Biocatalysis and Agricultural Biotechnology 3 (2014) 53–57

Contents lists available at ScienceDirect

Biocatalysis and Agricultural Biotechnology

journal homepage: www.elsevier.com/locate/bab

Review

Engineering bast fiber feedstocks for use in composite materials

Michael K. Deyholos [a,*], Simon Potter [b]

[a] Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada T6G 2E9
[b] Composites Innovation Centre, 158 Commerce Drive, Winnipeg, MB, Canada R3P 0Z6

ARTICLE INFO

Article history:
Received 27 July 2013
Received in revised form
27 August 2013
Accepted 1 September 2013
Available online 7 September 2013

Keywords:
Flax
Hemp
Composites
Fiber
Pectin
Retting

ABSTRACT

Bast fibers (i.e. the phloem fibers of crops such as flax and hemp) have been used for millennia in textiles and cordage and are now promising feedstocks for the production of strong, light weight, renewable composite materials. Several factors limit the broad commercial application of bast fibers in composites, including: (i) variability of fiber properties, (ii) their poor adhesion with conventional resins, (iii) moisture absorption by natural fibers and (iv) cost of production, especially as this relates to extraction of high-quality fibers. These problems will be discussed in the context of fiber developmental biology and of potential solutions enabled by genomics and biotechnology.

Contents

1. Biology of bast fibers

1.1. Definition of fibers

"Fiber" is a word with many different meanings. To a botanist, a fiber is as a cell that is much longer than its diameter, and that has

* Corresponding author. Tel.: +1 780 492 2995, fax: +1 780 492 3294.
E-mail addresses: deyholos@ualberta.ca (M.K. Deyholos), spotter@compositesinnovation.ca (S. Potter).

1878-8181/$ - see front matter
http://dx.doi.org/10.1016/j.bcab.2013.09.001

Table 1
Commercial bast fiber crops. Crops are listed in descending order according to their typical worldwide production.

Common name	Latin binomial	Major production areas	Current main uses of bast fibers	Sequence resources
Jute	*Corchorus olitorius; C. capsularis*	India, Bangladesh	Cordage, coarse textiles, packaging, furnishings	Whole genome assembly (unpublished)
Flax	*Linum usitatissimum*	France, China	Clothing and domestic textiles	Whole genome assembly (Wang et al., 2012)
Ramie	*Boehmeria nivea*	China	Clothing and domestic textiles	Transcriptome assemblies (Liu et al., 2013a; Liu et al., 2013b)
Hemp	*Cannabis sativa*	China, Spain, France	Clothing and domestic textiles	Whole genome assembly (Van Bakel et al., 2011)
Kenaf	*Hibiscus cannabinus*	China, India, South East Asia	Cordage, coarse textiles, packaging, furnishings	None

a thick cell wall with tapered ends (Gorshkova et al., 2012). Fibers provide a structural or protective function within the plant. In addition to the familiar xylem fibers of wood, many species develop fibers adjacent to the nutrient-conducting cells of the phloem. Phloem fibers are distinct from xylem fibers. In some species, phloem fibers are also called bast fibers, and are much longer and stronger than xylem fibers. Species producing bast fibers of commercial relevance are listed in Table 1. The length and strength of bast fibers makes them well-suited for use in textiles (e.g. linen) and cordage (e.g. rope). As will be discussed in this review, efforts are now being directed towards the production of composite materials using bast fibers. The biology of bast fibers has also been discussed in more detail in other recent reviews (Zimniewska et al., 2011; Gorshkova et al., 2012; Meshram and Palit, 2013; Summerscales, 2013).

Bast fibers develop as bundles of cells embedded within other tissues of the stem. Industrial users of bast fibers may use the terms “elementary fiber” or “ultimate fiber” to distinguish individual cells from “technical fibers”, which are fiber bundles. Technical fibers are the form of the feedstock that is most often used for production of textiles, cordage, and composites (i.e. fibers embedded in a polymer matrix). Other terms used industrially are “shive” and “hurd”, which both refer to woody xylem fibers of the stem, and “tow”, which are the shortest and coarsest phloem fibers extracted from bast fiber crops.

1.2. *Fiber development*

1.2.1. *Primary bast fibers*

Bast fiber development can be divided into three phases: specification, elongation, and wall thickening (Lev-Yadun, 2010). Stems of most flowering plants (with the notable exception of grasses) elongate by producing new cells at their shoot apices. After cell division, a series of signaling events specifies the identity of each new cell. The various cell types of the stem then proceed to elongate and to differentiate from each other. In some species, such as those listed in Table 1, phloem fibers continue to elongate after the surrounding cells of the stem have stopped growing. This is an example of intrusive growth, which is rare in plants, and which allows bast fibers to attain their remarkable length (Lev-Yadun, 2001). As phloem fibers complete their elongation, their cell walls undergo an extensive process of thickening (i.e. secondary wall deposition). Thus, each of these three phases of fiber development affects an economically relevant trait: the number of fibers that are produced is determined during specification, the length of fibers is determined during elongation, and fiber strength and other performance parameters are largely dependent on the process of wall thickening.

1.2.2. *Secondary bast fibers*

The developmental process outlined above (Section 1.2.1) describes primary fibers, which begin their development at the stem apex. All bast fiber crops produce primary fibers, and all of these except flax also produce secondary fibers (Table 1), which are much shorter than primary fibers, and which originate from a cylinder of dividing cells (i.e. vascular cambium) in the more mature parts of the stem. Almost all of the cells of wood likewise originate from the vascular cambium. The development of secondary fibers is therefore independent of primary fibers.

1.3. *Fiber composition*

Cellulose is the main structural constituent of fiber cell walls, and is an unbranched polymer of beta-1,4 linked glucose. Because of the nature of the beta-1,4 bond, adjacent glucose residues in a cellulose molecule are inverted with respect to each other. This arrangement allows multiple cellulose molecules to be packed together into cable-like microfibrils. Extensive networks of hydrogen bonding can develop between the cellulose molecules, leading to formation of rigid, crystalline regions within the microfibrils. Microfibrils are arranged in a roughly helical pattern that surrounds each cell. The angle of this helix affects both the natural and industrial properties of the wall. A low MFA (microfibril angle) means that the microfibrils are oriented almost longitudinally. Bast fibers generally have a low MFA angle compared to other types of cells, which contributes to their strength and stiffness (Bourmaud et al., 2013).

Microfibrils are embedded in a matrix of branched polymers of sugars (i.e. hemicelluloses), or sugars and sugar acids (i.e. pectin). Some cell walls also contain a complex phenolic polymer called lignin, although most bast fibers have high proportions of cellulose and low proportions of lignin. Adjacent cells are held together by a layer of material called the middle lamella, which is rich in pectin.

2. Production of bast fibers

2.1. *Retting*

Extraction of fibers or fiber bundles from harvested stems usually involves a process called retting, which weakens the middle lamella. For most crops, the traditional and still widely used approach is “dew retting”, in which harvested stems are left on the ground for several weeks, during which time microbes are allowed to invade the stems. The thick walls of fibers are more resistant to degradation than the middle lamella or primary wall of surrounding cells, allowing the fibers to be easily separated by subsequent mechanical processing (Section 2.2). Dew retting is an inconsistent process that risks weakening fibers, and is limited to climates with sufficient warmth and moisture to promote microbial activity. The large flax growing regions North America are too cold and dry for dew retting, thus almost all of the bast fibers of linseed varieties of flax that are grown there go unused (although the yield and quality of bast fibers from linseed varieties is lower,