Unexplored Vegetable Fibre in Green Fashion

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Abstract Unexplored and unexploited plant fibres are being used in fashion industries along with man-made fibres. Some of these fibres, such as flax, hemp, etc., which are quite popular in fashion industries and standard fashion market, are also available globally. There are quite a number of plant fibres that have huge potential in fashion and are now coming into focus in the field of "green" fashion. This chapter discusses the major unexplored plant fibres that can be used in green fashion commercially. It covers both wearable and nonwearable fashions made from these plant fibres. The chapter also emphasizes the aspects of cultivation and production of the fashion products and present technologies in the development of the green fashion products. Nevertheless, it highlights the future uses of these unexplored fibres in a sustainable fashion.

Keywords Natural fibres · Plant fibres · Unexplored fibres · Green fashion · Product diversification

1 Introduction—History, Importance in Today's Scenario

During the progress of human civilization, the application of natural fibres has been discovered, and these textile materials have been used for protection from different climatic conditions. Little is known about when exactly man switched from wearing tree bark and animal skins to fibre-based clothing in prehistoric times. With the passage of time, the textile fibres were converted into yarns, and subsequently those yarns were used for making fabric. In the latter half of the nineteenth century, synthetic and man-made fibres underwent immense

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development. From the end of nineteenth century to the beginning of twentieth century, human society understood and realized that most man-made fibres are petroleum based and as such the petroleum reserve may be diminished to a large extent over the long run. Apart from having good fibre strength, most man-made fibres are more lustrous and silky in nature. These qualities have affected the natural fibre industry. Recently, efforts have been made to reuse or recycle synthetic fibres as much as possible; at the same time, more emphasis has been placed on the production of the natural fibre as sustainable fibre resource materials. Thus, it is time to give more emphasis to natural fibres, which are renewable in nature and naturally degradable after disposal. Therefore, there is a craze to use and popularize more products and more applications in textiles, especially for development of fashion textiles. As far as plant fibre is concerned, flax, nettle, cotton, etc. are some of the fibres that were used in ancient days. Slowly, the look and appearance of textile material became important, and these qualities were achieved by using natural dye extracted mostly from different plant sources. Basu and Roy (2008) documented blending of various natural fibres, mostly of plant origin, for the development of valued-added products. Fashion textiles are the area of textile applications where textile materials are used to serve different purposes such as appearance, esthetic, fashion, appealing, design, comfort, etc. Mostly these fashion textiles are of two types: wearable fashion (fashion garments, fashion clothing, fashion sport, fashion ornaments, etc.) and nonwearable fashion (fashion items used for decoration of room, wall, floor, home, office, mall, hall, auditorium, etc.). Currently natural fibres are mostly used as luxury textiles and more recently the trend is to design and develop textiles, especially for fashion, from unexplored fibres. “Green” processes and technologies are used so that the overall manufacturing system is eco-friendly and profitable due to value addition.

Recently, more attention has been paid to the use of renewable resources, particularly from plant origin, considering the ecological concerns about the health of our planet. On the other hand, despite abundant availability from the renewable resource of ligno-cellulose materials, few attempts have been made to use them properly. This may be due to the lack of availability of sufficient structure/property data as well as lack of awareness of the users. However, systematic studies may bridge these gaps while leading to value addition for these natural fibrous materials in fashion textiles. History speaks: Several natural fibres were used from ancient times onward, and slowly their use was reduced due to problems with extraction, less remuneration in cultivation, labour intensive, etc.

This chapter provides an elaborate discussion of plant fibres that remain unexplored but which have enormous potential in the manufacture of green fashion products. Although there is a long list of fibres that can be extracted from plant sources, but many of them are not extracted. These ligno-cellulosic fibres, which are as yet unexplored but have a possible commercial market, are given much focus. This present chapter will also discuss in detail the merits and demerits of these unexplored natural fibre and their potential application emphasizing green fashion.

2 Different Unexplored Fibres—Fashion Textiles

Natural fibres can be classified by the source from which they are extracted. Basically, there are two categories: animal sources and plant sources. Wool, silk, etc. are example of animal sources, and cotton, flax, jute, etc. are some examples of plant fibres. If we talk about natural fibres, people in society are aware and customarily think of cotton, silk, and wool as being used in fashion or technical applications. However, in the arena of textiles, there are many unexplored natural fibres out of which technical and fashion textiles are being made. Presented below are some of the important applications of natural fibre-based textiles used for fashion and technical applications.

Fashion textiles can be classified into two categories: wearable textiles and nonwearble textiles. Wearable fashion textiles include trousers, shirts, shawls, jackets, coats, mufflers, neckties, ornaments, etc. Nonwearble textiles include curtains, furnishings (sofa, table, and bed covers), floor coverings/floor mats, doormats, flower vases, fruit baskets, models/idols, door chains, wall hangings, table mats, etc. Different unexplored fibres are used to produce these fashion products.

In terms of unique natural plant fibres, jute is second to cotton in terms of organized production and marketing. India is the largest producer of jute fibre. For a few centuries, jute fibre has been popular for use as packaging and carpet-backing material. Currently substitute synthetic packaging materials are competing with jute in the traditional market. Scientists have tried to find new application for jute in diverse areas. Today jute fibres are being used in diversified fashion applications such as jute-based dolls, idols, models, etc. As for decoration applications, jute is being used in floor mats, doormats, wall hangings, door chains, table mats, etc. There are also applications of jute-based furnishing materials such as curtains, sofa covers, bed covers, etc. Regarding wearable textiles, jute can be used in secondary dress materials. Currently jute-based materials are used for designing and developing warm fashion clothing such as shawls, jackets, blazers, coats, etc.

2.1 Jute

Jute is one of the bast fibres originating in the Mediterranean region (Stewart 1998) and eventually it came to India. Per historical records, jute was known as *patta* in 800 BC. Jute fibre has been popular for more than a century for its industrial applications, such as packaging material, in different sectors, geotextile application, and carpet-backing material (Debnath et al. 2009). However, in the last few decades, jute has been used diversified areas apart from its age-old applications. It has been found from the literature that jute with ornamentation—and using suitable modifications in spinning, weaving, and knitting—can be used to create nonwoven, hand-loom fabrics that have an attractive look of elegance (Anonymous 2006a). Fashion-design aspects have been considered at the fabric-manufacturing stage and

other in the manufacture of clothing using designed fabric (i.e., garment manufacturing). Furthermore, jute-based fashion garments were exhibited in fashion shows at GIFTEX Stationex and Jutex 2005 during August 2005 at Mumbai. The literature also reveals that apart from these conventional products, jute can be used for development of value-added green textiles. Some of these jute-based green textiles are fashionable, and some are of industrial application in nature. Fashionable green products from jute-based materials (Debnath et al. 2009) include fashion garments (Debnath 2013a, 2014b), bulked yarns for sweaters, jute slippers, decorative and utility products from hand-made paper, fashionable bags for school and office, curtain materials, etc.

When comes the question of technical fashion products (nonwearble) from jute apart from its exclusive technical products like improved geotextile and agro textile (Debnath 2014a), decorative composite and moulded products for different domestic and office applications, fancy file boards and file covers from jute pulp, etc. Apart from these fashion products made from jute-based material, particle board made from whole jute plant as well as jute stick also has immense potential in the fashion industry specifically for fashion photo frames, temporary partition walls, decorative false ceilings, table tops, etc. Jute-based particle board has a natural aesthetic look, which is one of the green fashion applications provided that the use of a bioadhesive in the preparation is ensured. Different possibilities of product development of composite and moulded products from jute and allied fibres can open up new avenue of using these natural fibres toward green technologies (Anonymous 2005a). These composite materials made from green plant fibres include chairs and table tops, wash basins, and jute-reinforced plastic tiles in place of porcelain tiles. In this study, the investigator also optimized jute–polypropylene compounding granules and jute-HDPE (high-density polyethylene) of different blends (80:20, 70:30, and 65:35).

2.2 Sunnhemp

Sunnhemp is an important legume crop with multiple uses in textiles (Chaudhury et al. 2015). Researchers developed value-added textiles from sunnhemp fibres (Anonymous 2005b). They found that the fibre procured from Nagpur, India, contained 60 % good spinnable fibre. The raw fibre showed an acceptable level of strength and fineness for subsequent processing. Common wet-processing technology can be adopted for sunnhemp fibre. However, chemical treatment resulted in some loss of strength, but it was sufficient to spin good yarn. After bleaching, substantial whiteness can be achieved, and different colour shades can be applied. Miniature jute spinning, as well as a commercial jute-spinning system, can be adapted to spin sunnhemp yarn, and the physical properties of the resulting spun yarn are comparable with that of conventional jute yarn of similar linear density. Sunnhemp-cotton fabric can be made for diversified application wherein the cotton is used in warp and sunnhemp in weft directions. This compound fabric can

have good colouration with suitable application of reactive dye. The finished sunnhemp-based products have an attractive look and feel (Anonymous 2005b).

2.3 Ramie

Ramie (*Boehmeria nivea*) is a bast fibre extracted from the bast of the ramie plant. China is the pioneer in ramie-fibre production. In China, ramie it is known as "China grass" and is used in different popular fashion products such as women's dress material, shirts, suits, handicraft products, etc. However, ramie-based technologies and fashion products have not spread to a greater extent in other part of the world. The important concern about the ramie is the removal of gum content from the extracted fibres. Gum comprises as much as 30 % of the weight of ramie fibre. An economical process of gum extraction from ramie fibre has been developed; furthermore, extracted natural gum has been used as natural resin for the development of jute particle board. With composite technology, the whole process of ramie-gum utilization for the development of green particle board has been demonstrated (Anonymous 2002a, b). Thakur et al. (1999), reported detailed findings on the chemical composition of ramie fibre. They found that complete removal of gum ramie fibre is similar to that of pure cellulose, thus indicating that ramie contains approximately 94–95 % alpha cellulose. As far as the fibre itself is concerned, ramie is a strong, lustrous, soft, and fine bast fibre obtained from the inner bark of the plant *Boehmeria nivea (L) Gaud*. Research results have shown the processing technology of cotton–ramie blends (Anonymous 2002a, b) on short staple–spinning system (i.e., cotton spinning). Because both fibres are of natural plant origin, it is expected that the products will be environmentally green. *Lisingphee*, fancy ramie-cotton woven towels, fancy designed fabrics, etc. are some of the novel fashion products developed form cotton–ramie blend yarns. The researchers also characterized fibre properties such as bundle tenacity, breaking elongation, fibre fineness in tex, Whiteness Index in Hunter scale, Yellowness Index and Brightness Index at different stages of fibre (decorticated, degummed, and bleached ramie fibre) used for development of cotton-ramie fashion fabrics (Anonymous 2003). Ahmed et al. (2004) found that the reduction of gum content from 20–30 % to 2–3 % using alkali treatment and subsequent bleaching of ramie fibre used in the blended cotton-ramie yarn spun in a cotton-spinning system resulted in deteriorated yarn strength.

2.4 Flax

The earliest example of preserved linen appears to be a needle-netted linen headpiece from Nahal Hemar Cave in Israel from 8500 years ago, and Swiss lake dwellers used native flax to make cloth 5000–6000 years ago. Linen was the

preferred textile of the ancient Egyptians who used it for clothing, bed linen, shrouds for mummies, and ships' sails. The earliest Egyptian linen cloth dates from the period of the Old Kingdom, but flax appears to be have been grown for linen approximately 5000 years ago in the Early Dynastic period. Flax fibre comes under the category of bast fibre and is extracted from the plant of the linseed/flax plant (*Linum usitatissium* L.). This plant is popular for two reasons: One is flax fibre, and the other is linseed oil (used for industrial applications), which is extracted from the seed of the plant (Basu and Dutta 2014). As far as fashion industry is concerned, flax and its blend with other fibres (natural/man-made) is quite popular; hence, an in-depth discussion of flax-based fashion is not provided herein.

2.5 Nettle

In research about the history of spinning, weaving, and knitting machines, English (1969) reported that nettle fibres have been used traditionally for spinning yarn and that apart from industrial applications, those yarns have been further used for apparel fabrics. Dunsmore (2006) and Dunsmore (1998), also explained the importance of nettle-fibre processing and hand spinning of nettle yarn considering different situations in Nepal. She also described the hand weaving of nettle fabric and the different possibilities of creating fashion apparel from sustainable nettle fibre. Guo et al. (2006), applied different spinning systems and techniques for the sustainable spinning of nettle fibers. Their results show that nettle fibers cannot be used for spinning singly because the common length of nettle fibers are short, and the discrete coefficient of length and fineness is varied. However, when nettle is admixed with other fibers, the test-yarn qualities are somewhat acceptable. Their research output can be useful for developing sustainable and fashionable products from wild nettle fibres.

Furthermore, it has been documented that the stem and fibre of stinging nettle are used to prepare traditional handicrafts in several Balkan countries (Dogan et al. 2008). This nettle fibrous material in Bulgaria, known locally as *kop riva*, is used for the sustainable development of cloth, sack, cord, and net manufacturing applications. In Romania, nettle is known as *urzica*, and it is used as a substitute for cotton in fishing-net production and paper-making. It is known as *kop riva* in Serbia, where nettle fibre is considered one of the major textile fibres used in the spinning industry to produce textile products. Overall, a wide range of possible handicraft products can be made from nettle either from fibre yarn or fabric or combination of these. Such products include doormats, flower vases, wall hangings, door chains, carpets, handbags, table mats, beach umbrellas, lamp shades, etc. All of these products have huge profit margin due to the high cost-to-benefit ratio. Most of the handicraft products fall under the category of fashion items. In Nepal, different handicraft products are made out of nettle fibres, and hand-spun yarn has well documented by Dunsmore (2006) and by Deokota and Chhetri (2009).

Bacci et al. (2010) also reported that for sustainable handicraft products can be made from nettle through enzyme retting, which is an example of a green technology. Anonymous (1998a) also described different sustainable fashion items made out of nettle fibre and its blend such as hats, jackets, room decorations, and various handicraft products.

2.6 Pineapple Leaf Fibre

Pineapple leaf fibre is an unexplored natural fibre extracted from the green pineapple plant leaf, which is normally considered agricultural waste (Banik et al. 2011). This fibre has also immense potential of using as fibre source in the arena of green fashion textiles (Debnath 2016). Piña is a fiber made from the leaves of the pineapple plant and is commonly used in the Philippines. It is sometimes combined with silk or polyester to create a textile fabric. Piña's name comes from the Spanish word *piña*, which literally means "pineapple." In the Philippines, pineapple silk is considered the "queen" of Philippine fabrics and is considered the fabric of choice of the Philippine elite. Literature reveals that Ghosh and Sinha (1977) are pioneers in developing textile products from pineapple leaf fibre. They used a special technique to spin pineapple fibre in jute-spinning machinery. In their studies, they found that fine pineapple leaf fibre could be spun into in yarns in 70- to 170-tex linear densities. However, in admixture with jute, 10–15 % pineapple fibre will improve the performance of jute-blended yarn, and fine jute–pineapple blended yarn can be produced. These fine pineapple and pineapple–jute blended yarns have been made into plain and twill cloth developed for fashion-fabric development. These lightweight fashion fabrics are further used to design fashion bags, curtains, and furnishing fabrics. Finally, the investigators concluded that these pineapple leaf or jute–pineapple leaf fibre blended products have huge potential for green fashion. Furthermore, Ghosh et al. (1982) documented the processing pineapple leaf fibre in a cotton-spinning system. Before processing in the cotton-spinning system, they studied and compared the physical and mechanical properties of cotton, jute, and pineapple leaf fibres. They found it is not possible to spin 100 % pineapple leaf fibre into yarn in cotton-spinning machinery. They tried doing so with different proportions of pineapple leaf fibre viz., 50, 33, and 20 %, combined with cotton. However, a 50:50 blend of pineapple fibre and cotton has finally been optimized. Although spinning performance is poor in the cotton-pineapple fibre blend, a huge amount of cotton can be saved and thereby a value-added green product can be made. In the same area of blending of pineapple leaf fibre, there is also evidence to study the performance of blending pineapple leaf with acrylic fibre in a jute-spinning system (Ghosh et al. 1987; Dey et al. 2009). The investigators studied the fibre properties of pineapple leaf and acrylic and compared the similarities and dissimilarities between them. Five different blends of pineapple leaf and acrylic fibre in different ratios have been tried, viz., 87:13; 67:33; 50:50; 33:67, and 13:87. From these blends, fine yarn of 84 tex was spun in a wet-spinning process where the rove

was passed through a temperature bath (80–100 °C) before spinning. They also spun the same yarns through a dry-spinning process. They compared the dry- and wet-spinning process and found that the breaking stress is reduced in wet spinning but the breaking strain was improved by 6 times. The optimum blend composition found from their studies is 67:33 pineapple-acrylic blended yarn. The wet-spinning performance is superior to the dry-spinning method. Finally, they also concluded that there is ample scope for development of green fancy apparel products made out of these pineapple-acrylic blended yarns (Dey et al. 2009, Ghosh and Dey (1988)).

Regarding fancy composite materials, pineapple leaf fibre-natural rubber composites (Lopattananon et al. 2006), soy-based bioplastic as natural resin, and pineapple leaf fibre as natural reinforcement fibre component (Liu et al. 2005; Mishra et al. 2001, 2004) are termed "green" composites. In this regard, natural fibers can replace glass fibers in fiber-reinforced plastics in some application areas (Mohamed et al. 2009) because pineapple leave fibers have high cellulose content (Saha et al. 1993) and are mechanically sound as a reinforcement in polymer composites.

2.7 Coconut Fibre

Coconut fibre, also known as coir fibre, is extracted from the outer fibrous material of coconut fruit. Although coconut palms grow throughout the world's tropical regions, the vast majority of commercially produced coir comes from India and Sri Lanka. White and brown coconut fibres are the two main types of fibres available. White fibres are extracted from the green (tender) coconut, and brown fibres are extracted from matured coconut, which takes 3–6 months of retting in brackish water (Bhattacharya and Basu 2009). There is evidence of processing coconut (coir) fibre (*Cocos nucifera*) in a small-scale jute-spinning system (Anonymous 2002b). The investigator compared the yarn properties obtained from yarns in different spinning systems (manual, semiautomatic, and automatic ratt machines) with a conventional jute-spinning system. They also attempted to blend jute and coir fibre (in ratios of 30:70, 40:60, 60:40, and 70:30, respectively) with the aim of developing value-added products. Experiments on blending coconut with jute fibre (Banerjee et al. 2000, 2001) and at spinning preparatory stage are presently concerning as technical textiles are focused more toward geotextile materials. Anonymous (2006a, b) developed different types of lightweight fancy-design handbags and fashion doormats from jute–coconut fibre blended coarse yarns. Furthermore, Anonymous 2012, revealed that jute (60 %) and coconut (40 %) fibres can be blended for the development of value-added jute–coconut fibre blended yarn. The blended yarn is used for the development of ornamental woven fabric, which can be used to make fashionable ladies slippers, decorative floor mats etc. There has been work to soften coir fibre for better flexibility and there have been attempts to develop dyed jute-coconut fibre blended yarn. Apart from these, sustainable fashion products—such as coconut fibre-based idols, decorative doormats, household decorations, etc.—have a good commercial market.

2.8 Banana Fibre

Banana fibre (*Musa sapientum*) can be a good source for the development of green fashion products. Fibres are extracted from the pseudo-stem of the banana plant. The fibres are bleached and blended with jute fibre aiming for diversified value-added fashionable products (Debnath and Das 2012). Because both jute and banana fibres derive from plant sources, products made of these fibre are environmentally green. Sinha (1974a, b) is a pioneer in blending banana-based fibres for the development of different products. This work elaborates the use of white jute, tossa jute, and kenaf, which were blended separately with 75 and 50 % banana sheath fibre (i.e., extracted from the sheath of banana stem) at the jute-finisher card. Banana reeds (a streak of fibre bundle extracted from the stem), after being softened with an oil-in-water emulsion and piling for 72 h, were stapled in 20 cm lengths to avoid roller lapping at the breaker-card stage. After piling, banana fibres were processed separately in a jute-breaker card followed by jute-finisher cared; finally, blending was accomplished in a jute-drawing machine. Yarns of 345 and 280 tex were spun using a jute-spinning system. Although the yarn quality deteriorated marginally with the increase the in percentage of banana fibre in the blend, the ratio of fibres in the jute–banana fibre blended yarn was judicious, and the yarn could successfully be used as hessian weft and sacking warp. Furthermore, Sinha (1974b) used jute-processing technology for producing coarse yarn and found that plying those individual yarns with the incorporation of suitable twist can lead to preparation of banana rope. Anonymous (2012b), showed that conventional hydrogen peroxide bleaching, which has been used for bleaching the fibre, and further dyeing has been accomplished. Studies have been performed on different blend ratios of jute to banana (100:0; 75:25; 50:50; 25:75; and 0:100) wherein the properties of the different resulting yarns were compared. Due to the coarseness and brittleness of the banana fibre, spinning of 100 % banana fibre showed poor results. Anonymous (2012c), reported that bleached and dyed jute–banana fibre yarns can be used to develop ornamental fibre using a jacquard attachment in handloom. The decorative fabrics are used for the manufacture of fashion jackets. Hence there is immense potential to design and develop green-banana fibre textiles.

2.9 Sisal

Sisal is a plant fibre (*Agave sisalana*) normally extracted from the leaf of the plant. It is very hard and robust, and the lingo-cellulosic fibre is extracted from green sisal leaves using a suitable sisal-fibre extractor. Due to the presence of a waxy coating on the fibre surface, this fibre normally is very slippery, lustrous, and less prone to microbial attack despite its high strength-to-weight ratio. In ancient days, this fibre was used for anchoring ships and boats due to its high resistance to sunlight and water. Sisal fibre was first cultivated in Brazil on a broad scale

and later its use spread to other part of the world. Initially, Brazil cultivated this fibre for rope twine, paper, cloth, wall coverings, dartboards, etc. (Anonymous 2015a). Apart from Brazil, Tanzania, Kenya, Madagascar, China, Mexico, Haiti, Venezuela, Morocco, and South Africa are major producer of sisal fibre products in the world. Basu et al. (2012) tested various Indian varieties of sisal fibres and compared their properties with those of other imported commercial fibres. There is evidence that (Anonymous, 2015b, c) there exist different commercial manufacturers of sisal-based fashion products. Thailand is a manufacturer/exporter/wholesaler of natural handmade handbags based in Bangkok including smart and trendy sisal ladies' handbags, shopping bags, cosmetic bags and cases, gift bags, promotional gifts, shoulder bags, hats, and handmade baskets at attractive prices. In Mexico, jewels are created to highlight the personality of every woman. All pieces are plated with 18k gold and fused with riches of the nature such as wood, sisal, leather, semiprecious stones, and feathers. Tanzania is a specialized exporter of hand-crafted fashion bags and baskets made of natural fibers such as raffia and sisal. These natural fibers originated in Indian Ocean islands. The company presents a wide range of products that are a statement in elegance and style. Kenya produces hand-crafted beaded sandals and flip-flops, beaded bracelets, leather belts, fashion belts, bone/horn jewelry, hand-woven sisal and leather bags/totes, and even home decor such as wood/stone sculptures, mirrors, hand-painted stone pen holders, decor plates, bowls, etc. Unlike found in other textiles, Sinclair (2015) highlighted the different aspects and products of sisal in the area of textiles and fashion. She emphasized its design aspects as well as different technologies for the preparation of sisal fashion products. There is a case study that, in 2012, after serving on big brands in the product development area, the stylist and manager of the fashion industry, Salvia (2012) decided to start his own business and innovated the creation of sisal fashion products. Over time, the service has been improved and now includes private service for customers registered to receive exclusive pieces even outside of the store's regular operating hours. They create a totally personalized service according to the profile and style of each consumer Salvia explained. Thus, the service is performed with every comfort for those people who do not have time to enjoy the warm décor of the stores, which are already in three locations: There are two in São Paulo and one in the Jequiti line in Guaruja, Sao Paulo coast. Sisal Store Mod a works with the women's brands Bobô, Calvin Klein Jeans, Calvin Klein Underwear, Espaço Fashion, Le Lis Blanc, Juicy Couture, Hit, John John Denim, Letage, Mob, Saad, Tigresse, Tryia, Rock Lilly, Chaos and the men's brands Calvin Klein Jeans, Calvin Klein Underwear, Los Dos, Mandi, and Zapala. Apart from these green fashion areas where sisal fibres are used, this fibre is also blended with wool and nylon for the manufacture of fashion carpets and rugs (Anonymous 2015d). One of important fashion as well as utility products made out of sisal is the sisal-based body scrubber. Anonymous (2005c) developed a processing technology using sisal-jute blends for the production of body scrubber that have potential to replace the existing shoddy nylon body scrubber.

2.10 Hemp

Processed hemp fibre can be used to manufacture fabric that is ideal for summer clothing with good ventilation and moisture absorption as well as antibacterial and anti-ultraviolet properties (Paolo and Gianpietro 2004). Hemp fibres are very rigid and rough to handle. Clothing made with the untreated fibres appears wrinkled and feel prickly. As a result of the high levels of friction and tension during the spinning and weaving processes, part of the short hemp fibre stands out from the surface of yarns and fabric, making them appear and feel hairy. Unlike flax fibre, hemp is also popularly known in the fashion industry, and therefore further detailed coverage is not offered herein.

2.11 Other Unpopular Plant Fibre

As far as unpopular fibres are concerned, these are mostly not successful due to present application areas of these fibres, the quantum of cultivation, yield of fibre from the green plant, fibre-collection difficulties etc. Fibres belong to these category include okra/*bhindi* fibre, kapok, khimp, etc. The possible reasons for their lack of popularity are discussed below.

2.11.1 Okra Fibre

The okra plant bark contains fibres, and these fibres can be extracted after proper retting and extraction. However, the okra plant is cultivated for the okra (*bhendi*/ ladies finger), which is popularly consumed as green vegetable. However, for fibre purposes, extraction must be done before formation of okra pods in the plant up to a maximum of the flowering stage. Extraction of fibres at this stage in not economically viable. Moreover, once the fruit develops, the fibres are overly mature, and after extraction the fibre is very coarse and brittle. Hence, this fibre is not popular although it is a potential source of green fibre.

2.11.2 Kapok Fibre

Kapok fibre is mainly seed fibre, and seeds are collected from uncultivated plant. The plant are very large, thus plucking of the fibre ball from the seed is difficult due to the height of the plant and the different growth periods of the fibre ball in each plant. Moreover, the production per volume of plant is quite low. Furthermore, the fibre has poor strength, which overall makes the fibre an unpopular one. Still, in some of the cases, kapok fibres are used in making hand-made quilts, soft toys, etc.

2.11.3 Alfa Fibre

Ghali et al. (2014) extracted alfa fibers from the plant *Stippa tenacissima* or esparto grass (*alfa* is the Arab name for *esparto*), which grows in the dry regions of North Africa. These fibers are used extensively in the production of paper. Given that this plant is very available in Tunisia and in order to make it a successful alternative crop, it must be incorporated into value-added products such as nonwoven materials for domestic textiles. The investigators used this fibre to make nonwoven materials for diverse uses. Bessadok et al. (2007), used alfa fibre and proved that this fibre provides excellent reinforcement for composite materials. However, the main disadvantage of these fibres is their hydrophilic nature; therefore, the ageing of composite materials can be pronounced because of the diffusion of water molecules leading to a swelling effect. Moreover, the adhesion between natural fibres and the polymer matrix is insufficient. Various chemical surface treatments have been performed on alfa (*Stipa tenacissima*) fibre. These different treatments (acetylation, acrylic acid, styrene, and maleic anhydride) are combined with chemicals such as (S), (AA), and (MA). It was found that treatments reduced the overall water uptake of alfa fibres. In particular, styrene treatment significantly increases the moisture resistance of these fibres.

2.11.4 Khimp Fibre

Khimp fibre (*Leptadenia pyrotechnica*) has been studied with a view to exploring its wider uses. Kundu et al. (2005) extracted khimp fibre from the khimp plant and they analysed the fibre properties Jamal et al. (2001) highlighted the importance of khimp fibre for the development of indigenous technologies in the pulp and paper industries. The high alpha-cellulose content and low contents of khimp fibre, along with its favorable length-to-breadth ratio, make it suitable for use in blending with cotton or polyester fibres. We examine the innovation process in selected firms engaged in paper making in India. The present firm-level analysis focuses on incremental innovations as a process to achieve indigenous technological capability (ITC), particularly to use imported technologies more effectively through a process of adaptation and improvement. The study confirms that the "learning by doing" process is one of the indicators for these firms in building the capability to "indigenise" and improve upon the technology. In-house R&D units at the firm level provide strong support for achieving indigenous technological capability.

3 Cultivation to Consumption—Consumption of Natural Resources, Shortcomings in Present Technology Used

Out of different lingo-cellulosic fibres, jute is one of the cheapest fibrous material available in bulk quantities and cultivated for fibre-production purposes. There are two types of jute fibre available: One is tossa jute, and the other is white

jute. Among these two, tossa jute is much more popular due to its high strength and greater productivity. The traditional technology of fibre extraction is a completely manual process wherein the fibres are retted in water for 15–20 days, and the fibres are then separated manually from the jute stick. The jute stick has commercial value, and it is normally used for domestic and farm activities as well as fuel purposes. The conventional retting in water causes environmental pollution, and the employees performing the extraction process often develop dermatomycosis (skin-related fungal disease). Scientists have introduced new technologies of extracting jute fibre wherein retting can be accomplished using less water. In this new technology, the jute ribbons (green bark containing the fibrous material) are separated from the stick, and the ribbons are then retted in water. This required low volume of water can lead to fast retting (6–8 days) with good fibre In some cases, researchers use fungicides to accelerate the retting process under low-water conditions. However, none of these technologies are commercially viable due to the unavailability of a high-production ribboning machine. However, a number of technologies can be employed when using jute to produce different fashion products and utility items (Basu et al. 2006) using green processing technologies (Basu et al. 2009). Although the jute fibre itself is natural, if all of the processes involves to make the end product are environmentally friendly, then the overall process is green. Basu et al. (2009) made an important contribution as far as jute processing is concerned. They used different vegetable oils and compared with commercial jute batching oil as bio-friendly conditioning agents in jute-fibre spinning. Recently, Debnath (2014a, b, c, d) discussed different machinery used for the processing of jute fibres and reported their recent developments in that area.

3.1 Sunnhemp Fibre

Sunnhemp is the fastest-growing species of the genus and is very effective in smothering weeds (Chaudhury et al. 2015). The extraction process for sunnhemp is similar to that for jute and requires a retting process to separate the fibre material from the plant stick. There is must develop an enzymatic/environmentally friendly chemical retting process so the environment remains unpolluted during retting.

3.2 Banana Fibre

In the case of banana fibre, the extraction process is both manual and mechanical. With the manual process, productivity is less, but the quality of the fibre is fine; with machine extraction, the fibres are comparatively coarse (Debnath and Das 2012). Debnath and Das (2012) also documented the different uses of the byproduct (i.e., sap) during the extraction of fibre from banana pseudo-stem.

This extracted sap has good medicinal value apart from its commercial application such as natural dye. All processes from extraction to yarn preparation are green. The investigators also discussed obtaining different fashion and utility products from banana fibre. Debnath (2013a, b, 2015b) demonstrated the process for manufacturing the jute as warm fashion fabrics such as shawls, jackets, blazers etc. Apart from its fashion appeal, banana fibre has good thermal insulation as well as breathability properties.

3.2.1 Flax Fibre

In India, flax fibre is another potential fibre that is extracted through retting for a few days (3–4) followed by drying in the sun and decortication using a decorticator machine. In Europe, the process of due retting is popular (Anonymous (1998b), Basu and Dutta 2014). The process involves an environmentally friendly system, and products manufactured from this fibre use green technology. The fine flax is used for fashion clothing and clothing suitable for extreme summer climates. Apart from its appearance, the material has high moisture-absorbing capacity and can be dyed in appealing color shades.

3.3 Coconut Fibre

Coconut fibre has many industrial as well as fashion applications. Coconut fibre-based ornaments are a luxury fashion item. Apart from its applications in apparel and accessories, coconut fibre has good scope in green fashion products such as doormats, floor mats, carpets, furnishing, and upholstery material when blended with jute (Anonymous 2012a, b, c). The conventional retting process, which creates pollution, can be minimized by controlled chemical retting as well as an enzyme retting process to make the fashion product more green. Recently, Basu et al. (2015), developed an eco-friendly accelerated retting process for coconut fibre that lead to faster productivity apart from the environment friendliness of the fibre itself.

3.4 Sisal Fibre

Sisal fibre is extracted by mechanical means that are environmentally green throughout the process from extraction to product development. Different decorative and fashion products can be made from sisal-based materials (Anonymous, 2015b, c). Fashion bags made of sisal are durable and aesthetically appealing.

3.5 Alfa Fibre

Ghali et al. (2014) reported the extraction process of alfa fibers from the organic matrix, in which three stages were considered. First, the leaves were separated from the stalks by manual cutting. Second, they were immersed in a caustic soda solution (NaOH, 3N) for 2 h at a temperature of 100 °C. The details of the extraction process were described in our previous work. Then they were subjected to bleaching treatment and air dried. After this chemical treatment, it was found that the fibers were not sufficiently separated. For this reason, they were finally separated from the leaves by a mechanical treatment using four passes through a Shirley trash separator. Although this process involves the application of toxic chemicals with the intervention of scientific methods, using green chemicals and enzymes can make the process environmentally friendly.

3.6 Ramie Fibre

Ramie is a very fine textile fibre; the main challenge is removal of gum from the fibre. Removal of the gum through a chemical process is not eco-friendly. Although enzymatic degumming is a green process, it is costly. Apart from this, the technology involved is green, and the products produced, mainly fashion items, can be claimed as green fashion products (Ahmed et al. 2004). Ahmed et al. (2004) used a cotton-spinning system to spin a blended yarn out of degummed ramie and cotton. The whole process from fibre extraction to yarn formation is very lengthy and consumes hazardous chemicals (alkali) for the extraction of gum from the ramie. Sometimes enzymes are also used for degumming, but doing so is costly and time consuming (Saikia et al. 2009). The investigators claimed that the complicated process of blending ramie with cotton is another disadvantage in the present scenario.

Apart from different unexplored fibres, nettle is another fibre from which green fashion products can be made. The extraction to the end product, including its disposal, is environmental friendly as reported in studies by Debnath (2015a). The investigator also described different fashion products such as bags, idols, garments, doormats, table mats, baskets, home decoration items, etc., made from nettle-based products. The overall process is geared toward producing green-fashion textiles.

3.7 Hemp

Hemp falls under the cannabis plant wherein hemp fibre is extracted from the plant stem and used to make rope, strong fabrics, fibre board, and paper (Abdul-Karim et al. 1995 Zhang and Zhang 2010). The extraction process of hemp fibre is a tedious process. Hemp fibre samples were processed by beating and washing and then

made into short fibres by fibre-opening and -carding machines. Special attention was paid to the moisture regain before mechanical handling of the samples. This hemp fibre has also huge potential for the development of green-fashion textiles.

4 Conclusions and Expected Trends for Tomorrow

It is now clear from this chapter that like man-made/synthetic fibres, plant fibres also have huge potential in the fashion industry. Some of the uncommon fibres, such as flax and hemp, no longer fall under the category of "unpopular plant fibre" used in fashion textile products. The main advantage of using natural fibre in the fashion industry is that because fashion changes very quickly, disposal of the products after use is environmental friendly. Many times toxic chemicals are used in different processes during extraction of fibre to produce final fashion textiles. To develop green-fashion textiles, environmentally friendly chemicals and enzymes may be used during extraction and processing of fibres to overcome this problem. Fashion products from these unexplored fibres will open up new avenues of production; hence, the present market of synthetic material may be replaced to some extent if not entirely. Product diversification from conventional to newer fashion areas will bring more income to the people involved in producing and processing these plant fibres for fashion products.

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