.*, 1988; Bourland *et al.*, 2003), although there are hairless, smooth-leaved varieties (Delattre, 1992); there are a large number of stomata mostly on the abaxial surface. The petiole is normally as long as the leaf lamina, and flanked by two stipules (persistent or falling early) at its juncture with the stem. Leaf characteristics differ considerably between *G. hirsutum* and *G. barbadense* (Wise *et al.*, 2000).

5. Generally the leaves of *G. barbadense* are 3- to 7-lobed (Fryxell, 1984, 1992) and mature leaves are larger and thinner than in *G. hirsutum*. The generally 3- to 5-lobed leaves of *G. hirsutum* are mostly flat throughout development and diheliotropic, tracking the sun to maximise light absorption. *Gossypium barbadense* leaves exhibit significant cupping or curling which reduces photoinhibition and allows for more light penetration into the plant's canopy over the course of the day. Although *G. barbadense* leaves have higher stomatal density than in *G. hirsutum*, the stomata are smaller, so there is less stomatal surface area per leaf (Lu *et al.*, 1997; Wise *et al.*, 2000).

6. Two types of branches are produced: vegetative or monopodial (continuing growth from terminal bud), and fruiting or sympodial (continuing growth from lateral bud). In terms of structure, the vegetative branches are much like the main stem. Flowers are produced only after secondary or tertiary branching. The fruiting branches develop mainly from the first axillary bud of the upper nodes of the plant. They are smaller in diameter and more horizontal than vegetative branches. The sympodial development of fruiting branches gives them a slightly zigzag appearance in contrast to the fairly straight vegetative branches.

7. Each fruiting branch produces six to eight solitary flower buds (called “squares”) (Hutmacher, 2004). The bud is a pyramidal structure, and has three large lacinate triangular bracts surrounding the flower (as an epicalyx or involucre). Just within these bracts is the true calyx, which consists of five short sepals fused together into a cup at the lowest, widest part of the flower (McGregor, 1976). Inside the calyx are five petals separated except at the base, which form the corolla. Inside the corolla (and fused to its base) is a staminal column with many (50 to 125 or more) shortly stalked unilocular anthers distributed along it; this tubular column surrounds the elongated style. The style terminates in a club-shaped lobed stigma exerted somewhat beyond the end of the staminal column and positioned sometimes below but usually beyond the distal-most anthers. Unlike *G. hirsutum*, the *G. barbadense* stigma extends well beyond the anthers (McGregor, 1976), which increases the potential for cross-pollination.

8. *Gossypium hirsutum* flowers are of a uniformly creamy white to pale yellow colour, with cream pollen, and secrete a low volume of nectar; *G. barbadense* flowers are yellow with maroon blotches at the inner base (that serve as a nectar guide), have orange pollen, and produce more nectar of a lower sugar concentration (McGregor, 1976; Moffett, 1983).

9. The pistil’s basal rather conical portion is the superior ovary, consisting of three to five carpels or locules. The ovary of *G. hirsutum* often has four or five carpels, each with 8 to 12 ovules, which are aligned in two parallel vertical grooves along the axile placenta (the central column where the carpels join). The capsular fruit, which splits open at maturity, is referred to as the “boll”; it is spherical or ovoid with a beak at the top, and differs among species in shape, size and colour. *Gossypium hirsutum* bolls are usually of a pale-green colour and relatively smooth with few punctate gossypol glands; those of *G. barbadense* are of darker green and conspicuously pitted with numerous glands.

10. The fertilised ovule develops into a seed, the epidermis of which gives rise to many single-celled seed hairs (epidermal trichomes) of two kinds: long hairs referred to as “lint” and coarser short hairs referred to as “fuzz” or “linters” (Applequist *et al.*, 2001; Zhang *et al.*, 2007). Differentiation between the hair types has been maximised to produce the white lint in elite cultivars. Cottonseed oil accumulates in the cytoplasm of the seed embryo cells (Gotmare *et al.*, 2004); it is not associated with the gossypol glands. Descriptions of the seed are provided by Hopper and McDaniel (1999) and Ritchie *et al.* (2007), and an overview of advances in knowledge of the development of seed and fibre is provided by Ruan (2005).

11. The cotton plant is characterised by the presence of small lysigenous cavities known as “gossypol glands”, which are found in most tissues except xylem. They contain terpenoid aldehydes in an oily water-soluble matrix, which forms an essential oil known as “gossypol” (Khan *et al.*, 1999). Gossypol is toxic to non-ruminant mammals, birds, and many insects and microbes, thus providing a constitutive as well as inducible defense against herbivory and microbial attack. Glandless cotton has been developed for food purposes, but the plants are more susceptible to damage (Lusas and Jividen, 1987; Delattre, 1992). Cotton plants also have usually a single extrafloral nectary on the midvein of the underside of the leaf blade (somewhat outward from its base), and nectaries as well at the base of each involucre bract (on the outer and the inner sides). Their sugary nectar can draw insects that may provide defense against herbivory or increase it, depending on the overall management or ecological context (Adjei-Maafa and Wilson, 1983a, 1983b; Wäckers and Bezemer, 2003; Wäckers and Bonifay, 2004; Röse *et al.*, 2006).

1.2. Uses

12. The main product of the cotton plant is fibres — their qualitative characteristics have been valued and analysed over many centuries (Vreeland, 1999; Wakelyn *et al.*, 2007a, 2007b). Cotton crops provide the world's premier source for natural fibres, which are mainly used in the manufacture of a large number of textiles. Low-quality fibre can be used for manufacturing felt, mattress filling and special paper, and the processed cellulose is used for various consumer products such as toothpaste, lipstick, ice cream and mayonnaise. There also is a range of applications in the chemical industry.

13. The seeds, even though extensively and intensively used worldwide as well, tend to be regarded as a secondary product or byproduct. The seeds are used to obtain edible oil, which is considered to be of very good quality within the range of vegetable oils (O'Brien *et al.*, 2005); as chaff for livestock feed; and as high-protein cake and flour, which are used mainly for livestock feed (Section VII). The flour is sometimes used for human consumption (in low amounts, or after extraction of the gossypol or from gossypol-free varieties). Gossypol has been used as a male contraceptive (Coutinho, 2002). Cottonseed oil is of interest as a lubricant and a biofuel (Karaosmanoğlu *et al.*, 1999).

14. The nations producing the most cotton lint and cottonseed in 2006 were China, USA, India and Pakistan (Table 1). *Gossypium hirsutum* is called long-staple cotton, and the characteristic length of its fibres is 22-36 mm. *Gossypium barbadense*, extra-long-staple cotton, has fibres usually over 35 mm in length; it is cultivated mainly in Egypt, Peru, Sudan, USA and some Central Asian countries. The combination of best agronomic practices, an increasing level of qualification of farmers, and application of technological advances has boosted unit yields. The highest yields in 2006 were 1861 kg/ha of lint, and 2793 kg/ha of cottonseed (Table 1).

Table 1. Countries with the highest yields and/or the most production of cotton lint and/or cottonseed in the 2006 growing season (FAO, 2007)

2006	Yield: kg/ha		Production: tonnes	
	lint	cottonseed	lint	cottonseed
Australia	1861	2631		
Brazil			1,210,000	1,784,672
Cambodia		2712		
China	1243	2485	6,730,000	13,460,000
India			3,563,880	7,127,760
Israel	1717	2732		
Pakistan			2,186,800	4,065,200
Syria	1409	2793		
Turkey	1646	2469	900,000	1,350,000
USA			4,498,000	6,665,900
Uzbekistan			1,171,000	2,376,200

SECTION II. TAXONOMY AND CENTRES OF ORIGIN, DIVERSITY AND DOMESTICATION

2.1. Taxonomy

15. The genus *Gossypium* L. is a member of the family Malvaceae, subfamily Malvoideae and tribe Gossypieae, which has about nine genera (*cf.* Seelanan *et al.*, 1997). The genus emerged as a separate evolutionary lineage some 11-14 million years ago (Senchina *et al.*, 2003; Wendel and Cronn, 2003). *Gossypium* has three main centres of biological diversity: Africa and the Arabian Peninsula, Australia, and Mexico (see Appendix 1); and three centres of domestication: Africa and Asia, Mesoamerica (*i.e.* Mexico and Central America), and South America. The two diploid cultivated species (*G. herbaceum* and *G. arboreum*) are from the Old World (Africa-Asia). The two tetraploid cultivated species are from the New World — Mesoamerica (*G. hirsutum*) and South America (*G. barbadense*). Although the record is less clear for Asia, each of the four cultivated species may have been domesticated independently (Sauer, 1993; Brubaker *et al.*, 1999c).

16. About 50 species of *Gossypium* are generally recognised (see Appendix 1) (Fryxell, 1992; Percival *et al.*, 1999), although some taxonomic study is still needed. About 45 of the species are diploids, which are divided into three geographical groups and corresponding subgenera; 5 species are tetraploids, which are included in one subgenus (Fryxell, 1984, 1992; Wendel and Cronn, 2003; Cronn and Wendel, 2004):

- African-Arabian group (subgenus *Gossypium*): about 14 species (possibly fewer); naturally distributed principally in Africa, also on the Arabian Peninsula, and reaching Pakistan and perhaps farther eastward (Vollesen, 1987; Fryxell, 1992; Stanton *et al.*, 1994; Wendel and Cronn, 2003). One species is endemic to the Cape Verde Islands;
- Australian group (subgenus *Sturtia*): about 17 species (16 taxonomically described), naturally distributed mostly in the northwestern Kimberley region, but also in the northern tropics and in the central arid zone, with one species reaching the eastern warm-temperate zone (Fryxell *et al.*, 1992; Seelanan *et al.*, 1999; Brown and Brubaker, 2000);
- American group (subgenus *Houzingenia*): about 14 species (13 taxonomically described), 12 occurring naturally in western Mexico (one reaching northward into Arizona, USA) and one each in the Galapagos Islands and in Peru (Fryxell, 1988; Small and Wendel, 2000; Cronn *et al.*, 2003; Álvarez *et al.*, 2005; Álvarez and Wendel, 2006; Ulloa *et al.*, 2006);
- American and Pacific group (subgenus *Karpas*): 5 tetraploid species; 3 naturally distributed in the Americas (one in Mesoamerica, 2 in South America), and one each in the Galapagos Islands and in the Hawaiian Islands (Small *et al.*, 1998; Wendell and Cronn, 2003).

17. The diploid species are placed into eight cytogenetic genome groups, and the tetraploids in one group (Endrizzi *et al.*, 1985; Stewart, 1995; Wendel and Cronn, 2003), as follows (Table 2):

Table 2. Genome groups of *Gossypium*

Genome group	Number of species	Native distribution
A	2	Africa, possibly Asia
B	3	Africa (including Cape Verde Islands)
E	7+	NE Africa, Arabian Peninsula, SW Asia
F	1	East Africa
C	2	Australia
G	3	Australia
K	11 (or 12)	NW & N Australia
D	13 (or 14)	Americas (primarily Mexico, also Peru), Galapagos Islands
AD	5	Americas, Galapagos Islands, Hawaiian Islands

18. The species of the genus usually recognised taxonomically are given in Appendix 1 along with their natural geographic distributions, designated genomes, and general groupings phylogenetically (Endrizzi *et al.*, 1985; Fryxell, 1992; Percival *et al.*, 1999; Wendel and Cronn, 2003).

2.2. Major evolutionary events

19. DNA-sequence phylogenetic data suggest that 6-7 million years ago, following a trans-oceanic dispersal event, a D genome diverged from the African lineage that eventually gave rise to the A genome, and became a separate lineage in the Americas (primarily Mexico) (Senchina *et al.*, 2003; Wendel and Cronn, 2003; Cronn and Wendel, 2004; *cf.* Graham, 2006). From another long-distance dispersal event 1-2 million years ago, a tetraploid originated through hybridisation of an African plant of the A-genome group, perhaps most closely related to the present-day species *G. herbaceum*, with a resident plant of the D-genome group, most closely related to the present-day species *G. raimondii* (Wendel *et al.*, 1992; Senchina *et al.*, 2003; Wendel and Cronn, 2003; Kebede *et al.*, 2007). The nascent disomic AD allotetraploid from that single polyploidisation event evolved into the five present-day tetraploid species (Endrizzi *et al.*, 1985; Cronn *et al.*, 1999).

20. *Gossypium raimondii*, a rare species of northwestern Peru, is considered to be the diploid with the genome that has retained the most similarity to this ancestral D-genome species (Liu *et al.*, 2001; Guo *et al.*, 2007); it is one of the more recently evolved of the DD species, having diverged in isolation as a result of a long-distance dispersal event from Mexico (Wendel and Cronn, 2003; Álvarez *et al.*, 2005). *Gossypium raimondii* has genetic similarities with *G. gossypioides*, which is a local species in southern Mexico (Oaxaca) and considered evolutionarily basal within the New World diploids. Nonetheless, *G. gossypioides* has a strikingly unusual history, involving several natural interspecific hybridisations — apparently including introgression from yet another African immigrant (evolutionarily prior to divergence of the African B, F and A genomes) (Cronn *et al.*, 2003; Cronn and Wendel, 2004; Álvarez *et al.*, 2005; Guo *et al.*, 2007).

21. Soon after separation of the D-genome lineage, African *Gossypium* further diverged with a long-distance dispersal event and establishment of an Australian lineage (which evolved into the three genome groups C, G and K). The lineage in Africa evolved further into four genome groups, first with divergence of the E-genome lineage, subsequently the B-genome lineage, and most recently the F- and A-genome lineages (Cronn *et al.*, 2002; Cronn and Wendel, 2004).

22. Chloroplast and mitochondrial DNA are inherited maternally in *Gossypium* (Small and Wendel, 1999). The means and route of the relatively recent long-distance dispersal of the A-genome fruit/seed(s) and place of origin of the progenitor allotetraploid continue to be researched (Wendel and Cronn, 2003). The A and D genomes of the South American tetraploid *Gossypium mustelinum* (northeastern Brazil) are genetically most similar to the ancestral type that differentiated into the five present-day widely dispersed tetraploids (Wendel *et al.*, 1994). The disseminule of an AA species may have travelled via sea currents from Africa to the Americas (Stephens, 1966; *cf.* Renner, 2004). Then, pollen from an American diploid (DD) species fertilised the immigrant, and chromosome doubling produced the original AADD tetraploid; the AA coloniser either did not persist or possibly established a small population that went extinct.

2.3. Domestication and early cultivation

2.3.1. Old World diploids

23. The cultivated AA diploids of the Old World are typically short-staple cottons, with a fibre length of less than 23 mm. These cottons can be important regionally, and still may be preferred especially in harsh or dry growing conditions (Basu, 1996; Rajendran *et al.*, 2005). The two species (with *G. arboreum* as the larger crop) now provide only about 4% of world production, however, and are largely displaced in much of the Old World by the New World tetraploids.

24. Both AA species have been studied thoroughly using many methodologies (*e.g.* agronomic, morphological, cytogenetic, genetic, molecular) and are definitely biologically distinct, although their differences are observable in divergent suites of shared characters rather than by obvious diagnostic characters (Wendel *et al.*, 1989; Stanton *et al.*, 1994; Rana and Bhat, 2004; Gao *et al.*, 2005; Desai *et al.*, 2006; Kebede *et al.*, 2007). *Gossypium herbaceum* typically has less anthocyanin (so becomes less “sun-red”), shorter leaves with shallower sinuses and broader lobes, epicalyx bracts broader and with twice as many apical teeth or lobes, smaller flowers, more rounded bolls, larger seeds and finer lint than *G. arboreum* (Abedin, 1979; Stanton *et al.*, 1994). *Gossypium arboreum* has an interchromosomal translocation in comparison to the generically typical arrangement in its sister species *G. herbaceum* (Song *et al.*, 1991; Desai *et al.*, 2006).

25. Wild (non-feral) *Gossypium herbaceum* subsp. *africanum* occurs naturally in the savanna biome across southern Africa (Vollesen, 1987; Wendel *et al.*, 1989; *cf.* Jürgens, 1997), whereas the domesticated plant *G. herbaceum* subsp. *herbaceum* is found disjunctly farther to the northeast, being grown mainly from Ethiopia to Central Asia, northwestern China and India (Wendel *et al.*, 1989; Guo *et al.*, 2006). *Gossypium arboreum* is grown primarily across Asia farther to the east, from India (where it is cultivated more than *G. herbaceum*) to Korea (Wendel *et al.*, 1989; Basu, 1996; Guo *et al.*, 2006). The original ranges or centres of domestication of *G. arboreum* and *G. herbaceum* subsp. *herbaceum* are unclear (Wendel *et al.*, 1989; Brubaker *et al.*, 1999c).

26. The archaeological evidence of early cotton use in the Old World is not at the species level. Circumstantially, *G. herbaceum* subsp. *herbaceum* might be from Southwest Asia (*e.g.* Abedin, 1979; Fuller, 2006) and *G. arboreum* possibly from India (Santhanam and Hutchinson, 1974). Early utilisation and probable cultivation of cotton have been reported from Pakistan before 5000 BC (Moulherat *et al.*, 2002); North Arabia (Jordan) about 4450-3000 BC, but perhaps present by trade according to Betts *et al.*

(1994); South India in 1500 BC (Fuller *et al.*, 2004); and southern Libya in 900 BC – 500 AD (Pelling, 2005). Both species may have reached North Africa and Greater Mesopotamia before earliest historic times (Watson, 1983; Potts, 1997). Cotton and weaving are mentioned in early texts in Asia (*e.g.* India and China) and the Mediterranean region.

2.3.2. New World tetraploids

Gossypium barbadense

27. Originally wild (*i.e.* non-feral) *Gossypium barbadense* is considered to occur naturally in the dry coastal region of northern Peru and southern Ecuador (Schwendiman *et al.*, 1985; Percy and Wendel, 1990; Westengen *et al.*, 2005). The earliest archaeological evidence of the cultivation of *G. barbadense* dates to 5500 BC in northwestern Peru (Dillehay *et al.*, 2007). This cotton species was apparently domesticated and grown extensively in the northwestern Peruvian and southwestern Ecuadorian region, and was spread into the Andes and farther eastward in South America, and onward to the Caribbean and southern Mesoamerica (Brubaker *et al.*, 1999c; Vreeland, 1999; Pearsall, 2003; Westengen *et al.*, 2005; Johnston *et al.*, 2006; Dillehay *et al.*, 2007).

Gossypium hirsutum

28. *Gossypium hirsutum* is native in Mesoamerica, but its natural range as well as its centres of domestication and development are obscured by millennia of use (Stephens, 1967; Lee, 1984; Jones *et al.*, 1989; Wendel *et al.*, 1992; Brubaker and Wendel, 1994; Stark *et al.*, 1998; Brubaker *et al.*, 1999c; Whitmore and Turner, 2002). Collections from this large and diverse region, even of free-living plants, generally have varying characteristics of domestication rather than of a genuinely wild species — for example, having larger and more flaring capsules, larger seeds, loss of seed dormancy and of day-length sensitivity, and more and finer lint which is also more easily detachable (Hutchinson, 1951; Stephens, 1958; Fryxell, 1979). The oldest archaeological remains of *G. hirsutum*, dating to 3500-2300 BC, seem to be domesticated forms and were found in the Tehuacan Valley of central Mexico (Smith and Stephens, 1971; WWF and IUCN, 1997; *cf.* Pope *et al.*, 2001).

29. Through intensive study of germplasm collections from the widespread complex in the region, Hutchinson (1951) distinguished six domesticated races (not botanical varieties) and one wild race based mainly on their habit and morphology, and found that these races had generally distinct geographic distributions, with the most differentiation of the domesticated types in southern Mexico:

- *morrilli* — inland montane, southern Mexican plateau and northward
- *palmeri* — Pacific slope, southern Mexico west of Isthmus of Tehuantepec
- *richmondi* — Pacific slope in Gulf of Tehuantepec region
- *punctatum* — Yucatan Peninsula, and northward on Atlantic slope, to Florida (USA) and Bahamas
- *yucatanense* — wild, northwestern coast of Yucatan Peninsula
- *latifolium* — Guatemala (both slopes) and southernmost Mexico (Chiapas), nearby areas
- *marie-galante* — northern Central America (Guatemala) southward to Colombia on both coasts, Caribbean region (Antilles) and northeastern Brazil

30. Research using isozymes (allozymes) only confirmed the distinction of Caribbean *marie-galante* (Wendel *et al.*, 1992); RFLP and SSR analyses have supported recognition of additional landraces (Brubaker and Wendel, 1993, 1994; Lacape *et al.*, 2007). The next most distinct lineage is *punctatum*, and then *latifolium*. Of these three major domesticated lineages (Iqbal *et al.*, 2001), *marie-galante* is a perennial, from which *mocó* cotton is still cultivated in Brazil (Freire and Moreira, 1991; Moreira *et al.*, 1995; Johnston *et al.*, 2006); *punctatum* and *latifolium* are annualised. The original Amerindian Hopi

Moencopi cotton (Arizona, southwestern USA) is considered to belong to *punctatum* (Lee, 1984). Race *palmeri* is closely related to race *latifolium*, and the SSR research found *morrilli* and *richmondi* to be distinct lineages that are close to *palmeri*. *Gossypium lanceolatum* is not a distinct species but a local Mexican landrace, in the domesticated race *palmeri* (Brubaker and Wendel, 1993).

31. The modern studies have maintained *yucatanense* as a truly wild ecotype, sprawling plants which are isolated in populations along the northwestern coastal strand of Mexico's Yucatan Peninsula (Hutchinson, 1951), but perhaps occur naturally eastward even as far as Guadeloupe island in the Lesser Antilles (Ano *et al.*, 1982; Lacape *et al.*, 2007). Wild-like or wild populations of *G. hirsutum* are widely scattered and rare, growing near beaches or confined on small islands; such populations do not occur inland from the coast, but feral plants are found inland (Brubaker and Wendel, 1994).

Origin of upland cotton

32. The upland type of *Gossypium hirsutum* and derived varieties are the mainstay of the worldwide industry (May and Lege, 1999). Upland cotton is thought to have its centres of origin and diversity near the border of Mexico with Guatemala (Hutchinson *et al.*, 1947; Hutchinson, 1951; Brubaker and Wendel, 1994), apparently within *G. hirsutum* race *latifolium*. This type appears to have become prevalent in southeastern USA around the middle of the 18th century (Phillips, 1976; Smith *et al.*, 1999). Somewhat later (about 1785), Sea Island cotton (*G. barbadense*) from the Bahamas was widely grown in the U.S. Atlantic coastal regions of Georgia and South Carolina (Brown and Ware, 1958; Smith *et al.*, 1999).

33. The first seed stocks of the cotton arriving in USA were called Georgia green seed (Hutchinson *et al.*, 1947). This type normally grew from a ginned seed with persisting green-coloured fuzz; the Sea Island-type had hairless or bare ginned seed, placing it among the "black-seed" cottons. Sea Island cotton was cultivated in the lowlands, whereas green-seed cotton was more inland and consequently became known as upland cotton (Smith *et al.*, 1999). In the 18th century similar stocks also were taken to Southeast Asia (Lee, 1984). In the 19th century further Mexican green-seed cultigens were introduced into the USA and came to be known as varieties of upland cotton (Brown and Ware, 1958; Smith *et al.*, 1999). Cotton was introduced into many tropical and subtropical countries during the U.S. civil war period (1861-1865), including Australia (Constable *et al.*, 2001). Crosses between many varieties of introduced cottons have caused the worldwide expansion of upland cotton (Lee, 1984; Smith *et al.*, 1999; Iqbal *et al.*, 2001). The intensive modern cotton industry only became established in Australia in the 1960s (Hearn and Fitt, 1992).

SECTION III. AGRONOMIC REQUIREMENTS AND PRACTICES

3.1. Abiotic environment

34. Although originating in the tropics and subtropics, cotton has come to be cultivated mostly in subtropical and warm-temperate zones — regions which provide more than half of world production (*cf.* Table 1). For this geographical shift to be possible as a crop, the species' photoperiod needed to change — the naturally short-day plant became a day-neutral plant that could be cultivated as an annual crop in the longer summers (Smith *et al.*, 1999).

Climate

35. The geographical distribution of the cotton crop reaches 43-45° N (Central Asia, China) but is primarily grown between 37° N and 32° S (e.g. Australia, northern Argentina). Temperature is the main climatic factor determining the geographic range in which cotton can be grown (Freeland *et al.*, 2006). Generally the plant is highly sensitive to temperature (Reddy *et al.*, 2006). Seeds do not germinate, nor seedlings begin their activity, until the temperature rises to 15°C; they are delayed above 38°C. *Gossypium barbadense* seedling development in the first 2 weeks is generally not sensitive to temperatures between 15°C and 40°C, but 3 weeks after emergence the young plants are generally more sensitive than *G. hirsutum* (e.g. having fewer fruiting branches at 35°/27°C than at 30°/22°C, and no fruiting branches at 40°/32°C) (Reddy *et al.*, 1992b). Nonetheless, there are *G. barbadense* cultivars with heat tolerance close to that of *G. hirsutum* (Cornish *et al.*, 1991; Radin *et al.*, 1994; Srivastava *et al.*, 1995). The optimum daytime temperature range for *G. hirsutum* is 30-35°C, with a loss of fruit above 35°C, and with a 50% yield reduction at 25°C (Reddy *et al.*, 1992a).

36. After planting *G. hirsutum*, 180-200 frost-free days are needed for normal development, with an average of 150 days of suitable temperatures (*i.e.* 1200 heat units above 15.5°C accumulated) (Duke, 1983); for *G. barbadense*, 200-250 days are needed (Unruh and Silvertooth, 1997). Although the values differ among varieties, from the planting of cotton to 60% boll opening about 2050 heat units (degree-days or day-degrees) are the required minimum (Ritchie *et al.*, 2007; OGTR, 2008).

Soil and water

37. Cotton plants are cultivated in a wide variety of soils, but the crop develops best in deep arable soils with good drainage, filled with organic matter and with a high moisture-retention capacity. Yet cotton is grown in cracking clays in some countries. Cotton is a salt-tolerant plant, with *G. barbadense* more salt tolerant than *G. hirsutum* (Ashour and Abd-El'Hamid, 1970). Salinity stress nonetheless has adverse effects on germination and emergence (Ashraf, 2002); the most common stress effect is general stunting of the plant's growth (Cothren, 1999).

38. Irrigation allows cultivation in poor-quality soils, with necessary moisture and nutrients provided in a controlled way. Irrigation is carried out mainly at ground level, flooding the furrows, which requires adequate leveling of the field.

39. At least 500 mm of rainfall is required during the growing season for dryland (non-irrigated) cotton crops. Cotton is also grown as an irrigated crop, and it is still common to use sprinklers with fixed

or mobile outlets, with total coverage. The use of drip irrigation has increased, which allows a saving in water and use of soil that is less than optimum (due to its sloping surface, lack of fertility, or an excessively high salt content). Generally *G. barbadense* has similar water requirements to *G. hirsutum*; the longer growing season of *G. barbadense* may however require additional irrigation to mature its later-set bolls (Silvertooth, 2001). Carefully timing the application of water optimises the plant's vegetative growth, flowering and boll production (McWilliams, 2003). Flower and boll formation in *G. barbadense* are enhanced by a short duration of sunshine, high minimum humidity and low evaporation rate (Sawan *et al.*, 2004, 2005).

3.2. Cultivation

Sowing

40. Sowing cotton is an operation that requires careful soil preparation, in order to achieve sufficient moisture, to allow favourable germination and rapid development of roots. Pre-prepared ridges are recommended, to obtain adequate drainage of water and maintain optimum temperature. The optimal sowing date is determined by temperature. Temperature is the dominant factor affecting the cotton plant's development and yield (ACCRC, 2001; Robertson *et al.*, 2007). The sowing can commence when the minimum soil temperature at a depth of 10 cm exceeds 14°C for at least 3 consecutive days. Lint yield is adversely affected if *G. hirsutum* is planted too early (due to cold temperatures) or too late (due to a shortened growing season) (Kittock *et al.*, 1987). Since *G. barbadense* prefers a longer growing season (> 200 days) for yield increase it is more sensitive to delays in planting (Kittock *et al.*, 1981, 1985; Silvertooth, 2001).

41. Acid-delinted seeds are treated with fungicides against seedling disease complexes and with insecticides to protect seedlings from sucking insect pests and wireworm soil insects (beetle larvae), and are sown at a rate of 20-25 kg/ha. Sowing is carried out with precision machines, in 4 or 6 rows with spacing of 95-105 cm to adapt to mechanical collection of bolls. A proportion of the crop is sometimes planted in an Ultra Narrow Row configuration, for example with row spacing of 30 cm and a target population of 25 to 30 plants per m².

42. Germination takes place under favourable conditions of temperature and humidity. Cotton remains in a seedling stage longer than some other crop species. Sometimes the seeds are sown under plastic, a technique that ensures high germination and enhances floral development. In Spain this practice is totally mechanised, and (depending on the year) may be applied on more than two thirds of the sown surface area.

Fertilisers

43. Phosphorus (P) and potassium (K) are applied according to soil content, at the base of the plants. Nitrogen (N) is distributed between the plant's base and top with an application rate of up to 200 or 250 units of N, depending on the environmental and crop conditions. *Gossypium barbadense* requires slightly more N, P and K per unit of lint produced (Unruh and Silvertooth, 1996). However it is more sensitive to a slight excess of N, which can stimulate higher vegetative growth and delay maturity (Silvertooth *et al.*, 1995).

Growth regulators

44. Growth regulators or herbicides may be applied to control vegetative growth and development of the crop, and to assist in its harvest. Examples include a growth regulator applied early in bud/flower production to reduce internode length, increase boll retention, promote early flowering and/or produce a

more open canopy, and a growth regulator applied to the crop close to harvest time to stimulate opening of mature bolls and to defoliate (Cothren, 1999; Ritchie *et al.*, 2007).

3.3. Biotic environment

Vesicular arbuscular mycorrhizae (VAM)

45. In most soils successful growth of cotton crops depends on the interaction with mycorrhizal fungi (Youssef and Mankarios, 1974; ACCRC, 2002; Nehl and Allen, 2004). The fungi (*e.g. Glomus mosseae*) grow intercellularly in the root cortex. They form vesicular arbuscules with the plasma membrane in the cortical cells, which are the sites of mineral exchange from the fungus to the plant and carbohydrate exchange from the plant to the fungus. Improvement in phosphate uptake is the main advantage for the cotton plants. VAM fungi also can reduce incidence and severity of diseases of the plants (Hu and Gui, 1991; Liu, 1995).

Pests

46. Pest and disease control is a highly significant cost (Oerke, 2006), and repeated applications of insecticides and fungicides may be employed. Numerous insect pests feed on cotton (Matthews, 1989; Delattre, 1992). Insects that are natural enemies of the pests are encouraged as part of integrated pest management systems. Cultivation of varieties with genetically engineered resistance to some insects has been a major advance in management of the crop against some major pests.

47. Arthropod pests may affect boll production or fibre quality. Aphids (*Aphis gossypii*, *A. craccivora*, *Myzus persicae*) and the silverleaf whitefly *Bemisia tabaci* are the usual pests which most affect fibre quality, producing sticky cotton with dark stains if not controlled late in the season. The pink bollworm *Platyedra gossypiella*, various Hemiptera such as *Lygus* bugs, and various mites such as the two-spotted spider mite *Tetranychus urticae* also diminish fibre yield and quality. Important pests affecting boll production include cotton bollworms (*Helicoverpa armigera*, *H. punctigera*), and the spiny bollworm *Earias insulana* mainly reduces fibre production. Lepidoptera such as the beet armyworm *Spodoptera exigua* and Egyptian cotton leafworm *Spodoptera littoralis* are less common. The cotton boll weevil *Anthonomus grandis* is a highly aggressive pest in some areas. Other important pests include the leafhopper *Empoasca lybica* (the cotton jassid).

48. *Gossypium barbadense* has some resistance to *Earias* spp. (Reed, 1994), jassids (Matthews, 1994) and spider mites, possibly due to its higher content of gossypol than *G. hirsutum* (Şengonca *et al.*, 1986; Matthews and Tunstall, 1994).

49. Nematodes that may be damaging in some regions or areas include particularly the root-knot nematodes *Meloidogyne incognita* (as well as *M. acronea*), reniform nematode *Rotylenchulus reniformis*, lance nematodes *Hoplolaimus columbus* (and several other spp.) and sting nematode *Belonolaimus longicaudatus* (Robinson, 1999), and as well associated ring nematodes *Criconebella* spp., spiral nematodes *Helicotylenchus* spp., needle nematode *Longidorus africanus*, stunt nematodes *Merlinius* spp. and *Tylenchorhynchus* spp., stubby-root nematodes *Paratrichodorus* spp., pin nematode *Paratylenchus hamatus*, lesion nematodes *Pratylenchus* spp., spiral nematodes *Scutellonema* spp., and American dagger nematodes — the *Xiphinema americanum* group.

Diseases

50. Among cotton diseases (Kirkpatrick and Rothrock, 2001), the most prominent is Verticillium wilt, which is caused by *Verticillium dahliae*. This fungal disease is extensively distributed in areas where *G. hirsutum* is cultivated; conventionally bred resistant varieties are available in Australia (OGTR, 2008). Other diseases, such as damping off, are caused by a complex of pathogens that have a major effect on the crop. The main causative agents are *Rhizoctonia solani*, *Pythium ultimum*, *Thielaviopsis basicola* and *Fusarium* spp.

51. Many other fungi have been associated with diseases of cotton, either as the primary agents or secondary invaders: *Alternaria* spp., *Ascochyta gossypii*, *Aspergillus flavus*, *Brasilomyces malachrae*, *Cladosporium herbarum*, *Fusarium* spp. (e.g. *F. oxysporum* f. sp. *vasinfectum*), *Glomerella gossypii* (anamorph *Colletotrichum gossypii*), *Lasiodiplodia theobromae* (synonym *Diplodia gossypina*), *Leveillula taurica* (anamorph *Oidiopsis haplophylli* [synonyms *O. gossypii*, *O. sicula*]), *Macrophomina phaseolina*, *Mycosphaerella* spp., *Nematospora* spp., *Phakopsora gossypii*, *Phymatotrichopsis omnivora*, *Phytophthora* spp., *Puccinia cacabata* and *P. schedonnardi*, *Pythium* spp. and *Sclerotium rolfsii*.

52. Boll rot caused by these diseases leads to serious production losses. Damage is more severe in crops cultivated with high humidity and low light intensity, and it increases if the bolls have mechanical lesions. Mainly, the damage these fungi cause is the contamination of fibres, especially if open bolls remain exposed to rain or high humidity for a long period. In addition to causing undesired discolouring of the fibre, these agents may give rise to enzyme degradation in some basic components, as frequently occurs in cellulose.

53. Other diseases of cotton are caused by bacteria, for example *Xanthomonas campestris* pv. *malvacearum*, and by viruses, for example abutilon mosaic geminivirus, cotton leaf crumple geminivirus, cotton leaf curl geminiviruses, cotton yellow mosaic geminiviruses and cotton anthocyanosis virus. Cotton bunchy top, cotton leaf mottle and cotton leaf roll diseases are of unknown etiology.

Weeds

54. Weed control in cotton fields is of considerable importance, and is carried out with mechanical methods by passing through the crop rows, and by chemical methods. Many different herbicides are employed in the cultivation of cotton, with their application during pre-sowing and/or pre-emergence of seedlings or less frequently in post-emergence (Table 3). Integrated weed management measures reduce reliance on single herbicide groups, and include crop rotations and farm hygiene to prevent weed seed spreading (Charles, 2002; Roberts and Charles, 2002). The cultivation of varieties with herbicide tolerance developed by genetic engineering has also significantly improved weed management of the crop.

Table 3. Timing of application of various herbicides

Land inclusion and pre-sowing
Pre-sowing
Pre- and post-sowing
Immediately post-sowing
Pre-sowing and pre-emergence
Pre-emergence
Pre- and post-emergence
Immediately post-sowing, and post-emergence
Post-emergence

55. The commonly occurring and the most troublesome weeds vary considerably by region and management practices. Genera often having species of notable concern in areas are listed in Appendix 2.

3.4. Harvest and processing (ginning, crushing)

56. To facilitate harvest and subsequent ginning (freeing up of fibres from seed to obtain the lint), the plant is defoliated by means of a chemical treatment. This improves cleanliness and the quality of the fibres. Mechanised harvest is done by means of spindle picker machines in two or four rows.

57. A final step is ginning the cotton in saw gins, to make bales classified according to grade and length of fibre. The separated cottonseed is further processed, first by separating the hulls from the kernels. The kernels are crushed, and the oil extracted and processed for use in human food or other products. The hulls are used for livestock feed or industrial products, and the remainder of the kernel (which is high in protein) is converted into cottonseed meal for livestock. In the case of *G. hirsutum*, the fuzzy seed (*i.e.* seed with linters) is delinted, *i.e.* processed mechanically or chemically to remove the linters. These residual short fibres are used for a variety of purposes, such as a cellulose base for food or other consumer products. To maintain its superior fibre quality, the picking and ginning techniques for *G. barbadense* cotton are different than those used for *G. hirsutum*. As *G. barbadense* does not produce linters, its seed exists either as the unprocessed “seed cotton” or processed black seed.

3.5. Crop rotation

58. Cotton crop rotation is usually carried out by alternating with other traditional crops in the area. However, in contrast to best agricultural practices, sometimes cotton is planted in the same field again, for 2 years or longer. The number of repetitions is hindered by the damage to the crop caused by diseases, especially Verticillium wilt.

SECTION IV. REPRODUCTIVE BIOLOGY, DISPERSAL AND ESTABLISHMENT

4.1. Floral biology, pollination and development of seeds

59. The sequence of flowering is from the lower to the upper part of the plant, and from the centre to the outside. Anthesis takes place 25-30 days after the appearance of the floral bud. Secretion of bracteal (extrafloral) nectar starts 5-6 days before flowering and initially peaks on the day of anthesis (Adjei-Mafo and Wilson, 1983a; Wäckers and Bonifay, 2004). On the day preceding anthesis the corolla extends well above the bracts, and early the following morning the large flower opens and secretion of floral nectar begins (Waller *et al.*, 1981); the petals turn dark pinkish and wilt by evening of the same day (Fryxell, 1979; Waller *et al.*, 1981; Eisikowitch and Loper, 1984; Sanchez and Malerbo-Souza, 2004). The anthers open soon after the flower and shed their pollen grains, some 900-350 per anther; the grains are spheroidal and very large (100-140 μm diameter), with *G. barbadense* having larger grains than *G. hirsutum* (Srivastava, 1982; Wetzal and Jensen, 1992; Kakani *et al.*, 1999; Savaşkan, 2002; Watanabe *et al.*, 2006). The stigma generally is receptive at anthesis (McGregor, 1976).

60. Self-pollination usually takes place. As the pollen grains are large, heavy and somewhat sticky, dissemination by wind is absent or negligible (McGregor, 1976; Umbeck *et al.*, 1991; Borém *et al.*, 2003). Under humid laboratory conditions, Richards *et al.* (2005) found that about 90% of the pollen grains were viable after 8 hrs, nearly 31% still viable after 16 hrs and about 7.5% viable after 32 hrs, but after 8 hrs on the proboscis of *Helicoverpa armigera* moths, pollen grains were about 81% non-viable.

61. Although cotton is mostly self-pollinating, in the presence of suitable insect pollinators it is also cross-pollinating at generally low levels, which improves yields (McGregor, 1976; Tanda, 1984; Mamood *et al.*, 1990; Rhodes, 2002; Sanchez and Malerbo-Souza, 2004; Llewellyn *et al.*, 2007). The species pool and concentration of pollinators vary according to region, location, season and timing. The extent of spontaneous (unaided) or natural outcrossing thus depends greatly upon local insect populations, including introduced and native species (Moffett *et al.*, 1976; Berger *et al.*, 1988; Freire *et al.*, 2002; Rhodes, 2002; Sanchez and Malerbo-Souza, 2004; Danka, 2005; Van Deynze *et al.*, 2005; Llewellyn *et al.*, 2007). Nectar from the extrafloral bracteal nectaries (epicalyx) is more accessible than nectar from the floral nectaries inside the calyx, so flower visitors are not always potential pollinators (Moffett *et al.*, 1975; McGregor, 1976; Tsigouri *et al.*, 2004; Danka, 2005). Bumble bees (*Bombus*), honey bees (*Apis*), *Anthophora*, *Melissodes* and *Halictus* bees and *Scolia* wasps are important pollinators in some areas (McGregor, 1976; Free, 1993; Delaplane and Mayer, 2000). *Apis mellifera* can be an important pollinator, but it does not prefer *Gossypium* pollen (McGregor, 1976; Eisikowitch and Loper, 1984; Vaissière *et al.*, 1984; Waller *et al.*, 1985; Loper, 1986; Vaissière, 1991; Vaissière and Vinson, 1994; Danka, 2005; Van Deynze *et al.*, 2005). In using insecticides to manage the crop, mitigation measures are taken to preserve the pollinator populations, for example by not applying insecticides during the effective period of flowering (Delattre, 1992; Bourland *et al.*, 2001; Sekloka *et al.*, 2007).

62. Isolation of test plots or the crop thus depends on the presence and flight distances of the insect pollinators, and the result desired (Llewellyn *et al.*, 2007). Conditions and objectives vary tremendously. Pollen-mediated gene flow declines steeply, typically being below 1% beyond 10 m from the source (Van Deynze *et al.*, 2005). From experiments, isolation distances suggested for field tests include 8-10 m (Turkey) (Sen *et al.*, 2004); 10 m (Greece) (Xanthopoulos and Kechagia, 2000); 20 m (Brazil) (Freire,

2002a); 33 m (India) (Singh and Singh, 1991); and 60 m (China) (Zhang *et al.*, 2005). Barriers composed of other cotton can be effective (Simpson and Duncan, 1956); in Australia the accepted practice has been a distance of 20 m with a cotton buffer or 50 m of bare ground, but somewhat larger distances may be preferable sometimes (Llewellyn *et al.*, 2007). Border rows of *Zea mays* 4 m wide reduced cotton cross-pollination in Brazil from 15% to 5%, and an isolation distance of 100 m has been recommended when maize barriers are used (Castro *et al.*, 1982; Freire, 2005).

63. As the field area under cultivation for cotton increases or the goal in separation becomes more strict, the recommended isolation distance increases, or there are large regions of exclusion. The OECD Seed Schemes recommend separation distances of 200 m for production of Certified commercial seed of *G. hirsutum* and 600 m for *G. barbadense*, and separation distances of 600 m and 800 m respectively for Basic (*i.e.* Foundation) seed (OECD, 2008). Suggestions for isolation of cotton crop fields in Brazil, depending on the objective, are a distance of 250 m or 800 m (Freire, 2005). In some situations an isolation distance of 1000 m (1 km) or more may be necessary (Australia) (Llewellyn *et al.*, 2007). Van Deynze *et al.* (2005) found 0.04% pollen-mediated gene flow at 1625 m (California, USA). In Hawaii, large-scale production of Bt cotton is prohibited to avoid crossing with the endemic *Gossypium tomentosum* (Hawkins *et al.*, 2005). In Northeast Brazil, to safeguard the few extant wild populations of the endemic *Gossypium mustelinum*, a mapped zone of exclusion of cotton cultivation of at least 3 km has been proposed (Barroso *et al.*, 2005; Freire, 2005).

64. Suitable pollen grains that have been deposited on the surface of the large sticky stigma via self-pollination or cross-pollination germinate within 30 min (Pundir, 1972). There is some sensitivity to the genotypic origin of the pollen, with effects ranging from positive to negative, even to incompatibility between some strains of *G. hirsutum* (McGregor, 1976; Gawel and Robacker, 1986; Pahlavani and Abolhasani, 2006). The pollen tube typically grows through the style for 12-30 hrs to the ovary and ovule, after which fertilisation is completed. Cell division in the zygote takes place 4-5 days after anthesis.

65. The young seed commences with fertilisation. Normal development follows a sigmoid curve, with the most rapid growth of the seeds and boll (fruit) occurring from about the 7th day to 18th day after anthesis (Oosterhuis and Jernstedt, 1999). Definitive size of the ovoid seed is reached about 25 days after anthesis. Boll development is characterised by three phases: enlargement, filling and maturation. Initially as the seeds grow the cotton fibres elongate; both seeds and fibres give maximum volume to the boll. Each fibre develops from a single epidermal cell of the seed coat. After 3 weeks, the boll-filling phase begins, with cellulose deposited inside the lumen of the elongated fibres. The filling phase continues into the 6th week, then the boll maturation phase begins and the boll dries out (Ritchie *et al.*, 2007).

66. Each mature boll has three to five locules or “locks”, within which are the seeds surrounded by their fibres. The average number of seeds in a boll depends on many factors, including genotype, location of the boll on the plant, and stresses during plant development and growth; roughly 20 to 35 (even 45) seeds per boll can be typical. Post-fertilisation failure can result in the development of “motes”, embryos that do not ripen into mature seeds but develop partially, including growth of immature fibres of various lengths that complicate lint production (Bolek, 2006).

4.2. Dispersal

67. The dispersal ability of the genus *Gossypium* is apparent from its unusual evolutionary history, including various trans-continental dispersal events and several interspecific hybridisations resulting in new lineages. For example, within the last 1-2 million years, there have been long-distance dispersals of the progenitor of *Gossypium darwinii* from South America to the Galapagos Islands, and the progenitor of *Gossypium tomentosum* from Mesoamerica to the Hawaiian Islands, and in each case, the tetraploid

coloniser evolved into an endemic species that became well established, dispersing to various islands within its archipelago (Wendel and Percy, 1990; Sherwood and Morden, 2004).

68. Over the several millennia that early peoples achieved domestication and expansion in cultivation of *Gossypium*, the four utilised species were spread beyond their natural centres of origin and diversity to new regions (Brubaker *et al.*, 1999c), and sometimes have become established and free-living or naturalised to varying degrees. In this way the genuinely wild distributions of the domesticated species were obscured (Stephens, 1958). The region where wild (non-feral) *Gossypium barbadense* occurs in South America is rather clear (Westengen *et al.*, 2005), but the original range of *G. hirsutum* in Mesoamerica (and perhaps the Caribbean) is quite unclear (Stephens, 1958; Brubaker and Wendel, 1994). Similarly, the original centres or ranges of *G. arboreum* and *G. herbaceum* subsp. *herbaceum* are obscure.

69. The dispersal of seeds varies in different areas or settings and situations and from one season to another (OGTR, 2008). In a natural setting, wind, water and birds may serve as dispersal agents (Stephens, 1958, 1966; HEPX, 2007). In an agricultural setting, greater dispersal of cottonseed generally may occur during transport (Addison *et al.*, 2007), stock-feeding (Coppock *et al.*, 1985; Sullivan *et al.*, 1993a, 1993b) or adverse weather conditions, and rarely by animals (Smith, 1995).

4.3. Seed dormancy and germination

70. Although *Gossypium* seeds can have a natural capability of 2-3 months of innate or induced dormancy, “hard” seeds are undesirable for crop production, and the trait has been minimised or completely eliminated in modern cultivars through domestication and selective breeding (Stephens, 1958; Hopper and McDaniel, 1999; Paiziev and Krakhmalev, 2006; OGTR, 2008).

71. The quality or vigour (potential for rapid, uniform emergence of seedlings) of *G. hirsutum* seeds can vary between seed lots (Hopper and McDaniel, 1999). Factors such as chemical composition of the mature seed and pre-harvest environmental conditions contribute to the relative quality of cottonseed. Selection to improve seedling vigour has been incorporated into *G. hirsutum* breeding programs (Bourland, 1996).

72. Germination depends largely on the type of cottonseed (Eastick and Hearnden, 2006). The *G. hirsutum* black seed used for planting (*i.e.* ginned and acid-delinted seed) has the highest germination rate. New seed has a low germination rate, attributed to mechanical hindrance of cotyledon emergence by the surrounding fibres. Fuzzy seed (*G. hirsutum*) has an intermediate germination rate.

73. The type of habitat that the seed is dispersed into affects germination. An experimental study on spread and persistence of *G. hirsutum* (Eastick and Hearnden, 2006) found germination highest in disturbed habitats such as stockyards and the edges of waterways, especially if the seed had been buried, and much less likely in undisturbed habitats and roadside sites. The experiments aimed to maximise germination and initial establishment of seedlings by sowing seeds into cleared ground, lightly burying the seeds and then hand-watering. Subsequent persistence and recruitment at a site were solely dependent on the habitat.

4.4. Weediness and naturalisation

74. *Gossypium hirsutum* and *G. barbadense* can occur as escapes from agriculture. Cotton can become feral and naturalise locally in suitable areas in many regions. Nonetheless cotton has been grown as a crop for decades to centuries in many countries without being reported as strongly invasive or a serious weed (*e.g.* Holm *et al.*, 1979, 1997; Randall, 2002; Weber, 2003). Abiotic and biotic factors determine whether introduced *Gossypium* will establish in the particular environment, including the length of the growing season and severity of a cold or a dry season, rainfall, soil type, competition from other

plants, herbivory (by insects and other animals), and physical destruction such as stock trampling or fire (Eastick and Hearnden, 2006).

75. Recently the weediness and naturalisation potentials of cotton were thoroughly reviewed for cotton-growing regions in Australia (OGTR, 2008). The crop species were not considered to threaten agricultural productivity, or native biodiversity (Tothill *et al.*, 1982; Lazarides *et al.*, 1997). *Gossypium hirsutum* has been grown since the 1960s or 1970s in a number of places in northern Australia. Isolated naturalised populations of *G. hirsutum* and *G. barbadense* occur, including within conservation areas (Sindel, 1997; Eastick, 2002).

76. Cotton volunteers are found in all Australian cotton-growing areas and are relatively common where cottonseed is used as livestock feed (Eastick and Hearnden, 2006). Typically such volunteers are grazed by livestock and/or killed by roadside management practices, limiting their potential to persist and reproduce (Eastick and Hearnden, 2006; Addison *et al.*, 2007).

77. Surveys in 2002, 2004 and 2005 along Australian routes for transporting ginned *G. hirsutum* seed for stockfeed indicated that plants infrequently established in the roadside environment, mostly as transient populations despite more than 12 years of using the routes (Addison *et al.*, 2007). *Gossypium hirsutum* volunteers tended to establish in highly and regularly disturbed environments.

78. In another study (Eastick, 2002; Eastick and Hearnden, 2006), persistence of *G. hirsutum* plants for more than 1–2 years was found only in habitats having increased availability of water and/or nutrients, such as cattle yards. Although the cotton plants in cattle yards might grow to reproductive maturity, persistence and seed dispersal were limited by trampling and grazing; no volunteers were found in undisturbed bush habitats surrounding the areas.

79. A rigorous model has been developed to predict the regions in Australia that are climatically suitable for long-term survival of feral cotton (Rogers *et al.*, 2007; OGTR, 2008). The modelling program predicted that the winter temperatures in current Australian cotton-growing areas are too cold to support the establishment of permanent populations. The model indicated that dry stress is the major limiting factor in northern Australia, and predicted potential naturalisation of cotton with matching climates on the northeastern coast. Soil fertility, plant competition and fire were identified as factors that could reduce the probability of permanent populations establishing.

SECTION V. GENETICS AND HYBRIDISATION

80. Germplasm resources of *Gossypium* have been described in detail (Percival *et al.*, 1999). The various objectives followed in breeding cotton and the technology used are dependent on factors such as biological constraints and abiotic stress resistances, and other factors such as market demands (Niles, 1980; Calhoun and Bowman, 1999; Mergeai, 2006a). A survey of breeders in 2000 showed that most of the breeding work in *G. hirsutum* involved crossing closely related parents followed by backcrossing or reselecting from existing crosses, with less than 3% of the breeding material coming from non-*G. hirsutum* sources (Bowman, 2000). In Australia breeding has contributed about 45% to the improvements in yield since 1983 (Constable *et al.*, 2001).

5.1. Genomes

81. *Gossypium* species are classified into eight diploid genomic groups and one tetraploid group (Section II, Table 2) based on cytogenetics, along with their capability to form viable or fertile interspecific hybrids experimentally (Edwards & Mirza 1979; Endrizzi *et al.* 1985; Stewart 1995). Generally species within a group can form hybrids with normal meiotic pairing and at least some F₁ fertility, whereas crosses between groups rarely form hybrids, and if so they have meiotic abnormalities and are infertile.

82. The D genome is the smallest, with a mean 2C nuclear DNA content of 1.81 picograms, and the A genome is almost twice as large — 3.47 pg; the mean DNA content of the AD-genome tetraploids is nearly additive, with 4.91 pg, and suggests a small loss of DNA subsequent to polyploidisation (Hendrix and Stewart, 2005; Grover *et al.*, 2007, 2008). The size difference in diploid genomes (and the tetraploid subgenomes) is primarily a result of differential amplification of repetitive DNA transposable elements (Hawkins *et al.*, 2006).

83. In the allotetraploid crop species ($2n = 4x = 52$), the A group's generally larger 13-chromosome set can be distinguished from the D group's generally smaller 13-chromosome set and the individual chromosomes in each subgenome identified (Muravenko *et al.*, 1998; Rong *et al.*, 2004; Wang *et al.*, 2006). In *G. barbadense*, the A-genome chromosomes average 4.20 μm in length, with the largest seven being 4.34 μm or more (the full range is 2.23 to 5.81 μm), whereas the D-genome chromosomes average 3.29 μm long (and range from 1.76 to 4.25 μm) (Muravenko *et al.*, 1998). The 13 individual chromosomes of the A-genome diploid ($2n = 2x = 26$) species *G. arboreum* have been identified and correlated with their counterparts in the A subgenome of *G. hirsutum* (Wang *et al.*, 2008).

84. Comprehensive overviews of the results from recent genomic investigations of *Gossypium* have been provided (Preetha and Raveendren, 2008; Zhang *et al.*, 2008). The most complete tetraploid genetic map so far (from *G. hirsutum* \times *G. barbadense* F₂S) comprises 2584 loci, at an average inter-marker distance of 1.72 cM (~ 606 kbp), in 26 linkage groups — thus covering all 13 individual chromosomes of each subgenome (Rong *et al.*, 2004). Genetic linkage maps of the *G. arboreum* genome have been made and correlated with the A subgenome of *G. hirsutum* (Desai *et al.*, 2006; Ma *et al.*, 2008).

85. Based on a mean 2C nuclear DNA content of 4.93 pg for *G. hirsutum*, the haploid DNA (1C-value) is estimated to be 2410 Mbp (Hendrix and Stewart, 2005). An international coalition of researchers has plans underway to completely sequence the nuclear genome of *G. hirsutum* (Chen *et al.*, 2007), first by sequencing the ancestrally close D-genome relative *G. raimondii*, which has a much smaller genome (1C

of 880 Mbp) (Hendrix and Stewart, 2005). The complete nucleotide sequences of the chloroplast genomes of *G. hirsutum* (Lee *et al.*, 2006) and *G. barbadense* (Ibrahim *et al.*, 2006) have been determined.

86. The complexity in the *Gossypium* genome occurs in a multitude of diverse dimensions. The diploid genus itself is considered a paleopolyploid (as is possibly the case for most angiosperms). An ancient polyploidisation event (whole genome duplication) (perhaps $2n = 14$ to $2n = 28$) appears to have occurred 13-15 (-30) million years ago in the Malvaceae lineage that evolved into what is treated as the emergent diploid genus *Gossypium* ($2n = 26$) (Muravenko *et al.*, 1998; Brubaker *et al.*, 1999a; Wendel and Cronn, 2003; Blanc and Wolfe, 2004; Rong *et al.*, 2004, 2005; Ma *et al.*, 2008). Consequently, genes were duplicated in that ancient originating event, the species continued genomic and genic evolution (Small *et al.*, 2004), and genes were duplicated again in the rather recent formation of the allotetraploid lineage that has provided the two predominant crop species.

87. The functioning and evolutionary fortune of the plethora of counterpart genes (homoeologs) subsequent to the *Gossypium* allopolyploidisation event have been receiving substantial investigation. A broad array of divergent outcomes can occur, in some cases immediately with the onset of the genome doubling (and gene duplicating) event, in other cases during the long course of evolutionary time (Wendel and Cronn, 2003; Adams and Wendel, 2004; Adams, 2007; Liu and Adams, 2007; Wang *et al.*, 2007; Flagel *et al.*, 2008). Paterson (2005) has sketched how some cotton QTLs for crop improvement relate to such homoeologs.

5.2. Intraspecific crossing

88. Typically, the profitability of production mostly depends on lint yield, so the ultimate objective of many breeding programs is to increase it. Using intraspecific hybrid vigour to increase the yield has long been an objective (Zhang and Pan, 1999). Lint yield is a complex trait under complex genetic and environmental interactions, requiring a good balance among yield components. Heterosis has not been easy to employ due to the lack of an efficient crossing system. Many male-sterile systems have been explored (Percy and Turcotte, 1991; Basu, 1996), but male steriles and their restorer factors often have not been stable in different environments. Heterosis is not used commercially except where a large labor force can make emasculations and crosses by hand. At least 40% of cotton production in India has been derived from intraspecific hybrids of *G. hirsutum* (Chaudhry, 1997). Meredith (1999) reported an average useful heterosis of 21.4% (or 276 kg/ha) for F₁ hybrids and 10.7% for F₂ hybrids, although heterosis for fibre properties averaged only 0-2% for most characteristics.

5.3. Interspecific crossing

89. Under intensive experimental conditions, species in a few other genera of Malvaceae have been reported to form fertile hybrids with *Gossypium* (Mehetre *et al.*, 1980), but spontaneous intergeneric hybridisation is highly improbable. Within the genus *Gossypium*, the sexual transmission of genetic material of cultivated cottons via pollen has been possible to certain of the species. For improvement of the main crops, *Gossypium* species can be grouped into three gene pools based on their ability to generate fertile hybrids and homoeologous recombination (Stewart, 1995; Percival *et al.*, 1999).

90. Most cultivated cotton is tetraploid (primarily *G. hirsutum*), and thus relatively incompatible with the diploid species — normally plants from these two groups do not hybridise spontaneously and produce fertile offspring, and experimental crosses are difficult and require complex breeding schemes (Mergeai, 2006b). Moreover, experimental F₁ hybrids between the genome groups of diploids are nearly always sterile, or are weak (Endrizzi *et al.*, 1984, 1985; Brown and Brubaker, 2000; Cronn and Wendel, 2004).

5.3.1. Primary gene pool — the tetraploids

91. The tetraploid (AADD) species are sexually compatible, which accords with their differentiation following a hybridisation event only 1-2 million years ago; since then they have diverged into three evolutionary lineages (Wendel and Cronn, 2003). The primary gene pool comprises the subgenus *Karpas*: the three wild tetraploid species (*G. mustelinum*, *G. darwinii*, *G. tomentosum*) and the wild, commensal, landrace, cultigen and feral *G. barbadense* and *G. hirsutum*. Experimental crosses among these entities are rather easy and genetic recombination frequency is high; favourable traits have been incorporated from this gene pool (particularly from *G. hirsutum* and *G. barbadense*) into the modern crops (Endrizzi *et al.*, 1984, 1985; Meredith, 1991; Stewart, 1995; Percival *et al.*, 1999).

Spontaneous hybridisation of tetraploids in the New World

92. Native populations of the three completely wild tetraploid species are widely separated biogeographically (Appendix 1). Moreover, the clearly genuinely wild native populations of *G. barbadense* and *G. hirsutum* are also completely separated from the other three species, and from each other (Brubaker and Wendel, 1994; Westengen *et al.*, 2005; Johnston *et al.*, 2006). Thus, fully natural hybridisations do not occur among the tetraploids; however, spontaneous (unaided) hybridisation might occur when cultivated plants are brought within range of these wild species or primordially wild populations. Spontaneous hybridisation between various other populations or plants of the cultivated species also may occur.

Gossypium mustelinum

93. *Gossypium mustelinum* is a local, very rare endemic in semi-arid northeastern Brazil (Freire *et al.*, 1998; Batista *et al.*, 2005; Barroso *et al.*, 2006; WWF and IUCN, 1997), and is considered most similar to the original allotetraploid progenitor (Wendel *et al.*, 1994). Experimentally, *G. mustelinum* can form fertile F₁ as well as F₂ hybrids and backcrosses with *G. hirsutum*, and to some extent with *G. barbadense* (Freire, 2002b; Freire *et al.*, 2002; Gardunia *et al.*, 2007). The evidence of spontaneous introgression in Brazil is uncertain, and relates particularly to *G. hirsutum* (Wendel *et al.*, 1994; Freire, 2002a; Freire *et al.*, 2002; Borém *et al.*, 2003; Johnston *et al.*, 2006).

Gossypium darwinii

94. *Gossypium darwinii* is a widespread endemic in the Galapagos Islands, and is considered most closely related to *G. barbadense* (Wendel and Percy, 1990; Lacape *et al.*, 2007). The *Gossypium barbadense* that settlers brought to the Galapagos apparently included plants that earlier had introgressed with *G. hirsutum*. The introduced domesticated cotton has not become widely naturalised, but spontaneous gene flow has occurred into *G. darwinii* (Wendel and Percy, 1990). Experimentally, F₂ hybrids produced from crosses of *G. barbadense* and *G. darwinii* are fertile and vigorous.

Gossypium barbadense and *Gossypium hirsutum*

95. The original native habitat of *G. barbadense* is considered to be the dry coastal region of northern Peru and southern Ecuador (Schwendiman *et al.*, 1985; Percy and Wendel, 1990; Westengen *et al.*, 2005). The original native habitat of *Gossypium hirsutum* is considered to involve central Mesoamerica (Hutchinson, 1951; Stephens, 1958; Brubaker and Wendel, 1994). The natural distribution of *G. hirsutum* as a wild species is particularly obscure because of millennia of early use, domestication and expanded cultivation.

96. Many of the advanced stocks of commercial *G. barbadense* have benefited from the introgression of *G. hirsutum* characteristics by plant breeding (Wang *et al.*, 1995). Reciprocally, introgression of *G. barbadense* into *G. hirsutum* has exploited (for example) the excellent fibre qualities of the former.

However, the hybrid vigour resulting is associated with excessive vegetative growth and late maturity, which make adaptation of such hybrids limited to those areas with a long growing season. This problem was reduced by obtaining precocious, short-growing season *G. barbadense*-types that may be used to produce the F₁ hybrids with *G. hirsutum* (Feaster and Turcotte, 1980).

97. Despite these commercial breeding successes, introgression of *G. hirsutum* into *G. barbadense* is conspicuously low in germplasm collections from Mesoamerica and the Caribbean where *G. barbadense* has been grown with the predominant *G. hirsutum* since prehistoric times (Brubaker *et al.*, 1993; Westengen *et al.*, 2005). The relative absence of introgression into *G. barbadense* may result from various isolating mechanisms, involving plant reproductive biology, agroecology and ecology (Percy and Wendel, 1990; Brubaker *et al.*, 1993; Jiang *et al.*, 2000; Freire *et al.*, 2002; Borém *et al.*, 2003; OGTR, 2008). In contrast, introgression of *G. barbadense* into *G. hirsutum* under such conditions is relatively common (Wendel *et al.*, 1992; Brubaker *et al.*, 1993; Brubaker and Wendel, 1994). Isozyme analysis found the most introgression into *Gossypium hirsutum* race marie-galante (Brubaker and Wendel, 1994; Brubaker *et al.*, 1999c), but SSR analysis of several samples of marie-galante from the Caribbean and mocó from Brazil did not detect such introgression (Lacape *et al.*, 2007; *cf.* Freire *et al.*, 2002; Borém *et al.*, 2003).

Gossypium tomentosum

98. *Gossypium tomentosum* is endemic in the Hawaiian Islands, and apparently the closest relative to *G. hirsutum* (DeJoode and Wendel, 1992; Hawkins *et al.*, 2005; Waghmare *et al.*, 2005; *cf.* Westengen *et al.*, 2005). The flowers of *G. tomentosum* reportedly are receptive at night rather than during the day and pollinated by moths, not bees (Stephens, 1964; Fryxell, 1979). Feral *Aethina concolor* beetles enhance its self-pollination, and perhaps effect cross-pollination (Burraston *et al.*, 2005; Burraston and Booth, 2006). Spontaneous movement of genetic material from cultivated *G. hirsutum* to the wild endemic remains speculative (*cf.* Waghmare *et al.*, 2005). Also, despite morphological suggestion of spontaneous hybrids between naturalised *G. barbadense* and the wild endemic (Stephens, 1964; Münster and Wieczorek, 2007), no allozyme evidence of introgression has been found (DeJoode and Wendel, 1992).

5.3.2. Secondary and tertiary gene pools — the diploids

99. All species in these gene pools are diploids. In addition to cytological barriers to hybridisation, varied physiological barriers exist between the diploids and *G. hirsutum*, the usual focus for improvement. *In vitro* culture of ovules partly solves the problem (Stewart and Hsu, 1978). Three main breeding strategies (Mergeai, 2006b) have been devised to overcome sterility barriers and can lead to successful introgression of desirable traits (Endrizzi *et al.*, 1985; Meredith, 1991; Stewart, 1995). In two schemes, crossing a diploid and *G. hirsutum* results in sterile triploids (3x), with few rare exceptions (Brown, 1951; Meyer, 1974). Hexaploids (6x) are then made (using colchicine) by chromosome doubling of the triploid genome. The hexaploid can then be crossed with a different diploid and result in a tri-species tetraploid hybrid. Or, *G. hirsutum* can be crossed with the hexaploid; the resultant pentaploids (5x) can be self-crossed, or crossed again with *G. hirsutum*, resulting in a tetraploid.

100. The secondary gene pool includes the evolutionarily closer diploids, thus comprising the D-genome species (subgenus *Houzingenia*) and the A-genome species, as well as the African B- and F-genome species (Appendix 1) (Phillips, 1966; Phillips and Strickland, 1966; Wendel and Cronn, 2003).

101. Bridge-crosses between two diploid species, induced genome doubling, and then crossing with *G. hirsutum* are another useful strategy for gene transfer (Mergeai, 2006b). Such an approach using the A-genome and D-genome species produces synthetic AD tetraploids, which may be readily crossed with *G. hirsutum*. Genes from the A or D genome may thus be transferred to the upland cotton crop (Stewart

and Stanton, 1988; Saravanan *et al.*, 2007). For example, the ATH tri-species hybrid (*G. arboreum* × *G. thurberi*) × *G. hirsutum* has been used to introduce fibre strength.

102. The tertiary gene pool includes the evolutionarily distant diploids, thus comprising the African-Arabian E-genome species, and the Australian C-, G- and K-genome species (Appendix 1) (Wendel and Cronn, 2003). Potential exploitation of desirable traits/genes in this gene pool (as well as evaluation of transgene diffusion potential) have stimulated considerable research in the Australian subgenus *Sturtia* (Brown *et al.*, 1997; Zhang and Stewart, 1997; Brubaker *et al.*, 1999b; Brown and Brubaker, 2000). Desirable traits include gossypol-free seeds, which occur in both the C- and G-genome species.

103. It has not been possible to obtain hybrids of *G. hirsutum* with the G-genome species, whereas hybrids can be obtained readily with the C-genome species; the situation is intermediate and variable with the K-genome species (Brown and Brubaker, 2000). The experimental hybrids among the species of subgenus *Sturtia* range from being totally infertile, to having some meiotic fertility in backcrosses but the plants are weak (Brown *et al.*, 1997; Brown and Brubaker, 2000). The first gene from the tertiary gene pool introgressed into *G. hirsutum* came from the C genome's *G. sturtianum*, and involved control of terpenoid aldehyde methylation (to reduce gossypol formation) (Bell *et al.*, 1994). Although *G. sturtianum* is the species in subgenus *Sturtia* that crosses most readily with *G. hirsutum*, the F₁ is completely infertile.

SECTION VI. BIOTECHNOLOGY AND GENETIC TRANSFORMATION

104. The efforts to domesticate and improve cotton span millennia, from selection and conventional breeding, to chemical and radiation mutagenesis, to advanced biotechnological techniques. Some of the traits of continuing interest to incorporate into cultivated cottons include disease and insect resistances and drought and salt tolerances for the crop, whereas other traits are focused on improving the crop's products (Basu, 1996; Paterson and Smith, 1999; Wilkins *et al.*, 2000; Jenkins and Saha, 2001; Hake, 2004). Embryo rescue is employed to obtain plants from interspecific hybridisations that will abort (Mehetre and Aher, 2004). A research focus in the 1960s and 1970s was development of new cell culture methods. Callus cultures were the starting point to isolate protoplasts, with a view to making wide crosses via protoplast fusion with sexually incompatible germplasm (Carlson *et al.*, 1972). Price *et al.* (1977) first defined the conditions for establishment of callus cultures, from six cotton species. The first report of a cell culture system to obtain somatic embryos from cotton callus cultures was by Price and Smith (1979), and improvements have continued (Kumar and Tuli, 2004; Sakhanokho *et al.*, 2004; Sun *et al.*, 2006).

105. The main vector used for introducing particular genes into cotton is *Agrobacterium tumefaciens*, with the first reports of transformations in the nuclear genome by Umbeck *et al.* (1987) and Firoozabady *et al.* (1987). A gene-transfer system was developed culturing *Agrobacterium* with sections of 6- to 7-day-old cotton-seedling hypocotyls (Fillatti *et al.*, 1989). The *Agrobacterium*-mediated approach continues to be of major utility (Wilkins *et al.*, 2004). The first report of cotton plants transformed using projectile bombardment was by Finer and McMullen (1990), which was followed by genotype-independent particle bombardment of four cultivars (McCabe and Martinell, 1993). The bombarded cells are grown in tissue culture to differentiate and develop into shoots or whole plants. A major problem has been achieving regeneration — only a limited number of cotton varieties (*i.e.* genotypes) regenerate relatively easily. Transformation has also been achieved in the chloroplast genome (Kumar *et al.*, 2004).

106. Insect-resistant and herbicide-tolerant cotton varieties have been developed by means of genetic engineering and are commercially grown in a number of countries. The first agronomically important gene inserted into cotton was for insect resistance, *cry1Ab* from *Bacillus thuringiensis* (Bt) (Perlak *et al.*, 1990). Other insecticidal genes from Bt have been introduced (especially *cry1Ac* and *cry2Ab*, and more recently *vip3A*), which encode particular proteins selectively toxic to various Lepidopteran pests. An insecticidal gene *AaHIT* from the scorpion *Androctonus australis* is also being explored in transgenic cotton against some lepidopterans (Wu *et al.*, 2008).

107. Cotton lines have been genetically engineered to tolerate the herbicides bromoxynil, glufosinate ammonium, glyphosate or sulfonyleurea. Transgenic cottons in commercial production include plants having stacked transgenes, for example a Bt (*Cry1Ac* + *Cry2Ab*) + glyphosate-tolerant cotton.

108. With continuing development, there are likely to be transgenic cottons improved in other ways, for example with fibres that are stronger (Zhu *et al.*, 2006; Shang-Guan *et al.*, 2007) or have non-crease characteristics similar to polyester (John and Keller, 1996); or with seeds that are gossypol-free (Sunilkumar *et al.*, 2006) or with improved oil composition (Chapman *et al.*, 2001; Liu *et al.*, 2002).

SECTION VII. HUMAN HEALTH AND BIOSAFETY

109. Cottonseed oil has been in common use since at least the middle of the 19th century (Jones and King, 1993). Cottonseed meal or flour is also sometimes used for human consumption when derived from gossypol-free varieties, or if the gossypol has been extracted or is present in the food at low levels. Information on processing of cottonseed (of both *G. hirsutum* and *G. barbadense*) and its major products (oil, meal, hulls and linters) and their composition including the key food and feed nutrients, toxins and anti-nutrients have been summarised by the OECD (2004).

110. Cottonseed is a valuable foodstuff for cattle, combining high energy, high fibre and high protein (Ensminger *et al.*, 1990b), and is used as whole seed, hulls, flour and cake. The whole seed of *G. hirsutum* also includes linter fibers (~ 10% of seed weight), which are nearly pure cellulose and highly digestible. The seed oil gives it high energy value (Coppock *et al.*, 1985). Cattle and sheep are fed cottonseed hulls as an important source of roughage. The hulls are removed from whole seed, and composed mainly of hemicellulose and lignin, with the linters remaining attached. Gin trash is also fed to ruminants, and has 90% of the food value of the hulls (Ensminger *et al.*, 1990a).

111. Extracts of cotton plants have been used medicinally (*e.g.* Sawyer, 1955; Hasrat *et al.*, 2004). Because of its several physiological effects, the medical potential of gossypol is being investigated (Dodou *et al.*, 2005), and it has been used as a male contraceptive (Coutinho, 2002).

7.1. Toxins

112. Cotton plants contain compounds that can have adverse effects on human and animal health (OGTR, 2008). Cotton tissue, particularly the seeds, can be toxic when ingested in large quantities because of the anti-nutritional and toxic compounds (Abou-Donia, 1976; Tumbelaka *et al.*, 1994; Smith, 1995). Most important with respect to human health and biosafety are gossypol, which is a terpenoid aldehyde, and cyclopropenoid fatty acids (CPFAs), as well as tannins.

113. The gossypol and CPFAs in cottonseed limit its use as a protein supplement in animal feed. Ruminants are less affected because these compounds are detoxified by digestion in the rumen (Kandyliis *et al.*, 1998). Cottonseed as a stockfeed is limited to a relatively small proportion of the diet, and must be introduced gradually to avoid the potentially toxic effects (Blasi and Drouillard, 2002).

114. Because *Gossypium barbadense* cottonseed possesses almost no linters, it is digested differently by cattle than *G. hirsutum*. The nearly naked seeds are thought to sink in the rumen and so be less masticated and digested (Coppock *et al.*, 1985; Sullivan *et al.*, 1993a, 1993b; Zinn, 1995; Solomon *et al.*, 2005). To improve digestibility of *G. barbadense* seed it is often cracked prior to feeding even though this increases the exposure to gossypol. Cows that consumed cracked *G. barbadense* seed at ~ 7.5% of their diet had reduced fertility (Santos *et al.*, 2003).

Gossypol

115. Gossypol is found primarily in the pigment glands of the roots, leaves, flower buds and seeds (Smith, 1961, 1967). It is toxic to non-ruminant mammals, birds, and many insects and microbes; in mammals the toxic effects can include reduced appetite, body weight loss and dyspnea (Berardi and Goldblatt, 1980). Gossypol can render lysine metabolically unavailable and impact on the normal functioning of mitochondria (Yannai and Bensal, 1983; Cuellar and Ramirez, 1993; Risco *et al.*, 1993).

116. Although glandless cotton has been developed for food purposes, the plants are more susceptible to pests (Delattre, 1992). Inactivation or removal of gossypol and CPFAs during processing has enabled use of cottonseed meal for catfish, poultry and swine (Jones and Wedegaertner, 1986; Lusas and Jividen, 1987).

117. Gossypol exists as two different isomers (mirror-image forms of the same compound), which are in different proportions in *G. barbadense* and *G. hirsutum* (Stipanovic *et al.*, 2005). *Gossypium barbadense* has more of the (-)-gossypol form (Sullivan *et al.*, 1993b), which has greater biological activity. The isomers have different toxicity levels and the toxicity varies in different animals (Wang *et al.*, 1987; Bailey *et al.*, 2000; Lordelo *et al.*, 2005, 2007).

118. Both isomers exist in free and bound forms. In intact whole cottonseed, gossypol is in the free form. The free form is more biologically active, whereas the bound form is generally not released in the rumen. In ruminants, with well-developed rumen microflora, free gossypol is converted to bound gossypol, thus preventing its entering the bloodstream (Santos *et al.*, 2002). During the processing of whole cottonseed, gossypol partitions into meal and oil components. Most of the gossypol in meal becomes bound to proteins, thus becoming less toxic.

119. The levels of gossypol and related terpenoids in cottonseed vary (0.4–2.0 %) by species, variety, fertiliser application, and environmental conditions including biotic pressure from insects and diseases (Bell, 1986). The amount of gossypol in *G. barbadense* is generally higher than in *G. hirsutum* and with more of the gossypol in the free form, which reduces the amount of cottonseed of *G. barbadense* that can be recommended for cattle feed (Kirk and Higginbotham, 1999).

Cyclopropenoid fatty acids

120. Cyclopropenoid fatty acids (CPFAs) are present in the cotton seeds, and tannins in the leaves and flower buds (Chan *et al.*, 1978; Lane and Schuster, 1981; Mansour *et al.*, 1997); both are thought to act as deterrents to insects. CPFAs such as malvalic, sterculic and dihydrosterculic acids constitute approximately 0.5–1.0% of the total lipid content of the seed (Schneider *et al.*, 1968). The level of CPFAs is generally higher in *G. hirsutum* than *G. barbadense* (Frank, 1987).

121. CPFAs are anti-nutritional compounds, which interfere with the metabolism of saturated fats (Rolph *et al.*, 1990; Cao *et al.*, 1993). They are destroyed by the processing of cottonseed oil for use in margarine or salad oil for humans, but in less-processed animal feed CPFAs can cause unwanted effects (Goodnight and Kemmerer, 1967; Hendricks *et al.*, 1980; Tumbelaka *et al.*, 1994).

7.2. Allergens

122. Processed cotton fibre contains over 99% cellulose (Wakelyn *et al.*, 2007a, 2007b), and is used widely in pharmaceutical and medical applications because of its low capacity to cause irritation. Inhalation of cotton dust by mill workers can cause an asthma-like condition called byssinosis (Nicholls, 1992), which may be complicated by fungal contamination of the cotton dust (Salvaggio *et al.*, 1986).

APPENDIX 1. *GOSSYPIUM* SPECIES¹

Species	Genome	Distribution
<i>G. arboreum</i> L.	A ₂	Asian cultigen
<i>G. herbaceum</i> L. subsp. <i>herbaceum</i>	A ₁₋₁	NE African - Central Asian cultigen
<i>G. herbaceum</i> subsp. <i>africanum</i> (G. Watt) Vollesen [synonym <i>G. herbaceum</i> var. <i>africanum</i> (G. Watt) J.B. Hutch. ex S.C. Harland]	A ₁₋₂	southern Africa
<i>G. longicalyx</i> J.B. Hutch. & B.J.S. Lee	F ₁	C-E Africa
<i>G. triphyllum</i> (Harv.) Hochr.	B ₂	SW Africa
<i>G. anomalum</i> Wawra ex Wawra & Peyr.	B ₁	SW & N sub-Saharan Africa
<i>G. capitis-viridis</i> Mauer	B ₃	Cape Verde Islands
<i>G. trifurcatum</i> Vollesen ²	?	NE Africa
<i>G. stocksii</i> Masters	E ₁	Somalia to Pakistan
<i>G. areysianum</i> Deflers	E ₃	Arabia
<i>G. incanum</i> (O. Schwartz) Hillcoat	E ₄	Arabia
<i>G. somalense</i> (Gürke) J.B. Hutch.	E ₂	NE Africa
<i>G. benadirensis</i> Mattei	E	NE Africa
<i>G. bricchettii</i> (Ulbrich) Vollesen	E	NE Africa
<i>G. vollesenii</i> Fryxell	E	NE Africa
<i>G. robinsonii</i> F. Muell.	C ₂	W Australia
<i>G. sturtianum</i> J.H. Willis var. <i>sturtianum</i>	C ₁	C to E Australia
<i>G. sturtianum</i> var. <i>nandewarensis</i> (Derera) Fryxell	C _{1-n}	E Australia
<i>G. bickii</i> Prokh.	G ₁	N-C Australia
<i>G. australe</i> F. Muell.	G ₂	NW Australia
<i>G. nelsonii</i> Fryxell	G	N-NE Australia
<i>G. cunninghamii</i> Todaro	K	N Australia
<i>G. anapoides</i> J.M. Stewart, Craven & Wendel, ined.? ³	K	NW Australia
<i>G. costulatum</i> Todaro	K	NW Australia
<i>G. enthyle</i> Fryxell, Craven & J.M. Stewart	K	NW Australia
<i>G. exiguum</i> Fryxell, Craven & J.M. Stewart	K	NW Australia
<i>G. londonderrisense</i> Fryxell, Craven & J.M. Stewart	K	NW Australia
<i>G. marchantii</i> Fryxell, Craven & J.M. Stewart	K	NW Australia
<i>G. nobile</i> Fryxell, Craven & J.M. Stewart	K	NW Australia
<i>G. pilosum</i> Fryxell	K	NW Australia
<i>G. populifolium</i> (Bentham) F. Muell. ex Todaro	K	NW Australia
<i>G. pulchellum</i> (C.A. Gardner) Fryxell	K	NW Australia
<i>G. rotundifolium</i> Fryxell, Craven & J.M. Stewart	K	NW Australia
<i>G. gossypoides</i> (Ulbrich) Standley	D ₆	W Mexico

Species	Genome	Distribution
<i>G. armourianum</i> Kearney	D ₂₋₁	NW Mexico (Baja California)
<i>G. harknessii</i> Brandegees	D ₂₋₂	NW Mexico (Baja California)
<i>G. turneri</i> Fryxell	D ₁₀	NW Mexico
<i>G. laxum</i> L.L. Phillips	D ₈	CW Mexico
<i>G. aridum</i> (Rose & Standley) Skovsted	D ₄	NW-SW Mexico
<i>G. lobatum</i> Gentry	D ₇	CW Mexico
<i>G. schwendimanii</i> Fryxell & S.D. Koch	D ₁₁	CW Mexico
<i>G. thurberi</i> Todaro	D ₁	NW Mexico, Arizona
<i>G. trilobum</i> (Sessé & Moc. ex DC.) Skovsted	D ₉	W Mexico
<i>G. davidsonii</i> Kellogg	D _{3-d}	NW Mexico (Baja California)
<i>G. klotzschianum</i> Andersson	D _{3-k}	Galapagos Islands
<i>G. raimondii</i> Ulbrich	D ₅	NW Peru
<i>G. hirsutum</i> L. ⁴	(AD) ₁	Mesoamerica
<i>G. tomentosum</i> Nuttall ex Seemann	(AD) ₃	Hawaii
<i>G. barbadense</i> L.	(AD) ₂	W South America
<i>G. darwinii</i> G. Watt	(AD) ₅	Galapagos Islands
<i>G. mustelinum</i> Miers ex G. Watt	(AD) ₄	NE Brazil

¹Mostly after Endrizzi *et al.* (1984), Fryxell (1992), Fryxell *et al.* (1992) and Percival *et al.* (1999).

²*Gossypium trifurcatum* was described by Vollesen (1987) and is accepted by Fryxell (1992). Percival *et al.* (1999) indicated that it might belong in the genus *Cienfuegosia*, but cpDNA analysis by Rapp *et al.* (2005) supports its placement in *Gossypium*.

³*Gossypium anapoides* has been noted in recent literature (Stewart *et al.*, 1997; Zhang and Stewart, 1997; Brubaker *et al.*, 1999b; Percival *et al.*, 1999; Brown and Brubaker, 2000; Cronn and Wendel, 2004), but it may (as yet) not have been published as a new species in accord with the *International Code of Botanical Nomenclature*.

⁴*Gossypium lanceolatum* Todaro is not a distinct species, but instead considered to be a local Mexican landrace — in domesticated *Gossypium hirsutum* race palmeri (Brubaker and Wendel, 1993).

APPENDIX 2. GENERA OF WEEDS REGIONALLY COMMON IN COTTON

Dicotyledons	Monocotyledons
<i>Abutilon</i>	<i>Alopecurus</i>
<i>Achyranthes</i>	<i>Cenchrus</i>
<i>Alternanthera</i>	<i>Commelina</i>
<i>Amaranthus</i>	<i>Cynodon</i>
<i>Boerhavia</i>	<i>Cyperus</i>
<i>Capsella</i>	<i>Dactyloctenium</i>
<i>Celosia</i>	<i>Digitaria</i>
<i>Chamaesyce (Euphorbia)</i>	<i>Echinochloa</i>
<i>Chenopodium</i>	<i>Eleusine</i>
<i>Convolvulus</i>	<i>Leptochloa</i>
<i>Croton</i>	<i>Lolium</i>
<i>Datura</i>	<i>Panicum</i>
<i>Desmodium</i>	<i>Paspalum</i>
<i>Diptotaxis</i>	<i>Poa</i>
<i>Fumaria</i>	<i>Rottboellia</i>
<i>Geranium</i>	<i>Setaria</i>
<i>Heliotropium</i>	<i>Sorghum</i>
<i>Hibiscus</i>	
<i>Ipomoea</i>	
<i>Matricaria</i>	
<i>Merremia</i>	
<i>Oxalis</i>	
<i>Papaver</i>	
<i>Parthenium</i>	
<i>Pavonia</i>	
<i>Plantago</i>	
<i>Polygonum</i>	
<i>Portulaca</i>	
<i>Raphanus</i>	
<i>Ridolfia</i>	
<i>Senna (Cassia)</i>	
<i>Sesbania</i>	
<i>Sida</i>	
<i>Sinapis</i>	
<i>Solanum</i>	
<i>Stellaria</i>	
<i>Trianthema</i>	
<i>Tribulus</i>	
<i>Urtica</i>	
<i>Xanthium</i>	

REFERENCES

- Abedin, S. 1979. Malvaceae, No. 130 in E. Nasir and S.I. Ali, eds., Flora of West Pakistan. 107 pp.
- Abou-Donia, M.B. 1976. Physiological effects and metabolism of gossypol. Pp. 126-160 in Residue Reviews – Residues of Pesticides and Other Contaminants in the Total Environment, Vol. 61 (F.A. Gunther and J.D. Gunther, eds.). Springer Verlag, New York.
- ACCRC. 2001. NUTRIpak – A Practical Guide to Cotton Nutrition (I. Rochester, ed.). Australian Cotton Cooperative Research Centre, Narrabri, New South Wales. 60 pp.
- ACCRC. 2002. Integrated Disease Management [for Australian Cotton] (by S.J. Allen, D.B. Nehl and N. Moore). Australian Cotton Cooperative Research Centre, Narrabri, New South Wales. ca. 52 pp.
- Adams, K.L. 2007. Evolution of duplicate gene expression in polyploid and hybrid plants. *Journal of Heredity* 98: 136-141.
- Adams, K.L., and J.F. Wendel. 2004. Exploring the genomic mysteries of polyploidy in cotton. *Biological Journal of the Linnean Society* 82: 573-581.
- Addison, S.J., T. Farrell, G.N. Roberts and D.J. Rogers. 2007. Roadside surveys support predictions of negligible naturalisation potential for cotton (*Gossypium hirsutum*) in north-east Australia. *Weed Research* 47: 192-201.
- Adjei-Mafo, I.K., and L.T. Wilson. 1983a. Association of cotton nectar production with *Heliothis punctigera* (Lepidoptera: Noctuidae) oviposition. *Environmental Entomology* 12: 1166-1170.
- Adjei-Mafo, I.K., and L.T. Wilson. 1983b. Factors affecting the relative abundance of arthropods on nectaried and nectariless cotton. *Environmental Entomology* 12: 349–352.
- Álvarez, I., and J.F. Wendel. 2006. Cryptic interspecific introgression and genetic differentiation within *Gossypium aridum* (Malvaceae) and its relatives. *Evolution* 60: 505-517.
- Álvarez, I., R. Cronn and J.F. Wendel. 2005. Phylogeny of the New World diploid cottons (*Gossypium* L., Malvaceae) based on sequences of three low-copy nuclear genes. *Plant Systematics and Evolution* 252: 199-214.
- Ano, G., J. Schwendiman, J. Fersing and J.-M. Lacape. 1982. Les cotonniers primitifs de *G. hirsutum* race yucatanense de la Pointe des Châteaux en Guadeloupe et l'origine possible des cotonniers tétraploïdes du Nouveau Monde. *Coton et Fibres Tropicales* 37: 327-332.
- Applequist, W.L., R. Cronn and J.F. Wendel. 2001. Comparative development of fiber in wild and cultivated cotton. *Evolution & Development* 3: 3-17.

- Ashour, N.I., and A.M. Abd-El'Hamid. 1970. Relative salt tolerance of Egyptian cotton varieties during germination and early seedlings development. *Plant and Soil* 33: 493-495.
- Ashraf, M. 2002. Salt tolerance of cotton: Some new advances. *Critical Reviews in Plant Sciences* 21: 1-30.
- Bailey, C.A., R.D. Stipanovic, M.S. Ziehr, A.U. Haq, M. Sattar, L.F. Kubena, H.L. Kim and R.de M. Vieira. 2000. Cottonseed with a high (+)- to (-)-gossypol enantiomer ratio favorable to broiler production. *Journal of Agricultural and Food Chemistry* 48: 5692-5695.
- Barroso, P.A.V., E.C. Freire, J.A.B. do Amaral and M.T. Silva. 2005. Zonas de Exclusão de Algodoeiros Transgênicos para Preservação de Espécies de *Gossypium* Nativas ou Naturalizadas. Ministério da Agricultura, Pecuária e Abastecimento, EMBRAPA Algodão Comunicado Técnico 242. Campina Grande, Paraíba, Brazil. 7 pp.
- Barroso, P.A.V., C.E.A. Batista, L.V. Hoffmann and A.Y. Ciampi. 2006. Genetic structure and *in situ* conservation of natural populations of *Gossypium mustelinum*. Abstract 10 in International Cotton Genome Initiative (ICGI) Research Conference, Brasilia, Brazil, September 18-20, 2006. ICGI, Webpage <http://icgi/tamu.edu/>
- Basu, A.K. 1996. Current genetic research in cotton in India. *Genetica* 97: 279-290.
- Batista, C.E. de A., A.Y. Ciampi, L.V. Hoffmann and P.A.V. Barroso. 2005. Conservação, diversidade e estrutura genética de populações naturais de *Gossypium mustelinum* presente no Semi-Árido Nordeste. 5 pp. in Anais, V Congresso Brasileiro de Algodão, Salvador, Bahia, 29 Agosto – 1 Setembro 2005. EMBRAPA-CNPA (Centro Nacional de Pesquisa de Algodão), Campina Grande, Paraíba, Brazil. CD-ROM.
- Bell, A.A. 1986. Physiology of secondary products. Pp. 597-621 in J.R. Mauney and J.McD. Stewart, eds., *Cotton Physiology*. The Cotton Foundation, Memphis, Tennessee, USA.
- Bell, A.A., R.D. Stipanovic, M.E. Mace and R.J. Kohel. 1994. Genetic manipulation of terpenoid phytoalexins in *Gossypium*: Effects on disease resistance. Pp. 231-249 in *Genetic Engineering of Plant Secondary Metabolism* (B.E. Ellis, G.W. Kuroki and H.A. Stafford, eds.). *Recent Advances in Phytochemistry* Vol. 28. Plenum Press, New York.
- Berardi, L.C., and L.A. Goldblatt. 1980. Gossypol. Pp. 184-238 in I.E. Liener, ed., *Toxic Constituents of Plant Foodstuffs*, 2nd ed. Academic Press, New York.
- Berger, L.A., B.E. Vaissière, J.O. Moffett and S.J. Merritt. 1988. *Bombus* spp. (Hymenoptera: Apidae) as pollinators of male-sterile upland cotton on the Texas High Plains. *Environmental Entomology* 17: 789-794.
- Betts, A., K. van der Borg, A. de Jong, C. McClintock and M. van Strydonck. 1994. Early cotton in North Arabia. *Journal of Archaeological Science* 21: 489-499.
- Blanc, G., and K.H. Wolfe. 2004. Widespread paleopolyploidy in model plant species inferred from age distributions of duplicate genes. *The Plant Cell* 16: 1667-1678.
- Blasi, D.A., and J. Drouillard. 2002. Composition and Feeding Value of Cottonseed Feed Products for Beef Cattle. Kansas State University Agricultural Experiment Station and Cooperative Extension Service MF-2538. 22 pp.

- Bolek, Y. 2006. Genetic variation among cotton (*Gossypium hirsutum* L.) cultivars for mote frequency. *Journal of Agricultural Science (Cambridge)* 144: 327-331.
- Borém, A., E.C. Freire, J.C.V. Penna and P.A.V Barroso. 2003. Considerations about cotton gene escape in Brazil: A review. *Crop Breeding and Applied Biotechnology* 3: 315-332.
- Bourland, F.M. 1996. Selecting of improved cotton planting seed quality. Page 624 in Proceedings – Beltwide Cotton Conferences, Nashville, Tennessee, 9-12 January 1996. National Cotton Council of America, Memphis, Tennessee, USA.
- Bourland, F.M., N.R. Benson, E.D. Vories, N.P. Tugwell and D.M. Danforth. 2001. Measuring maturity of cotton using nodes above white flower. *Journal of Cotton Science* 5: 1-8.
- Bourland, F.M., J.M. Hornbeck, A.B. McFall and S.D. Calhoun. 2003. A rating system for leaf pubescence of cotton. *Journal of Cotton Science* 7: 8-15.
- Bowman, D.T. 2000. Attributes of public and private cotton breeding programs. *Journal of Cotton Science* 4: 130-136.
- Brown, A.H.D., and C.L. Brubaker. 2000. Genetics and the conservation and use of Australian wild relatives of crops. *Australian Journal of Botany* 48: 297-303.
- Brown, A.H.D., C.L. Brubaker and M.J. Kilby. 1997. Assessing the risk of cotton transgene escape into wild Australian *Gossypium* species. Pp. 83-94 in Commercialisation of Transgenic Crops: Risk, Benefit and Trade Considerations. Proceedings of a Workshop, Canberra, 11-13 March 1997 (G.D. McLean, P.M. Waterhouse, G. Evans and M.J. Gibbs, eds.). Cooperative Research Centre for Plant Science and Bureau of Resource Sciences, Commonwealth of Australia, Canberra.
- Brown, H.B., and J.O. Ware. 1958. Cotton, 3rd ed. McGraw-Hill Book Co., New York. 566 pp.
- Brown, M.S. 1951. The spontaneous occurrence of amphiploidy in species hybrids of *Gossypium*. *Evolution* 5: 25-41.
- Brubaker, C.L., and J.F. Wendel. 1993. On the specific status of *Gossypium lanceolatum* Todaro. *Genetic Resources and Crop Evolution* 40: 165-170.
- Brubaker, C.L., and J.F. Wendel. 1994. Reevaluating the origin of domesticated cotton (*Gossypium hirsutum*; Malvaceae) using nuclear restriction fragment length polymorphisms (RFLPs). *American Journal of Botany* 81: 1309-1326.
- Brubaker, C.L., J.A. Koontz and J.F. Wendel. 1993. Bidirectional cytoplasmic and nuclear introgression in the New World cottons, *Gossypium barbadense* and *G. hirsutum* (Malvaceae). *American Journal of Botany* 80: 1203-1208.
- Brubaker, C.L., A.H. Paterson and J.F. Wendel. 1999a. Comparative genetic mapping of allotetraploid cotton and its diploid progenitors. *Genome* 42: 184–203.
- Brubaker, C.L., A.H.D. Brown, J.M. Stewart, M.J. Kilby and J.P. Grace. 1999b. Production of fertile hybrid germplasm with diploid Australian *Gossypium* species for cotton improvement. *Euphytica* 108: 199-213.

- Brubaker, C.L., F.M. Bourland and J.F. Wendel. 1999c. The origin and domestication of cotton. Pp. 3-31 in W.C. Smith and J.T. Cothren, eds., *Cotton: Origin, History, Technology and Production*. John Wiley & Sons, New York.
- Burraston, K.N., and G.M. Booth. 2006. Pollination biology of *Gossypium tomentosum* by the nitidulid beetle, *Aethina concolor*. Abstract, 91st Annual Meeting, Ecological Society of America, Memphis, Tennessee, USA.
- Burraston, K.N., J.S. Gardner and G.M. Booth. 2005. SEM evaluation of the plant-pollinator interactions between nitidulid beetles and a native tropical Malvaceae species, *Gossypium tomentosum* on Kauai. *Microscopy and Microanalysis* 11(Suppl. S02): 1150-1151.
- Calhoun, D.S., and D.T. Bowman. 1999. Techniques for development of new cultivars. Pp. 361-414 in W.C. Smith and J.T. Cothren, eds., *Cotton: Origin, History, Technology and Production*. John Wiley & Sons, New York.
- Cao, J., J.P. Blond and J. Bezar. 1993. Inhibition of fatty acid -6- and -5- desaturation by cyclopropane fatty acid in rat liver microsomes. *Biochimica et Biophysica Acta* 1210: 27-34.
- Carlson, P.S., H.H. Smith and R.D. Dearing. 1972. Parasexual interspecific plant hybridization. *Proceedings of the National Academy of Sciences of the United States of America* 69: 2292-2294.
- Castro, E.M., I.L. Gridi-Papp and E. Paterniani. 1982. Eficiência de barreiras vegetais no isolamento de parcelas de algodoeiro. *Pesquisa Agropecuária Brasileira* 17: 1155-1161.
- Chan, B.G., A.C. Waiss and M. Lukefahr. 1978. Condensed tannin, an antibiotic chemical from *Gossypium hirsutum*. *Journal of Insect Physiology* 24: 113-118.
- Chapman, K.D., S. Austin-Brown, S.A. Sparace, A.J. Kinney, K.G. Ripp, I.L. Pirtle and R.M. Pirtle. 2001. Transgenic cotton plants with increased seed oleic acid content. *Journal of the American Oil Chemists' Society* 78: 941-947.
- Charles, G. 2002. Managing weeds in cotton. Pp. B3.1-B3.22 in *WEEDpak – A Guide for Integrated Management of Weeds in Cotton*. Australian Cotton Cooperative Research Centre, Narrabri, New South Wales.
- Chaudhry, M.R.. 1997. Commercial cotton hybrids. *The International Cotton Advisory Committee Recorder* 15(2): 3-14.
- Chen, Z.J., B.E. Scheffler, E. Dennis, *et. al.* 2007. Toward sequencing cotton (*Gossypium*) genomes. *Plant Physiology* 145: 1303-1310.
- Constable, G.A., P.E. Reid and N.J. Thomson. 2001. Approaches utilised in breeding and development of cotton cultivars in Australia. Pp. 1-15 in J.N. Jenkins and S. Saha, eds., *Genetic Improvement of Cotton: Emerging Technologies*. Science Publishers, Enfield, New Hampshire, USA.
- Coppock, C.E., J.R. Moya, J.W. West, D.H. Nave, J.M. Labore and C.E. Gates. 1985. Effect of lint on whole cottonseed passage and digestibility and diet choice on intake of whole cottonseed by Holstein cows. *Journal of Dairy Science* 68: 1198-1206.

- Cornish, K., J.W. Radin, E.L. Turcotte, Z. Lu and E. Zeiger. 1991. Enhanced photosynthesis and stomatal conductance of Pima cotton (*Gossypium barbadense* L.) bred for increased yield. *Plant Physiology* 97: 484-489.
- Cothren, J.T. 1999. Physiology of the cotton plant. Pp. 207-268 in W.C. Smith and J.T. Cothren, eds., Cotton: Origin, History, Technology and Production. John Wiley & Sons, New York.
- Coutinho, E.M. 2002. Gossypol: A contraceptive for men. *Contraception* 65: 259-63.
- Cronn, R., and J.F. Wendel. 2004. Cryptic trysts, genomic mergers, and plant speciation. *New Phytologist* 161: 133-142.
- Cronn, R.C., R.L. Small and J.F. Wendel. 1999. Duplicated genes evolve independently after polyploid formation in cotton. *Proceedings of the National Academy of Sciences of the United States of America* 96: 14406-14411.
- Cronn, R.C., R.L. Small, T. Haselkorn and J.F. Wendel. 2002. Rapid diversification of the cotton genus (*Gossypium*: Malvaceae) revealed by analysis of sixteen nuclear and chloroplast genes. *American Journal of Botany* 89: 707-725.
- Cronn, R.C., R.L. Small, T. Haselkorn and J.F. Wendel. 2003. Cryptic repeated genomic recombination during speciation in *Gossypium gossypioides*. *Evolution* 57: 2475-2489.
- Cuellar, A., and J. Ramirez. 1993. Further studies on the mechanism of action of gossypol in mitochondrial membrane. *Indian Journal of Biochemistry* 225: 1149-1155.
- Danka, R.G. 2005. High levels of cotton pollen collection observed for honey bees (Hymenoptera: Apidae) in south-central Louisiana. *Journal of Entomological Science* 40: 316-326.
- DeJoode, D.R., and J.F. Wendel. 1992. Genetic diversity and origin of the Hawaiian Islands cotton, *Gossypium tomentosum*. *American Journal of Botany* 79: 1311-1319.
- Delaplane, K.S., and D.F. Mayer. 2000. Crop Pollination by Bees. CABI Publishing, Wallingford, UK. 344 pp.
- Delattre, R. 1992. [The complexity of cotton/insect relationships: A few examples.] *Comptes Rendus de l'Académie d'Agriculture de France* 78(8): 3-24.
- Desai, A., P.W. Chee, J. Rong, O.L. May and A.H. Paterson. 2006. Chromosome structural changes in diploid and tetraploid A genomes of *Gossypium*. *Genome* 49: 336-345.
- Dillehay, T.D., J. Rossen, T.C. Andres and D.E. Williams. 2007. Preceramic adoption of peanut, squash, and cotton in northern Peru. *Science* 316: 1890-1893.
- Dodou, K., R.J. Anderson, D.A.P. Small and P.W. Groundwater. 2005. Investigations on gossypol: Past and present developments. *Expert Opinion on Investigational Drugs* 14: 1419-1434.
- Duke, J.A. 1983. *Gossypium hirsutum* L. Handbook of Energy Crops. Center for New Crops & Plant Products, Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, Indiana, USA.
http://www.hort.purdue.edu/newcrop/duke_energy/Gossypium_hirsutum.html

- Eastick, R. 2002. The Potential Weediness of Transgenic Cotton in Northern Australia. Australian Northern Territory Government, Department of Business, Industry and Resource Development, Technical Bulletin No. 305. 199 pp.
- Eastick, R., and M. Hearnden. 2006. Potential for weediness of Bt cotton (*Gossypium hirsutum*) in northern Australia. *Weed Science* 54: 1142-1151.
- Eisikowitch, D., and G.M. Loper. 1984. Some aspects of flower biology and bee activity on hybrid cotton in Arizona, U.S.A. *Journal of Apicultural Research* 23: 243-248.
- Endrizzi, J.E., E.L. Turcotte and R.J. Kohel. 1984. Qualitative genetics, cytology, and cytogenetics. Pp. 81-129 in R.J. Kohel and C.F. Lewis, eds., Cotton. Agronomy Monograph No. 24. ASA, CSSA and SSSA, Madison, Wisconsin, USA.
- Endrizzi, J.E., E.L. Turcotte and R.J. Kohel. 1985. Genetics, cytology and evolution of *Gossypium*. *Advances in Genetics* 23: 271-375.
- Ensminger, M.E., J.E. Oldfield and W.W. Heinemann. 1990a. By-product feeds/crop residues. Pp. 433-490 in Feeds and Nutrition, 2nd ed. Ensminger Publishing Company, Clovis, California, USA.
- Ensminger, M.E., J.E. Oldfield and W.W. Heinemann. 1990b. Grains/high energy feed. Pp. 363-392 in Feeds and Nutrition, 2nd ed. Ensminger Publishing Company, Clovis, California, USA.
- FAO. 2007. FAOSTAT ProdSTAT: Crops. Food and Agriculture Organization of the United Nations. <http://faostat.fao.org/site/567/default.aspx>
- Feaster, C.V., and E.L. Turcotte. 1980. Registration of American Pima cotton germplasm. *Crop Science* 20: 831-832.
- Fillatti, J., C. McCall, L. Comai, J. Kiser, K. McBride and D. Stalker. 1989. Genetic engineering of cotton for herbicide and insect resistance. Pp. 17-19 in Proceedings of the Beltwide Cotton Production Research Conferences, Nashville, Tennessee, 2-7 January 1989, Vol. 1. National Cotton Council of America, Memphis, Tennessee, USA.
- Finer, J.J., and M.D. McMullen. 1990. Transformation of cotton (*Gossypium hirsutum* L.) via particle bombardment. *Plant Cell Reports* 8: 586-589.
- Firoozabady, E., D.L. DeBoer, D.J. Merlo, E.L. Halk, L.N. Amerson, K.E. Rashka and E.E. Murray. 1987. Transformation of cotton (*Gossypium hirsutum* L.) by *Agrobacterium tumefaciens* and regeneration of transgenic plants. *Plant Molecular Biology* 10: 105-116.
- Flagel, L., J. Udall, D. Nettleton and J. Wendel. 2008. Duplicate gene expression in allopolyploid *Gossypium* reveals two temporally distinct phases of expression evolution. *BMC Biology* 6: 16, doi: 10.1186/1741-7007-6-16. (9 pp.)
- Frank, A.W. 1987. Food uses of cottonseed protein. Pp. 31-80 in B.J.F. Hudson, ed., Development in Food Proteins, Vol. 5. Elsevier Applied Science, New York.
- Free, J.B. 1993. Insect Pollination of Crops, 2nd ed. Academic Press, London, UK. 684 pp.
- Freeland Jr., T.B., B. Pettigrew, P. Thaxton and G.L. Andrews. 2006. Agrometeorology and cotton production. Chapter 13A in Guide to Agricultural Meteorological Practices, 3rd ed. (in preparation).

WMO Publication No. 134. Commission for Agricultural Meteorology, World Meteorological Organization, Geneva. 17 pp. <http://www.wmo.ch/pages/prog/wcp/agm/gamp/documents/chap13A-draft.pdf>

- Freire, E.C. 2002a. Fluxo gênico entre algodoeiros convencionais e transgênicos. *Revista Brasileira de Oleaginosas e Fibras (Campina Grande)* 6: 471-482.
- Freire, E.C. 2002b. Viabilidade de cruzamentos entre algodoeiros transgênicos e comerciais e silvestres do Brasil. *Revista Brasileira de Oleaginosas e Fibras (Campina Grande)* 6: 465-470.
- Freire, E.C. 2005. Zoneamento ambiental do algodão: Uma estratégia de biossegurança para o cultivo comercial do algodão transgênico no Brasil. *Jornal da ABRAPA* Ano 6, No. 64 (Maio): 1-2.
- Freire, E.C., and J. de A.N. Moreira. 1991. Relações genéticas entre o algodoeiro mocó e diferentes espécies e raças de algodoeiro. *Revista Brasileira de Genética* 14: 393-411.
- Freire, E.C., J. de A.N. Moreira, J.W. dos Santos and F.P. de Andrade. 1998. Relações taxonômicas entre os algodoeiros mocó e *Gossypium mustelinum* do Nordeste brasileiro. *Pesquisa Agropecuária Brasileira* 33: 1555-1561.
- Freire, E.C., P.A.V. Barroso, J.C.V. Penna and A. Borém. 2002. Fluxo gênico: Análise do caso de algodão no Brasil. *Biotecnologia, Ciência e Desenvolvimento* 29: 104-113.
- Fryxell, P.A. 1979. The Natural History of the Cotton Tribe (Malvaceae, Tribe Gossypieae). Texas A&M University Press, College Station and London. 245 pp.
- Fryxell, P.A. 1984. Taxonomy and germplasm resources. Pp. 27-57 in R.J. Kohel and C.F. Lewis, eds., Cotton. Agronomy Monograph No. 24. ASA, CSSA and SSSA, Madison, Wisconsin, USA.
- Fryxell, P.A. 1988. Malvaceae of Mexico. *Systematic Botany Monographs* Vol. 25. 522 pp.
- Fryxell, P.A. 1992. A revised taxonomic interpretation of *Gossypium* L. (Malvaceae). *Rheedea* 2: 108-165.
- Fryxell, P.A., L.A. Craven and J.M. Stewart. 1992. A revision of *Gossypium* sect. *Grandicalyx* (Malvaceae), including the description of six new species. *Systematic Botany* 17: 91-114.
- Fuller, D.Q. 2006. Agricultural origins and frontiers in South Asia: A working synthesis. *Journal of World Prehistory* 20: 1-86 & 127.
- Fuller, D., R. Korisettar, P.C. Venkatasubbaiah and M.K. Jones. 2004. Early plant domestications in southern India: Some preliminary archaeobotanical results. *Vegetation History and Archaeobotany* 13: 115-129.
- Gao Y.-H., Zhu S.-J. and Ji D.-F. 2005. Studies on the cytological characters of the interspecific hybrid F₁ among the cultivated species in *Gossypium* and their genetic relationship. *Acta Genetica Sinica* 32: 744-752.
- Gardunia, B.W., C.W. Smith, D. Stelly and M. Menz. 2007. Utilization of short-day winter nursery for evaluation of *Gossypium mustelinum* introgression. In Proceedings – Beltwide Cotton Conferences, New Orleans, Louisiana, 9-12 January 2007. National Cotton Council of America, Memphis, Tennessee, USA.

- Gawel, N.J., and C.D. Robacker. 1986. Effect of pollen-style interaction on the pollen tube growth of *Gossypium hirsutum*. *Theoretical and Applied Genetics* 72: 84-87.
- Goodnight Jr., K.C., and A.R. Kemmerer. 1967. Influence of cyclopropanoid fatty acids on the cholesterol metabolism of cockerels. *Journal of Nutrition* 91: 174-178.
- Gotmare, V., P. Singh, C.D. Mayee, V. Deshpande and C. Bhagat. 2004. Genetic variability for seed oil content and seed index in some wild species and perennial races of cotton. *Plant Breeding* 123: 207-208.
- Graham, A. 2006. Modern processes and historical factors in the origin of the African element in Latin America. *Annals of the Missouri Botanical Garden* 93: 335-339.
- Grover, C.E., HR Kim, R.A. Wing, A.H. Paterson and J.F. Wendel. 2007. Microcolinearity and genome evolution in the *AdhA* region of diploid and polyploid cotton (*Gossypium*). *The Plant Journal* 50: 995-1006.
- Grover, C.E., Y. Yu, R.A. Wing, A.H. Paterson and J.F. Wendel. 2008. A phylogenetic analysis of indel dynamics in the cotton genus. *Molecular Biology and Evolution* 25: 1415-1428 + suppl. Tables 1-4.
- Guo, W.-Z., B.-L. Zhou, L.-M. Yang, W. Wang and T.-Z. Zhang. 2006. Genetic diversity of landraces in *Gossypium arboreum* L. race sinense assessed with simple sequence repeat markers. *Journal of Integrative Plant Biology* 48: 1008-1017.
- Guo, W.Z., Z.Q. Sang, B.L. Zhou and T.Z. Zhang. 2007. Genetic relationships of D-genome species based on two types of EST-SSR markers derived from *G. arboreum* and *G. raimondii* in *Gossypium*. *Plant Science* 172: 808-814.
- Hake, K. 2004. Cotton biotechnology: Beyond Bt- and herbicide-tolerance. Pp. 9-13 in Proceedings of the World Cotton Research Conference-3: Cotton Production for the New Millennium, Cape Town, South Africa, 9-13 March 2003 (A. Swanepoel, ed.). Agricultural Research Council, Institute for Industrial Crops, Pretoria.
- Hanan, J.S., and A.B. Hearn. 2003. Linking physiological and architectural models of cotton. *Agricultural Systems* 75: 47-77.
- Hasrat, J.A., L. Pieters and A.J. Vlietinck. 2004. Medicinal plants in Suriname: Hypotensive effect of *Gossypium barbadense*. *Journal of Pharmacy and Pharmacology* 56: 381-387.
- Hawkins, J.S., J. Pleasants and J.F. Wendel. 2005. Identification of AFLP markers that discriminate between cultivated cotton and the Hawaiian island endemic, *Gossypium tomentosum* Nuttall ex Seemann. *Genetic Resources and Crop Evolution* 52: 1069-1078.
- Hawkins, J.S., HR. Kim, J.D. Nason, R.A. Wing and J.F. Wendel. 2006. Differential lineage-specific amplification of transposable elements is responsible for genome size variation in *Gossypium*. *Genome Research* 16: 1252-1261.
- Hearn, A.B., and G.P. Fitt. 1992. Cotton cropping systems. Pp. 85-142 in C.J. Pearson, ed., *Ecosystems of the World: Field Crop Ecosystems*. Elsevier, Amsterdam.

- Hendricks, J.D., R.O. Sinnhuber, P.M. Loveland, N.E. Pawlowski and J.E. Nixon. 1980. Hepatocarcinogenicity of glandless cottonseeds and cottonseed oil to rainbow trout (*Salmo gairdneri*). *Science* 208: 309-311.
- Hendrix, B., and J. McD. Stewart. 2005. Estimation of the nuclear DNA content of *Gossypium* species. *Annals of Botany* 95: 789-797.
- HEPX (Hotel Eco Paraíso Xixim). 2007. Yucatan Endemic and Special Birds Description: Yucatan Wren, Matraca Yucateca, *Campylorhynchus yucatanicus*. Ecoturismo Yucatán, Mérida, Yucatán, Mexico. <http://www.ecoyuc.com.mx/articles.php?task=detail&aid=47> (1 p.)
- Holm, LeR.G., J.V. Pancho, J.P. Herberger and D.L. Plucknett. 1979. A Geographical Atlas of World Weeds. John Wiley & Sons, New York. 391 pp.
- Holm, LeR., J. Doll, E. Holm, J. Pancho and J. Herberger. 1997. World Weeds: Natural Histories and Distribution. John Wiley & Sons, New York. 1129 pp.
- Hopper, N.W., and R.G. McDaniel. 1999. The cotton seed. Pp. 289-317 in W.C. Smith and J.T. Cothren, eds., Cotton: Origin, History, Technology and Production. John Wiley & Sons, New York.
- Hu S.-A. and Zhao Q.-L. 1992. Studies on epidermal hairs of *Gossypium*. *Acta Botanica Sinica* 34: 311-314. (in Chinese)
- Hu, Z., and X. Gui. 1991. Pretransplant inoculation with VA mycorrhizal fungi and Fusarium blight of cotton. *Soil Biology and Biochemistry* 23: 201-203.
- Hutchinson, J.B. 1951. Intra-specific differentiation in *Gossypium hirsutum*. *Heredity* 5: 161-193.
- Hutchinson, J.B., R.A. Silow and S.G. Stephens. 1947. The Evolution of *Gossypium* and the Differentiation of the Cultivated Cottons. Oxford University Press, London, UK. 160 pp.
- Hutmacher, B. 2004. Square and early fiber development – timing and stress. *California Cotton Review* 72: 8.
- Ibrahim, R.I.H., J.-I. Azuma and M. Sakamoto. 2006. Complete nucleotide sequence of the cotton (*Gossypium barbadense* L.) chloroplast genome with a comparative analysis of sequences among 9 dicot plants. *Genes and Genetic Systems* 81: 311-321.
- Iqbal, M.J., O.U.K. Reddy, K.M. El-Zik and A.E. Pepper. 2001. A genetic bottleneck in the 'evolution under domestication' of upland cotton *Gossypium hirsutum* L. examined using fingerprinting. *Theoretical and Applied Genetics* 103: 547-554.
- Jenkins, J.N. 1993. Cotton. Pp. 61-70 in Traditional Crop Breeding Practices: A Historical Review to Serve as a Baseline for Assessing the Role of Modern Biotechnology. OECD, Paris.
- Jenkins, J.N., and S. Saha, eds. 2001. Genetic Improvement of Cotton: Emerging Technologies. Science Publishers, Enfield, New Hampshire, USA. 344 pp.
- Jiang, C.-X., P.W. Chee, X. Draye, P.L. Morrell, C.W. Smith and A.H. Paterson. 2000. Multilocus interactions restrict gene introgression in interspecific populations of polyploid *Gossypium* (cotton). *Evolution* 54: 798-814.

- John, M.E., and G. Keller. 1996. Metabolic pathway engineering in cotton: Biosynthesis of polyhydroxybutyrate in fiber cells. *Proceedings of the National Academy of Sciences of the United States of America* 93: 12768-12773.
- Johnston, J.A., C. Mallory-Smith, C.L. Brubaker, F. Gandara, F.J.L. Aragão, P.A.V. Barroso, V.D. Quang, L.P. de Carvalho, P. Kageyama, A.Y. Ciampi, M. Fuzatto, V. Cirino and E.C. Freire. 2006. Assessing gene flow from Bt cotton in Brazil and its possible consequences. Pp. 261-299 in A. Hilbeck, D.A. Andow and E.M.G. Fontes, eds., *Environmental Risk Assessment of Genetically Modified Organisms: Volume 2, Methodologies for Assessing Bt Cotton in Brazil*. CABI Publishing, Wallingford, UK.
- Jones, L.A., and C.C. King, eds. 1993. *Cottonseed Oil*. National Cottonseed Products Association and The Cotton Foundation, Memphis, Tennessee, USA. 60 pp.
- Jones, L.A., and T.C. Wedegaertner. 1986. Advances in feeding cottonseed products. Pp. 195-199 in *Proceedings: World Conference on Emerging Technologies in the Fats and Oils Industry*, Cannes, France, November 3-8, 1985 (A.R. Baldwin, ed.). American Oil Chemists' Society, Urbana, Illinois, USA.
- Jones, R.W., J.R. Cate and H.R. Burke. 1989. Phenology and ecology of wild cotton (Malvales: Malvaceae) and the boll weevil (Coleoptera: Curculionidae) in Tamaulipas, Mexico. *Journal of Economic Entomology* 82: 1626-1632.
- Jürgens, N. 1997. Floristic biodiversity and history of African arid regions. *Biodiversity and Conservation* 6: 495-514.
- Kakani, A., S. Saha, V.T. Sapra, A. Zipf and D.M. Stelly. 1999. Genetic mechanism and chromosomal location of pollen-specific gene(s) in *Gossypium*. *Crop Science* 39: 668-673.
- Kandylis, K., P.N. Nikokyris and K. Deligiannis. 1998. Performance of growing-fattening lambs fed whole cotton seed. *Journal of the Science of Food and Agriculture* 78: 281-239.
- Karaosmanoğlu, F., M. Tüter, E. Göllü, S. Yanmaz and E. Altintiğ. 1999. Fuel properties of cottonseed oil. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 21: 821-828.
- Kebede, H., G. Burow, R.G. Dani and R.D. Allen. 2007. A-genome cotton as a source of genetic variability for upland cotton (*Gossypium hirsutum*). *Genetic Resources and Crop Evolution* 54: 885-895.
- Khan, M.A., J.McD. Stewart and J.B. Murphy. 1999. Evaluation of the *Gossypium* gene pool for foliar terpenoid aldehydes. *Crop Science* 39: 253-258.
- Kirk, J.H., and G.E. Higginbotham. 1999. Pima cotton, gossypol and dairy cattle: Is it a bad combination? http://www.vetmed.ucdavis.edu/vetext/INF-DA/INF-DA_GOSSYPOL.html 2 pp.
- Kirkpatrick, T.L., and C.S. Rothrock, eds. 2001. *Compendium of Cotton Diseases*, 2nd ed. APS Press, St. Paul, Minnesota, USA. 100 pp.
- Kittock, D.L., T.J. Henneberry and L.A. Bariola. 1981. Fruiting of upland and Pima cotton with different planting dates. *Agronomy Journal* 73: 711-715.

- Kittock, D.L., R. Selley and B.B. Taylor. 1985. A summary of 25 years of cotton date of planting tests in Arizona. *In Cotton, A College of Agriculture Report*. University of Arizona College of Agriculture Series P-63.
- Kittock, D.L., B.B. Taylor and W.C. Hofmann. 1987. Partitioning yield reduction from early cotton planting. *Crop Science* 27: 1011-1015.
- Kumar, M., and R. Tuli. 2004. Plant regeneration in cotton: A short-term inositol starvation promotes developmental synchrony in somatic embryogenesis. *In Vitro Cellular & Developmental Biology – Plant* 40: 294-298.
- Kumar, S., A. Dhingra and H. Daniell. 2004. Stable transformation of the cotton plasmid genome and maternal inheritance of transgenes. *Plant Molecular Biology* 56: 203-216.
- Lacape, J.-M., D. Dessauw, M. Rajab, J.-L. Noyer and B. Hau. 2007. Microsatellite diversity in tetraploid *Gossypium* germplasm: Assembling a highly informative genotyping set of cotton SSRs. *Molecular Breeding* 19: 45-58.
- Lane, H.C., and M.F. Schuster. 1981. Condensed tannins of cotton leaves. *Phytochemistry* 20: 425-427.
- Lazarides, M., K. Cowley and P. Hohnen. 1997. CSIRO Handbook of Australian Weeds. CSIRO, Canberra. 264 pp.
- Lee, J.A. 1984. Cotton as a world crop. Pp. 1-25 in R.J. Kohel and C.F. Lewis, eds., Cotton. Agronomy Monograph No. 24. ASA, CSSA and SSSA, Madison, Wisconsin, USA.
- Lee, S.-B., C. Kaittanis, R.K. Jansen, J.B. Hostetler, L.J. Tallon, C.D. Town and H. Daniell. 2006. The complete chloroplast genome sequence of *Gossypium hirsutum*: Organization and phylogenetic relationships to other angiosperms. *BMC Genomics* 7: 61, doi: 10.1186/1471-2164-7-61. (12 pp.)
- Liu, Q., C.L. Brubaker, A.G. Green, D.R. Marshall, P.J. Sharp and S.P. Singh. 2001. Evolution of the *FAD2-1* fatty acid desaturase 5' UTR intron and the molecular systematics of *Gossypium* (Malvaceae). *American Journal of Botany* 88: 92-102.
- Liu, Q., S.P. Singh and A.G. Green. 2002. High-stearic and high-oleic cottonseed oils produced by hairpin RNA-mediated post-transcriptional gene silencing. *Plant Physiology* 129: 1732-1743.
- Liu, R.-J. 1995. Effect of vesicular-arbuscular mycorrhizal fungi on Verticillium wilt of cotton. *Mycorrhiza* 5: 293-297.
- Liu, Z., and K.L. Adams. 2007. Expression partitioning between genes duplicated by polyploidy under abiotic stress and during organ development. *Current Biology* 17: 1669-1674.
- Llewellyn, D., C. Tyson, G. Constable, B. Duggan, S. Beale and P. Steel. 2007. Containment of regulated genetically modified cotton in the field. *Agriculture, Ecosystems and Environment* 121: 419-429.
- Loper, G.M. 1986. Cotton pollen: Honeybee (*Apis mellifera*) avoidance and absence of gossypol. *Journal of Economic Entomology* 79: 103-106.
- Lordelo, M.M., A.J. Davis, M.C. Calhoun, M.K. Dowd and N.M. Dale. 2005. Relative toxicity of gossypol enantiomers in broilers. *Poultry Science* 84: 1376-1382.

- Lordelo, M.M., M.C. Calhoun, N.M. Dale, M.K. Dowd and A.J. Davis. 2007. Relative toxicity of gossypol enantiomers in laying and broiler breeder hens. *Poultry Science* 86: 582-590.
- Lu, Z., J. Chen, R.G. Percy and E. Zeiger. 1997. Photosynthetic rate, stomatal conductance and leaf area in two cotton species (*Gossypium barbadense* and *Gossypium hirsutum*) and their relation with heat resistance and yield. *Functional Plant Biology* 24: 693-700.
- Lusas, E.W., and G.M. Jividen. 1987. Glandless cottonseed: A review of the first 25 years of processing and utilization research. *Journal of the American Oil Chemists' Society* 64: 839-854.
- Ma, X.-X., B.-L. Zhou, Y.-H. Lü, W.-Z. Guo and T.-Z. Zhang. 2008. Simple sequence repeat genetic linkage maps of A-genome diploid cotton (*Gossypium arboreum*). *Journal of Integrative Plant Biology* 50: 491-502.
- Mamood, A.N., G.D. Waller and J.R. Hagler. 1990. Dispersal of upland and Pima cotton pollen by honey bees (Hymenoptera: Apidae) visiting upland male-sterile flowers. *Environmental Entomology* 19: 1034-1036.
- Mansour, M.H., N.M. Zohdy, S.E. El-Gengaihi and A.E. Amr. 1997. The relationship between tannins concentration in some cotton varieties and susceptibility to piercing sucking insects. *Journal of Applied Entomology* 121: 321-325.
- Marur, C.J., and O. Ruano. 2001. A reference system for determination of developmental stages of upland cotton. *Revista de Oleaginosas e Fibrosas (Campina Grande)* 5: 313-317.
- Marur, C.J., and O. Ruano. 2004. Escala do algodão: Um método para determinação de estádios de desenvolvimento do algodoeiro herbáceo. *Informações Agronômicas (Piracicaba)* No. 105: 3-4.
- Matthews, G.A. 1989. Cotton Insect Pests and Their Management. Longman Scientific & Technical, Harlow, Essex, UK, and John Wiley & Sons, New York. 199 pp.
- Matthews, G.A. 1994. Jassids (Hemiptera: Cicadellidae). Pp. 353-357 in G.A. Matthews and J.P. Tunstall, eds., *Insect Pests of Cotton*. CABI Publishing, Wallingford, UK.
- Matthews, G.A., and J.P. Tunstall, eds. 1994. *Insect Pests of Cotton*. CABI Publishing, Wallingford, UK. 593 pp.
- May, O.L., and K.E. Lege. 1999. Development of the world cotton industry. Pp. 65-97 in W.C. Smith and J.T. Cothren, eds., *Cotton: Origin, History, Technology and Production*. John Wiley & Sons, New York.
- McCabe, D.E., and B.J. Martinell. 1993. Transformation of elite cotton cultivars via particle bombardment of meristems. *Bio/Technology* 11: 596-598.
- McGregor, S.E. 1976. *Insect Pollination of Cultivated Crop Plants*. Agriculture Handbook No. 496. U.S. Department of Agriculture, Agricultural Research Service. GPO, Washington, D.C. 411 pp.
- McWilliams, D. 2003. *Drought Strategies for Cotton*. New Mexico State University Cooperative Extension Service Circular 582. 6 pp.
- Mehetre, S.S., and A.R. Aher. 2004. Embryo rescue: A tool to overcome incompatible interspecific hybridization in *Gossypium* Linn. – a review. *Indian Journal of Biotechnology* 3: 29-36.

- Mehetre, S.S., M.V. Thombre and M.A. Tyyab. 1980. Cytomorphological studies in an intergeneric hybrid between *Gossypium hirsutum* L. ($2n = 52$) and *Hibiscus panduraeformis* Burm. *Euphytica* 29: 323-330.
- Meredith Jr., W.R. 1991. Contributions of introductions to cotton improvement. Pp. 127-146 in H.L. Shands and L.E. Wiesner, eds., Use of Plant Introductions in Cultivar Development, Part 1. Proceedings of a Symposium, Las Vegas, Nevada, 19 October 1989. CSSA Special Publication 17. Crop Science Society of America, Madison, Wisconsin, USA.
- Meredith Jr., W.R. 1999. Cotton and heterosis. Pp. 282-283 in J.G. Coors and S. Pandey, eds., The Genetics and Exploitation of Heterosis in Crops. An International Symposium, CIMMYT, Mexico City, 17-22 August 1997. ASA and CSSA, Madison, Wisconsin, USA.
- Mergeai, G. 2006a. Contributions possibles des innovations génétiques pour l'amélioration de la compétitivité des filières cotonnières africaines. *Biotechnologie, Agronomie, Société et Environnement* 10: 345-350.
- Mergeai, G. 2006b. Introgressions interspécifiques chez le cotonnier. *Cahiers Agricultures* 15: 135-143.
- Meyer, V.G. 1974. Interspecific cotton breeding. *Economic Botany* 28: 56-60.
- Moffett, J.O. 1983. Pollination of entomophilous hybrid seed parents — hybrid cotton. Pp. 508-514 in C.E. Jones and R.J. Little, eds., Handbook of Experimental Pollination Biology. Van Nostrand Reinhold, New York.
- Moffett, J.O., L.S. Stith, C.C. Burkhart and C.W. Shipman. 1975. Honey bee visits to cotton flowers. *Environmental Entomology* 4: 203-206.
- Moffett, J.O., L.S. Stith, C.C. Burkhart and C.W. Shipman. 1976. Fluctuation of wild bee and wasp visits to cotton flowers. *Arizona Academy of Science* 11: 64-68.
- Moreira, J. de A.N., E.C. Freire, J.W. dos Santos and R.M. Vieira. 1995. Use of numerical taxonomy to compare "mocó" cotton with other cotton species and races. *Revista Brasileira de Genética* 18: 99-103.
- Moulherat, C., M. Tengberg, J.-F. Haquet and B. Mille. 2002. First evidence of cotton at Neolithic Mehrgarh, Pakistan: Analysis of mineralized fibres from a copper bead. *Journal of Archaeological Science* 29: 1393-1401.
- Münster, P., and A.M. Wieczorek. 2007. Potential gene flow from agricultural crops to native plant relatives in the Hawaiian Islands. *Agriculture, Ecosystems and Environment* 119: 1-10.
- Muravenko, O.V., A.R. Fedotov, E.O. Punina, L.I. Fedorova, V.G. Grif and A.V. Zelenin. 1998. Comparison of chromosome BrdU-Hoechst-Giemsa banding patterns of the A_1 and $(AD)_2$ genomes of cotton. *Genome* 41: 616-625.
- Nehl, D., and S. Allen. 2004. Symptoms of Diseases and Disorders of Cotton in Australia. Australian Cotton Cooperative Research Centre, Narrabri, Australia. 38 pp.
- Nicholls, P.J. 1992. Vegetable dust and lung disease. Pp. 161-182 in G.B. Leslie and F.W. Lunau, eds., Indoor Air Pollution: Problems and Priorities. Cambridge University Press, Cambridge, UK.

- Niles, G.A. 1980. Plant breeding and improvement of the cotton plant. *Outlook on Agriculture* 10: 152-158.
- O'Brien, R.D., L.A. Jones, C.C. King, P.J. Wakelyn and P.J. Wan. 2005. Cottonseed oil. Pp. 173-279 in Bailey's Industrial Oil & Fat Products, 6th ed. (F. Shahidi, ed.), Vol. 2, Edible Oil and Fat Products: Edible Oils (Part 1). John Wiley & Sons, Hoboken, New Jersey, USA.
- Oerke, E.-C. 2006. Crop losses to pests. *Journal of Agricultural Science (Cambridge)* 144: 31-43.
- OECD. 2004. Consensus Document on Compositional Considerations for New Varieties of Cotton (*Gossypium hirsutum* and *Gossypium barbadense*): Key Food and Feed Nutrients and Anti-nutrients. OECD Series on the Safety of Novel Foods and Feeds No. 11. OECD, Paris. 32 pp.
- OECD. 2008. OECD Seed Schemes "2008", Annex VII to the Decision: OECD Scheme for the Varietal Certification of Crucifer Seed and Other Oil or Fibre Species Seed Moving in International Trade. OECD Document C(2000)146/FINAL Incl. 2003, 2004, 2005, 2006 & 2007 Amendments. OECD, Paris. 45 pp.
- OGTR. 2008. The Biology of *Gossypium hirsutum* L. and *Gossypium barbadense* L. (Cotton), Ver. 2. Office of the Gene Technology Regulator, Australian Government Department of Health and Ageing, Canberra. 91 pp.
- Oosterhuis, D.M., and J. Jernstedt. 1999. Morphology and anatomy of the cotton plant. Pp. 175-206 in W.C. Smith and J.T. Cothren, eds., Cotton: Origin, History, Technology and Production. John Wiley & Sons, New York.
- Pahlavani, M.H, and K. Abolhasani. 2006. Xenia effect on seed and embryo size in cotton (*Gossypium hirsutum* L.). *Journal of Applied Genetics* 47: 331-335.
- Paiziev, A.A., and V.A. Krakhmalev. 2006. Microstructure of dormant cotton seeds. *Asian Journal of Plant Sciences* 5: 492-497.
- Paterson, A.H. 2005. Polyploidy, evolutionary opportunity, and crop adaptation. *Genetica* 123: 191-196.
- Paterson, A.H., and R.H. Smith. 1999. Future horizons: Biotechnology for cotton improvement. Pp. 415-432 in W.C. Smith and J.T. Cothren, eds., Cotton: Origin, History, Technology and Production. John Wiley & Sons, New York.
- Pearsall, D.M. 2003. Plant food resources of the Ecuadorian Formative: An overview and comparison to the Central Andes. Pp. 213-257 in J.S. Raymond and R.L. Burger, eds., Archaeology of Formative Ecuador. Dumbarton Oaks Research Library and Collection, Washington, D.C.
- Pelling, R. 2005. Garamantian agriculture and its significance in a wider North African context: The evidence of the plant remains from the Fazzan project. *Journal of North African Studies* 10: 397-412.
- Percival, A.E., J.F. Wendel and J.M. Stewart. 1999. Taxonomy and germplasm resources. Pp. 33-63 in W.C. Smith and J.T. Cothren, eds., Cotton: Origin, History, Technology and Production. John Wiley & Sons, New York.
- Percy, R.G., and E.L. Turcotte. 1991. Inheritance of male-sterile mutant ms₁₃ in American Pima cotton. *Crop Science* 31: 1520-1521.

- Percy, R.G., and J.F. Wendel. 1990. Allozyme evidence for the origin and diversification of *Gossypium barbadense* L. *Theoretical and Applied Genetics* 79: 529-542.
- Perlak, F.J., R.W. Deaton, T.A. Armstrong, R.L. Fuchs, S.R. Sims, J.T. Greenplate and D.A. Fischhoff. 1990. Insect-resistant cotton plants. *Bio/Technology* 8: 939-943.
- Phillips, L.L. 1966. The cytology and phylogenetics of the diploid species of *Gossypium*. *American Journal of Botany* 53: 328-335.
- Phillips, L.L. 1976. Cotton: *Gossypium* (Malvaceae). Pp. 196-200 in N.W. Simmonds, ed., *Evolution of Crops Plants*. Longman, London, UK.
- Phillips, L.L., and M.A. Strickland. 1966. The cytology of a hybrid between *Gossypium hirsutum* and *G. longicalyx*. *Canadian Journal of Genetics and Cytology* 8: 91-95.
- Pope, K.O., M.E.D. Pohl, J.G. Jones, D.L. Lentz, C. von Nagy, F.J. Vega and I.R. Quitmyer. 2001. Origin and environmental setting of ancient agriculture in the lowlands of Mesoamerica. *Science* 292: 1370-1373.
- Potts, D.T. 1997. *Mesopotamian Civilization: The Material Foundations*. Cornell University Press, Ithaca, New York. 366 pp.
- Preetha, S., and T.S. Raveendren. 2008. Molecular marker technology in cotton. *Biotechnology and Molecular Biology Review* 3(2): 32-45.
- Price, H.J., and R.H. Smith. 1979. Somatic embryogenesis in suspension cultures of *Gossypium klotzschianum* Anderss. *Planta* 145: 305-307.
- Price, H.J., R.H. Smith and R.M. Grumbles. 1977. Callus cultures of six species of cotton (*Gossypium* L.) on defined media. *Plant Science Letters* 10: 115-119.
- Pundir, N.S. 1972. Experimental embryology of *Gossypium arboreum* L. and *Gossypium hirsutum* L. and their reciprocal crosses. *Botanical Gazette* 133: 7-26.
- Radin, J.W., Z. Lu, R.G. Percy and E. Zeiger. 1994. Genetic variability for stomatal conductance in Pima cotton and its relation to improvements of heat adaptation. *Proceedings of the National Academy of Sciences of the United States of America* 91: 7217-7221.
- Rajendran, T.P., M.V. Venugopalan and C.S. Praharaj. 2005. Cotton research towards sufficiency to Indian textile industry. *Indian Journal of Agricultural Sciences* 75: 699-708.
- Rana, M.K., and K.V. Bhat. 2004. A comparison of AFLP and RAPD markers for genetic diversity and cultivar identification in cotton. *Journal of Plant Biochemistry and Biotechnology* 13: 19-24.
- Randall, R.P. 2002. *A Global Compendium of Weeds*. R.G. and F.J. Richardson, Melbourne. 905 pp.
- Rapp, R.A., I. Álvarez and J.F. Wendel. 2005. Molecular confirmation of the position of *Gossypium trifurcatum* Vollesen. *Genetic Resources and Crop Evolution* 52: 749-753.
- Reddy, K.R., and H.F. Hodges. 2006. Exploring the limitations for cotton growth and yield. *Journal of New Seeds* 8(2): 1-22.

- Reddy, K.R., V.R. Reddy and H.F. Hodges. 1992a. Temperature effects on early season cotton growth and development. *Agronomy Journal* 84: 229-237.
- Reddy, K.R., H.F. Hodges, J.M. McKinion and G.W. Wall. 1992b. Temperature effects on Pima cotton growth and development. *Agronomy Journal* 84: 237-243.
- Reed, W. 1994. *Earias* spp. (Lepidoptera: Noctuidae). Pp. 151-176 in G.A. Matthews and J.P. Tunstall, eds., *Insect Pests of Cotton*. CABI Publishing, Wallingford, UK.
- Renner, S. 2004. Plant dispersal across the tropical Atlantic by wind and sea currents. *International Journal of Plant Sciences* 165(Suppl.): S23-S33.
- Rhodes, J. 2002. Cotton pollination by honey bees. *Australian Journal of Experimental Agriculture* 42: 513-518.
- Richards, J.S., J.N. Stanley and P.C. Gregg. 2005. Viability of cotton and canola pollen on the proboscis of *Helicoverpa armigera*: Implications for spread of transgenes and pollination ecology. *Ecological Entomology* 30: 327-333.
- Risco, C.A., P.J. Chenoweth, R.E. Larsen, J. Velez, N. Shaw, T. Tran and C.C. Chase Jr.. 1993. The effect of gossypol in cottonseed meal on performance and on hematological and semen traits in postpubertal Brahman bulls. *Theriogenology* 40: 629-642.
- Ritchie, G.L., C.W. Bednarz, P.H. Jost and S.M. Brown. 2007. Cotton Growth and Development, rev. ed. University of Georgia Cooperative Extension Bulletin 1252. 16 pp.
- Roberts, G., and G. Charles. 2002. Integrated weed management (IWM) guidelines for Australian cotton production. Pp. B2.1-B2.10 in WEEDpak – A Guide for Integrated Management of Weeds in Cotton. Australian Cotton Cooperative Research Centre, Narrabri, New South Wales.
- Robertson, B., C. Bednarz and C. Burmester. 2007. Growth and development – first 60 days. *Cotton Physiology Today* 13(2): 1-5.
- Robinson, A.E. 1999. Cotton nematodes. Pp. 595-615 in W.C. Smith and J.T. Cothren, eds., *Cotton: Origin, History, Technology and Production*. John Wiley & Sons, New York.
- Rogers, D.J., R.E. Reid, J.J. Rogers and S.J. Addison. 2007. Prediction of the naturalisation potential and weediness risk of transgenic cotton in Australia. *Agriculture, Ecosystems and Environment* 119: 177-189.
- Rolph, C.E., R.S. Moreton and J.L. Harwood. 1990. Control of acyl lipid desaturation in the yeast *Rhodotorula gracilis* via use of the cyclopropenoid fatty acid, sterculate. *Applied Microbiology and Biotechnology* 34: 91-96.
- Rong, J., C. Abbey, J.E. Bowers, *et al.* 2004. A 3347-locus genetic recombination map of sequence-tagged sites reveals features of genome organization, transmission and evolution of cotton (*Gossypium*). *Genetics* 166: 389-417.
- Rong, J., J.E. Bowers, S.R. Schulze, V.N. Waghmare, C.J. Rogers, G.J. Pierce, H. Zhang, J.C. Estill and A.H. Paterson. 2005. Comparative genomics of *Gossypium* and *Arabidopsis*: Unraveling the consequences of both ancient and recent polyploidy. *Genome Research* 15: 1198–1210.

- Röse, U.S.R., J. Lewis and J.H. Tumlinson. 2006. Extrafloral nectar from cotton (*Gossypium hirsutum*) as a food source for parasitic wasps. *Functional Ecology* 20: 67-74.
- Ruan, Y.-L. 2005. Recent advances in understanding cotton fibre and seed development. *Seed Science Research* 15: 269-280.
- Sakhanokho, H.F., A. Zipf, K. Rajasekaran, S. Saha, G.C. Sharma and P.W. Chee. 2004. Somatic embryo initiation and germination in diploid cotton (*Gossypium arboreum* L.). *In Vitro Cellular & Developmental Biology – Plant* 40: 177-181.
- Salvaggio, J.E., C.E. O’Neil and B.T. Butcher. 1986. Immunologic responses to inhaled cotton dust. *Environmental Health Perspectives* 66: 17-23.
- Sanathnam, V., and J.B. Hutchinson. 1974. Cotton. Pp. 89-100 in J.B. Hutchinson, ed., *Evolutionary Studies in World Crops: Diversity and Change in the Indian Subcontinent*. Cambridge University Press, Cambridge, England, UK.
- Sanchez Jr., J.L.B., and D.T. Malerbo-Souza. 2004. Frequência dos insetos na polinização e produção de algodão. *Acta Scientiarum. Agronomy (Maringá)* 26: 461-465.
- Santos, J.E.P., M. Villasenor, E.J. DePeters, P.H. Robinson and B.C. Baldwin Jr. 2002. Type of cottonseed and level of gossypol in diets of lactating dairy cows: Effects on lactation performance and plasma gossypol. *Journal of Dairy Science* 85: 1491-1501.
- Santos, J.E.P., M. Villasenor, P.H. Robinson, E.J. DePeters and C.A. Holmberg. 2003. Type of cottonseed and level of gossypol in diets of lactating dairy cows: Plasma gossypol, health, and reproductive performance. *Journal of Dairy Science* 86: 892-905.
- Saravanan, N.A., S.G. Ram, V. Thiruvengadam, R. Ravikesavan and T.S. Raveendram. 2007. Production and fertility restoration of an interspecific hybrid between *Gossypium hirsutum* L. and *G. raimondii* Ulbr. *Cytologia* 72: 195-203.
- Sauer, J.D. 1993. *Historical Geography of Crop Plants: A Select Roster*. CRC Press, Boca Raton, Florida, USA. 309 pp.
- Savaşkan, Ç. 2002. The effects of gamma irradiation on the pollen size of *Gossypium hirsutum* L. *Turkish Journal of Botany* 26: 477-480.
- Sawan, Z.M., L.I. Hanna and W.L. McCuiston. 2004. Effects of climatic factors prevailing prior to flowering or subsequent to boll setting on flower and boll production and retention of cotton in Egypt. *Journal of Agronomy and Crop Science* 190: 287-297.
- Sawan, Z.M., L.I. Hanna and W.L. McCuiston. 2005. Response of flower and boll development to climatic factors before and after anthesis in Egyptian cotton. *Climate Research* 29: 167-179.
- Sawyer Jr., W.H. 1955. Medicinal uses of plants by native Inaguans. *The Scientific Monthly* 80: 371-376.
- Schneider, E.L., S.P. Loke and D.T. Hopkins. 1968. Gas-liquid chromatographic analysis of cyclopropanoid fatty acids. *Journal of the American Oil Chemists’ Society* 45: 585-590.
- Schwendiman, J., G. Ano and A.E. Percival. 1985. Cotton collecting in continental Ecuador and Galapagos Islands. *Plant Genetic Resources Newsletter* 64: 33-37.

- Seelanan, T., A. Schnabel and J.F. Wendel. 1997. Congruence and consensus in the cotton tribe (Malvaceae). *Systematic Botany* 22: 259-290.
- Seelanan, T., C.L. Brubaker, J.McD. Stewart, L.A. Craven and J.F. Wendel. 1999. Molecular systematics of Australian *Gossypium* section *Grandicalyx* (Malvaceae). *Systematic Botany* 24: 183-208.
- Sekloka, E., J. Lançon, B. Hau, E. Gozé, S. Lewicki and G. Thomas. 2007. A simple method for estimating the end of effective flowering in upland cotton (*Gossypium hirsutum*). *Experimental Agriculture* 43: 163-171.
- Sen, I., M. Oglakci, Y. Bolek, B. Cicek, N. Kisakurek and S. Aydin. 2004. Assessing the out-crossing ratio, isolation distance and pollinator insects in cotton (*Gossypium hirsutum* L.). *Asian Journal of Plant Science* 3: 724-727.
- Senchina, D.S., I. Álvarez, R.C. Cronn, B. Liu, J. Rong, R.D. Noyes, A.H. Paterson, R.A. Wing, T.A. Wilkins and J.F. Wendel. 2003. Rate variation among nuclear genes and the age of polyploidy in *Gossypium*. *Molecular Biology and Evolution* 20: 633-643.
- Şengonca, Ç., M.S. Lababidi and S. Gerlach. 1986. The effects of different cotton varieties on the carmine spider mite, *Tetranychus cinnabarinus* (Boisd.) (Acari: Tetranychidae). *Plant Breeding* 97: 297-303.
- Shang-Guan X.-X., Wang L.-J., Li Y.-E., Liang Y.-S. and Wu X. 2007. Analysis of cotton (*Gossypium hirsutum* L.) plants transformed with a silkworm fibroin light chain gene. *Acta Agronomica Sinica* 33: 697-702.
- Sherwood, A.R., and C.W. Morden. 2004. RAPD analyses of the endemic Hawaiian cotton (*Gossypium tomentosum* Nutt. ex Seem.) reveal unexpected levels of genetic diversity. Pp. 43-44 in The 2004 Hawai'i Conservation Conference, June 29-30, 2004, Honolulu. Hawai'i Conservation Alliance, Honolulu.
- Silvertooth, J.C. 2001. Agronomic Guidelines for Pima Cotton Production in Arizona. University of Arizona College of Agriculture and Life Sciences, Cooperative Extension AZ1242. 4 pp.
- Silvertooth, J.C., E.R. Norton, B.L. Unruh, J.A. Navarro, L.J. Clark and E.W. Carpenter. 1995. Nitrogen management experiments for upland and Pima cotton. Pp. 311-326 in Cotton, A College of Agriculture Report. University of Arizona College of Agriculture Series P-99.
- Simpson, D.M., and E.N. Duncan. 1956. Cotton pollen dispersal by insects. *Agronomy Journal* 48: 305-308.
- Sindel, B.M. 1997. Outcrossing of transgenes to weedy relatives. Pp. 43-81 in Commercialisation of Transgenic Crops: Risk, Benefit and Trade Considerations, Proceeding of a Workshop, Canberra, 11-13 March 1997 (G.D. McLean, P.M. Waterhouse, G. Evans and M.J. Gibbs, eds.). Australian Department of Primary Industries and Energy, Bureau of Resource Sciences, Canberra.
- Singh, I.P., and D.P. Singh. 1991. Estimation of extent of natural crossing in upland cotton (*Gossypium hirsutum*) in Haryana, India. *Indian Journal of Agricultural Sciences* 61: 629-633.
- Small, R.L., and J.F. Wendel. 1999. The mitochondrial genome of allotetraploid cotton (*Gossypium* L.). *Journal of Heredity* 90: 251-253.

- Small, R.L., and J.F. Wendel. 2000. Phylogeny, duplication, and intraspecific variation of *Adh* sequences in New World diploid cottons (*Gossypium* L., Malvaceae). *Molecular Phylogenetics and Evolution* 16: 73-84.
- Small, R.L., J.A. Ryburn, R.C. Cronn, T. Seelanan and J.F. Wendel. 1998. The tortoise and the hare: Choosing between noncoding plastome and nuclear *Adh* sequences for phylogeny reconstruction in a recently diverged plant group. *American Journal of Botany* 85: 1301-1315.
- Small, R.L., R.C. Cronn and J.F. Wendel. 2004. Use of nuclear genes for phylogeny reconstruction in plants. *Australian Systematic Botany* 17: 145-170.
- Smith Jr., C.E., and S.G. Stephens. 1971. Critical identification of Mexican archaeological cotton remains. *Economic Botany* 25: 160-168.
- Smith, C.W. 1995. Cotton (*Gossypium hirsutum* L.). Pp. 287-349 in C.W. Smith, *Crop Production: Evolution, History, and Technology*. John Wiley & Sons, New York.
- Smith, C.W., R.G. Cantrell, H.S. Moser and S.R. Oakley. 1999. History of cultivar development in the United States. Pp. 99-171 in C.W. Smith and J.T. Cothren, eds., *Cotton: Origin, History, Technology and Production*. John Wiley & Sons, New York.
- Smith, F.H. 1961. Biosynthesis of gossypol by excised cotton roots. *Nature* 192: 888-889.
- Smith, F.H. 1967. Determination of gossypol in leaves and flower buds of *Gossypium*. *Journal of the American Oil Chemists' Society* 44: 267-269.
- Solomon, R., G. Adin, S.J. Majeesh, M. Nikbachat, E. Yosef, D. Ben-Ghedalia and J. Miron. 2005. Digestibility in lactating cows of diets containing whole Pima treated with sodium hydroxide versus Akala or Pima cottonseed. *Journal of Dairy Science* 88: 1745-1751.
- Song P., Ji D.-F. and Xu F.-H. 1991. Comparative studies on karyotypes of cultivated diploid cotton species *Gossypium herbaceum* and *G. arboreum*. *Acta Agronomica Sinica* 17: 102-106. (in Chinese)
- Srivastava, A., Z. Lu and E. Zeiger. 1995. Modification of guard cell properties in advanced lines of Pima cotton bred for higher yields and heat resistance. *Plant Science* 108: 125-131.
- Srivastava, D. 1982. Studies in the Pollen Biology of Certain Cultivated Malvaceae. *Advances in Pollen-Spore Research* Vol. 9. 165 pp.
- Stanton, M.A., J.McD. Stewart, A.E. Percival and J.F. Wendel. 1994. Morphological diversity and relationships in the A-genome cottons, *Gossypium arboreum* and *G. herbaceum*. *Crop Science* 34: 519-527.
- Stark, B.L., L. Heller and M.A. Ohnerson. 1998. People with cloth: Mesoamerican economic change from the perspective of cotton in south-central Veracruz. *Latin American Antiquity* 9: 7-36.
- Stephens, S.G. 1958. Factors Affecting Seed Dispersal in *Gossypium* and their Possible Evolutionary Significance. North Carolina Agricultural Experiment Station Technical Bulletin No. 131. 32 pp.
- Stephens, S.G. 1964. Native Hawaiian cotton (*Gossypium tomentosum* Nutt.). *Pacific Science* 18: 385-398.

- Stephens, S.G. 1966. The potentiality for long-range oceanic dispersal of cotton seeds. *American Naturalist* 100: 199-210.
- Stephens, S.G. 1967. Evolution under domestication of the New World cottons (*Gossypium* spp). *Ciência e Cultura (São Paulo)* 19: 118-134.
- Stewart, J.McD. 1995. Potential for crop improvement with exotic germplasm and genetic engineering. Pp. 313-327 in *Challenging the Future: Proceedings of the World Cotton Research Conference-1*, Brisbane, Australia, 13-17 February 1994 (G.A. Constable and N.W. Forrester, eds.). CSIRO, Melbourne.
- Stewart, J.M., and C.L. Hsu. 1978. Hybridization of diploid and tetraploid cottons through *in ovulo* embryo culture. *Journal of Heredity* 69: 404-408.
- Stewart, J.M., and M. Stanton. 1988. Screening for resistance in the Asiatic cotton. Pp. 43-44 in *Proceedings of the 1988 Cotton Research Meeting: Research Aimed at Managing the Cotton Plant. Proceedings of a Conference*, Helena, Arkansas, February 16, 1988 (D.M. Oosterhuis, ed.). Arkansas Agricultural Experimental Station, Special Report 132. Fayetteville, Arkansas, USA.
- Stewart, J.McD., L.A. Craven and J.F. Wendel. 1997. A new Australian species of *Gossypium*. Page 448 in *Proceedings – Beltwide Cotton Conferences*, New Orleans, Louisiana, 7-10 January 1997. National Cotton Council of America, Memphis, Tennessee, USA.
- Stipanovic, R.D., L.S. Puckhaber, A.A. Bell, A.E. Percival and J. Jacobs. 2005. Occurrence of (+)- and (-)-gossypol in wild species of cotton and in *Gossypium hirsutum* var. *marie-galante* (Watt) Hutchinson. *Journal of Agricultural and Food Chemistry* 53: 6266-6271.
- Sullivan, J.L., J.T. Huber, R.L. Price and J.M. Harper. 1993a. Comparison of digestibility, nutritive value, and storage characteristics of different forms of cottonseed in diets fed to lactating dairy cows. *Journal of Animal Science* 71: 2837-2842.
- Sullivan, J.L., J.T. Huber and J.M. Harper. 1993b. Performance of dairy cows fed short-staple, Pima, and cracked Pima cottonseed and feed characteristics. *Journal of Dairy Science* 76: 3555-3561.
- Sun, Y., X. Zhang, C. Huang, X. Guo and Y. Nie. 2006. Somatic embryogenesis and plant regeneration from different wild diploid cotton (*Gossypium*) species. *Plant Cell Reports* 25: 289-296.
- Sunilkumar, G., L.M. Campbell, L. Puckhaber, R.D. Stipanovic and K.S. Rathore. 2006. Engineering cottonseed for use in human nutrition by tissue-specific reduction of toxic gossypol. *Proceedings of the National Academy of Sciences of the United States of America* 103: 18054-18059.
- Susín, J., M. Clemente and J.E. Hernández-Bermejo. 1988. Valoración de caracteres taxonómicos procedentes de estructuras de origen epidérmico para la diferenciación intraespecífica en *Gossypium hirsutum* L. *Agronomie* 8: 61-70.
- Tanda, A.S. 1984. Bee pollination increases yield of two interplanted varieties of Asiatic cotton (*Gossypium arboreum* L.). *American Bee Journal* 124: 539-540.
- Tothill, J.C., J.J. Mott and P. Gillard. 1982. Pasture weeds of the tropics and subtropics with special reference to Australia. Pp. 403-427 in W. Holzner and M. Numata, eds., *Biology and Ecology of Weeds*. Dr W. Junk Publishers, The Hague.

- Tsigouri, A., M. Passaloglou-Katrali and O. Sabatakou. 2004. Palynological characteristics of different unifloral honeys from Greece. *Grana* 43: 122-128.
- Tumbelaka, L.I., O. Slayden and F. Stormshak. 1994. Action of a cyclopropanoid fatty acid on the corpus luteum of pregnant and nonpregnant ewes. *Biology of Reproduction* 50: 253-257.
- Ulloa, M., J.McD. Stewart, E.A. García-C., S. Godoy-A., A. Gaytan-M. and N.S. Acosta. 2006. Cotton genetic resources in the western states of Mexico: *In situ* conservation status and germplasm collection for *ex situ* preservation. *Genetic Resources and Crop Evolution* 53: 653-668.
- Umbeck, P., G. Johnson, K. Barton and W. Swain. 1987. Genetically transformed cotton (*Gossypium hirsutum* L.) plants. *Bio/Technology* 5: 263-266.
- Umbeck, P.F, K.A. Barton, E.V. Nordheim, J.C. McCarty, W.L. Parrot and J.N. Jenkins. 1991. Degree of pollen dispersal by insects from a field test of genetically engineered cotton. *Journal of Economic Entomology* 84: 1943-1950.
- Unruh, B.L., and J.C. Silvertooth. 1996. Comparisons between an upland and a Pima cotton cultivar: II. Nutrient uptake and partitioning. *Agronomy Journal* 88: 589-595.
- Unruh, B.L., and J.C. Silvertooth. 1997. Planting and irrigation termination timing effects on the yield of upland and Pima cotton. *Journal of Production Agriculture* 10: 74-79.
- Vaissière, B.E. 1991. Honey bee stocking rate, pollinator visitation, and pollination effectiveness in upland cotton grown for hybrid seed production. *Acta Horticulturae* 288: 359-363.
- Vaissière, B.E., and S.B. Vinson. 1994. Pollen morphology and its effect on pollen collection by honey bees, *Apis mellifera* L. (Hymenoptera: Apidae), with special reference to upland cotton, *Gossypium hirsutum* L. (Malvaceae). *Grana* 33: 128-138.
- Vaissière, B.E., J.O. Moffett and G.M. Loper. 1984. Honey bees as pollinators for hybrid cotton seed production on the Texas High Plains. *Agronomy Journal* 76: 1005-1010.
- Van Deynze, A.E., F.J. Sundstrom and K.J. Bradford. 2005. Pollen-mediated gene flow in California cotton depends on pollinator activity. *Crop Science* 45: 1565-1570.
- Vollesen, K. 1987. The native species of *Gossypium* (Malvaceae) in Africa, Arabia and Pakistan. *Kew Bulletin* 42: 337-349.
- Vreeland Jr., J.M. 1999. The revival of colored cotton. *Scientific American* 280(4): 112-118.
- Wäckers, F.L., and T.M. Bezemer. 2003. Root herbivory induces an above-ground indirect defence. *Ecology Letters* 6: 9-12.
- Wäckers, F.L., and C. Bonifay. 2004. How to be sweet? Extrafloral nectary allocation by *Gossypium hirsutum* fits optimal defense theory predictions. *Ecology* 85: 1512-1518.
- Waghmare, V.N., J. Rong, C.J. Rogers, G.J. Pierce, J.F. Wendel and A.H. Paterson. 2005. Genetic mapping of a cross between *Gossypium hirsutum* (cotton) and the Hawaiian endemic, *Gossypium tomentosum*. *Theoretical and Applied Genetics* 111: 665-676.

- Wakelyn, P.J., N.R. Bertoniere, A.D. French, D.P. Thibodeaux, B.A. Triplett, M.-A. Rousselle, W.R. Goynes Jr., J.V. Edwards, L. Hunter, D.D. McAlister and G.R. Gamble. 2007a. Cotton Fiber Chemistry and Technology. CRC Press, Boca Raton, Florida, USA. 176 pp.
- Wakelyn, P.J., N.R. Bertoniere, A.D. French, D.P. Thibodeaux, B.A. Triplett, M.-A. Rousselle, W.R. Goynes Jr., J.V. Edwards, L. Hunter, D.D. McAlister and G.R. Gamble. 2007b. Cotton fibers. Pp. 521-666 in M. Lewin, ed., Handbook of Fiber Chemistry, 3rd ed. CRC Press, Boca Raton, Florida, USA.
- Waller, G.D., F.D. Wilson and J.H. Martin Jr. 1981. Influence of phenotype, season and time of day on nectar production in cotton. *Crop Science* 21: 507-511.
- Waller, G.D., J.O. Moffett, G.M. Loper and J.H. Martin. 1985. Evaluation of honey bees foraging activity and pollination efficacy for male-sterile cotton. *Crop Science* 215: 211-214.
- Wang, G.-L., J.-M. Dong and A.H. Paterson. 1995. The distribution of *Gossypium hirsutum* chromatin in *G. barbadense* germplasm: Molecular analysis of introgressive plant breeding. *Theoretical and Applied Genetics* 91: 1153-1161.
- Wang, K., X. Song, Z. Han, W. Guo, J.Z. Yu, J. Sun, J. Pan, R.J. Kohel and T. Zhang. 2006. Complete assignment of the chromosomes of *Gossypium hirsutum* L. by translocation and fluorescence *in situ* hybridization mapping. *Theoretical and Applied Genetics* 113: 73-80.
- Wang, K., W. Guo and T. Zhang. 2007. Detection and mapping of homologous and homoeologous segments in homoeologous groups of allotetraploid cotton by BAC-FISH. *BMC Genomics* 8: 178, doi: 10.1186/1471-2164-8-178. (8 pp.)
- Wang, K., B. Guan, W. Guo, B. Zhou, Y. Hu, Y. Zhu and T. Zhang. 2008. Completely distinguishing individual A-genome chromosomes and their karyotyping analysis by multiple bacterial artificial chromosome-fluorescence *in situ* hybridization. *Genetics* 178: 1117-1122.
- Wang, N.G., L.F. Zhou, M.H. Guan and H.P. Lei. 1987. Effect of (-)- and (+)-gossypol on fertility in male rats. *Journal of Ethnopharmacology* 20: 21-24.
- Watanabe, S., T. Sano, H. Kamada and H. Ezura. 2006. Reducing gene flow from pollen dispersal of genetically modified plants in special screened greenhouses. *Plant Biotechnology* 23: 129-135.
- Watson, A.M. 1983. Agricultural Innovation in the Early Islamic World: The Diffusion of Crops and Farming Techniques 700-1100. Cambridge University Press, Cambridge, England, UK. 272 pp.
- Weber, E. 2003. Invasive Plant Species of the World: A Reference Guide to Environmental Weeds. CABI Publishing, Wallingford, UK. 548 pp.
- Wendel, J.F., and R.C. Cronn. 2003. Polyploidy and the evolutionary history of cotton. *Advances in Agronomy* 78: 139-186.
- Wendel, J.F., and R.G. Percy. 1990. Allozyme diversity and introgression in the Galapagos endemic *Gossypium darwinii* and its relationship to continental *G. barbadense*. *Biochemical Systematics and Ecology* 18: 517-528.
- Wendel, J.F., P.D. Olson and J.M. Stewart. 1989. Genetic diversity, introgression and independent domestication of Old World cultivated cottons. *American Journal of Botany* 76: 1795-1806.

- Wendel, J.F., C.L. Brubaker and A.E. Percival. 1992. Genetic diversity in *Gossypium hirsutum* and the origin of upland cotton. *American Journal of Botany* 79: 1291-1310.
- Wendel, J.F., R. Rowley and J.McD. Stewart. 1994. Genetic diversity in and phylogenetic relationships of the Brazilian endemic cotton, *Gossypium mustelinum* (Malvaceae). *Plant Systematics and Evolution* 192: 49-59.
- Westengen, O.T., Z. Huamán and M. Heun. 2005. Genetic diversity and geographic pattern in early South American cotton domestication. *Theoretical and Applied Genetics* 110: 392-402.
- Wetzel, C.L.R., and W.A. Jensen. 1992. Studies of pollen maturation in cotton: The storage reserve accumulation phase. *Sexual Plant Reproduction* 5: 117-127.
- Whitmore, T.M., and B.L. Turner II. 2002. *Cultivated Landscapes of Middle America on the Eve of Conquest*. Oxford University Press, New York. 338 pp.
- Wilkins, T.A., K. Rajasekaran and D.M. Anderson. 2000. Cotton biotechnology. *Critical Reviews in Plant Sciences* 19: 511-550.
- Wilkins, T.A., R. Mishra and N.L. Trolinder. 2004. *Agrobacterium*-mediated transformation and regeneration of cotton. *Journal of Food, Agriculture & Environment* 2: 179-187.
- Wise, R.R., G.F. Sassenrath-Cole and R.G. Percy. 2000. A comparison of leaf anatomy in field-grown *Gossypium hirsutum* and *G. barbadense*. *Annals of Botany* 86: 731-738.
- Wu, J., X. Luo, Z. Wang, Y. Tian, A. Liang and Y. Sun. 2008. Transgenic cotton expressing synthesized scorpion insect toxin *AaHIT* gene confers enhanced resistance to cotton bollworm (*Heliothis armigera*) larvae. *Biotechnology Letters* 30: 547-554.
- WWF and IUCN. 1997. *Centres of Plant Diversity: Volume 3, The Americas*. IUCN Publications Unit, Cambridge, England, UK. 562 pp.
- Xanthopoulos, F.P., and U.E. Kechagia. 2000. Natural crossing in cotton (*Gossypium hirsutum* L.). *Australian Journal of Agricultural Research* 51: 979-983.
- Yannai, S., and D. Bensal. 1983. Gossypol in cottonseed products: Toxicology and inactivation. *Archives of Toxicology* 53 (Suppl. 6): 167-174.
- Youssef, Y.A., and A.T. Mankarios. 1974. Studies on the rhizosphere mycoflora of broad bean and cotton. *Mycopathologia* 54: 173-180.
- Zhang, B.-H., X.-P. Pan, T.-L. Guo, Q.-L. Wang and T.A. Anderson. 2005. Measuring gene flow in the cultivation of transgenic cotton (*Gossypium hirsutum* L.). *Molecular Biotechnology* 31: 11-20.
- Zhang, D.-Y., T.-Z. Zhang, Z.-Q. Sang and W.-Z. Guo. 2007. Comparative development of lint and fuzz using different cotton fiber-specific developmental mutants in *Gossypium hirsutum*. *Journal of Integrative Plant Biology* 49: 1038-1046.
- Zhang, H.-B., Y. Li, B. Wang and P.W. Chee. 2008. Recent advances in cotton genomics. *International Journal of Plant Genomics* 2008: Article ID 742304 (20 pp.)

- Zhang, J., and J.McD. Stewart. 1997. Hybridization of new Australian *Gossypium* species (section *Grandicalyx*) with cultivated tetraploid cotton. Pp. 487-490 in Proceedings – Beltwide Cotton Conferences, New Orleans, Louisiana, 7-10 January 1997. National Cotton Council of America, Memphis, Tennessee, USA.
- Zhang, T.Z., and J.J. Pan. 1999. Hybrid seed production in cotton. Pp. 149-184 in A.S. Basra, ed., Heterosis and Hybrid Seed Production in Agronomic Crops. Haworth Press/Food Production Press, New York.
- Zhu, S.-W., P. Gao, J.-S. Sun, H.-H. Wang, X.-M. Luo, M.-Y. Jiao, Z.-Y. Wang and G.-X. Xia. 2006. Genetic transformation of green-colored cotton. *In Vitro Cellular & Developmental Biology – Plant* 42: 439-444.
- Zinn, R.A. 1995. Characteristics of digestion of linted and lint-free cottonseed in diets for feedlot cattle. *Journal of Animal Science* 73: 1246-1250.

QUESTIONNAIRE TO RETURN TO THE OECD

This is one of a series of OECD Consensus Documents that provide information for use during regulatory assessment of particular micro-organisms, or plants, developed through modern biotechnology. The Consensus Documents have been produced with the intention that they will be updated regularly to reflect scientific and technical developments.

Users of Consensus Documents are invited to submit relevant new scientific and technical information, and to suggest additional related areas that might be considered in the future.

The questionnaire is already addressed (see reverse). **Please mail or fax this page (or a copy) to the OECD, or send the requested information by E-mail:**

**OECD Environment Directorate
Environment, Health and Safety Division
2, rue André-Pascal
75775 Paris Cedex 16, France**

**Fax: (33-1) 45 24 16 75
E-mail: ehscont@oecd.org**

For more information about the Environment, Health and Safety Division and its publications (most of which are available electronically at no charge), consult <http://www.oecd.org/ehs/>

- =====
1. Did you find the information in this document useful to your work?
 Yes No

 2. What type of work do you do?
 Regulatory Academic Industry Other (please specify)

 3. Should changes or additions be considered when this document is updated?

 4. Should other areas related to this subject be considered when the document is updated?

Name:..... Institution or company:..... Address:..... City: Postal code: Country:..... Telephone: Fax: E-mail: Which Consensus Document are you commenting on?.....
--

FOLD ALONG DOTTED LINES AND SEAL

PLACE STAMP HERE

**OECD Environment Directorate
Environment, Health and Safety Division
2, rue André Pascal
75775 Paris Cedex 16
France**
