Sustainable Luxury Natural Fibers—Production, Properties, and Prospects

T. Karthik, R. Rathinamoorthy and P. Ganesan

Abstract Increasingly, the world is realizing that better use must be made of precious natural resources. Today, with the enrichment of people's awareness on environment problems and the demand of environment-friendly fabric, natural fibers have received a great deal of attention due to their great importance of "green" and health protection properties and have been widely used in many fields, such as textile industry and daily life. Traditional resource of four natural fibers, cotton, wool, silk, and flax is after all limited. So, many new plant fibers, such as hemp, apocynum, mulberry bast fiber, pineapple leaf fiber, banana fiber, bamboo fiber, kapok fiber, and so on, have been exploited in recent years. The luxury sector, particularly fashion has a high environmental footprint and is responsible for a significant amount of waste. Designers committed to sustainable processes face a severe lack of options in terms of the actual goods used to make their products, with everything from fabric to embellishments being in short and expensive supply. This chapter aims to give an insight into the comprehensive details of conventional as well as unconventional sustainable luxury fibers which are going to be dominated in luxury fashion industry in the forthcoming years.

Keywords Sustainability · Luxury · Natural fibers · Silk · Milkweed · Lotus fiber · Pine fiber · Soy fiber

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1 Introduction

Environmental awareness has prompted many industries, particularly in developed countries, to consider more sustainable ways of operating. Now, industries increasingly are looking directly at natural inputs in a more positive and proactive manner: Natural inputs are considered not only as technically valid components, but also as elements that can contribute to the premium pricing of final products because of their superior environmental attributes and their compatibility with socially responsible production and disposal requisites [1].

The luxury sector, particularly fashion has a high environmental footprint and is responsible for a significant amount of waste. There is an emerging demand for sustainable luxury, which a number of key industries are well placed to develop and promote to consumers. Emerging biomaterials offer new design considerations that fully engage the sustainability challenges of the twenty-first century [2]. A typical, nonsustainable garment can make use of over 8000 toxic chemicals in textile creation processes. However, these same processes are what we can thank for many of the materials that have come to define luxury fashion [3].

Designers committed to sustainable processes face a severe lack of options in terms of the actual goods used to make their products, with everything from fabric to embellishments being in short and expensive supply. This results in two major dilemmas: First, creative concepts become casualties of an inability to source the right materials to see it through to execution. And second, attempts to creatively source those materials, by direct trade or other means result in a product so costly the idea must be canned. Hence the raw material selection plays an important role in sustainable luxury textile and fashion arena [4].

This chapter aims to provide the comprehensive details of conventional luxury fibers such as silk and animal fibers and unconventional fibers such as lotus, milkweed, pine, and soy protein fibers related to their production, properties, and prospects as sustainable luxury fashionable products in the market.

2 Conventional Luxury Fibers

2.1 Silk Fiber

Silk is the ultimate luxury raw material and fiber. It is the darling of the haute couture set for the luxurious feel and drape; villain of vegans and PETA (People for the Ethical Treatment of Animals) for the doomed silk worm who labors to spin the fine fiber and then is gassed or boiled alive. There are many indigenous varieties of wild silk moths found in a number of different countries. The key to understanding the great mystery and magic of silk, and China's domination of its production and promotion, lies with one species: the blind, flightless moth, *Bombyx mori* [5].

2.1.1 Life Cycle of a Mulberry Silk

The life cycle of silk worm is shown in Fig. 1. A *B. mori* egg hatches in 10 days and becomes a larva—the silkworm caterpillar. The silkworm larva will voraciously eat mulberry leaves almost nonstop for 35 days increasing its weight 10,000 times from a tiny speck to a chubby grub. Silkworms are very delicate and will go off their feed from loud noises, temperature fluctuations of more than a few degrees above or below 76°, or even strong smells. When it is full grown, the silk worm (called a pupa) climbs a twig and begins spinning a cocoon. This stage of silkworm life is called pupating. The silkworm produces a fibroin protein compound in two salivary glands called sericteries that is mixed in the mouth of the silkworm with a gooey substance called sericin and forced out through an opening in the silkworm's under lip. When this stream of sticky fluid comes into contact with air, it solidifies and becomes a continuous strand of silk that becomes the silkworm's cocoon. The silkworm will spin a thousand yards of silk fiber in 3 days to form its completely enclosed cocoon. To fashion its cocoon, the silkworm will continually weave its head in a figure eight pattern, an estimated 300,000 times while continually spinning and secreting its silk fiber.

When the transformation is complete, the newly formed *B. mori* moth secretes an alkali fluid that begins to dissolve a hole in the cocoon so that the moth can emerge. The silk farmers do not want their silk cocoons damaged so they kill the

Fig. 1 Mulberry silk worm life cycle. *Source* central silk board, India

worms by tossing the cocoons into boiling water or hot ovens before they transform into moths and emerge from their cocoons. A small percentage of silkworms in cocoons are left to live so that a few moths will emerge to lay the next generation of silk machines. The sightless, flightless, and toothless moth will mate almost immediately after emerging from the cocoon and lay 500 silkworm eggs during their first 4 or 5 days and then die [6, 11, 15].

2.1.2 Sustainable Luxury Silk

The raising of domesticated silkworms and the life of wild silkworms is, by nature, sustainable. Silk fabric when produced by weavers on handlooms has a near zero energy footprint and satisfies most of the guidelines for sustainable fabric production.

Organic Silk

The organic silk production is the more environmentally friendly, nonviolent, and sustainable practice of silk cultivation. Zero chemicals or treatments are required for raw silk, which is readily biodegradable. The silkworms are allowed to live out their full lives and die naturally. Organic silk is a highly sustainable crop with cocoons being produced when the silkworms are about 35 days old. The silkworm continues it's natural cycle to morph into a moth. Then it lays eggs and dies naturally about 5 days later. Natural silk colors are produced but some organic silk is dyed with natural dyes. Raw silk has the versatility to be blended with just about any other fiber. Blends with cotton and other fibers will produce a silken sheen and added softness [7, 12].

Organic silk farming has reaching effects by also promoting the sustainability of mulberry trees, which are the silkworms food source. One mulberry tree will feed roughly 100 silkworms. One acre of renewable trees sustains silkworm life to produce 30–35 pounds of raw silk. Highly sought after natural reddish or golden silk colors are produced, depending on the specific silkworm breed and its feed. These trees, in turn, provide a valuable renewable resource for local production of baskets, furniture, even folk remedies [15].

Peace Silk

Silk production has sparked an interesting debate among environmentalists and animal rights activists. In traditional silk production, thousands of silkworms are killed to make just a small amount of material. Each cocoon is made from a single silk thread about a mile long, but when the caterpillar emerges from their cocoon as a moth, the silk cocoon is broken apart, which essentially destroys the silk thread. In the manufacturing of regular silk, the silk worms inside their cocoons

are immersed in boiling water to kill them so they do not pierce and damage the cocoon when they emerge from it.

The manufacturing method of peace silk entails that no silkworms are harmed or killed in the production process by allowing the silkworms to emerge from their cocoons. With peace silk the silk is extracted after the silkworm has completed metamorphosis and emerged from the cocoon as a moth. The broken cocoons are then collected and the segments of threads are mended using a spinning process. Each cocoon is checked individually to ensure the moth has emerged before the silk thread is spun. Because the one continuous silk fiber woven by the silkworm has been broken into many smaller strands by the emerging moth, the cocoon is degummed to remove the sericin and then spun like other fibers such as cotton or hemp rather than being reeled onto spools of one continuous strand [8]. This silk is slightly discolored by the alkaline solution secreted by the moth to create the hole and the peace silk is not as strong and has a slightly different look and feel to the knowing designer than conventional *B. mori* silk. This specialized production is a laborious process but the result is the quality of silk is softer and finer in comparison to regular silk and it has a soft pearl natural finish instead of a satin look. This process of silk production ensures there is no killing, no cruelty, and at the same time the eco-friendly fabric quality is totally protected. Peace silk is more expensive because it takes more time and skill to salvage and spin the abandoned cocoons and less people are trained in this type of sericulture [9, 10].

Wild Silk

The *B. mori* silkworm is not the only silkworm that spins a silk cocoon that can be used to produce silk fabric for silk clothing and these are called as wild silks or peace silks because the silk caterpillars are allowed to live complete and natural lives in the wild without being sacrificed for fashion. Wild Silk (Tussah or Tussur) is 100 % natural, organically produced by worms that thrive in their natural habitat. They complete their full life cycle and emerge as moths before mating and dying as nature intended. Wild silk is very labor-intensive. Indigenous people collect the cocoons and hand spin the fibers or handloom into cloth for sale. Wild silk is earth-friendly and protects lands otherwise threatened by deforestation. As well, employment is provided for the local villagers. These wild caterpillars spin a silk that is different in texture and color from the domesticated *B. mori* and the wild silk cocoon strands are shorter because they come from cocoons that have been damaged by the wild silk moth's emergence from the cocoon [11].

Eri (from the domesticated silkworm *Philosmia rinini*) is a fine silk that is almost as white in color as the *B. mori* silks. Even though Eri is spun from the cocoons of domesticated silkworms, it is a peace silk because the Antherea assamensis silk caterpillars are not destroyed in the cocoon but are allowed to emerge as moths and live a full lifecycle. Eri silk has the look of wool mixed with cotton but feel and softness of silk.

Matka Silk

Matka is an Indian term for "rough handloom silk fabric" made from very thick yarns spun out of pierced cocoon in the weft (peace silk) and organzine in warp. The yarns are obtained from short ends of silk from Mulbery silkworms and spun by hand without removing the gum. As such, there are slubs and irregularities that give the fabric unique characteristics. It looks something like tweed, but the fibers are all the same color. It is lustrous and strong like other silks, and it promotes to use of peace silk and sustainable processes. Matka silk is biodegradable [12].

Recycled and Vintage Silk

A vintage silk dress, if it is free from rot and stains (which sadly never come out) is a great investment. Silk, when cared for, can last for thousands of years—silk textiles over 4000 years old have been found in Chinese tombs. Vintage silks lend themselves perfectly to recycling and reworking. Recycling old silks seems like a great alternative. Since the fabrics rarely degrade, it makes perfect sense to reuse and restyle [15].

2.1.3 Silk in Sustainable Luxury Fashion

Silk has always been associated with luxury and wealth. The silk makes individual to feel important and when people wear an authentic silk piece, the confidence level goes up a couple of levels immediately for sure. Silk is used for a variety of fashion-related pieces. It can be used for skirts, dresses, blouses, scarves, pajamas, and lingerie.

Samant has adapted the grainy, tactile peace silk to high-end couture, producing stylish sherwanis, boucle-like jackets, and ethereal dresses. The waste generated when harvesting and beginning to process the cocoons presented an opportunity for Samant to develop a new kind of silk with a much coarser weave yet a feel like wool, he has used this textile in panels on men's jackets [13]. Waste produced at the fabric cutting stage becomes the textured layers of appliqué and decoration which characterized, for example, the latest collection which also featured catwalk models adorned with headdresses of silk worm cocoons and reels of yarn as shown in Fig. 2.

It is not entirely clear how much the ethical aspects of the peace silk and support for traditional weaver's livelihoods influence customer's purchase of his clothes. Besides being organic, an "ahimsa" silk processed from cocoons without killing the larvae inside, has thermal properties and is mostly used to make shawls and stoles. Syiem's initial challenges included convincing weavers to supply the fabric in new dimensions, but he adds that since the fabric is dyed with vegetable dyes, it severely limits the brand's color palette to shades of white and natural earthy tones. To compliment the handlooms, he avoids using machine-made

Fig. 2 Upcycled cocoons and upcycled applique adorn model's headdresses [13]

embellishments or fasteners and relies instead on drawstrings, knots, and buttons made from natural materials [14]. Syiem's Meghalaya's Silk root Khadi handlooms showed at fashion week are shown in Fig. 3.

If the primary concern from the consumer is healthy and organic silk then consider raw silk, noil silk, muga silks, or eri silks that are undyed or dyed with low-impact, fiber-reactive dyes. If the primary concern from the consumer is about the ethics of silk raising then choose wild silk, spun silk, or eri silks which do not destroy the silk worms to harvest the silk cocoons. If concerned about sustainability and eco-friendly silk, then seek silks dyed using low-impact and fiber-reactive dyes or vegetable dyes without finishes.

Fig. 3 Meghalaya's silk root Khadi handlooms at London fashion week [14]

2.2 Cashmere

Cashmere is perhaps the most widely recognized of all the luxury fibers. Cashmere wool is the best sustainable and renewable fiber with virtues to protect the user from the surrounding rudiments. Fibers from these garments will not peel and will retain its form for many years, even for generations. More than 3000 tons of cashmere is made every year with the majority of them from Mongolia, followed by Australia, New Zealand, Iran, and Afghanistan [15]. The Cashmere goat and their product are shown in Fig. 4.

Cashmere is prized for its exceptionally fine texture and is strong, ultra light, and soft. It provides a superior insulative function without bulkiness, and the fibers are highly adaptable and easily spun. Like wool, cashmere has a high moisture content that allows the insulating properties to change with the relative humidity in the air. It is however, weight for weight, warmer than wool. The finest Cashmere is obtained from the neck area of the goat. Cashmere goats produce a double fleece that consists of a fine, soft undercoat or under-down of hair which is mingled with a straighter and much coarser outer coating of hair called guard hair. In order to sort the fine under-down and be processed further, it must be dehaired. Dehairing can be a mechanical or manual process that separates the coarse hairs from the fine hair. After dehairing and washing, the resulting cashmere is ready to be dyed and converted into yarn, fabrics, and ultimately garments [11].

The ever-growing lust for the beautiful and soft cashmere fabrics encouraged the breeding of cashmere goats. During the past century, making of cashmere wool has increased up to that extent that it has become unsustainable, and is posing a threat to the environment. What were once beautiful, unspoilt grasslands are now becoming deserts, ravished by the goats breed for their cashmere clip. This is now creating a devastating effect on the ecological balance of the planet. The impact is more visible in Mongolia. The country produces 90 % of the cashmere fabrics sold worldwide. The increase in demand for these products is taking their toll on the country's environment both socially and ecologically [16]. Sustainable cashmere fabrics are made from nonallergenic natural goat fibers. They are animal-friendly, sustainable, and do not wrinkle. They posses durability with little or no pilling,

Fig. 4 Cashmere goat and its products [15]

and become softer with the age. The luxurious fibers from the pashmina goats have inspired many designers, and are preferred by consumers who are luxury lovers [17–19]. With all the exposure of ecological living, sustainable cashmere fabrics are sought by consumers who want to own luxurious clothing line and also remain eco-chic.

The Sustainable Cashmere fiber could be produced by [19]

- Harvesting the fiber from healthy goats that have been raised ethically and treated humanely their entire lives
- Raising the goats respecting their natural instincts, social structure, and needs, and still produce a luxury product
- Growing the goats who have never been tied or tethered, never been treated with chemicals or hormones, and have grazed only overgrown, untreated, unusable farmland, and their fiber has been processed without the use of chemicals or industrial coloring
- Hand combing of our sustainable cashmere is painless and innocuous—the goats are not maimed, wounded, or killed to harvest their fiber and have an average life span of 10–15 years, that is easily double that of goats raised intensively for milk or meat production

2.3 Alpaca

Alpacas are a domesticated species of South American *camelidae* family that resemble small llamas. They produce one of the world's most luxurious fibers that are softer than cashmere and lighter, warmer, and more durable than wool. Alpaca is an enigmatic fiber which is valued for its fine, soft, and silky characteristics [15]. Alpacas have provided vitality, sustenance, and warmth to the Peruvian people for over 6000 years. There are nearly 3 million Alpacas in Peru, representing about 80 % of the entire world's population.

Alpacas graze at elevations of 10,000–14,000 ft on the harsh altiplano of the Peruvian Andes. As a result, alpacas have incredibly insulating coats that are warmer and stronger than wool, yet remarkably lighter in weight. Their thick, luxurious coats naturally grow in over 40 shades, ranging from white to black with all the grays and browns in between. The Alpaca of various shades are shown in Fig. 5.

This provides a glorious palette when left undyed, although the lighter shades of fleece dye to beautiful shades as well. Alpaca's unique durability and delicious softness make it one of the most luxurious fibers in the world [16]. Alpaca fleece has some similarities to sheep's wool, but unlike wool its fibers have a minimal lanolin content, which makes it almost hypoallergenic. It is naturally impermeable, thermally responsive, and has a low flammability point. It is a soft, durable, luxurious, and silky natural fiber. Its softness comes from the small diameter of the fiber, and is to merino wool. Its glossiness is due to low height of the individual fiber

Fig. 5 Various natural shades of Alpaca [20]

scales compared to sheep wool. Alpaca fibers have a higher tensile strength than wool fibers. The alpaca has a very fine and light fleece. It does not retain water, is thermal even when wet, and can resist solar radiation effectively. These characteristics guarantee the animals a permanent and appropriate coat to protect against extreme changes of temperature. Although it feels soft to the touch, the hard surface of the fiber makes alpaca a very durable yarn. It has excellent thermal insulation properties with an apparent lightness of weight [20].

There are two types of alpaca: Huacaya (which produce a dense, soft, crimpy sheep-like fiber), and the Suri (with silky pencil-like locks, resembling dreadlocks but without matted fibers). Suris, prized for their longer and silkier fibers, are estimated to make up 19–20 % of the North American alpaca population [20].

Alpaca fibers are processed in a similar way to sheep wool. They are sheared annually or in their native Andean habitat, generally sheared once every two years. Alpaca farming has a low environmental impact and is therefore an interesting alternative for some sheep farmers. Furthermore in their native South American habitat, alpaca herds are less intensively managed than many sheep herds in the developed world. In addition the financial precedes from their fiber benefits poorer rural communities. In terms of sustainability, alpaca is a natural fiber made of protein so it will naturally biodegrade when disposed of and blends into the earth

within a relatively short period of time when compared to synthetic or man-made fibers which take a long time to degrade and has a negative impact on environment [21–23].

2.4 Vicuna

The vicuna is the smallest of the wild South American camelids. It lives in the plains, grasslands, and mountain regions of the Andes, at altitudes of 4000–5500 m. Vicuna is the world's most valuable natural fiber, and fabrics produced from it can command up to $3000/m. Vicuna fibers are extremely warm and are possibly the finest of all the animal fibers, with a diameter of 6–14 μm [11, 15].

In the past the huge commercial demand for Vicuna fiber and unrestricted hunting had resulted in the species becoming almost extinct, and it was declared an endangered species. In the mid 1970s, as a result the trade of vicuna fiber was prohibited worldwide. The conservation efforts of Peru, Argentina, Chile, and to a lesser extent Bolivia has led to a dramatic comeback of vicuna herds [20]. As the vicuna population grew, all four countries relaxed the laws and sustainable commercial harvesting is now practiced, it is a cash crop that can benefit some very poor communities. Peru has taken the lead in vicuna conservation; it has introduced a traceable labeling system that shows that a garment has been created through a government-sanctioned "Chacu." Chacu is an Inca term for a ritual tradition where the animals are communally captured and shorn and then released back into the wild. They are tagged to ensure that they are not mistakenly herded again for another two years. The Vicuna and its luxury products are shown in Fig. 6.

Recent crossbreeding with alpacas has resulted in offspring that is called Paco-Vicuna which has a coat that is as fine as that of the alpaca but with a longer fleece than that of the vicuna. This makes the paco-vicuna easier to shear, and it can also be shorn annually rather than only once every three years. The outer guard hairs are easily removed from the shorn fleece. The wool is very sensitive to chemical treatments therefore it is always left in its natural color, which is a rich golden honey [24, 25].

Fig. 6 Vicuna and its luxury products [25]

Loro Piana is one of the world's most prestigious fashion houses, whose passion and dedication are to the sourcing of sustainable raw materials. Close cousins of the humble camel, vicuñas have been brought back from the brink of extinction by luxury fashion brand Loro Piana. Each year, only 13,000–17,500 pounds of vicuña become available to Loro Piana, a major purveyor of vicuña garments—a fraction of the 22 million pounds of cashmere the company works with annually. The Italian tailoring house Kiton makes only about 100 vicuña pieces a year; an off-the-rack sport coat costs at least $21,000, while the price of a made-to-measure suit starts at $40,000. A single vicuña scarf from Loro Piana is about $4000. Ermenegildo Zegna produces just 30 vicuña suits a year. Vicuna has a luxurious lineage going back to antiquity and Loro Piana has smartly secured its supply. Loro Piana Vicuna itself comes in a rather limited array of colors as the fine wool does not take to dying very well and loses its natural beauty. Vicuna typically came in natural colors because of this but Loro Piana has succeeded in adding some variation using very sophisticated dying methods. These are namely warm and very Loro Piana colors like beige, cream, caramel rusty reds, and browns. Handling and seeing the cloth is amazing. The color texture and feel are extremely seductive. The cloth is also available through Loro Piana in scarves, knitwear, and in their Interiors (home furnishings) line in limited numbers [26].

2.5 Guanaco

The guanaco is a vulnerable animal native to the arid, mountainous regions of South America. Guanaco are found in the altiplano of Peru, Bolivia, Ecuador, Colombia, Chile, and Argentina. Guanacos are elegant and fine boned and stands approximately 3 ft 6″ (1.06 m) at the shoulder and weighs around 200 lb [15]. Guanacos have a double coat similar to cashmere; guanaco has a rough outer coat containing guard hairs beneath which lies an extremely soft, silky undercoat, fine fiber that ranges in color from honey brown to dark cinnamon. The undercoat accounts for 80 % of the fleece and once dehaired, the resultant spun fiber is of luxury quality, superior to that of alpaca and second only in quality to pure vicuna fiber. The outer coat consists of much coarser fibers, guard hairs, these are a much darker cinnamon (the belly and neck contain white guard hairs) and act to keep debris and moisture out [27].

Like their domestic descendant, the llama, the guanaco is double coated with a coarse guard hair and soft undercoat, which is about 16–18 μ in diameter and comparable to the best cashmere. The average sheep has a micron of 15–30, fiber itself has fewer scales than sheep's wool, it has a much softer, less scratchy feel, and handle. Guanaco fiber has an average length of about 30 mm. It has more thermal capacity than almost any other animal fiber. Microscopic air pockets make garments that are lightweight with high insulation values [15, 28]. It is also naturally water repellent. It does not shrink during washing or processing and has a lesser tendency to feel when washed. It has a high luster, giving garments a high visual appeal [28]. The guanaco and its luxury products are shown in Fig. 7.

Fig. 7 Guanaco and its premium products [29]

Guanaco fiber is particularly prized for its soft, warm feel and is found in luxury fabric [30]. The guanaco's soft wool is valued second only to that of the vicuña. It is finer than cashmere and three times warmer than wool (Lichtenstein). Dormeuil's exclusive fabric Guanashina® is recognized as one of the most luxurious in the world. Guanashina® is a blend of three precious and rare fibers, Kid Pashmina, Baby Cashmere, and Guanaco, creating an inimitable effect in both appearance and handle.

2.6 Camel Hair

Textiles from camel hair are some of the finest, humanely harvested animal fibers in the world. Camels, those two-humped, desert animals that have played a hardy form of transportation in many historical adventures, also provide us with some of the most amazing fiber for fabrics. Today's luxury apparel market vies for camel hair yarns and textiles, as the slow and humane process of obtaining the fiber makes it one of the scarcest in the world.

The camels have been domesticated for over 3000 years and have been primarily used as pack animals. They shed their coats naturally and the fibers are collected and separated. This down fiber is extremely fine, soft, and warm. Unlike wool, camel fiber lacks the pronounced overlapping scales, and therefore does not feel very well. The fiber structure of camel hair is similar to that of cashmere and it also grows a down undercoat covered by an outer coat of long, coarse guard hairs [11].

The production of camel hair is a five-step process of collecting, sorting, dehairing, spinning, and finally weaving or knitting. Collecting or gathering camel hair is carried out by one of several methods: Combing and shearing, or natural shedding during the molting season. The camel sheds its winter coat in clumps of both outer hair and inner down, which is still hand collected. The second stage

Fig. 8 Bactrian camel and its luxury product application [31]

is sorting, where coarse hairs are separated from the fine soft hairs. It is then washed removing all dirt and debris. The third stage is the final dehairing; this is a mechanical process to remove the balance of the coarse hairs, dandruff and any vegetable matter, before the raw fiber is spun. It is only the softer undercoat that is used for premium textiles, either as pure camel hair or blended with lamb's wool. If it has been blended, usually the camel hair is likely to be of an inferior quality or possibly even recycled [15].

The best-quality hair producing Bactrian camels live in the extreme climatic conditions of Inner Mongolia in Northern China and Outer Mongolia. Camel hair is also often blended with extravagant cashmere, obtained from the fine-haired cashmere goats, for a highly luxurious material sought after by high-end apparel manufactures and designers [31]. The coarse fiber is also extremely waterproof, which is why the Mongolian herdsmen use it for coats and the outer layers of their yurts. The Bactrian camel with the luxury fashion products are shown in Fig. 8.

The very best camel hair is from the underside of a Mongolian baby camel and is said to be almost comparable to cashmere in softness. Camel hair is a golden tan color with varying tones of red. Traditionally it is left in its natural color, as this is part of its unique selling point, although contemporary developments in dyeing technology allows it to respond to dye as successfully as wool [32].

2.7 Angora

The wool of Angora (Ankara) rabbit (Fig. 9) is known as Angora wool or Angora. Angora wool is produced only by Angora rabbits and it is the lightest natural fiber ever known; exhibiting original qualities of fineness, luster, and feel, for the production of high value-added luxury items. Angora is often considered one of the "noble" fibers. Angora (Ankara) rabbit is the only animal breed that produces the finest and the longest white silky wool amongst other wool producing animal

Fig. 9 Angora rabbit and the luxury product [32]

breeds such as sheep, goat, lama, alpaca, and camel each at outputs of 5000–30,000 tons annually [11, 15].

Angora hair is unusually long owing to the prolongation of the active phase of the hair follicle cycle: the hair grows for approximately 14 weeks, whereas that of the rabbit with ordinary (short) hair grows at the same rate but for only five weeks. This is due to the presence of a recessive gene in Angora rabbits. The interval between hair collections is a decisive factor in hair length. Though the period of shearing varies due to the length of fiber that is targeted, the Angora (Ankara) rabbits are generally shorn every 3 months, 4 times in a year; which approximates to a total amount of 1 kg. As the Angora wool is shorn from the rabbits, there is no hardship to the rabbits and no rabbits die in the production of Angora wool. The length of Angora hair accounts for its textile value, because it permits cohesion in the thread [32].

Wool is obtained through different shearing or collection methods such as electric or manual shears, scissors, plucking, or depilation:

1. Most commonly used hair collection method is shearing: it is preferred due to its advantages; it is less stressful for the rabbit, less time, and labor consuming, provides protection against cold, and provides possibility of obtaining more wool through shorter shearing intervals. It takes 10–20 min to shear an Angora (Ankara) rabbit.
2. Clipping method (with scissors) increases the amount of sheer wool (less than 10 mm length) because of the post-shearing corrections. It is very important that the skin should not be harmed during clipping. Especially, the nipples are very sensitive to injuries.
3. While plucking thick ended, immature hair is collected. This process takes 30–40 min. In China, wool is hand plucked to obtain the maximum amount of wool.
4. Depilation has long been the technique of choice in France, synchronizing the reactivation of hair follicles with a well-structured coat with good guide hairs. Since the 1980s French breeders have been using a depilatory fodder sold under the name Lagodendron.

A point to be considered very carefully is that Angora (Ankara) rabbit production is labor-intensive and also requires great expertise. The slightest mistake may result in the loss of productive adults: the animals have to be over a year old to return a profit. Hair collection is always a delicate operation and careless sorting irredeemably downgrades the product. Above all, not all climates are suitable: excessive heat and intense light are very bad elements for especially albinos. In cold countries, or in countries with cold winters, the solution is to use buildings that shelter the animals against the rigors of the winter, and to regulate the temperature of the interiors. Recently, denuded animals require special care, however. The feed requirements of Angora (Ankara) rabbits are also very important: a poor, deficient diet will always mean qualitatively and quantitatively poor hair production. The quantity and quality of wool are primarily very much dependent on genes and inheritance of the breed; though factors including feeding, hygiene, age, sex, weight, season, climate, and pregnancy also affect the production and quality of wool. Therefore, selection of pure breed Angora rabbits with high wool production capacity is essential for the sustainability of high quality wool standard [33].

Angora fibers are short, and therefore usually mixed with other soft fibers, such as cashmere and lambs wool. After processing and spinning the yarn may be used (as with other animal fibers), for blends and also to create novelty effects in woven fabrics, but generally angora is more popular for knitwear yarns [15]. Angora is generally viewed as a luxury fiber, and most angora wool products are very expensive, which is reflective of the laborious harvesting process and the small number of cottage industry style producers. China currently dominates world angora production, and is responsible for over 80 % of the 3000 ton global yield.

3 Unconventional Luxury Fibers

Regional textiles are increasingly rare. Most of our clothing comes from familiar sources such as cotton, linen, silk, wool, and man-made fibers. Yet in Philippines, traditional blouses are made from pineapple fiber. In Scandinavian countries, stinging nettles produce fibers that resemble linen. In Japan, special kimonos are made from banana plants that have been nurtured to be especially tender. There is even silk taken from spider webs, rather than silkworm cocoons. It is often difficult and costly to translate traditional fabric-making techniques into mass production.

3.1 Lotus Fiber

Lotus (*Nelumbo nucifera*) is one of the most ancient angiosperms originally planted in South America and now grown in semitropical and temperate zones such as Western Asia, Middle Asia, North America, India, China, Japan, etc. Lotus

has a long planting history and abound resources in China. As the collection of ornamental, edible, and medicinal values, lotus is a kind of special crop with unique research value. Almost all parts of lotus, i.e., leaves, flowers, seeds, and rhizomes can be used for both edible and medical purposes [34].

3.1.1 History of the Fiber

The lotus flower is adored for its characteristic of rising above the muddy water, indicating how one can rise above defilements of life. Apart from motivation for life, the plant also provides fibers which are used for making a rare kind of cloth matching with the flawless virtues of the silk. Fibers extracted from the lotus flowers of the Myanmar lakes are spun by hand and woven within 24 h making a fabric similar to silk [35, 36].

Extracting fibers from lotus stems have been in practice since 1910. Later during the 1990s designers of Japan setup workshops to create a foreign market for their fabric. But due to low demand in Japan, lotus fiber fabric remained a rare and handmade textile. Lotus plant is believed to have healing abilities and wearing a fabric made from lotus fibers is also believed to have the same effects. Lotus plants are pure by virtue, and they radiate this purity through their fibers. By wearing lotus fiber fabrics, one feels calm, peaceful, and meditative. It also cures the wearer from headaches, heart ailments, asthma, and lung issues. The fabrics are 100 % organic, and hence are environmentally friendly.

Lotus weaving was conceived nearly a century ago when a woman named Daw Sa U picked a lotus flower from Inle Lake to offer at a Buddhist temple. A variety of lotus called *Padonma Kyar* grows wild in the shallows of the lake and produces a large, fragrant pink flower. Daw Sa U saw thin fibers trailing from the end of the lotus stem and was inspired to create a thread from the fibers, and from those threads she wove the first lotus robe (*Padonma Kyathingan*), which she offered to a venerable Buddhist monk from Golden Peacock Hill. In return, the monk renamed her Daw Kyar U (Madam Lotus Egg) and she continued to create lotus robes throughout her life, including small robes for the Buddha statues at Hpaung Daw U Pagoda, the most sacred shrine on the lake [36, 38].

3.1.2 Production of Lotus Fiber Yarn

The entire process of fiber extraction, spinning it into yarn and making the fabric is completely handmade making the process time consuming. This also limits the quantity of the fabric produced. Stems of the lotus plants are collected, cut, snapped, and twisted to expose their fibers. Ideally, the lotus flower should be in full bloom when the stems are picked, and the deep pink flowers contain the best lotus fibers. Various stages in extraction of fiber from the lotus stem is shown in Fig. 10.

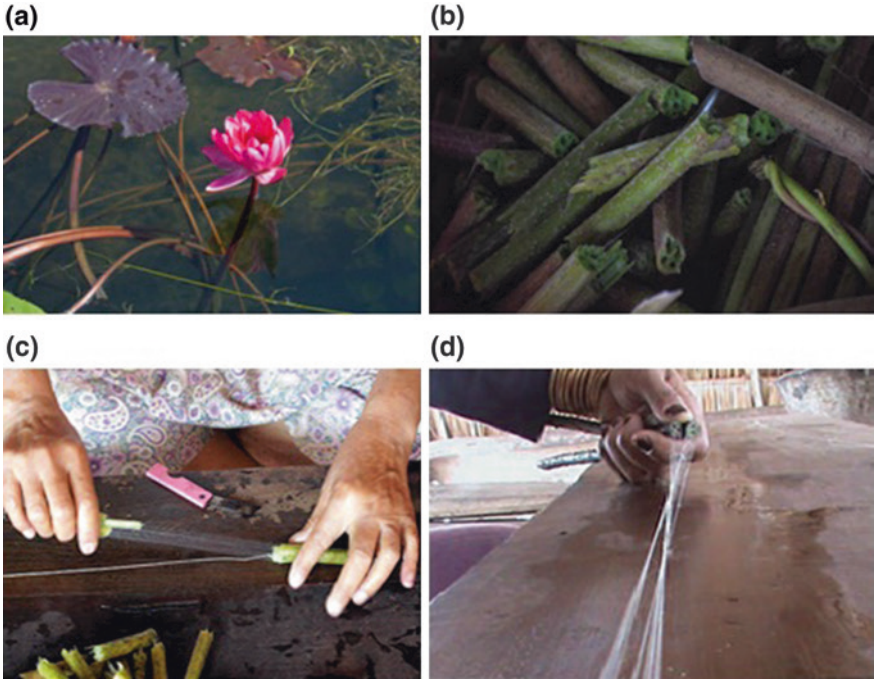


Fig. 10 Various stages of extraction of fiber from lotus stem **a** Lotus flower with stem. **b** Broken lotus stem. **c** Extraction of lotus fiber from stem. **d** Hand twisting the bundle of fibers for weaving [34, 36]

Once a stem is picked, its fibers are extracted within 3 days while still fresh. The lotus leaf stems are gathered in the morning. On a small wooden table, after removing the nubbly prickets with a coconut husk, a handful of about five stems are simultaneously cut, which are quickly snapped off and twisted to reveal some 20–30 fine white filaments that are drawn and rolled into a single thread which is coiled onto a plate. Then, the fibers are spun, washed, and woven. It takes approximately 15 women making thread to keep one weaver busy. A small neck scarf requires about 4000 lotus stems, a large scarf requires about 40,000 stems, and a full set of monk's robes (30 m) requires about 220,000 lotus stems and 60 weavers to complete over a 10-day period [34, 36].

Fibers extracted from the stem are spun into yarn (Fig. 11). Extracted fibers are placed in the skeins on a bamboo spinning frame preparing them for warping. Yarns are made by placing the fibers on a bamboo spinning frame and transferring the thread into winders for warping. With much care, not to get tangles, threads are made; up to 40 m long. The threads are then taken from the warping posts, and are coiled into huge plastic bags. Yarns for the weft are wound into bamboo bobbins [38].

Fig. 11 Lotus yarn [38]

3.1.3 Weaving of Lotus Fabric

Lotus fabric is woven on a traditional Cambodian frame loom. Weaving components include a cloth beam, a large warp spacer–beater, and a pair of heddles supported by a transverse bar resting above the frame. The heddles are connected by rope to a pair of wooden, disk-shaped foot treadles. There is no warp beam on a Cambodian loom. The excess warp is stored behind the weaver and released as weaving progresses. This limits the width of cloth woven to around 24″ (60–75 cm). The use of a temple keeps the selvages straight while water is on hand to moisten the threads during the course of weaving. Given the aquatic origin of the fabric, weavers feel that lotus fibers need to "remain cool." The lotus fabric is woven in 100 yard (90-m) batches, which take about a month and a half to complete. The weavers have estimated that fibers from around 120,000 lotus stems are needed to weave a set of monk's robes. The cambodian lotus fabric is then dyed either with chemical or natural dyes to a reddish-brown shade before being cut into patches of different sizes and machine sewn together in rows to resemble the mosaic-like appearance of community-owned rice fields prevalent at the time of Buddha. Figure 12 shows the handweaving, dyeing, and the resultant luxurious lotus fiber fabric [34–37].

3.1.4 Properties of Lotus Fabric

The lotus fabric looks like a blend of linen and silk, with unique properties, such as being light, soft, and special breathable. It was not as warm as the cashmere but it breathed like linen without wrinkling badly and repel stains as well. Cool in summer and warm in winter, lotus fabric is highly breathable and wearable

Fig. 12 Weaving of lotus fabric and its application [37]

year-round. With a texture similar to raw silk and linen, lotus fabric is soft, lightweight, and naturally waterproof. Besides its supposed calming powers, the Burmese claim that it helps relieve headaches, neck aches, and health issues related to the throat, lungs, and heart [35, 38].

As Myanmar opens its doors and shares its cultural treasures with the world, lotus weaving stands out as a unique cultural heritage that will not remain "undiscovered" for long. Recently, Italian fashion designer Loro Piana developed a line of lotus clothing and introduced it at the Parisian design fair. His 100 % lotus double-breasted sport jacket valued at around €4000 ($5600) made waves in the luxury fashion world. Japanese buyers have also shown great interest in the lotus fabric.

Due to the limited number of lotus plants on Inle Lake and the thousands of lotus required for a single garment, lotus stalks are now being brought in from elsewhere in Myanmar to meet the growing demand. For long-term development of this micro-industry, sustainable lotus growing and harvesting practices are needed, as well as respect for the lake's fragile ecology, the Intha ("sons of the lake") people and culture, and the Guardian Spirit of the Lotus [38].

3.1.5 Future of Lotus Fiber in Luxury Market

As one of the world's top fashion labels, Loro Piana's latest extraordinary venture has the announcement of the "discovery" of a natural and antique raw material, never before used in the textile industry of Western countries: the Lotus flower fiber (*Nelumbo Nucifera*). Extracted from the stems of these sacred flowers which grow naturally on Burma lakes, especially on Lake Inle, this extraordinary raw material has an unmistakeable morphology, similar to perforated tape, light in weight and breathable. It is one of the finest aquatic fibers ever weaved.

The resulting fabric has the appearance of antique linen or raw silk, with an irregular weft; it is soft, exceptionally breathable and crease-resistant. Available only in its natural color (ecru), it will be offered during the forthcoming months in extremely limited quantities (20/30 cuts) and packed in special Burma lacquered boxes, resulting from the local century-long craftsmanship. The Lotus flower represents for Loro Piana another opportunity to support a magic, marvelous world threatened with extinction. Through cooperation with the local population, this material can be introduced to and appreciated by enthusiasts of extreme quality and nature. The development of this project will give the native people, the Intha, the possibility to work in their original environments, so this very antique tradition will not be lost. On the contrary, it will become the means to support future generations, thus allowing this art to survive.

3.2 Milkweed Fibers

Milkweed, a perennial plant can adapt to adverse soil conditions, is being considered as an alternative source of fiber in recent years. Milkweed belongs to the genus *Asclepias*, with over 80 distinct species of which 45 are indigenous to the United States [39, 45]. It previously belonged to the family *Asclepiadaceae,* but is now classified into the subfamily *Asclepiadoideae* of the dogbane family *Apocynaceae*. Farmers and scientists joined hands in the late 1980s to develop milkweed as an alternative fiber source. *Asclepias* species produce their seeds in follicles. The seeds, which are arranged in overlapping rows, have white silky filament-like hairs known as silk or floss. The follicles ripen, split open and the seeds, each carried by several dried floss, are blown by the wind [40, 42, 46].

After Second World War, the use of floss gained importance though it was difficult to be spun. It was mainly considered for stuffing material. The shortage of kapok during the world war was a major reason for this. The floss is made of fibers with a large lumen and very thin walls that have an elastic springiness characteristic of the kapok fiber. The fibers also have a waxy coating that makes them water resistant.

Fig. 13 Different types of milkweed pods and fiber [42]

3.2.1 Types of Milkweed Species

The four important species of milkweed are:

1. Incarnata Swamp Milkweed
2. Speciosa Showy Milkweed
3. Syriaca Common Milkweed
4. Tuberosa Pleurisy Root

All the species produce tough fibers in their stems which can be used to make cloth, twine, etc. and were traditionally harvested from the dead stems in autumn and winter, a fairly simple process [39–45]. Dry summers produce the strongest fiber. The different milkweed fiber pods are shown in Fig. 13.

3.3 Pine Fiber

Pina fiber is the ingenious fabric derived from the leaves of the Spanish Red Pineapple and is the finest of all Philippine handwoven fabrics. Pineapple fibers are an ivory white color and naturally glossy. This delicate and dreamy cloth is translucent, soft, and fine with a high luster.

3.3.1 About the Plant

Piña fiber is extracted from the leaves of the pineapple plant, Ananas comosus (*Linn*) Merr. The plant, particularly the native or "Red Spanish" variety, has leaves that yield excellent fibers for handweaving. The crop is replanted with new plant in about 3 years and during this period the fruit is harvested only twice [48]. The

Fig. 14 Pine plant [48]

plant has a very short stem, which produces at first a roses of leaves and latter grows longitudinally as shown in Fig. 14. Each plant after fully grown bears a fruit. Between the second harvest and replantation in the third year, the plants are uprooted and are either thrown away or brunt in the fields rendering them practically as agriculture leaf fiber being multicellular lignocelluloses fiber is about nearly 10 times coarser than cotton [11].

3.3.2 Scrapping of Pineapple Leaf

Pineapple plant is widely cultivated for the fruit in tropical and subtropical regions of the world. The leaves of pineapple plant contain approximately 3 % of strong white silky fibers. These fibers can be extracted from the leaves either by retting or mechanical means, leaf fibers are obtained from the leaves of monocotyledonous plant. The fiber occurs in bundles in aggregates of individual cells, with the ends over lapping so as to produce continues filament throughout the length of the leaf. The fibers are concentrated in large quantity nearer to the lower surface of the leaf. The leaves are generally thicker and fleshy often with hard surface. The fibers are held in position by the cellular tissues of the leaf by gummy and waxy substance [49–51].

The machine used for scrapping the pineapple leaf has three rollers, (i) feed roller, (ii) leaf scratching roller, and (iii) serrated roller as shown in Fig. 15. The leaves were fed through the feed roller and then passed through the scratching roller. The upper surface of the leaves is first scratched by scratching roller blades to remove the waxy layer and then passed through the serrated roller where the closely fitted blades of the roller macerates the leaf and produces several breaks on the leaf surface for easy entry of the retting microbes [51].

Fig. 15 Scrapping machine of pine leaves [50]

3.3.3 Extraction of Pineapple Leaf Fibers

Extraction of fibers means separation of fibers from the commenting subtonics such as pectin's or lignin's, wax resins, fats, and other carbohydrates, fibers from vegetable plants are extracted by any one method, retting or mechanical. The choice of extraction method will largely depend upon the quality of fibers to be regained. After extraction the fibers are thoroughly washed and dried. For extraction of fibers, the leaves are to be harvested and used due to presences of gummy matter near about 17–18 % on the total weight of fibers. The extraction of fibers can be done by three methods [49, 50].

(a) Hand extraction method
(b) Retting Method
(c) Raspador method
(d) By decorticating machine

Pineapple Fiber Extraction by Hard Working Hands

In spite of all the advancements in mechanization introduced, hand extraction is the most prevalent method for extracting fiber pineapple out of pineapple leaves. In this method, pineapple leaves are scraped using a coarse stone or knife as shown in Fig. 16 and the extracted pine fibers are shown in Fig. 17.

The outer layers of the leaf are removed and what remains is the fine fiber. Hand scraping of the leaves must be done in the first 3 days after harvesting. If left any longer, the leaves will become dry and the fibers will be difficult to extract. The gathered leaves must be sorted to remove any damaged, diseased, or broken leaves.

Extraction of Fibers by Retting Method

This is very old and conventional method used for obtaining fibers from pineapple leaves. This method is very economic but it is very much time consuming.

Fig. 16 Hand scrapping of pine leaves [49]

Fig. 17 Extracted pine fibers [50]

The first stage of obtaining the fibers from the pineapple leaves is called as retting which consists of softening of pineapple leaves in water. In fermentation bacteria developed into the process degrade the partition of the softer cells of the leaf leaving the fiber cells unaffected there by facilitating the separation of fiber bundles (2–4″ in length). After retting the leaves are removed and dried. After drying the leaves are subjected to breaking. It is the first mechanical process to which pineapple leaves are subjected. This is done manually by beating with hammer [53].

Raspador Method

The pineapple leaf fibers are also extracted mechanically by using the machine called "Raspador" which was invented and patented in France. The machine

consists of a rotating beater mounted on a shaft. A number of blades are mounted on the circumference of the beater for beating purpose as it is driven by an electrical motor. As the beater rotates one end of a bunch of leaves (6–8 in numbers) are fed slowly between the beater and the feed plate while the other end is held firmly by the operator when the leaves are halfway through it is pulled back and the other half is fed in the same manner. Due to crushing, beating, and pulling action the pulpy material gets removed. The leaf fibers are then washed and allowed to dry [52].

Decorticating Machine

To increase the pineapple leaf fiber production and enhance the quality of the fibers SITRA has developed a decorating machine. The main principle consists of alternatively beating and scratching of the pineapple leaf as they are fed at constant rate through a pair of feed rollers. Both plain and toothed beating blades are placed alternatively to perform beating and scraping action [54].

3.3.4 Pineapple Leaf Fiber Properties

The physical properties of pineapple leaf fiber are as shown in Table. From table it can be studied that fiber tenacity and L/B ratio of the pineapple leaf fiber suggest that pineapple leaf fiber is superior to jute and therefore stringer and finer yarn (finer than 100 % jute yarn) could be spun using pineapple leaf fiber. Porosity and swelling of pineapple leaf fiber indicates its suitability for good dying, moisture absorption, and feel. Moisture regain of pineapple leaf fiber is about 12 % due to this pineapple leaf fiber has higher dye absorbing tendency as compared to cotton fibers.

3.3.5 Weaving of Pine Fabric

Handwoven piña cloth embroidered intricately were greatly prized then and believed to have matched, or even surpassed, the most intricate laces or other luxurious handiworks in vogue in Spain and France at the time. Piña cloth was such an important novel cloth material that in 1571, it was used to pay royal tribute or poll tax imposed on the inhabitants. Piña cloth weaving reached its peak of perfection in the late eighteenth century and in the first half of the nineteenth century. Piña cloth became one of the most sought after handwoven materials because it was a suitable wear to tropical climate and due to its uniqueness and beauty, it offered the most feminine and refined look in an age of elegance and romanticism. The handweaving of pine fibers are shown in Fig. 18.

Since pineapple fabric is handloomed by only a few weavers, it is very precious and scarce, which also makes it expensive. One meter of pine fabric costs as high as US$16/m. It is used for table linens, mats, bags, and other clothing items.

Fig. 18 Handweaving of pine fiber fabric [54]

Because it is lightweight but stiff, this sheer fabric can be used in any creative design. These handwoven fabrics can be colored with vegetable dyes originating from leaves, and barks of different trees [47, 55].

Pina fiber is often blended with cotton, abaca, and silk to create wonderful light, breezy fabrics. When woven with silk, it is called piña seda or piña-silk. Piña jusi is blended with jusi (abaca or silk) for strength and sheerness and is less expensive than 100 % piña. Filipino designers are using pina fabric for domestic ethnic designs (like the barong). Recently, Philippine fibers have been promoted to top fashion houses and piña pineapple fabric was officially reintroduced to the world. Global fashion designers are always searching for innovative materials and new ideas to give them an edge in the industry. Pina fibers have the potential to greatly influence fashion [53, 55, 56].

3.3.6 Pineapple Fabric Benefits

- Regal and timeless are the two words that come to mind. In fact, piña is often traditionally used for wedding attire
- lightweight
- blends well with other fibers
- similar in appearance to linen
- softer than hemp
- more texture than silk
- washable and easy care
- no dry cleaning

3.4 Soy Protein Fiber

Although natural protein fibers such as wool and silk have good physical properties and have been used extensively in the textile industry, they are

relatively expensive to use and process. In silk, a large quantity of mulberry leaves is required for the production of a very small quantity of silk resulting in an increased cost of production [57].

Soybean protein fibers (SPF) are manufactured fibers, produced from regenerated soya *Glycine Max* soybean proteins in combination with synthetic polymer (polyvinyl alcohol) as a predominant component. The invention of SPF is the contribution of mankind to the protection of natural rare minerals, the protection of resources, the care of the environment, and the consideration of the global balance. It is an active fiber, a new green textile fiber is an advanced textile fiber. It is also known as "vegetable cashmere" or "soy silk." It is made from the soybean cake after oiling by new bioengineering technology. The main component of soybean fiber is it possesses the superiorities of many natural fibers and synthesized ones and it is quite similar to those of cashmere and silk, featuring fine denier, low density, and good tenacity and elongation. The resulting fabric can give cashmere-like hand touch, silk-like luster, cotton-like moisture conduction, and wool-like warm retentiveness [58].

3.4.1 Manufacturing of Soy Protein Fiber

The manufacturing process of soybean fiber is presented in Fig. 19.

Five main production stages can be identified:

1. Separation: "clarifying" the soya bean meal and precipitating out the protein.
2. Solubilisation: dissolving the resulting washed and dried curd to form the "spinning" solution.

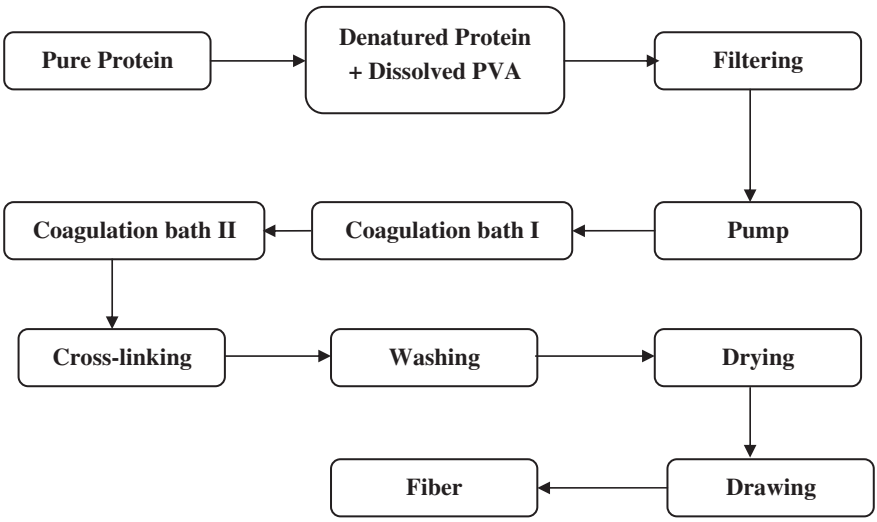


Fig. 19 Manufacturing process of soybean protein fiber [58]

3. Hardening: forcing this solution, when sufficiently ripened, through spinnerets into a coagulating bath resulting in the formation of fibers.
4. Insolubilising: stretching and hardening this fiber, often using formaldehyde.
5. Controlled washing and drying followed by cutting into staple lengths.

3.4.2 Woven Fabric

Weaves made of soybean fiber blends with other natural or chemical fibers have so far been used in shirting and home textiles. A series of such products, too, has already been developed. Their special feature is the luster and soft hand found in silk. Their economic effects are extremely high. SPF are soft and smooth as well as absorbent; it is ideal for products that are worn close to the skin such as underwear, sleepwear, sportswear, and children's and infant's clothes, bed sheets, towels, and blankets [59].

3.4.3 Characteristic of Soybean Protein Fiber Fabrics [60, 61]

- Cashmere feel—The fabric made of Soybean Protein Fiber is soft, smooth, light. It has cashmere feel, but smoother than cashmere; it is as comfortable to the skin as human's second skin.
- Luxurious appearance—To the senses of the consumer, the appearance of a garment's shell fabric shows luster, drapability, and a fine degree of weave. The shell fabric made of soybean protein fiber shows the luster of real silk; its drapability is also very good, giving people the sense of elegance; the textile woven with high-count yarn has fine and clear grain, suitable for high-grade shell fabric for shirts.
- Good comfort—The knitting shell fabric which uses soybean protein fiber has a soft and smooth handle, and the texture is light and thin, with the sense of blending real silk and cashmere. Its moisture absorption performance is equivalent to cotton, and its permeability is greatly better than cotton, ensuring comfort and health while worn.
- Good chromaticity—The natural color of soybean protein fiber is light yellow, very like the color of oak silk. It can be dyed with acidic or active dyestuffs. Particularly when dyed with active dyestuff, the color of product will be fresh and lustrous. With good fastness to light and perspiration, it also has good dyeing brilliance and dyeing fastness in comparison with real silk products.
- Good mechanical and physical performances—The breaking strength of single filament of this fiber is over 3.0 cN/dtex, higher than the strength of wool, cotton, and silk, and only slightly less than terylene and other commonly used high-strength fibers, while the fineness can reach even 0.9 dtex. At present, 6 dtex high-quality yarn can be woven in cotton spinning equipment with 1.27 dtex cotton-type fiber, to develop high-grade, high-count, and high-density shell

fabric. Because the initial modulus of soybean protein fiber is quite high, the boiling water shrinkage is low, and so the size stability of shell fabric is good. In common cleaning, there is no worry about the shrinkage of textile, the anti-crease performance is also outstanding, and it is easily and quickly cleaned and dried.

- Health care function—The soybean protein fiber, with its good affinity to human skin, contains several amino acids and has good health effects. In the fiber spinning process of the soybean protein fiber, the addition of Chinese herbal medicine with the effects of sterilization and anti-inflammation will combine with the side chain of the protein in the manner of a chemical bond. The medical effect is outstanding and permanent, avoiding the disadvantage that the medical effect is less long-lasting when functional products of cotton goods are developed with the after-finishing method.
- Anti-ultraviolet—Its anti-ultraviolet property is superior to cotton fiber, much more superior to viscose and silk. The absorptive of ultraviolet radiation could reach up to 99.7 %.
- Far-infrared function—The emissivity of far-infrared could reach up to 87 %, have the function of heat effect, promoting microcirculation of skin, enforcing the immunity, etc.
- Skin evaporation—Its amino acid can activate the collagen protein in the skin, resist tickling and evaporate the skin.
- Antibacterial—Soybean protein fiber has antibacterial properties that resist colibacillus, staphylococcus aurous, and candica albicans. Fabrics made from soya protein fiber and linen or other fibers are ideal for functional underwear and summer wear.

3.4.4 Recycled Soy Fabric Fiber

Known as "vegetarian cashmere," soy protein fiber is soft and supple with luxurious luster and elegant drape. It has a cashmere feel, but is smoother on the surface. The moisture absorption is similar to that of cotton but its ventilation is superior. Soy fabric has high breathability, excellent absorbency, great color retention, natural wrinkle resistance, and does not shrink from heat as much as other natural fabrics. Soy fabric is extremely durable, with a breaking strength greater than cotton, silk, and wool. The structure and pigment of the fibers make soy fabric easy to color with low eco-impact dyes. And its ultraviolet resistant properties protect it from fading and splotching. So it has vibrant longevity of color. Soy fiber fabric also contains bacteria resisting compounds that actually help protect the body from harmful bacteria [58].

This exceptional eco-friendly fiber is made from the renewable resource of the unused soy protein remaining after the production of other soy products like tofu, soy milk, and soy oil. While this is a chemically intensive process it is a closed loop system, meaning they reuse the chemicals over and over rather than dumping them after a single use. This practice of converting waste materials into other products of

better quality or higher environmental value is known as "upcycling." Our "upcycled" soy cashmere is blended with organic cotton and a little spandex for the perfect fit to create an eco-friendly fabric that is both sensual and practical [60].

3.5 Future Prospects of Milkweed, Pine, and Soy Fibers in Premium and Luxury Products

The search continues for the ideal natural fiber—organically cultivated with zero or minimal artificial assistance, ethically manufactured, sustainable, processed without chemical aid, with reusable by-products, and completely biodegradable. Global fashion designers are always looking for innovative materials and new ideas to give an edge in the industry. The applications of nonconventional fibers are limited mainly due to inadequate supply of raw material.

The milkweed fibers have more positive properties to be used as premium and luxury products due to its silk-like lustrous, better moisture transfer properties, and light weight. Milkweed floss is similar in density to high quality down. Milkweed floss transmits 62 % of the maximum amount of perspiration uptake allowed by air. Floss is highly resilient. It has a noncollapsing lumen in both wet and dry applications. The genus *Asclepias* contains over 80 distinctive species, of which approximately 45 are indigenous to America. The milkweed plants are presently gathered in the wild state. For better yield, the milkweed plant needs to be cultivated rather than gathered from wild state. If cultivated, they are perennial and need little irrigation and attention compared to cultivation of cotton fibers. The milkweed plant can adapt to almost any soil condition from swampy and moist to sandy and arid. It is a perennial plant and hence, once planted does not require replanting each season. This encourages as an alternative crop because theoretically it should be easy and economical to cultivate. Like cotton, the milkweed seeds are planted in the month of April/May and harvested in the month of September/October which produces good quality fibers compared to fiber harvested in the second season in the month of March/April. In cultivation, only 3–5 % of the flowers produce mature pods. The analysis showed reveals that, approximately 400–500 matured milkweed pods are required to get 1 kg of milkweed floss. The average yield of milkweed plants is in the range of 550 kg/ha, which is lower when compared to cotton fibers. Successful commercialization of milkweed as a crop is dependent upon mechanized harvesting, handling, drying, and floss processing system. To improve the yield of milkweed plants, first thing to be considered is selection of superior strains and hybrid seeds and then the proper cultivation methods. Currently, Natural Fibres Corporation, Ogalla, US is cultivating and marketing the milkweed floss commercially at a price of $ 28/kg. As they are monopoly in this market, the prices are relatively high. The prices will come down when many players enter this market. Currently, Monark Company (Encore3, USA) has commercialized the knitted milkweed fabric for premium sector [61].

Pineapple fiber fabric, due to its inherent qualities of being a bit stiffer than cotton and not as soft as cotton make this fabric unlikely to replace cotton at the

fabric of choice for textile production. The major end use of Pina fiber is the Barong Tagalong, wedding dresses, and other traditional Philippine formal dress. It is also used for table linens, mats, bags, and other clothing items. Because it is lightweight but stiff, this sheer fabric can be used in any creative design. The traditional decoration for this fabric is a style of hand embroidery called *calado.* An embroidered piña garment is called piña calado. These handwoven fabrics are colored with vegetable dyes originating from leaves, and bark of different trees. Pina fiber is often blended with cotton, abaca, and silk to create wonderful light, breezy fabrics. When woven with silk, it is called piña seda or piña-silk. Piña jusi is blended with jusi (abaca or silk) for strength and sheerness and is less expensive than 100 % piña.

Pineapple textiles are not a viable large-scale substitute for cotton; however, this fiber can help to lessen the demand for cotton in the future. The large-scale international production of pineapples is associated with the environmental and social problems; however, a useful textile can now be made on a large scale from a by-product of pineapple cultivation. Pineapple fiber can be blended with cotton to reduce the need for cotton cultivation on a world level. In the future, pineapple fiber should be looked at as only a supplemental textile fiber to cotton. There is still a relatively high price tag on pina cloth and a limited number of suppliers worldwide. The variety and styles of pina cloth are still somewhat limited at this time. Filipino designers are using pina fabric for domestic ethnic designs (like the barong). Recently, Philippine fibers have been promoted to top fashion houses and piña pineapple fabric was officially reintroduced to the world. Pina fibers have the potential to greatly influence fashion. Consumers can play a pivotal role in the reintroduction of pina fabric with demand and support for natural fibers for clothing [62].

In order to fully revive this traditional industry, cooperatives need to work together for development, funding, and international fair trade. Currently, designers and retailers are making the most money. The key is to increase profits for the local weavers. Through the return to their ethnic roots and age-old traditions, the piña salvation is just beginning to enter the limelight. Businesses are striving to meet current export orders to Japan, Hong Kong, USA, France, and UK. International awareness, promotion, and marketing of pina cloth will help change the regions economy by putting piña fabric industry on the map. A research team from Brazil has developed a new form of plant fiber-based plastic that is claimed to be stronger, lighter, and more eco-friendly than plastics currently in use. The nanocellulose fibers can be almost as stiff as Kevlar, but that the plastic differs from many in widespread use because the source material—such as pineapple and banana—is completely renewable. The pineapple leaves and stems, or the closely related curauá, could be a promising source of readily available nanocellulose. The leaves and stems are placed in a kind of pressure cooker, where certain chemicals are added to the mix. After several heat cycles, a fine powder is produced which could be used for manufacturing of automotive composites [63].

Soy fabric has sparked the interest of designers to utilize soy yarn to weave into garments. Most of the styles produced so far tend to be relaxed and casual. Soy is breaking into the marketplace with a promising future ahead of it. China,

the largest textile manufacturer and exporter, has begun mass producing soy-based yarn. Right now soy clothing is mainly found as underwear, socks, scarves, sheets, and yoga or exercise apparel. It is also a popular choice for very soft, comfortable baby clothing. Soy can be blended with other textiles like cotton, bringing the benefits of each to fabrics and beautifully colored using low-impact dyes. A big selection of clothing is hard to find and since the nature of soy is to be very soft most styles are casual and relaxed [64].

Bombay Dyeing has a range of soy bath towels in their premium home range, available at select retail outlets across the country. Naina's Apparel Private Limited, another Mumbai-based export house, have featured soy in their collections (for retail and export), but in limited pieces, due to higher manufacturing costs. Faeries Dance an earth-friendly fashion shop carries soy fabric clothing with a little style and fun. That green sweater at the top of the page is a soy fabric blend from their line [65].

4 Conclusion and Recommendations Going Forward

Environmental and social impacts of the fashion industry are growing, but there are many ways that we can not only reduce negative environmental impact, but also increase positive environmental and social benefits through informed choices of materials and intelligent design. The search continues for the ideal natural fiber (where it all begins)—organically cultivated with zero or minimal artificial assistance, ethically manufactured, sustainable, processed without chemical aid, with reusable by-products, and completely biodegradable.

The term "Luxury" is a buzz word in the high-end fashion industry. The luxury comes for a textile material is not because of the designer or because of a brand. The terminology comes from the quality of the material and also due to the sustainable/eco-friendly manufacturing process. Hence, the products are often with high price range. In order to fulfill the requirements of the ever-changing market, designers always look for new colors, fabrics, styles etc., to offer designs to the market. In today's world, fashion is not limited to esthetic look of the garment but also functional features of the garment play an important role. Further, due to increase in expectations of the consumers, designers as well as manufacturers are also focusing on the new dimensions of fashion by using unconventional fibers.

The chapter mainly focused on utilizing the natural conventional and unconventional fibers in the era of luxury textile fibers and fabric, with the idea of reducing the carbon footprint level of each manufactured luxury product. The shift toward lighter, softer fabrics is changing in today's textile market. In addition to improved milling techniques and an increased appetite for novelty, changing life styles have brought a dramatic transformation in the fabrics that high-end consumers are looking for.

In the first section of the chapter, the possible animal fibers like silk, cashmere, alpaca, vicuna, guanaco, camel hair, and angora fibers were discussed along with

their verity and availability. The section also discusses about the different limitations and advantages about the animal fibers in the sector of luxury fashion and textile. The specialty hairs presently have vital spectra in the ever-changing fashion world. Utilization and application of specialty hair is the emerging trend, growing slowly yet steadily. The qualities of specialty hair fabrics appear different individually though found to be similar in most of the cases. It is no secret that the world's softest garment fiber comes from a docile and adorable animal called Angora rabbit and it has huge commercial value. These fibers possess excellent thermal characteristics and hence provide the necessary comfort in cold weather clothing. Innovative blends of these fibers with wool, cotton, and other fibers need to be explored to produce value-added products with improved yarn quality characteristics at an acceptable process cost is still a challenge for the spinners.

The second part of the chapter details the unconventional textile fibers like lotus, milkweed, pina, and soy fiber. Where, the fiber separation methods, fabric manufacturing technologies, and the benefits and limitations of individual fibers were enlightened in detail with respect to the luxury-based textile applications. Till date, most of the pineapple fibers are used for making traditional dresses. Recently, pine fibers have been promoted to top fashion houses and pina pineapple fabric was officially reintroduced to the world. Pina fibers have the potential to greatly influence the fashion. As pina fiber production gains momentum, thousands of jobs for weavers will be created. This will lead to huge potential and economic rewards for indigenous weavers, their families, and their communities.

Among the discussed conventional and unconventional fibers many of the fibers were still in the research level. The commercialization of the product or development of fibers in the industrial aspect or in the bulk quantity is not achieved due to the technical problems. Especially in the unconventional fibers, the availability of the raw material is abundance, the utilization in the manufacturing sector is very meager. Hence, the opportunities in this unconventional fiber research opens a new era for the fashion designers and fabric manufactures to explore more in the luxury sector. At the same time, unlike the synthetic or artificial materials the impact of those products on the environment and ecosystem is considerably less. The luxury sector in the textile and fashion industry has very high-end users, hence, the researchers can focus on reducing the carbon footprint of the individual manufacturing process of the material, from plant cultivation to fabric manufacture rather than the cost reduction by using artificial materials and process.

The application areas are not limited with the apparels. The textile materials are nowadays used in various sectors especially based on the luxury requirement. Home furnishing sector is one of the major markets where the luxury textile materials widely have been used. These fabrics will bring luxury and elegance to homes and other interiors where only the finest quality will suffice. Fabric used for decorations such as curtains, bed sheets, covers, and so on, must have their properties which make them ideal for specific purpose. Natural fiber is usually made of natural supplements and often expensive to be used in this sector. However, as its name suggests natural fabric is more durable, soft, luxurious, and resilient. Some of the commonly used natural luxury fibers that are used to make fabric are silk,

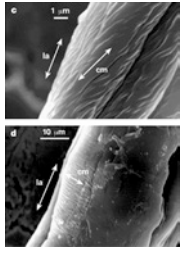
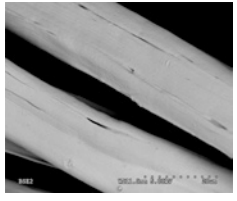
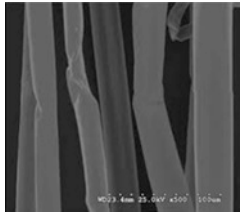
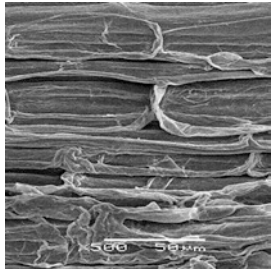
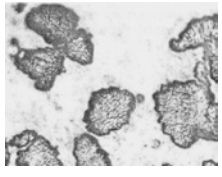
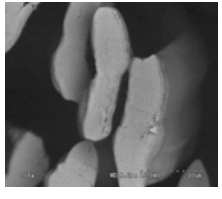
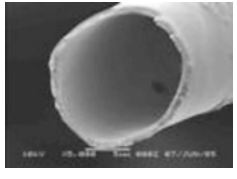
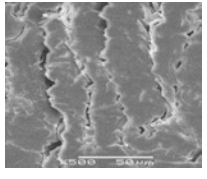
hemp, wool, horsehair, cashmere, mohair, camelhair. Rubelli, Ralph Lauren, and Etro textiles are the world's leading top three luxury home textile producers. Most of these companies are still completely handmade on traditional looms, the way it was done hundreds of years ago. For rubelli, the handmade products are the iconic trademarks. All textiles are produced from natural materials—linen, silk. The Ralph Lauren textiles have excellent quality and great design. Impressive upholstery and drapery fabrics always become an outstanding and memorable detail of the interior. The most popular designs include floral, leopard, and geometric patterns. The hallmarks of Etro textiles are the famous Paisley motif which gives to them oriental flavor and sumptuous look. The founder of the brand Gimmo Etro from the beginning has set the goal to produce the most luxurious and quality fabrics made only from natural fibers—silk, cashmere, cotton, and linen.

The next important potential sector is luxury brand automotives upholsteries. The high-end cars like Mercedes, Lamborghini, Jaguar, and Rolls-Royce., were utilizing textile fiber-based upholsteries either with functional requirements like sound and thermal insulation or with the decorative aspects. Recently, Rolls-Royce Motor Cars Ltd recognized the trend of individual personalisation and subsequent rise in bespoke customer commission. The importance of luxury fiber was apparent in Serenity, a Phantom Extended Wheelbase, created in the finest quality raw silk, hand painted and hand embroidered with a tree in full bloom, evoking an atmosphere of calm tranquility. The fabric has been designed to provide texture to the interior of the motor car. Each thread has been hand placed to reflect light and bring the motif to life. The designers feel that bringing the evoked notions of the Emperors from the Far East into a car design makes them more luxury. Hence the designers selected the materials and textures used in this culture, where the silk defined opulence, the color of the raw silk we used could often be found in robes worn by the Japanese Royal Family, and the Blossom motif in full bloom, which envelops the motor car, is to this day often viewed as a symbol of hope and renewal.

In all the cases, the primary and important factor which influences the customer is the appearance of the product, how pleasing they are matters much. However, nowadays the customer also bothers about the environmental impacts of the products they purchased. Hence, the companies were more focused on these kinds of sustainable fibers. This ultimately reduces the carbon footprint and improves the sustainable nature of the product. The designers and fabric manufacturers who focus in this sector have huge potential with the conventional and unconventional fibers. This chapter is an insight to the available details of various luxury-based fibers. The impending scope of these fibers were also heartening the researchers and manufactures in the era of sustainability and luxury.

Appendix

Physical and chemical properties of unconventional fibers

	Pine	Soybean fiber	Milkweed	Lotus
Plant family	Bromliaceae	Fabaceae	Asclepiadaceae	Nelumbonaceae
Genus	*Anans cosmo's*	*Glycine*	*Asclepias*	*Nelumbo nucifera*
Longitudinal appearance	Ovuliferous scale with two-layer structure, sclerids 	Bean-shaped 	Smooth, single cell, cylindrically shaped, without any convolution 	Strips and cracks 
Cross section		Bean-shaped 	Oval to round 	Slitting 

(continued)

Table (continued)

	Pine	Soybean fiber	Milkweed	Lotus
Diameter (μm)	–	–	20–50	3–4
Linear density (tex)	2.44–3.56	6.2 tex	0.11	2.54
Length (mm)	3–9	38	20–30	50–150
Strength (cN/tex)	30–51	2.5	16–25	1.71
Elongation (%)	2.5–3.5	18–21	1.5–3.0	6–7
Moisture regain (%)	11.5–12	8.6	10.5–10.9	9.3
Density (g/cm^3)	1.5260	1.29	Wall density—1.4	–
			Considering lumen—0.27, wall thickness—1.4 μm	–
Chemical composition	α cellulose—69.5 %	–	Cellulose—55 %	Cellulose—77.42
	Hemicelluloses—16–19		Hemicellulose—24 %	Hemicelluloses—6.87
	Pentosans—17.8		Lignin—18 %	Lignose—10.73
	Lignin—4.4		Extractables—3 %	Pectin—1.34
	Fat and wax—3.3			Lipid wax—1.05
	Pectin—1.1 Nitrogenious matter—0.9			Water soluble matters—2.59
Crystallinity (%)	57.5	–	32–39	–
Degree of polymerization	1178	–	4000	–

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