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Value-added industrial products from bast fiber crops

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ABSTRACT

Lignocellulosic crops like kenaf, flax and hemp have been extensively studied the last years with the help of new technology and many new products fabricated with them are ready for the market or have already been marketed. Both the core material and the bast fibers of these crops are ideal feedstocks for the production of yarns and paper of high quality, for rendering flame retardant properties to composites reinforced with them, for the production of energy via a sustainable way without polluting the environment and for use as alternative materials to wood for the manufacturing of panels like particleboards and fiber boards (MDF, HDF, etc.). The investigation of lignocellulosic feedstock as potential source for the sustainable production of materials, products and energy has resulted in promising solutions for the successful replacement of their counterparts made from fossil raw materials. However, the related industries still have some challenges to face, like the cost of materials from lignocellulosic plants in comparison with those derived from fossil sources and the availability of the feedstock throughout the year.

1. Introduction

The fact that fossil oil sources are finite and on the other hand the finding that some of the diseases of our time may be due to the use of petrochemical products, have led the scientific community and entrepreneurs in finding solutions for materials, products and energy from renewable sources. The exploitation of biomass is a prominent solution for addressing this problem since it is the most abundant renewable organic resource (∼200 billion tons annually) on Earth (Da Silva et al., 2012). Especially biomass derived from agricultural cultivations is an inexhaustible source not only for food and feed but also for the production of a variety of chemicals and products, as well as fuels. Particularly the lignocellulosic crops have been extensively investigated to this direction and the bast fiber crops hemp, flax and kenaf have been widely studied not only for the improvement of their productivity and farming practices but also for the chemicals we can receive through their cascade biorefining and the products we can make with their feedstock. Some of the most successful products from these crops and a review of the relative state of the art are presented in this paper.

2. Products with raw materials from Kenaf, Hemp and Flax

Products from bast fiber crops increase in popularity as science makes progress in their study and utilization. Today, a wide range of products for different applications is available at lab, pilot or industrial production scale. This collection includes products suitable for construction and furniture, like particleboards and medium density fiber boards (MDF), insulation panels, yarns for special textiles, composites from polymers reinforced with lignocellulosic particles that are suitable for 3D objects or interior parts of cars and aircrafts, pulp and paper, energy, chemicals and many others. The state of the art for many of these applications is presented below.

2.1. Yarns

Flax and hemp fiber, belong to the so-called poly-cell fibers and differ substantially from cotton fibers (Table 1). Following these differences, historically different technologies were developed for spinning bast fibers (flax, hemp) and cotton. Unfortunately, flax spinning technologies are far less efficient as compared with the

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Table 1
Average parameters and properties of some plant fibers.

Parameter	Flax	Hemp	Cotton
Length of elementary fibers [mm]	13–40	15–25	12–36
Fiber strength [G/tex]	53	57	30
Linear density of elementary fibers [tex]	0.29	0.33	0.143–0.200

Table 2
Output of particular types of flax and hemp fiber from 1 t of dew-retted straw.

Parameter	Flax	Hemp grown for seed and fiber
Total output of fiber	280 kg (100%)	300 kg (100%)
Output of long fiber:		
- Scutched	140 kg (50%)	225 kg (75%)
- Scutched after ends cut-off	–	144 (48%)
- Hackled	75.6 kg (27%)	60.5 kg (20.2%)
Output of short fiber:		
- Noils	60.2 kg (21.5%)	77.8 kg (25.8%)
- Tow	140 kg (50%)	75 kg (25%)

ones for cotton and hence pure flax yarns are much more expensive. Flax and hemp fibers in traditional flax spinning methods are treated as technical fibers (Cierpucha, 1967; Cierpucha and Feglerska, 1978). Therefore in order to spin these fibers into yarns blended with cotton or wool, modifications are needed in terms of fiber length and thickness. Even more difficult is the spinning of kenaf. Unlike flax and hemp, this fiber can be spun only after being subjected to chemical (mercerization) or enzymatic treatment (Bel-Berger et al., 1999; Zhang, 2003).

Dividing technical fibers into thinner and shorter fiber aggregates during the so-called cottonization process, cotton-like or wool-like fibers are produced, which are useful for the manufacture of blended yarns by cotton spinning techniques like the rotor spinning system.

The most important parameters of flax, hemp and cotton (Cierpucha et al., 2004) are presented in Table 1.

Traditional processing of flax and hemp dew-retted straw yields long scutched fiber and short fiber – tow (Cierpucha, 1967; Cierpucha and Feglerska, 1978). The long scutched fiber is then hackled, which yields long hackled fiber and short fiber – noils (Table 2).

Among types of flax and hemp fiber practically only noils are used for production of cottonized fiber. This is a fiber from the middle part of stem, characterized by high degree of divisibility and high purity (traces of shive).

In the attempts of cost reduction in flax and hemp fiber production, a different straw processing was developed in which the final product is no longer long or short fiber but a fiber with length falling between the traditional fiber types – the so-called homomorphic fiber.

The fibers shown in Table 2 are used to obtain mechanically produced cottonized fiber (Cierpucha et al., 2004) with parameters as shown in Table 3.

It is possible to obtain thinner cottonized fiber by using chemical or enzymatic processing. However, these are laborious and costly treatments that decrease the effectiveness of flax and hemp cottonization and therefore are not discussed here.

Table 3
Parameters of flax and hemp cottonized fiber.

Item	Fiber length [mm]	Linear density off fibers [tex]
Flax cottonized fiber	18–35	1.2–2.0
Hemp cottonized fiber (from hemp grown for seed and fiber)	20–32	1.46–2.3

The studies conducted jointly by the Institute of Natural Fibers and "ZAMATEX" Company allowed the production of a variety of yarns using the rotor spinning system of "ZAMATEX". For example linen yarns (30 tex 40% linen, 50 tex 54% linen or 100 tex 54% of linen) and hemp yarns (50 tex 54% of hemp, 80 tex 54% hemp, or 120 tex 54% of hemp) were manufactured in commercial scale and conditions (Cierpucha et al., 2004).

Such blended cotton-like yarns produced by rotor system may find application in various blends for textiles. Some examples are: (i) apparel fabric TEXAS (400 g/m^2; warp – 40 × 2 tex, 54% linen; weft – 100 tex 42–54% hemp); (ii) apparel fabric FILIP in natural color with aerial density of 440 g/m^2; warp – 50 × 2 tex, 54% linen; weft – 100 tex 42.2 – 54% hemp; (iii) knitted fabric (double needle-bed knitted) natural color finished with aerial density of 273 g/m^2; paraffin yarn – 50 tex, 40% hemp (Cierpucha et al., 2004).

Bel-Berger et al. (1999) and Zhang (2003), showed that it is also possible to spin kenaf yarn blended with cotton that can be further used for the manufacturing of apparel and upholstery fabrics. The best results were obtained with 20–30% kenaf in the blend while for flax and hemp the optimum level was 54%.

2.2. Pulp, paper and lignin production

The use of annual crops for producing chemical pulp, and ultimately paper, has been practiced successfully in areas where wood fibers are in short supply or otherwise less suited for certain applications. One argument for using annual crops is also the high dry material yield of certain crops, such as hemp and kenaf (Pahkala et al., 1997). These crops produce an annual growth comparable with fast-growing eucalyptus, which is widely used as a primary raw material source for pulp. Annual crops are presently being used for pulping particularly in Asia, but also in other parts of the world. The global production 2011 of non-wood fibers is approximately 17 Mt (FAO Yearbook of Forest products, 2011). Only a fraction of this amount originates from hemp, flax and kenaf, although these are used as a raw material in some mills in France, Spain and Germany for producing special paper grades, such as cigarette and banknote paper.

A summary of the main advantages and disadvantages of annual crop fibers in papermaking are presented in Table 4 (Hunt, 2002).

The basis for successful utilization of annual crops in pulp and papermaking is primarily depending on the fiber properties. Compared with wood fibers which have a maximum length of 3 mm, the annual plant fibers are much longer and in many cases also stronger (Table 5) (Dittenber and Ganga Rao, 2012). For that reason, annual crop fibers can be used as reinforcement in conventional papermaking, enabling stronger paper and lower basis weight. The pulping process can be either chemical or mechanical. The feasibility of using crop fibers depends largely on the availability of the fibers, i.e. it is crucial that the resources are located within a reasonable distance from the pulp and paper mill. In contrast to wood, crop fibers are available only during harvest season and need to be transported and stored properly in order to benefit the paper production.

In addition to the fiber strength benefits, the lignin and hemicellulose contents are lower than for both softwood and hardwood fibers.

Non-wood fibers have physical properties superior to softwoods and can lower amounts of them are needed when used as a softwood substitute. In some cases, such as banknotes, cigarette papers, tea bags, dielectric paper, etc., the paper can be made from a furnish of 100% non-wood pulps (Hurter, 1997). A selection of applications is listed in Table 6.

A benefit of chemical pulping is that the dissolved part of the biomaterial, which contains hemicellulose and lignin, can be utilized. The waste liquor contains most of the original lignin which can be