Sustainable Development and Biodiversity 13

K.G. Ramawat
M.R. Ahuja *Editors*

Fiber Plants

Biology, Biotechnology and Applications

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Kishan Gopal Ramawat
Botany Department, M.L. Sukhadia University, Udaipur, Rajasthan, India

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Editors
K.G. Ramawat
Botany Department
M.L. Sukhadia University
Udaipur, Rajasthan
India

M.R. Ahuja
Genetics and Biotechnology
Zobel Forestry Associates
New Paltz, NY
USA

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Preface

Fiber plants have been integral part of the human society. Fiber and subsequently fabric preparation was associated with rise and fall of various civilizations as well as considered as a parameter of living standards. Cultivation of fiber crops is as old as human civilization. Acceleration in population growth, reduction in cultivable land, and availability of freshwater for irrigation associated with climate change have profound effects for the capability of agriculture to meet the world's demands for food, feed, fiber, and fuel. Success depends on the recognition and exploit of existing molecular techniques, finding new sources as well as the increasing development of farming systems that use saline water and integrate nutrient flows.

The productivity of fiber crops, worldwide, is severely hampered by the prevalence of pests, weeds, and pathogens apart from various environmental factors. Several beneficial agronomic traits, viz. early maturity, improved fiber quality, and heat tolerance, have been successfully incorporated into fiber crops by employing conventional hybridization and mutation breeding.

Now, new advances in biotechnology are making it possible to develop plants that contain new genes which could not be introduced by sexual means. These advances in genetic engineering offer great new opportunities for improvement and sustainable use of fiber crops.

Fiber plants: Biology, biotechnology, and applications are presented with an aim to provide information about resources, their utilization, and technology available for their improvement. The purpose of this book is to assess the potential effects of biotechnological approaches particularly genetic modification on present scenario of fiber crop cultivation and improved production. The topics covered include biology, biotechnology, genomics, and applications of fiber crops such as cotton, flax, jute, and banana. The proposed book is to provide comprehensive and broad subject-based reviews, useful for students, teachers, researchers, and all others interested in the field. The field has been kept wide and general to accommodate the wide-ranging topics. How biotechnology can affect and solve the problems of fiber crops has been presented by world's leading scientists and expert of the field. This book will be useful to agriculturists, biotechnologists, botanists, industrialists, and those governments involved in planning of fiber crop cultivation.

Udaipur, India K.G. Ramawat
New Paltz, NY, USA M.R. Ahuja

Contents

Contributors

M.R. Ahuja New Paltz, NY, USA

David M. Anderson Dow AgroSciences LLC, Phytogen Seed Company, Corcoran, CA, USA

Kumar Anupam Physical Chemistry, Pulping and Bleaching Division, Central Pulp and Paper Research Institute, Saharanpur, Uttarpradesh, India

Saikat Kumar Basu Department of Biological Sciences, University of Lethbridge, Lethbridge, AB, Canada

Vimlesh Bist Physical Chemistry, Pulping and Bleaching Division, Central Pulp and Paper Research Institute, Saharanpur, Uttarpradesh, India

Julio Bruna Food Packaging Laboratory, Department of Food Science and Technology, Faculty of Technology, University of Santiago de Chile, Estación Central, Santiago, Chile; Center for the Development of Nanoscience and Nanotechnology (CEDENNA), University of Santiago de Chile, Estación Central, Santiago, Chile

William Cetzal-Ix Instituto Tecnológico de Chiná, Campeche, Mexico

Debajeet Das Division of Crop Improvement, Biotechnology Unit, ICAR-Central Research Institute for Jute and Allied Fibres (CRIJAF), Nilganj, Barrackpore, Kolkata, West Bengal, India

Rodrigo Duno de Stefano Herbario CICY, Centro de Investigación Científica de Yucatán, A. C. (CICY), Mérida, Mexico

Chandrakanth Emani Department of Biology, Western Kentucky University-Owensboro, Owensboro, KY, USA

María J. Galotto Food Packaging Laboratory, Department of Food Science and Technology, Faculty of Technology, University of Santiago de Chile, Estación Central, Santiago, Chile; Center for the Development of Nanoscience and

Nanotechnology (CEDENNA), University of Santiago de Chile, Estación Central, Santiago, Chile

Benjamin P. Graham Department of Plant and Microbial Biology, North Carolina State University, Raleigh, NC, USA

Abel Guarda Food Packaging Laboratory, Department of Food Science and Technology, Faculty of Technology, University of Santiago de Chile, Estación Central, Santiago, Chile; Center for the Development of Nanoscience and Nanotechnology (CEDENNA), University of Santiago de Chile, Estación Central, Santiago, Chile

Candace H. Haigler Department of Crop Science, North Carolina State University, Raleigh, NC, USA; Department of Plant and Microbial Biology, North Carolina State University, Raleigh, NC, USA

Pran Gobinda Karmakar Biotechnology Unit, Division of Crop Improvement, ICAR-Central Research Institute for Jute and Allied Fibres (CRIJAF), Nilganj, Barrackpore, Kolkata, West Bengal, India

Yasuo Kato Biotechnology Research Center and Department of Biotechnology, Toyama Prefectural University, Imizu, Toyama, Japan

Takao Kishimoto Biotechnology Research Center and Department of Biotechnology, Toyama Prefectural University, Imizu, Toyama, Japan

Priti Shivhare Lal Physical Chemistry, Pulping and Bleaching Division, Central Pulp and Paper Research Institute, Saharanpur, Uttarpradesh, India

Nur Alam Mandal Division of Crop Improvement, Biotechnology Unit, ICAR-Central Research Institute for Jute and Allied Fibres (CRIJAF), Nilganj, Barrackpore, Kolkata, West Bengal, India

Taiji Nomura Biotechnology Research Center and Department of Biotechnology, Toyama Prefectural University, Imizu, Toyama, Japan

Shinjiro Ogita Biotechnology Research Center and Department of Biotechnology, Toyama Prefectural University, Imizu, Toyama, Japan; Department of Life Sciences, Faculty of Life and Environmental Sciences, Prefectural University of Hiroshima, Shoubara, Japan

Arun K. Patra Department of Textile Chemistry, The Technological Institute of Textile and Sciences, Bhiwani, India

Kanniah Rajasekaran USDA-ARS Southern Regional Research Center, New Orleans, LA, USA

K.G. Ramawat Badgaon, Udaipur, India

Francisco Rodríguez Food Packaging Laboratory, Department of Food Science and Technology, Faculty of Technology, University of Santiago de Chile, Estación

Central, Santiago, Chile; Center for the Development of Nanoscience and Nanotechnology (CEDENNA), University of Santiago de Chile, Estación Central, Santiago, Chile

Hamidou F. Sakhanokho Thad Cochran Southern Horticultural Laboratory, USDA-ARS, Poplarville, MS, USA

Debabrata Sarkar Division of Crop Improvement, Biotechnology Unit, ICAR-Central Research Institute for Jute and Allied Fibres (CRIJAF), Nilganj, Barrackpore, Kolkata, West Bengal, India

Pratik Satya Division of Crop Improvement, Biotechnology Unit, ICAR-Central Research Institute for Jute and Allied Fibres (CRIJAF), Nilganj, Barrackpore, Kolkata, West Bengal, India

Arvind Kumar Sharma Physical Chemistry, Pulping and Bleaching Division, Central Pulp and Paper Research Institute, Saharanpur, Uttarpradesh, India

Nagendra Kumar Singh ICAR-National Research Centre on Plant Biotechnology (NRCPB), Pusa, New Delhi, India

Solichin Solichin Department of Mechanical Engineering, Universitas Negeri Malang, Malang, East Java, Indonesia

Michael R. Stiff Department of Crop Science, North Carolina State University, Raleigh, NC, USA

Heru Suryanto Department of Mechanical Engineering, Universitas Negeri Malang, Malang, East Java, Indonesia

J. Rich Tuttle Department of Crop Science, North Carolina State University, Raleigh, NC, USA

Uun Yanuhar Biotechnology Laboratory, Department of Fisheries and Marine Science, University of Brawijaya, Malang, Indonesia

Part I
Biology

Chapter 1
Fiber Plants: An Overview

K.G. Ramawat and M.R. Ahuja

Abstract Fiber cells are present in all plants with varied shape, sizes, and composition. Fiber crops are source of commercially exploited fibers since beginning of civilization and fiber/fabric consumption is used as indicator of civilization of society. Much of the need of rural populations for fiber is met with material harvested from wild. That is of great concern for biodiversity conservation and sustainable utilization of resources. New technologies are used to understand the fiber development and formation, diversity of plants, and consequently improvement strategies are developed using plant cell cultures and genetic engineering. New technologies are being developed to obtain fiber and fiber products from sources as diverse as agriculture waste, baggasses, vegetable and fruit processing, and other industrial waste. Plant fibers are finding new and diverse applications and usage like dietary fibers, biodegradable films in food industry, natural fiber composites, biopolymers, biofuels, and pharmaceuticals besides improved textiles. This article summarizes the scenario about new technologies and sustainable exploitation of fiber plants and their products.

Keywords Fiber plants · Biotechnology · Natural fiber composites · Biofuels · Cotton · Linen · Flax

1.1 Introduction

Increase in population, particularly in developing countries has forced us to develop new technologies to meet the demand for food and clothes; fiber comes second to food. Natural fiber is a preferred material for fabric. Textile fiber is a generic term

K.G. Ramawat (✉)
221, Landmark Treasure Town, Badgaon, Udaipur 313011, India
e-mail: kg_ramawat@yahoo.com

M.R. Ahuja
60, Shivertown Road, New Paltz, NY 12561, USA
e-mail: mrahuja@hotmail.com

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for any type of fiber (natural, synthetic, or artificial) that form the basis of a textile product (yarns, fabrics, knits, nonwovens, etc.) and having a length at least hundred times greater than its diameter. Viscose fiber is obtained by chemical modification of cotton. Cotton, flax, ramie, jute, sun hemp, hemp, and kenaf are commonly used and commercially exploited fibers. When we talk about plants, basic questions come to our mind are sustainable resource utilization, conservation of germplasm of fiber plants, efficient use of new technologies to increase quality and quantity of fiber, and to make life of farmers better.

Photosynthesis is the largest photochemical reaction on the planet Earth and $\sim$40 % of the carbon assimilated is used to produce cellulose, one of the main components of plant cell walls. Much of this cellulose is accumulated in the form of plant fibers. Cellulose may be present in pure form in plants, but it is generally associated by hemicelluloses, lignins, and comparably small amounts of soluble compounds (Wondraczek and Heinze 2015). Cellulose is the main component of wood (40–50 wt %), baggasses (35–45 wt%), bamboo (40–55 wt%), straw (40–50 wt%), flax (70–80 wt%), hemp (75–80 wt%), jute (60–65 wt%), kapok (70–75 wt%), and ramie (70–75 wt%). As compared to this cotton is a pure cellulose fiber containing more than 90 wt% (Hon 1996). Cellulose is accumulated not only in fibers like cotton but also in tree woods (1,750,000 kilo tons, kt), bamboo (10,000 kt), cotton linters (18,450 kt), jute (2300 kt), flax (830 kt), sisal (378 kt), hemp (214 kt), and ramie (100 kt) in 1 year (Eichhorn et al. 2001). Biotechnological methods and genetic engineering used to improve the quality of fiber are described in this book in Chap. 8.

Fibers are present in all plants, and when commercially exploited, the plants become fiber crops. Cellulose is a homoglycan constituted by β (1 → 4) linked D-glucopyranose units. Cellulose is a high molecular weight polysaccharide made up of repeating cellobiose units producing a linear chain in which both intra-chain and inter-chain molecular hydrogen bonds occur to link the chains (Donato et al. 2015), which in turn produce microfibrils, matrices, and multilayered cell walls (Fig. 1.1). These molecules are arranged very systematically and symmetrically in the supramolecular structures, from small initial fibrils (with a length between 1.5 and 3.5 nm), microfibrils (between 10 and 30 nm), to macrofibrillar bands whose length can be on the order of several hundred nm (Klemm et al. 2005). The process of polymerization and structures formation varies depending on the plant source. Plant fibers from different sources vary in length, color, composition, strength, durability, and resistance to water. Cellulosic fibers are more resilient than lingo-cellulosic fibers. Wood fibers are relatively large fibers. During secondary wall formation, lignin is deposited over the primary cellulose wall making the fiber thick, hard, and strong. Cotton fiber is an elongation of seed coat cells and an example of one of the longest cells (Hill 1972). These physical, chemical, morphological, and anatomical properties of plant fibers are discussed in Chap. 12 in this book in order to assess their potential toward production of pulp and paper.

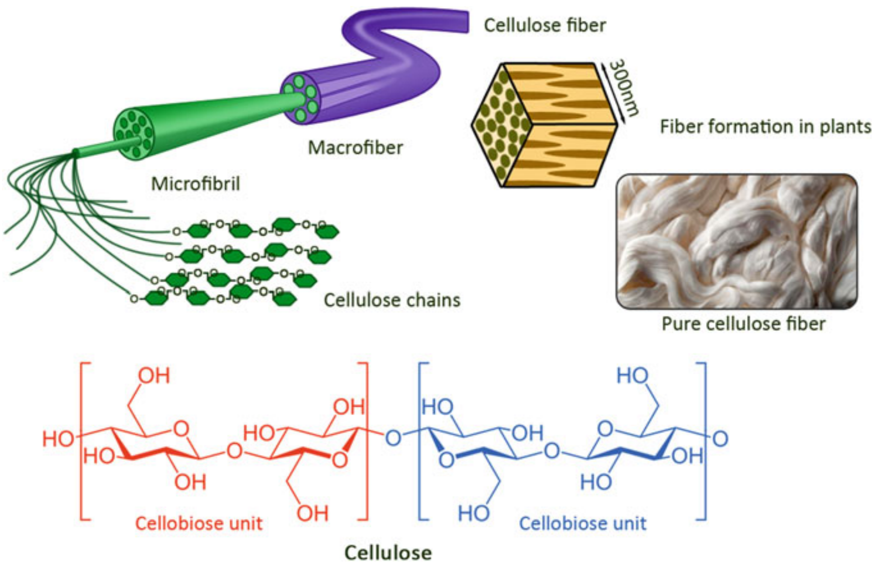

Fig. 1.1 Fiber formation from cellulose chains and structure of cellulose

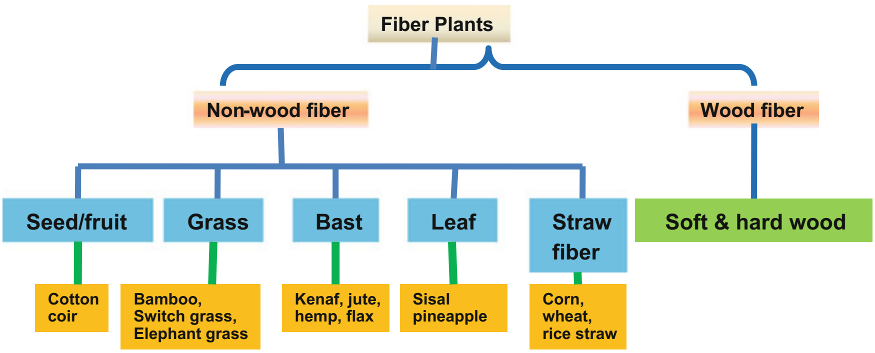

Fig. 1.2 Different sort of fibers obtained from plants

Fibers are distributed all over the plant from roots to leaf, stem and fruits and seeds. These fibers are harvested from the plant part for commercial and/or local usage. Now we know more and more about health beneficial effects of fiber present in fruits, vegetables, and grains, known as dietary fibers. Fibers are classified as soft or hard fibers, surface fibers, or endogenous fibers. Natural fibers are processed to make them suitable for different purposes. Different types of fibers obtained from plants are presented in Fig. 1.2.

1.2 Fiber and Fabrics from Historical Perspective

Fiber is fabric of civilization and comes after requirement of food. Fiber plants are useful to humans in many ways. These include leaves to cover the body; loosely woven cloth and finally to very fine cotton fabric in India (~2300 BCE); linen fabric in Egypt (~1300 BCE); and silk in China (1500 BCE) are glaring examples of rapid development of craft for fiber isolation and weaving in earlier civilizations (Pandey and Gupta 2003; Good et al. 2009). Application of modern tools and techniques of molecular biology and carbon dating resulted in determination of precise nature of plant materials used during ancient civilizations which is revealed by following examples. A collection of plant-derived rope and fabric samples obtained from the 'Christmas Cave' (a cave in the Qidron Valley near the Dead Sea and Qumran), primarily showed the presence of the DNA from flax (*Linum usitatissamum* L.). These samples also contained a trace of hemp (*Cannabis sativa* L.) DNA. These works of art from the Christmas Cave were from Roman times. Accelerator mass spectrometry (AMS) based on carbon (^{14}C) dating confirmed that the samples contained bits and pieces from both the Roman and Chalcolithic periods (Murphy et al. 2011). Similarly, excavations at the site of Kara Tepe in northwestern Uzbekistan made known evidence for the production of cotton (*Gossypium* sp.) in this region dated to ~300–500 CE (Brite and Marston 2013). These archaeobotanical remains help to understand the spread of Old World cotton production. Recently, analysis of a conserved structure of jute on a ceramic objet d'art from the site of Harappa showed its period about 2200–1900 BCE. Jute cloth was never identified in the Indus Valley Civilization at such an early period (Wright et al. 2012). Therefore, there are clear evidences that man had ample knowledge of fiber plants and learnt the fabric production during the early civilization.

1.3 Major Fiber Plants

Cotton, jute, and linen are principal fiber crops, and the world production share of cotton and jute is presented in Figs. 1.3 and 1.4. Current cotton production (~120 Million bales, MB) spreads throughout the world with China, USA and India are major producers while jute (~3.3 MT) is mainly produced in India and Bangladesh. France is major producer of hemp (65,00 Million Tons) and flax (113,000 Million Tons) (Holbery and Houston 2006; http://faostat3.fao.org/browse/Q/QC/E). Cotton has many species and cultivar varieties like Egyptian cotton (*Gossypium barbadense*), upland cotton (*G. hirsutum*), Levant cotton (*G. herbaceum*), and tree cotton (*G. arboreum*) due to cultivation in different continents since time immemorial while most of the bast fiber crops have limited geographical distribution and cultivars such flax (*Linum usitattisimum*), jute (*Corchorus*

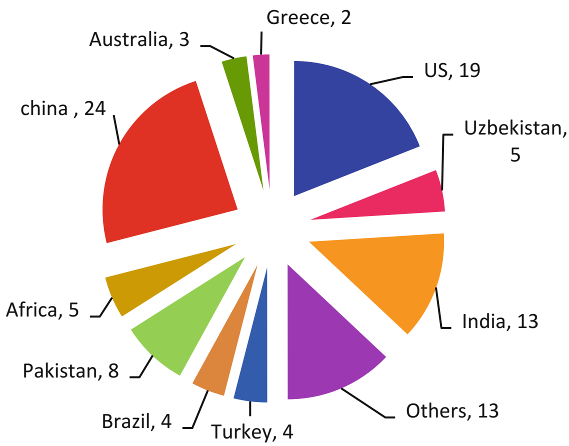

Fig. 1.3 Production share of major cotton producing countries in the world, based on FAO

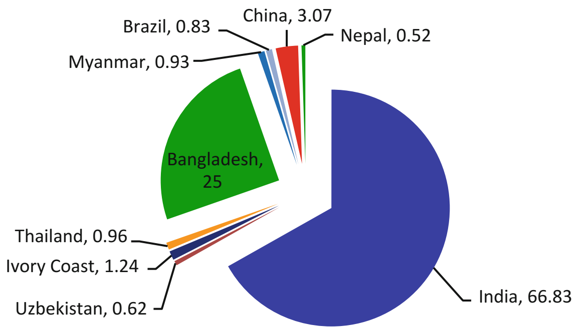

Fig. 1.4 Production share of major jute producing countries in the world, based on FAO

capsularis, *C.olitorius*), ramie (*Boehmeria nivea*), and kenaf (*Hibiscus cannabinus*). Details of varieties, cultivation practices, processing and distribution in the world are beyond scope of this paper but can be viewed in books on economic botany (Hill 1972; Levetin and McMahon 2008). Several Chaps. (2, 5–10) in this book are devoted about applications of modern tools to improve the quality and the plants (cotton, linen, jute, and bamboo) and the fiber obtained from these plants.

1.4 Lesser Known Fiber Plants

Several hundred plant species in different geographical regions of the world are used as source of various types of finished or unfinished fibers and collected from wild. Fiber-yielding weeds hold the second position after edible weeds in their economic importance. In almost all parts of the world, local agriculturists use various types of fiber plants for their daily need to tie their agricultural produce, fuel wood, packaging small households and straw, and women prepare household articles from fiber obtained from such plants (Anonymous 2010; Isaza et al. 2013; Sahu et al. 2013; Pandey and Gupta 2003). The fiber production at local/regional level contributes significantly to the economy of the region in various ways, including agricultural implements, clothing, and products for other household operations. Some of the chapters in this book describe some new promising fiber plants of Indonesia, Guatemala, Colombia, and Mexico (Chaps. 3, 4). Each region has long list of such fiber-yielding plants and is beyond the scope of this brief overview. A few chapters have been included in this book on such new plants and some examples of such plants are given in the Table 1.1. There is no taxonomic correlation between fiber-yielding plants and their families or geographical region. Similarly, fiber materials are obtained from herbs (*Agave*, *Ananas*, *Leptadenia*), shrubs (*Urtica*), climbers (*Cissampelos*), and tree species (*Bombax* spp.).

1.5 Biodiversity of Fiber Plants

Biodiversity is a contraction of the term 'biological diversity' and refers to the diversity of 'life.' In context to biodiversity of fiber plants, it implies to biodiversity in the region pertaining to number of plant species used for obtaining fiber and/or diverse germplasm within a genus or species. Information about wild plants used for obtaining fiber is sparse. Rural communities are completely dependent on forests for their day-to-day need of fiber-yielding plants (Anonymous 2010; Isaza et al. 2013; Sahu et al. 2013). Hence, it is not possible to estimate the number of species of fiber plants used by man throughout the globe. However, the number of plant species used for fibers are very large, e.g., in America over 1000, in the Philippines over 800, and in India over 450 species (representing 82 families and 273 genera). In India, presently eight species contribute as major cultivated fiber crops. Major families (with number of genera) contributing as fiber genetic resources are Malvaceae (63), Fabaceae (31), Arecaceae (25), Utricaceae (24), Tiliaceae (21), Sterculiaceae (21), and Asclepiadaceae (15) (Pandey and Gupta 2003). Continuous collection of plant material from wild without replenishing them results in loss of germplasm and biodiversity. Therefore, domestication of plants by developing appropriate techniques of cultivation, understanding their seed biology, and methods of propagation and conservation efforts are required to exploit these plants and developing sustainable agroecosystem. Effective use of biotechnological methods such as in vitro cryopreservation, DNA fingerprinting-based breeding system, micropropagation, and ecorestoration supports the in situ conservation which is need of hour for overexploited plants (Goyal et al. 2014, 2015).

Table 1.1 Lesser known fiber plant resources (based on Anonymous 2010; Sahu et al. 2013; Pandey and Gupta 2003)

Plant species	Family	Plant part	Usage/remarks
Ananas comosus (L.)Merr.	Bromeliaceae	Leaves	Ropes, fishing nets, strings, and fabrics
Agave cantula Roxb, *A. sisalana* Perrine *ex* Engelm	Agavaceae	Leaf	Making ropes, mats, twines, nets, cordage
Boehmeria nivea (L.) Gaud.	Urticaceae	Bast	Thread, cord, sacks, paper, gas mantles
Bombax ceiba L., *Ceiba pentandra* (L.) Gaertn.	Bombacaceae	Fruit inner wall	Filling pillow, mattresses
Calotropis procera (Ait.) Rox Br *Leptadenia pyrotechnica*	Asclepiadaceae	Stem bark	Ropes
Cannabis sativa L.	Cannabaceae	Stem bark	Textile industry; production of cordage; manufacturing Sailcloth; canvas goods
Cissampelos pariera L.	Menispermaceae	Stem	Ropes
Crotalaria juncea L.	Fabaceae	Stem bark	Fishing nets, gunny bags, coarse cloths and mattress
Desmodium elegans DC.	Fabaceae	Stem, bark	As rope
Erianthus arundinaceus (Retz.) Jesw.ex Heyne	Graminaceae	Leaf	Ropes, twine, paper
Erianthus munja (Roxb.) Jesw	Graminaceae	Leaf and stem	Baskets, mats, cordage
Furcaria foetida (L.) Haw.	Amaryllidaceae	Leaf	Mats, ropes, cordage
Helicteres isora L.	Sterculiaceae	Stem, bark	Ropes
Hibiscus cannabinus L.	Malvaceae	Stem bark	Ropes, mask, collar belt, carry bag
Musa textilis Nees	Musaceae	Leaf	Marine cordage, bags
Saccharum spontaneum L.	Poaceae	Leaf	Mats, ropes
Typha angustata Bory and Chaub.	Typhaceae	Leaf	Mats, ropes, basket
Urtica dioica L.	Urticaceae	Stem	Cordage, sacks

1.6 Biotechnological Approaches

Biotechnological tools and techniques applied to understand and improve the fiber and fiber plants are presented in Fig. 1.5. These include understanding the basic structure and function of genome of the fiber plants for obtaining various value-added products to uplift the socioeconomic status of the farmers. Development of technology for nanomaterials, new biomolecules, biosensors, enzymes, and biofuels

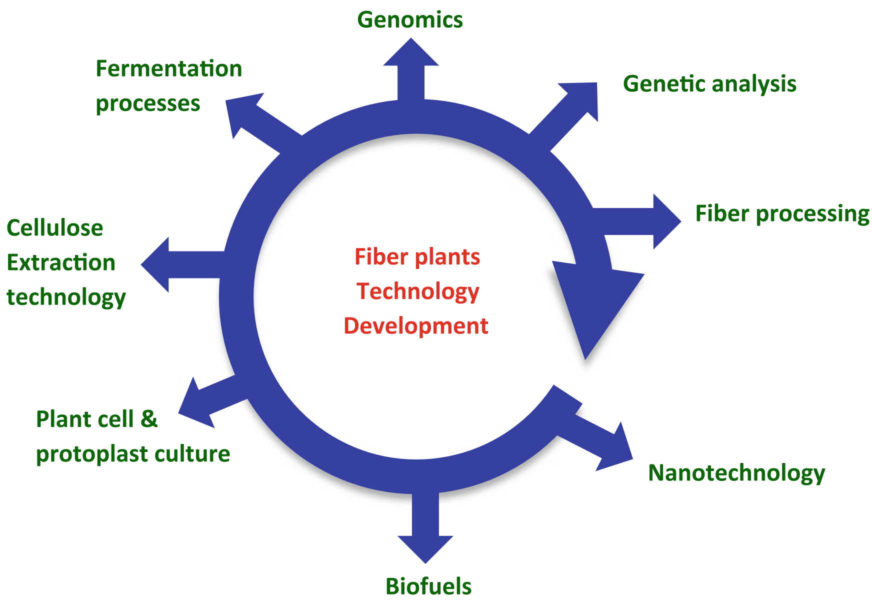

Fig. 1.5 Different technologies being developed using plant fibers and fiber plants

from various plant resources have economic and environmental consequences because of their renewable, biodegradable, and ecofriendly nature. Biotechnological inputs are explored to increase the quality and quantity of fibers in plants. Enzymes have replaced the chemicals used in the processing of fibers and preparation of fabric (see Chaps. 5 and 12). It is needless to mention that enzymes are economically sustainable and environmentally friendly reusable biomolecules (Radhakrishnan 2014). Toward the development of cheap fiber-based sensor, paper-based sensing devices do not require hardware or definite technical skill. The immobilization of biomolecules onto cellulose is a key step in the development of these sensing devices (Credou and Berthelot 2014). These are inexpensive, rapid, and user-friendly and therefore can easily used at diagnostic centers.

Biotechnological approaches like regeneration and micropropagation are gaining importance in past decades (Goyal et al. 2014, 2015). Somatic embryogenesis is not only a method of rapid multiplication but can also leads to improvement through genetic transformation. A few chapters on regeneration of cotton (Chap. 6), bamboo (Chap. 7) and transgenic cotton (Chaps. 8, 10) are included in this book where details of techniques and literature survey can be viewed. Plant cell and tissue regeneration, somatic embryogenesis, protoplast isolation, culture and fusion and cell suspension cultures, anther and microspore culture, and gene transfer and expression by genetic transformation in flax were presented in an excellent review by Millam et al. (2005). With the understanding of fiber development, the main objective of breeding fiber plants is to increase growth rate and gibberellins accumulation may lead to higher growth rate and fiber formation. In a model system, GA-2 oxidase enzyme production was blocked resulting in higher production of fiber material in tobacco plants (Dayan et al. 2010). Fiber based materials are used to develop newer technological material such as nanomaterials. Therefore, biotechnological inputs are making a dent not only in understanding process of fiber formation but also in its improvement and diversification of products produced to make the life more comfortable.

1.7 Applications of Fiber

A wide range of applications of fiber and fiber products are being developed because large quantities of agricultural by-products are available as renewable sources. Agro-based biofibers are very suitable for composite, biofuels, textile, pulp and paper manufacture because of their composition, properties, and structure. Additionally, they can also produce fuel, chemicals, enzymes, and food (Fig. 1.6). Agricultural residue from the cultivation of corn, wheat, rice, sorghum, barley, sugarcane, pineapple, banana, and coconut are the major sources of agro-based biofibers (Michelin et al. 2015; Reddy and Yang 2005). Natural fiber composites

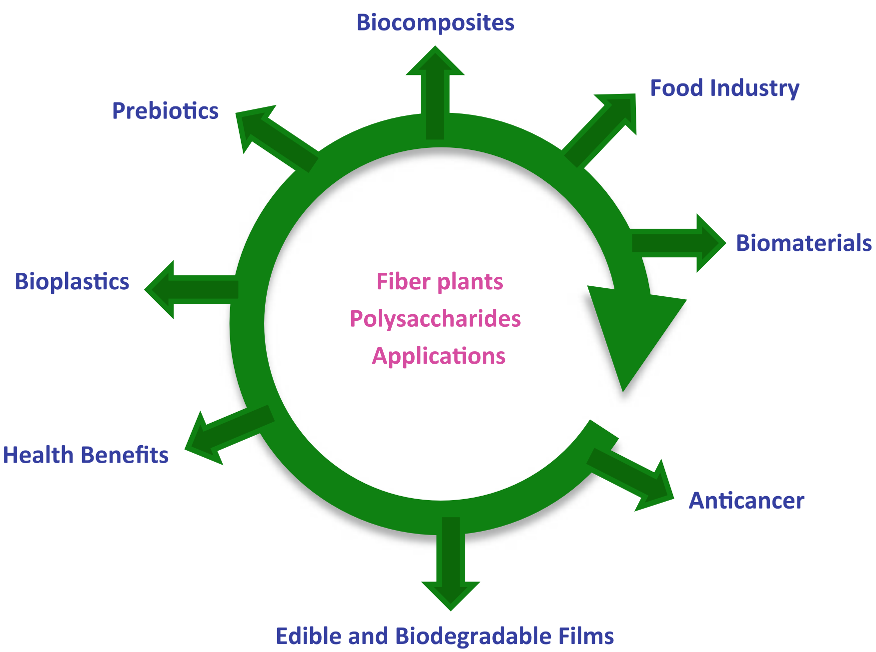

Fig. 1.6 Applications of plant fibers and their products

prepared from kenaf, hemp, flax, jute, and sisal with thermoplastic and thermoset matrices are finding way as automotive parts because of reductions in weight, cost, and CO_2 emission (Ashori 2008; Holbery and Houston 2006). Bioenergy and biomaterials obtained from fiber crops are considered as promising substitutes for conventional sources and fossil fuel, considering the increased concern about rapidly depletion of non-renewable resources and emission of carbon. As bioenergy and biomaterials raw material, fiber crops offer ecological advantages over conventional ones, such as carbon sequestration, energy savings, the reduction of greenhouse gases, and are renewable resources. However, other environmental factors such as acidifying the soil and eutrophication emissions should also be considered before advanced use of fiber crops (Fernandoa et al. 2015).

Plant residues available from industrial process like cane sugar production, paper mills, agricultural produce, seed oil production, vegetable and fruit production and processing waste, and cotton and other fiber waste are important sources of many products such as energy in the form of alcohol, fermentation products, new biomolecules for various usage including pharmaceuticals and several types of composites for industrial use (Costa et al. 2015; Donato et al. 2015; Reddy and Yang 2005). Cellulose-based biomaterials are being developed for human health and welfare as never drying wound healing membranes, various types of implants, and for tissue engineering (Wondraczek and Heinze 2015).

It is rightly stated that ‘you are what you eat’(Brüssow and Parkinson 2014). Eating foods rich in plant fiber promotes health by changing the composition and metabolic products of gut bacteria. The growing public awareness about nutrition and health care results in more intake of dietary fiber for their health beneficial properties (Whitney and Manore 2015). Therefore, there is requirement to identify newer sources of neutraceuticals and understand their mechanism of health benefit.

Polysaccharides from fibers in particular and plants in general, are valuable building blocks for preparation of composites or bioplastics. Cellulose nanofibers extracted from cereal straw have been used for reinforcing of polypropylene composites, for preparation of biocomposites for the production of earthquake resistant panels (Kalia et al. 2011). Various types of biocomposites prepared from natural fibers and their applications are discussed in Chap. 3 in this book. Ragauskas et al. (2006) discussed the various fiber and wood products, particularly use of hemicelluloses for biofuels production. Increasing percent use of biodiesel and ethanol in fossil fuel in the next decade requires the development of technology for their economic production from forest and agriculture waste. Carbohydrate-rich plant cell walls are the primary energy sink in plant biomass (Hisano et al. 2009). The major biofuel expenses involved are in the form of growth and harvest of biomass, pretreatment to breakdown cell walls, and lastly by saccharification and their conversion into biofuels (Rubin 2008). Conversion of woody biomass by enzymatic breakdown, particularly lignin molecules, into biofuel is a major challenge. Modification in lignin in transgenic alfalfa by down-regulating in each of six lignin biosynthetic enzymes resulted in improvement in fermentable sugar yields for biofuel production (Poovaiah et al. 2014; Chen and Dixon 2007). It is evident from the above account that applications of fiber and its products are as diverse as the fiber plants itself. These applications are at various stages of development and industrial processes based on these technologies will be available soon for the benefit of human health and environment.

1.8 Conclusions

In this chapter, we have presented a brief scenario of fiber crops from ancient civilization to modern technology of molecular biology and genomics. Newer applications of fibers in diverse fields such as health, composites, biodegradable films, biofuels, biopolymers, and pharmaceuticals are presented in brief. The major emphasis of present-day research is to find out alternatives for non-renewable resources and plants offer both, renewable resources and are environmental friendly too.

Efforts are required to understand the mechanism of fiber formation and elongation, control of genes involved in fiber elongation, conservation by in situ and ex situ techniques of germplasm resources of vast number of plants used by local communities, value-added products formation to uplift economic situation of local people, creation of inventory of such plants, and breeding of crops based on their evaluation on the basis of techniques of molecular biology. Diversification of products from fiber plants such as healthy biodegradation and edible biofilms, automotive components, new bioactive molecules for pharmaceutical industries, biopolymers and biofuels offers new avenues for the crops plants containing fiber and holds promise for better economic strengthening of agriculture-based communities, which is a major share of population of the world. This has also beneficial environmental consequences and less dependence on fossil fuel.

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Chapter 2
The Global Importance of Transgenic Cotton

David M. Anderson and Kanniah Rajasekaran

Abstract The origins of transgenic cotton are reviewed including the original objectives, early efforts to establish the technical capabilities, selection of initial traits for development, market place benefits, and global acceptance of the technology. Further consideration is given to cotton's place in the effort to meet the projected demands for food and fiber over the next 50-year horizon, traits and technologies under development, and the need for close public and private research collaboration in order to address the issues facing the world's farmers as they work to meet those demands. Impact of transgenic cotton on global economy, environment, genetic diversity, and safety is also highlighted.

Keywords Cotton · Transgenic cotton · Cotton traits · Global economy · Genetic diversity

2.1 Historical Perspective

In a book published in 1957 (Brown et al. 1957), James Bonner emphasized that significant problems would face the world's agricultural producers as they sought to keep pace with the needs of the growing population. First, James envisioned ongoing pressure on agricultural productivity and an elevation of the costs of production as a consequence of industrialization attracting more and more of the world's labor force at the expense of farm labor. Science and technology were posited as the most likely means of increasing overall farm output in order to produce the food (calories) and fiber required to feed and clothe the world's

D.M. Anderson
Dow AgroSciences LLC, Phytogen Seed Company, P.O. Box 787, 850 Plymouth Avenue, Corcoran, CA 93212-0787, USA

K. Rajasekaran (✉)
USDA-ARS Southern Regional Research Center, 1100 Robert E. Lee Blvd., New Orleans, LA 70124-4305, USA
e-mail: Kanniah.Rajasekaran@ars.usda.gov

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