REVIEW ARTICLE

Eco-sustainability with Plant Based Natural Fibers

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Abstract

Fabrics and fibers have long been a crucial component of all human endeavors. Research indicates that the output of chemical and synthetic fibers increased by approximately 23.94 million metric tonnes to 105.6 million metric tonnes between 1975 and 2018. With the rise in demand for fabrics, issues about the environmental effects of fiber manufacturing and the ensuing disposal processes have also gained prominence. Many recent studies have demonstrated that the textile industry is a threat to the atmosphere and freshwater micro-system because it uses a lot of toxic and hazardous chemicals during the production process and releases pollutants across the lifecycle of a textile product. High energy use, difficult transportation, and unnecessary packing materials all contribute to other types of contamination. Finally, the issue of disposing of big solid volumes has emerged due to the enormous waste output. According to Polymers 2021, the textile sector is responsible for 20% of global pollution. Therefore, sustainable, biodegradable, and superior natural fibers are in great demand. Cotton, jute, and bamboo are some natural fibers that have been in use for ages. This paper reviews plant-based uncommon sources of natural fibers, their manufacturing process, and their applications. Like lotus (*Nelumbo nucifera*) stems are used for extraction of lotus silk, which can be woven into fabric. Banana fiber is a natural absorbent fiber that can be used to make safe, sanitary napkins. There is no negative effect on the environment and it is considered eco-friendly. Fibers from pineapple leaves is used in making thread for textile fabrics for various purposes, such as sports items, automobiles, baggage, mats, and carpets. *Agave americana* is used to extract pita fibers, which are strong, biodegradable, and eco-friendly. While vegan leathers are lacking in breathability; cactus leather, a bio-based substance, excels in this regard. With several other sources reported, this paper will give an insightful view of eco-friendly clothing, which is a boon to the fashion industry.

Keywords: Sustainability, Natural fiber, Eco-friendly clothing.

Highlight

- The amount of chemical and synthetic fibers produced increased from 23.94 million metric tonnes to 105.6 million metric tonnes between 1975 and 2018.
- The environmental impact of synthetic fiber production is high.
- High energy use, difficult transportation, and unnecessary packaging increase environmental impact.
- The subsequent disposal activities have also become more prominent.
- The textile sector is to blame for 20% of global pollution.
- The only way to mitigate this environmental impact is to increase the production and use of sustainable, biodegradable, and superior natural fibers.

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Introduction

Fabrics and fibers have always been an important aspect of every human activity throughout history. Fabrics are used to manufacture clothes to protect and shield the human body from poor weather, as well as to indicate social standing and respond to shifting fashion trends. Every house has materials such as sofas and chairs, upholstery, curtains, tablecloths, towels, napkins, tea towels, and bed linens. Fabrics are used in transportation also. Airbags, seat belts, carpets, seat upholstery, and tires are used in automobiles, trains, boats, and airplanes. Fabrics are also employed in the building industry as structural reinforcing elements.

Fabrics are either natural or synthetic. The majority of textiles are created with synthetic materials derived from synthetic fibers and petrochemical blends like polyester, rayon, and nylon. People prefer synthetic fibers over natural ones because the majority of synthetic fibers are pliable and do not wrinkle easily. Fabrics produced from synthetic fibers are typically more durable, less expensive, and more widely available than natural fiber fabrics. The majority of synthetic fibers can withstand enormous loads without breaking. But they also have several disadvantages like synthetic fibers are not heat resistant and catch fire very easily. Moreover, synthetic fibers absorb very little moisture and thus are uncomfortable to wear during hot and humid climates.

According to Garside M. (2019), from 1975 to 2018, the production of chemical and textile fibers increased nearly fourfold, from 23.94 million metric tons to 105.6 million metric tons: in about 40 years (Achuthan *et al*., 2021). Over 20 million textiles are wasted annually in China alone; 10 million textiles

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are expected to be abandoned annually in Europe and the US. Meanwhile, Malaysia produces approximately 2000 tonnes of textiles and discarded apparel every day. Approximately 8% of the nation's total solid waste is composed of manufactured waste. Methane is a dangerous greenhouse gas that is produced when naturally occurring textile waste degrades and greatly adds to global warming. Textile dyes and chemicals, as well as other garment components, are absorbed into the soil, resulting in soil contamination and drainage, which eventually reaches the water table and enters our food chains.

The recent need of the hour is to protect the earth and try to follow sustainable development. In 1987, Brundtland Commission (United Nations), defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Its goals are to preserve every species of plant and animal as well as to guarantee the continued productivity of natural resources that can be exploited. A sustainable lifestyle seeks to minimize the use of the planet's natural resources by an individual or by society. Its adherents regularly change their home and transportation plans, energy usage, and dietary habits to lessen their ecological footprint, including their carbon footprint. Proponents of this lifestyle approach aim to lead sustainable, naturally balanced lives while acknowledging humanity's symbiotic relationship with the earth's natural ecology. The practice and idea of ecological living are strongly aligned with the larger principles of sustainable development (Kaur *et al*., 2019).

Natural fibers, which are renewable and extracted from environmentally favorable raw materials, have played an important role in human civilization (Petchimuthu *et al*., 2019). Natural fibers are superior to synthetic fibers in many ways, including lower density, lighter weight, cheaper price, biodegradability, fewer health risks during processing, easy availability, low production cost, low energy requirements, and lower CO_2 emissions. As a result, natural fibers have a lot of potential as a substitute for glass, carbon, and other synthetic fibers. Because of their availability and technical viability, natural fibers are desired bio-sourced materials as an alternative to non-sustainable glass and carbon fiber-reinforced composites (Vayabari *et al*., 2023).

Most agro-textile products are made from synthetic materials derived from petroleum, making them a type of manufactured trash that pollutes the environment (Abu Hassan *et al*., 2023; Hui *et al*., 2023). The global agro-textiles market was estimated at USD 9.05 billion in 2020 and is predicted to increase at a 4.7% annual pace from 2021 to 2028. Rising demand for higher-quality agricultural goods is predicted to boost production and market growth throughout the forecast period (Nie *et al*., 2023).

Inadequate and incorrect disposal of synthetic polymeric waste causes disintegration in fragmented plastic particles, known as microplastics, due to the influence of ultraviolet radiation, physical abrasion, thermal oxidation, and microbial synthesis (Hui *et al*., 2023; Al-Snafi, 2018; Mahbubul Islam, 2019; Afzal *et al*., 2022; Xu *et al*., 2020). Microplastic pollution of the environment is regarded as a new danger to biodiversity and ecosystem function. The buildup of microplastics in the soil can harm crop productivity. It leads to a drop in plant species and crop nutrient content, as well as a decrease in microbial activity in the soil, all of which have a detrimental impact on crop growth (Darmo & Sutanto, 2023; Sim & Nyam, 2021). Microplastic contamination of soil has a deleterious impact on soil structure, moisture, and nutrient transport, resulting in root growth retardation and greenhouse gas emissions (C. S. Hassan, 2018; Rana & Thakur, 2021; Leluk *et al*., 2020; Thakur *et al*., 2013a).

Gossypium sp., or cotton fiber, is the most widely used natural fiber. This particular kind of fruit fiber is frequently used as a vital raw material in products related to health, beauty, and textiles. On an 11.287 Ha plantation, about 2.558 tonnes of cotton is produced. The demand for cotton in the country is growing, but the supply is not keeping up. There is little farmer interest in planting cotton due to the low yield. Training in cultivation techniques, as well as the utilization of superior seeds, are required to increase its productivity. The next commonly used natural fiber is that of jute fibers (*Corchorus capsularis* and *C. olitorius*). They are harvested from the skin or bast of the plant and range in color from off-white to brown, varying in length from 1 to 4 m. It takes four to six months to develop jute fibers with minimal extensibility and high tensile strength. They have higher fabric breathability and are free of drugs or other substances. They are very insulating and anti-static and have low thermal conductivity. Jute fibers are desirable because they are biodegradable, recyclable, and environmentally friendly. These fibers are creep, brittle, and coarse, limiting the fineness of the yarn.

32 significant garment firms signed the Fashion Pact at the 2019 G7 conference as a commitment to environmental sustainability. Several major names in fashion, like Adidas, Burberry, and others, have signed the agreement. The three main tenets of the agreement are reducing global warming, regenerating biodiversity, and safeguarding the oceans. The signatories have agreed to specific actions and goals under each of these pillars to promote change. To foster innovation and hasten the adoption of sustainable practices, the Fashion Pact promotes cooperation and knowledge exchange among its signatories. Working together, it is intended to make the fashion industry a more sustainable and ecologically responsible sector. Here in this review, we discuss some very uncommon fibers that can be extracted from plants and thus help us with sustainability efforts.

Sources, manufacturing steps, and applications of natural fibers

Lotus

Lotus (*Nelumbo nucifera*) is the national flower of India and has a lot of religious and cultural importance. It also has medicinal properties (Kavita Patil, 2018). Thailand and Myanmar are popular for the production of textiles that are extracted from lotus. Lotus stems are edible and are very nutritious especially because it fulfils the fiber requirements of our body. Other than its edible properties, lotus stems are used for the extraction of lotus silk, which can be woven into fabric. Lotus silk is a luxurious fabric because it can be extracted only by skilled craftspeople across the world. The procedure of extraction is

highly time-consuming. It has silk-like properties and hence is called 'lotus silk' (Aishwariya & Thamima, 2019). Since 1910, the extraction of lotus silk has been in practice. In the 90s, textile industries were set up in Japan so that they could export their fabric but because of its low demand, the fabric remained as exclusive and handmade. Lotus seeds are spread across the water body and harvested during the rainy season. In the morning, stems of lotus flowers are collected. The lotus stems of lotus plants are gathered, cut, snapped, and then twisted to extract or expose fibers from the stem. 5 to 6 stems are snapped together to extract 20 to 35 fine filaments of fibers. These fibers are then drawn out of the stem, hung, and dried. Later, these thin filaments are rolled into a single thread. It is a very time-consuming process and approximately 25 women make thread to keep just one weaver busy throughout the day (Aishwariya & Thamima, 2019). Another important thing is fibers should be extracted within 24 hours from the harvest of lotus stems or else they go to waste.

Long fibers are used for handlooms and short fibers are rolled into a single thread, which is used for frame looms., making sure that not a scrape of the precious fabric is wasted (Aishwariya & Thamima, 2019). The collected lotus silk is dipped in sodium hydroxide and then boiled in water. Later it is bleached in hydrogen peroxide. Weaving off lotus fibers takes place from June to November once the fibers are extracted from the stem. They are formed into skeins and then reeled for wrapping and placed on a weaving bamboo spinning frame. The yarns are prepared by weaving the skeins on a bamboo frame. Then, these yarns are transferred onto winders in readiness for the wrapping process. The long threads (fabric) are coiled into huge plastic bags. The fabric is then dyed using chemicals and natural dye in different colors and shades. There is an estimate that around 1,20,000 lotus stems are required to weave the fabric for a costume. The yarns should be woven within 24 hours of being extracted to prevent deterioration (Fig. 1). There are numerous advantages of fiber extracted from lotus. It is environmentally friendly and has GOTS (Global Organic Textile Standard) certification because it is produced without the use of chemicals. Fabric is breathable and wrinkle-free. The fabric has negative oxygen ions generated by lotus fibers, which is good for developing the immune system of the body. The lotus plant is pure as virtue and thus, by wearing lotus fabric, a feeling of calmness, peacefulness, and meditativeness is generated. This fabric also absorbs moisture when in contact with the atmosphere and, therefore provides good ventilation (Aishwariya & Thamima, 2019). It also cures wearers of lung issues, headaches, and asthma. Since it is 100% organic fabric, it is environmentally friendly and helps us with our sustainability efforts, unlike synthetic fibers (Sharan & Haldar, 2021).

Lotus fabrics are considerably more expensive than traditional fabrics like linen or cotton because of their unique characteristics and labor-intensive manufacturing methods. Since lotus is revered as a spiritual plant in religions like Hinduism and Buddhism, it is commonly used to make robes for high-ranking monks. Men's shirts manufactured of lotus fiber are sold under the well-known brand Nomark Lotus Shirt. Kyar Hi produces scarves for both export and the home market. Another well-known manufacturer of Lotus fabrics is Samatoa.

Fig. 1: Process of extraction of lotus stem

In 2012 they sent a handcrafted lotus sarong to UNESCO and received the SOE – Seal of Excellence (Kavita Patil, 2018). All these properties make the fabric more popular among various fashion designers around the world. The market scope is high for lotus fabric.

Banana

Another unconventional plant-based fiber is extracted from bananas, is highly absorbent, and can help us go ahead in an eco-friendly, sustainable way. One of the major challenges is associated with both women's menstrual health needs and those of the environment. The main problem is the manufacturing and disposal of sanitary pads. Every year, discarded sanitary napkins alone generate 113,000 tonnes of menstrual waste in India alone (Achuthan *et al*., 2021). Napkins produced by various companies are not degradable and unsafe for women's health. Companies also add chemicals in the scented napkins that can cause complications in women's health. We can use sustainable sanitary napkins or pads, which are produced using alternative materials with antibacterial qualities and improved retentiveness and biodegradability in nature, to lessen or eliminate these issues.

Banana fiber is a natural absorbent fiber (Petchimuthu *et al*., 2019). There is no negative effect on the environment and is considered eco-friendly. In India, banana plants are grown more than anywhere else in the world but more than half of the plant's part gets wasted. Banana stem is not much of a use in our country. One company (Saathi) is turning waste that could help more people have safer periods as compared to disposable plastic pads. Without creating more plastic trash and finding a solution for farm waste, just one banana stem can yield up to 3000 pads. The banana plant's stock bears fruit only once and therefore, after each harvest, farmers clean the field to make suitable room for new growth. So, we can use the leftovers and turn banana plant fibers into fabric.

The methodology used to convert stem into fiber is not that daunting. Workers collect the leftover pseudo stem of the banana plant from the farm and then cut the stocks in half. Thereafter, workers pull each part apart, layer by layer. They feed these celery-like chunks into a machine that leaves just the stringy fibers behind. Fibers are then washed and dried on a line so that they are ready for a second life. The liquid extracted from the stem after squeezing can be used as fertilizers. The next step is turning those pieces into cotton-like fluff. Later on, the fluff is pressed into thinner and thinner sheets such that it

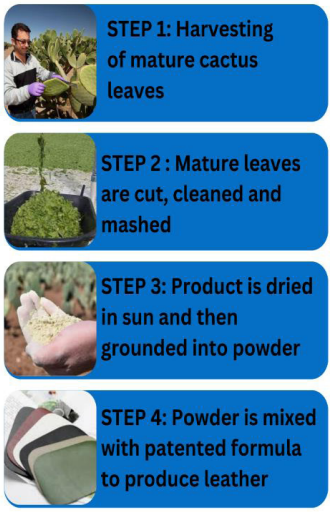

Fig. 2: Process of extraction of leather from Nopal cactus

becomes absorbent (Achuthan *et al*., 2021; Petchimuthu *et al*., 2019). This makes the core of the pad. All the different layers of the pad are put together. The replacement of non-degradable material with biodegradable material for developing hygienic feminine products is eco-friendly and cost-effective. The use of banana fiber in pads will be economical and accessible to those with lesser incomes, allowing us to come up with a workable solution to improve the world for the coming generations.

Banana fibers are used in textile industries (in Japan, Nepal, and India). Banana fiber is used for neckties, cushion covers, tablecloths, and bedsheets as well. These inherent characteristics created a ready-made market for shipping cables. In addition, it is extensively utilized in the production of fishing nets, lines, wall drilling cables, power transmission ropes, and other kinds of cordage. Given that banana fiber has a high cellulose content and may effectively substitute wood pulp in the paper industry, it can lessen the negative environmental effects of deforestation. Japan's currency, Yen is also made using banana fibre.

Cactus

Cactus (Nopal cactus) leather is a bio-based material lauded for its breathability, an area in which other vegan leathers fall short (Asabuwa Ngwabebhoh *et al*., 2022). Since cactus leather is made directly from prickly pear cacti, it is a reasonably sustainable material. Cactus leather is well-liked as a vegan alternative to leather because of its flexible application and silky feel. An organic, robust, and long-lasting material, cactus leather has a high resistance to tearing, rubbing, and abrasion. The leaves of the Nopal (*Opuntia ficus-indica*) cactus plant are used to make cactus leather.

Herbicides and pesticides are not necessary for the cactus to grow. Mature cactus leaves are gathered without cutting the cactus itself to manufacture cactus leather. As a result, there can be a fresh harvest every 6 to 8 months, and cactus plants can live for up to 8 years. The leaves are cleaned and ground after being collected. Leaves are then left to dry under the sun for three days, which reduces extra energy to assist the drying process (Fig. 2). After combining the contents with safe chemicals, they are coated on a carrier. The final product obtained from cactus is toxic-free, smooth vegan leather that's durable, waterproof, and aesthetically pleasing and can be used to create a variety of fashion accessories, including furniture, purses, shoes, and handbags.

There are several advantages of this vegan leather. First of all, cacti fields are a huge carbon sink, meaning that even the act of growing cacti helps to sequester carbon from the atmosphere. Dessert, a cactus leather farm, for instance, produces only 15.30 tonnes of CO_2 a year but absorbs 8,100 tonnes from its 14 acres of cactus plantation. Cacti don't need a lot of water. One kilogram of cactus biomass, for example, requires only 200 liters of water to grow, and the plants usually get this water naturally from the humidity in the air.

When cactus leather is contrasted with animal leather, animal abuse is a significant concern, and the toxins used to tan the leather are frequently criticized. In a study comparing artificial leather to natural leather, Desserto was appropriate in its range of thickness for shoes, gloves, and apparel goods (Meyer *et al*., 2021). Vegan leather is flexible, breathable, durable, and does not get stained, making it an ideal replacement for animal and synthetic leather. It also happens to be less water-intensive and free from phthalates, PVC (Polyvinyl chloride), and other toxic chemicals.

In many nations, Nopal cacti can be used to restore degraded land. The Nopal tree, a CAM (Crassulacean Acid Metabolism), is known for its unusual daily pattern of water loss and carbon fixation, which mostly happens at night. This pattern is largely responsible for the tree's ecological success. The Nopal, like other CAM plants, opens its stomata at night to fix CO_2 because the temperature is usually lower and the relative humidity is higher at night. When CAM plants are compared to C3 and C4 plant species, they transpire approximately three to four times less. The plant's ability to survive in semi-arid conditions and its use of water are both greatly increased as a result. The water content and storage of CAM plants are 90 to 95%, whereas that of C3 and C4 are 40 to 70%. CAM plants lose water 20 to 30% less than C3 and C4 plants. Low root proportions cause CAM to grow more quickly. With all these ecological benefits, the future of Cactus leather appears to have a bright future ahead (Van Rensburg *et al*., 2020).

Kenaf (Hibiscus spp.)

Plant fibers, as well as plant fibers-fortified composite materials, are of enormous importance in both industry and fundamental research (Rana & Thakur, 2021). Much of this biomaterial (plant fibers) is recycled into other useful products, but the leftover wastes pose significant disposal problems. The benefits of utilizing bio-fibre include their low cost, plentiful availability, biocompatibility, biodegradability, low density, good mechanical properties, and reduced energy requirements during production (Leluk *et al*., 2020; Rana & Thakur, 2021; Thakur *et al*., 2013b). Here, we will discuss the extraction of fibers from *Hibiscus sabdariffa, Hibiscus cannabinus L., and Hibiscus tiliaceust,* which belongs to the family Malvaceae (Sim & Nyam, 2021).

Kenaf (*Hibiscus cannabinus L.*), is a tall annual dicotyledonous herb that has gained widespread attention for its potential in diverse industries such as food and beverages, medicine, cosmetics, and many more (Vayabari *et al*., 2023). At first, Kenaf

was prized for its ability to produce paper. However, in the last 20 years, it has developed into a versatile crop with a wide range of industrial uses. Kenaf is grown for various reasons such as the delicate bast fiber found in its stem, leaves, and seeds are used in the medical field as it is rich in medicinal value, including antioxidants, anticancer, hepatoprotective activities, analgesic, aphrodisiacs, and anti-inflammatory properties (Vayabari *et al*., 2023; Hui *et al*., 2023). Kenaf has garnered significant interest worldwide due to its versatility and ease of cultivation compared to other fiber crops (Darmo & Sutanto, 2023). According to Hassan 2023, this plant exhibits wider adaptability to environmental conditions, climates, and soil types, making it a superior source of cellulose (Abu Hassan *et al*., 2023). Additionally, kenaf possesses excellent moisture absorption properties and is both renewable and biodegradable (Nie *et al*., 2023). Solo kenaf fibers have been found to exhibit impressive tensile strengths and moduli, reaching up to 11.9 gigapascals (GPa) and 60 GPa, respectively (Vayabari *et al*., 2023). These fibers were initially used to make fabrics, ropes, cords, and storage bags. Now, they are mixed with other materials to make composites that are utilized in a variety of sectors, including building, packaging, and furniture.

Different parts of the kenaf plant have unique characteristics and functions. For example, the stem of kenaf is sturdy and can be used to make durable textiles, while the leaves are a source of fiber that can be used to make paper. The bark is also rich in fiber and can be used for insulation or as a source of biofuel. To improve the mechanical properties of Glass Fiber Reinforced Polymers, composites are hybridized with natural fibers to increase applications in the field of engineering. It has several advantages: low density, lightweight, corrosion resistance, cheaper price, easier fabrication process, and environmentally friendly compared to low carbon steel plate bumpers. By using bio-composite material for the bumper structure, the car will weigh less, consume less fuel, emit fewer greenhouse gas pollutants, and have superior impact and corrosion resistance (Hassan *et al*., 2018). *Hibiscus sabdariffa L*., which is also known as roselle, is grown for the extraction of natural fiber, which is further utilized in the fabrication of ropes, cords, and cordage (Rana & Thakur, 2021). It has a degree of purity from woody debris and pectin equal to 99% and is highly appreciated in the construction of mats with thermoset natural fibers for the automotive industry.

Coconut

The tall tree known as the coconut palm, or *Cocus nucifera*, belongs to the monocotyledon family of palms, or Arecaceae. Coconut is a very important tree in tropical areas since it provides food, employment, and business opportunities to millions of people (Kaur *et al*., 2019). The three countries that produce the most coconuts worldwide are Indonesia, the Philippines, and India, with yearly production of 61, 18, and 15.85 million tonnes, respectively.

Of all the commercial natural fibers, coir (fiber made from coconuts) is the thickest and has the highest resistance. Coir is a coarse, short fiber extracted from the outer shell of coconuts i.e., from the husk surrounding the nut. Its low decomposition rate is a key advantage for making durable geotextiles from it. Coir has one of the highest concentrations of lignin, which makes it stronger but less flexible than cotton and thus unsuitable for dyeing.

The methodology to prepare coir is a long process. Husks are divided into quarters, placed in enormous water tanks, and supported by a system of iron rails. The husks are taken off after five days and put through a machine made of two rollers made of corrugated iron, which smashes them and gets them ready for the drum machine. The processed husks are held against the revolving drums and protruding spikes tear out the woody part, leaving the long, coarse fibers separated. Fibers are then made into hanks (a coil).

Two types of coirs are offered. One is made from fully ripened coconuts, known as brown coir. It resists abrasion well and is robust and thick. The other type is white coir wherein the fibers are harvested from the coconuts before they are ripe.

Coir fibers and yarns are used for making coarse cloths, cordages, doormats, rugs, mattresses, insulation panels, packaging materials. and bristles for brushes. Coir also has applications in geotextiles. It offers a cost-effective, low-impact solution to the issues of soil erosion and landslides. Coir is still chosen over jute for natural geotextiles because of its strength, longevity, and high lignin content. In the upholstery industry, coir is also frequently utilized as a healthy alternative to processed synthetic rubber. In addition, it is combined with natural rubber to fill mattresses, car seats, couches, settees, and other seating arrangements. As an alternative to plywood, coir ply is a cutting-edge material that can be used to create a variety of robust furniture and structures when combined with resin and selected pre-treated timber veneers. Environmentally friendly coconut husk plates and bowls are also made. Coconut scrubber, made up of coconut fiber, is used as a cleaning tool. The Cocona brand uses coconut shells to make sweaters. Coconut fibers are the only fiber that can withstand saltwater, dry faster, naturally eliminate odors, shield against harmful UV rays, and are 100% biodegradable.

Water hyacinth

Water hyacinth (*Eichhornia crassipes*) is a free-floating perennial aquatic plant and a widely distributed aquatic weed throughout the globe. Water hyacinth is highly resistant to extremes of nutrient supply, pH, and temperature and has a high reproductive capacity, because of which it doubles in 10 to 15 days (George *et al*., 2023; Punitha *et al*., 2015). Because it has wreaked havoc in so many nations by lowering the oxygen content of water, obstructing water flow, frequently killing aquatic life, etc., it is sometimes referred to as the "cancer of Bengal," given how common it is in West Bengal, India. Water hyacinth is thought to pose a major threat to biodiversity because it can completely cover lakes and ponds. However, it has several advantages. For example, it's high-water absorption and rich fiber content are comparable to those of cotton fiber.

Water hyacinth fiber is a new approach to get wealth out of waste. It not only has good tensile properties but also has a high C.V% value (Punitha *et al*., 2015). These days, water hyacinth plants are used primarily for decorative purposes and are a key component of handcrafted goods such as mats, wallets, flower pots, handbags, and fashion accessories. Many creative

Fig. 3: Process of extraction of fiber from water hyacinth

Fig. 4: Process of extraction of fiber from pineapple leaves

and decorative home furnishing products are manufactured from water hyacinth stems (George *et al*., 2023; Punitha *et al*., 2015). Other uses for water hyacinth include the production of paper, handicrafts, and fertilizers. Due to its high fiber content (20% by weight), water hyacinth is a viable option for use as a raw material in the textile and composites industries. Initially, blended yarns with a 20 to 35% water hyacinth component were produced by processing the fibers with polyester staples. The plant's glue-like or gum content was reduced, the stalks underwent several chemical and mechanical treatments, and the fibers were softened to make them suitable for making fashion accessories. All of these processes were intended to give the stalks the crimp property of wool for improved processing.

The procedure of fiber extraction from the plant is quite meticulously done. The matured water hyacinth plants are identified and collected. The water hyacinth plant is about 15 to 30 inches long and 0.15 to 1.2 inches in diameter (Punitha *et al*., 2015). Collected plants are washed well in water, and later, leaves and roots are separated from the stem. The stems are laid into a machine that has three scrapping roller drums. The feeding inlet is used to insert the water hyacinth stems. The high-speed rotating action of the scrapping roller drum causes the scraping action on the stem. Consequently, the fibers become separated (Fig. 3). To get rid of any remaining stem material, if any, a light combing is done on the fibers following fiber extraction. The height of the feeding inlet may be adjusted according to the requirement (George *et al*., 2023).

The fiber has proven to be a good option for use in matrix material reinforcement due to its high cellulose content and low hemicellulose content. Additionally, the composite mechanical strength attained is very good. It is one of the favorite fibers for making lightweight composite material with a density of 1.15g/cc (Arivendan *et al*., 2022). Bag Maverick brand sells products that are made from water hyacinth fibers. Fibers from the stems have also been used as raw material and blended with polyester to make clothing and home furnishings, thus turning this troublesome weed into a useful fabric. Global Mamas is also one of the popular brands laid by Abigail Atter since 2015 which sells products made from water hyacinth.

Pineapple

Pineapple (*Ananas comosus*) belongs to the Bromeliaceae family (Pandit *et al*., 2020). This is a fruit-bearing, tropical, herbaceous perennial that grows near the equator. Pineapple is a scaly fruit and its leaves are elongated with a rosette arrangement around the shoot. Pineapple is grown in a field with sandy loam soil having a pH of 5.0-6.0. The cultivation of pineapple is confined to high rainfall areas with approximately 100-150 cm in the humid coastal region (Pandit *et al*., 2020). The mature leaves are used for the extraction of leaf fibers and make one of the best natural fibers called PALF (Pineapple Leaf Fiber). Natural pineapple leaf fiber also acts as filler or reinforcement in plastic to reduce cost and increase productivity.

Worldwide, post-harvest waste in agriculture is burnt or thrown and sometimes, it is used as organic crop fertilizers. But they do not generate additional lucrative income. Per shoot, 40 to 50 leaves or 2.5 kg of post-agro waste is difficult to manage since it contains high amounts of cellulose and it takes time to decompose. It has abundant availability, cheap prices, good thermal and acoustic insulation, excellent tensile strength, and high toughness. As a result, PALF is preferred (Todkar & Patil, 2019).

PALF can be extracted from the leaves both mechanically or manually. In manual extraction, scraping and conventional methods are used to extract PALF. A scraping tool known as "ketamine" is used for scraping pineapple leaves, after which the extracted fiber is kept under running water and dried directly under the sun (Rafiqah *et al*., 2020) (Fig. 4).

Whereas in mechanical extraction, similar methods are conducted by conventional machines known as pineapple decorticator machines. Another method of extraction is also known as retting extraction, wherein during the saturating process, the leaves are immersed in water in the presence of

Table 1: Experimental results of tensile test Table adapted from (Msahli *et al.,* 2007)

	Load	*Tenacity (Cn/tex)*	*Stress (Mpa)*	*Strain (%)*	*Initial modulus (cN/tex)*	*Work facture (J)*
Minimum value	3.8	15.556	211.7	29.36	20.11	0.023
Average value	6.9	28.3	384.6	49.6	61	0.046
Maximum value	10.05	41.078	558.14	62.36	145.49	0.076
CV%	22.9	22.9	22.9	12.5	55.6	30.14
Confidense interval (95%)	0.45	1.84	0.25	1.76	9.6	0.004

diammonium phosphate (DAP) or urea, which improves the retting process. It takes around 15 to 18 days of immersion of the PALF in a water tank until the unwanted material sticking to the PALF surface gets removed, resulting in clear fibers (Jose *et al*., 2016). Pineapple fibers are the most delicate in texture among all vegetable fibers. They are 60 cm long, lustrous-like silk and can easily take the dye (Pandit *et al*., 2020, Das *et al*., 2010). It can be used as an available and abundant substitute for synthetic fiber. Fibers can be successfully dyed with direct reactive vat and azo dye with better fastness properties as compared to cotton. It also has a limited maximum processing temperature which limits it for high-temperature processing (Mohammed *et al*., 2015). PALF fabric is marketed as pina fabric in the Philippines (Pandit *et al*., 2020).

Century plant

Agave americana (AA), commonly called a century plant, is the most abundant variety of agave. It belongs to the *Agavaceae* family and is native to Mexico, tropical America, South Africa, and South Asia. This variety is characterized by the fact that it is a very voluminous plant with long, fleshy, rigid, hard subfigure and lanceolate leaves, which grow directly out from the central stock to form a dense rosette (Msahli *et al*., 2006).

Since 1998, a research program has been undertaken to evaluate the potential of AA as a new source of textile fiber (Belaadi *et al*., 2013). Agave fibers are extracted from the leaves of this plant. The mechanical properties of the textile fiber are probably the most important: As tabulated in Table 1, the most important parameters studied in a tensile mechanical test are the rupture stress, rupture strain, work facture, and initial modulus (Msahli *et al*., 2007). When mechanical properties are compared with other textile fibers, *Agave americana* fibers present a high tenacity, weak initial modulus, relatively high rupture energy, and very high rupture strain, as shown in Table 2. (Msahli *et al*., 2007).

Thus, according to their properties, *Agave americana L*. fibers can be used in technical applications such as reinforced materials and geotextiles (Alawar *et al*., 2009; Davidson, 2006). *Agave americana* fibers are preferred these days because they are environmentally friendly (Boguslavsky *et al*., 2007; Zwane & Masarirambi, 2011). Some items that are made using these fibers include ropes, mats, brooms, cords, clothes, and footwear made up of *Agave* fibers. *Agave* represents a continuous renewable source of biodegradable and relatively low-cost structural material and currently supports many civil engineering applications on roads, railroads, airfield embankments, retaining structures, canals, and construction site fences.

Table 2: Comparison of mechanical properties between textile fibers. The table is adapted from (Msahli *et al.,* 2007).

	Tenacity	*Strain*	*Initial modulus*	*Work facture*
AA	15-41	29-62	0.2-1.45	7.7-25.7
Sisal	36-45	3.0-1.0	25-26	0-0
Henequen	20-24	3.5-5	0-0	0-0
Flax	23-24	2.7-3.3	18-0	0-8
Jute	26-51	1.2-1.9	17.2-0	2.7-0

Snake plant

Sansevieria trifasciata var. laurentii plants are notorious indoor and outdoor ornamental xerophyte plants worldwide. The *Sansevieria genus (*Asparagaceae family) are herbaceous perennial plants that originated from India and Southeast Asia. The snake plant has thin, erect, sword-shaped leaves with color combinations that vary, but typically, the plant has deep green leaves with light grey or yellow stripes (El Oudiani, 2015).

Snake plants are used to reduce indoor pollution and absorb the heavy metals from the environment. The cultivation of snake plants is used for the treatment of ear inflammation, swelling, bumps, bruises, pain, poisonous snake bites, etc. Due to their high adaptability to growing in unfavorable conditions, *S. trifasciata* species are now widely considered as an alternative crop. Fibers from snake plants have median values for diameter, density, and thermal and mechanical properties compared to other herbaceous leaf fibers. *S. trifasciata* fibers have unique properties, especially if it is capable of withstanding pressure without any fiber degradation.

Fiber strength is considered next to fiber length and fitness in order of importance among fiber properties. The developed fabric's breaking strength at 4.8% reveals that it has the physical potential to be used in manufacturing goods made of fabric (El Oudiani, 2015). Fibers extracted from snake plants are commonly used as rope, fishing lines/nets, cordage, bowstring, and clothing materials. This fiber has low costs, wide availability, high specific strength renewability, and low density and thus can be used as reinforcement in polymer composites. Numerous studies show that this fiber and other parts of this plant have the potential for wide-scale use and diversified product development for the use as a raw material in different industries such as textile and garments, pulp and paper, pharmaceuticals and cosmetics along with various decorative furnishing industries (Abdullah *et al*., 2021).

Fig. 5: The process of extracting fiber from an okra plant

Okra

An enormous amount of okra (*Abelmoschus esculentus*) plant stem is thrown away in the field every year due to improper use. It is a member of the Malvaceae family and one of the most important vegetable crops grown in the Indian subcontinent. It has excellent strength and modulus and good thermal properties and contains about 60 to 70% of cellulose (Islam *et al*., 2022). Due to its drought resistance and minimal water needs, okra is a crop that is simple to grow. The stem wastes of the okra plant that remain in the fields after harvest are used to make okra fibers. Okra fibers have a low ratio of lignin (7.1%), which causes yellowing and photochemical degradation (Kocak *et al*., 2018). After harvesting the vegetable crop, fiber is extracted from the remaining plant biomass using a procedure akin to that of bast fiber extraction.

The manufacturing process of fiber from the plant is a laborious one (Gupta *et al*., 2021). The plant's stem typically reaches a height of 90 to 200 cm. Harvested plants are gathered while still green and then the stems are removed from the plant to begin the extraction process. After that, they are combined for the retting procedure (Fig. 5). The waxy epidermal tissue, adhesive pectin, and hemicelluloses that hold the fiber bundles together are eliminated during the retting process. 350 to 400 okra plants are bundled, and for ten days, each bundle is submerged in a concrete tank filled with soft water. Afterward, the soft pulp in the plant stalks is removed by lightly tapping them with a wooden hammer. A knife is used to scrape the pulp to separate it. This is submerged once more and kept in the tank for five days. After that, the fibers are carefully separated from the pulp, cleaned, combed, and left in the sun for two days to get rid of the smell. For raw okra fibers, scouring is done with a material liquor ratio of 1:10, five liters of water, and sodium hydroxide (NaOH). Scoured okra fiber samples are bleached with hydrogen peroxide (Vasugi *et al*., 2019).

Similar to some traditional bast fibers like jute, hemp, and ramie, okra bast fiber has been found to have a high cellulose content, excellent mechanical strength and stiffness, and good thermal resistance. Some okra bast fiber-reinforced biocomposites were successfully fabricated with different matrices, including biodegradable corn starch, poly-lactic acid, P-vinyl alcohol, urea-formaldehyde resin, etc. via the application of various processing methods (Arifuzzaman Khan *et al*., 2017). An online shopping website named Etsy sells fabrics made from okra fibers, which can be used as dress or quilt fabrics.

Corn

Corn *(Zea mays)* fiber is an abundant and inexpensive byproduct of corn. Corn wet milling process comprises about 10% of the processed dry corn. The increasing demand for bioethanol worldwide led to a rise in corn processing. Whereas the demand for animal feed has remained stagnant or is decreasing (Zheng *et al*., 2022). Corn is one of the major food crops in the world. Growing takes only about 4 months. Natural corn husk (NCH), a byproduct of the processing of corn, is the perfect material for making bio-fibers because it is both readily available and reasonably priced. NCH is 0.1–1 mm thick and has a high cellulose content (~46%), together with an inherent 2D structure of oriented lignocellulose nanofibers. In China alone, 261 million tons of corn were produced in 2019, accompanied by ~20 million tons of NCH, based on a ratio of 7% corn husk to corn. The majority of the NCH is burned or discarded as garbage, contributing significantly to environmental degradation (Zheng *et al*., 2022). Only a small portion of the NCH is used for animal feed or carpet/handbag weaving.

Since it is affordable, environmentally benign, and can be obtained sustainably, corn husk fiber has a lot of potential as a reinforcement material in composites (Baghestany *et al*., 2015). A better understanding of the absorption process and the effect of water absorption on the composite microstructure may enable CHF composites to be used for building materials, especially for outdoor use (e.g., decking, exterior walls, and windows) (Sari *et al*., 2020).

Recent scientific progress has opened up opportunities for utilizing NCH in cellulose fibers (Zheng *et al*., 2022), cellulose nanofibrils (Mendes *et al*., 2015; Yang *et al*., 2017), hierarchical porous carbon, anthocyanin pigment, corn husk cellulose-based films (Bernhardt *et al*., 2017), corn husk fiber-polyester/epoxy composites (Sari *et al*., 2021) and corn husk-based products (Rastogi *et al*., 2022). Corn fiber is used to make clothing because it is a great alternative to synthetic fiber. Corn fiber is currently utilized in non-woven textiles like wipes and feminine hygiene products. Because it can be composted in a commercial setting, it is a good fit for use in outer garments, sportswear, knitwear, socks, diapers, or nappies. Home textiles, athletic wear, trousers, undergarments, and casual t-shirts are all made of corn yarn and fabric. It is ideal for novel fiber fill combinations with distinct organic insulating qualities used in thermal wadding. Corn yarns are also ideal for breezy summer clothing.

Hemp

Cannabis sativa L. is a dioecious plant of the Cannabaceae family, and it is also known as industrial hemp (Pellati *et al*., 2018; Vandepitte *et al*., 2020). In ancient times hemp was used as a psychoactive drug, as a folk medicine ingredient, and as a source of textile fibers (Andre *et al*., 2016). Genus *Cannabis* has been divided into three main species (Appendino *et al*., 2011). *C. sativa*- a fiber type, *C. indica*- a drug type that contains high levels

Fig. 6: Process of extraction of fibers from hemp

of psychoactive compounds, and *C. ruderalis* with intermediate properties, contains both psychoactive compounds and fibers (Pellati *et al*., 2018).

The parameters of hemp fiber, like linear density and length as well as fiber properties, are strongly related to the hemp variety (Zimniewska, 2022). The tenacity of the long hemp fiber is overall high and comparable to flex (Vandepitte *et al*., 2020). They have high tensile strength, which means they can withstand tension without breaking easily, are relatively lightweight, and naturally breathable, allowing air to pass through the fabric easily. It has antimicrobial properties, which inhibit the growth of bacteria and fungi, and this fiber is resistant to ultraviolet rays. Retting is a popular technique for extracting hemp fiber (Ribeiro *et al*., 2015). Once the fiber has been extracted, mechanical forces are applied to split the technical fiber into smaller fiber complexes and separate the fiber from the woody portion (Fig. 6). Scutched long fibers are used for high-quality textile production. Short fibers are converted into thicker yarns for thick fabric.

The hemp fibers are strong, durable, and have a natural resistance to mold, bacteria, and UV light. They are used to make a wide range of fabrics, including canvas, twill muslin, and denim (Promhuad *et al*., 2022). These yarns can be blended with cotton and silk to enhance their properties. Products are also of industrial interest and are used in bio-building and thermal-insulated materials (Irakli *et al*., 2019).

Conclusions

In today's fashion world, the use of synthetic fibers is on a great rise because of their cheap pricing, easy availability, durability, and lustrous look. But it has a huge impact on the environment. Polyester fabric takes 200 years to decompose and nylon fabric takes 20-40 years to decompose completely. However, due to the interconnectedness of the textile sector and the international commitment to sustainability, cooperative solutions are required. India has emerged as a key participant in providing these urgently required solutions through sustainable sourcing because of its vertical integration across the textile value chain. The sector may reduce its environmental impact and help create a brighter future by implementing sustainable materials, cutting-edge production techniques, and transparent supply chains. For the sake of a sustainable planet, industry stakeholders must commit to ongoing cooperation and sustainable practices. Only a textile business that is socially conscious, economically successful, and environmentally sustainable can accomplish this.

Other cutting-edge sustainable manufacturing techniques have advanced recently as well. For instance, waterless dyeing technology does away with the requirement for the substantial amounts of water that are often needed in dyeing procedures. This method dramatically lessens the impact on the environment by reducing water use, energy use, and chemical waste. Thus, we should try to increase the productivity, accessibility, and affordability of natural fabrics to the common man.

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Conflict of Interest

There is no conflict of interest among the authors.

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