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RETTING OF UNCONVENTIONAL BAST FIBRES : COMPREHENSIVE REVIEW

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ABSTRACT

Plants are the primary source of natural textile fibres, with cotton being a significant cellulosic fibre used since ancient times. India, an agriculture-based country, can obtain textile fibre from underutilized plants or farm trash. Bast or stem fibres from plant stems contain significant cellulosic fibres, which can bring value to the textile industry and contribute to its sustainability. With cultivation unconventional plant sources in many regions worldwide has become an effective and acceptable approach to meet future fibre demands. Unconventional bast fibres are coarse in nature due to presence of high amount of lignin with cellulose. These fibres must be treated to eliminate impurities and enhance their appearance and spinning properties. This review study explored several retting processes, including dew, water, chemical, mechanical, enzymatic, and physical treatments. In this review paper, the existing retting practices of fibres extracted from unconventional plant sources such as okra, ashoka, cluster fig tree, China rose, *marorphali*, *phalsa*, cotton stalk, sugarcane bagasse, nettle and *dhaincha* are discussed. The physical properties and chemical composition of these fibres are also studied to compare the effect of retting processes. Water and dew retting are environmentally favourable; however they do not remove the non-cellulosic component completely. Water retting along with enzymatic or chemical treatment provides good quality fibre suitable for various textile applications such as yarn spinning, weaving, nonwoven fabric production, handicrafts and composite development. Researchers are exploring various natural underutilized for extraction of textile fibres to ensure sustainable development. Therefore, this review study will be valuable for future researcher for processing of unconventional fibres.

***Keywords* :** Unconventional, bast fibres, retting, biodegradability

Introduction

Natural fibres have been used for various purposes in textiles for centuries. Natural fibres offer several advantages over synthetic materials, including cost, density, renewability, recyclability, and sustainability (Khan *et al.,* 2009). India, a tropical country, has abundant renewable resources from the plant kingdom. Bast or stem fibres along with other natural cellulosic fibres are increasingly important due to their biodegradability and eco-friendliness. Other natural cellulosic fibres can be obtained from various parts of plants such as seed, fruit, leaves and husk (Kesarwani, 2012; Vanishree, 2016).

Bast fibres have been used since ancient times, with flax being used in textiles as early as 6000 BC. After the discovery of cotton fibre, flax became largely replaced bast fibre due to difficulty of extracting them from plant stems. However, interest in bast fibres has resurged due to environmental concerns associated with cotton farming. Bast fibres offer benefits like improved air quality and soil health, biodegrading crop residue into organic compounds and potential applications in composite materials (Stanescu, 2023). Bast fibres, also known as skin fibres, are extracted from the inner bark (phloem) of dicotyledonous plants, providing strength and flexibility to the stem. They are distinct from leaf fibres and can be derived from the cortex, pericycle and vascular tissues. The fibre bundles in the stem consist of elongated, thick-walled sclerenchymous cells that overlap to form continuous filaments. Bast fibres like flax, hemp and ramie are cultivated for agricultural purposes, but can also be obtained from wild plants like stinging nettle. Traditionally, bast fibres were used for ropes, twines and burlap but they are now gaining attention for textiles, composites, high-quality paper production, apparel, upholstery and value-added accessories (Khan *et al.,* 2009; Devi, 2011; Upreti, 2017).

A bast fibre plant is made up of approximately 30% bast fibres, 60% hurd, and 10% bark, cortex and cambium when viewed at macro level. The three main structural elements of the plant are the xylem, fibre bundles and bark (Fig. 1a). Primary and secondary fibres are found in the phloem region, directly beneath the outer bark and are referred to as bast fibres. Gums, waxes and pectin are among the materials that naturally bind these fibres to the plant's matrix. The bark serves as the plant's protective outer layer, preventing moisture loss and shielding the plant from environmental damage and physical stress. Beneath the bark, the fibre bundles provide strength and flexibility, contributing to the plant's structural support. Lastly, the xylem is responsible for water transportation throughout the plant. It forms the woody central part of the stem and provides additional structural support (Upreti, 2017; Lyu *et al.,* 2021; Angulu and Gusovius, 2024).

Each fibre has an internal lumen and a multilayered cell wall on a microscopic level (Fig. 1b and1c). The middle lamella, an intercellular matrix made of lignin, pectin and hemicellulose, divides the several cell wall layers, which include the primary, secondary and sometimes tertiary walls. Fibre bundles, which are found in the phloem below the bark, are composed of individual fibres that are joined by the middle lamella and need to be separated during retting or degumming. A retting process is required to release the matrix substance that holds the fibres together and to the rest of the stem's structure. However, in fibre extraction, retting refers to the process of separating the whole bast (i.e., phloem fibres and other phloem material) from the xylem (woody core). Typically, bast fibre plants have a hollow structure with a central cavity. The secondary wall, which is thicker and more intricate than the primary wall, is divided into three sub-layers: S1, which provides lateral stability; S2, the thickest layer, contributing 70-80 percent for mechanical strength of the fibres; and S3, which stabilizes cells by resisting pressure. The innermost lumen is enclosed by the S3 layer (Lyu *et al.,* 2021; Angulu and Gusovius, 2024).

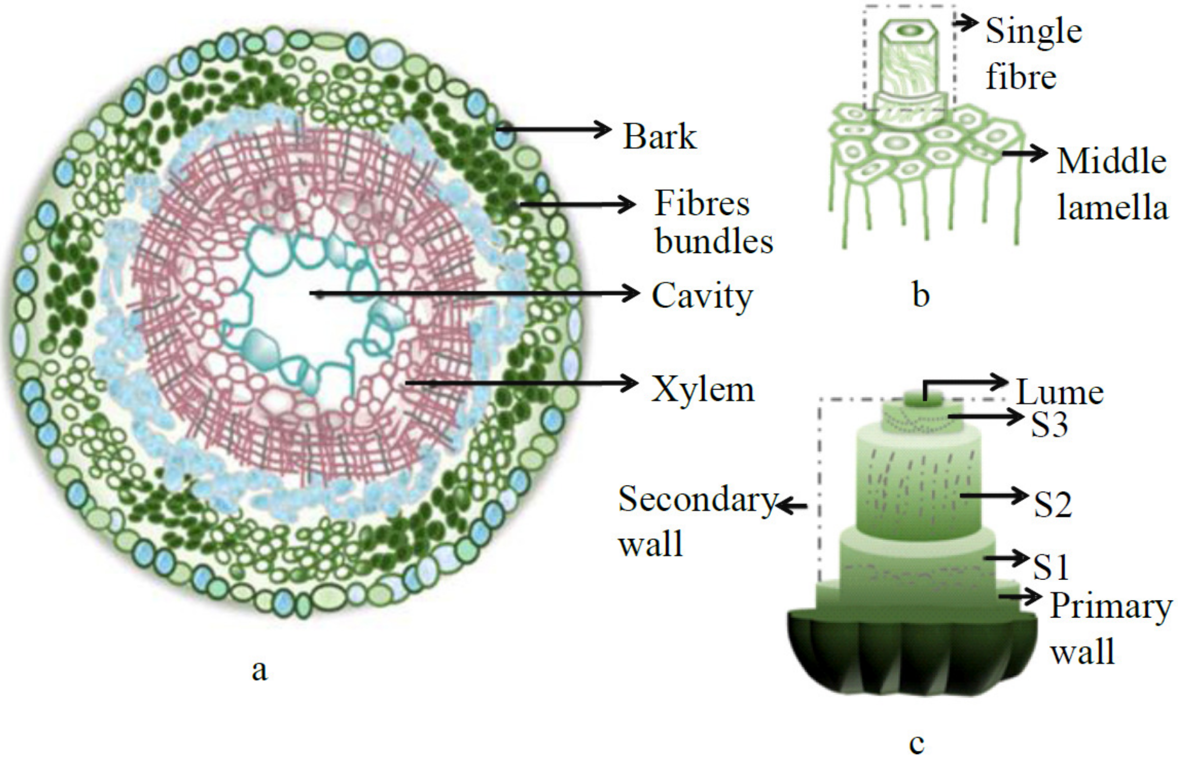

Fig. 1:(a) The cross-section model of a bast fibre stalk, **(b)** a bast fibre bundle, **(c)** model of a single fibre (Source: Sadrmanesh and Chen, 2019)

Retting

Bast fibres are embedded in plant stems by pectin, which must be decomposed to extract them. Retting or degumming process breaks down the outer layer of the stem, allowing the fibres to be separated from the woody core or xylem. Retting or degumming involves bacterial activity to degrade pectin, which acts as the primary binding agent. The process depends on various factors like temperature of retting bath, local conditions, season and weather, retting bath depth and stalk thickness. There are several retting techniques which can be used for extraction of bast fibres such as dew, water, mechanical, physical, chemical and enzymatic retting. Water retting produces high-quality fibres but can have environmental implications. Dew retting uses natural moisture from dew and rain, while enzymatic retting uses enzymes to speed up pectin breakdown. Mechanical and chemical retting involves physical and chemical processes but may create environmental concerns. A combination of methods, such as chemical and enzymatic treatments, can improve fibre quality but can be expensive and complex. The retting process is critical to producing high-quality bast fibres, and careful consideration of environmental impacts is essential to minimize pollution and waste (Tortora 1978; Tahir *et al.* 2011; Angulu and Gusovius 2024). This review paper explores the existing retting methods used for extraction of bast fibres as well as the retting processes for some unconventional bast fibres and their effect on fibresproperties.

Dew Retting: Dew retting is a cost-effective method for fibre extraction, requiring minimal equipment and relying on natural elements like sunlight, rain and ambient air. The process takes 7-21 days, depending on weather conditions and is beneficial for soil fertility due to degradable natural residues. However, the straw laid on the field occupies the soil for several weeks, limiting land use for other agricultural purposes. Bacteria and fungi such as *Rhizomucor pusillus* and *Fusarium lateritium* produce respective enzymes that break down non-cellulosic components like pectin, allowing fibres to separate. Dew retting is less labour-intensive and cheaper than water retting, making it the preferred method in regions with limited water supplies. However, it introduces variability, making it difficult to achieve consistent fibre quality each year. The best results are achieved in areas with heavy dew at night and warm daytime temperatures. Dew retting is environmental friendly as it does not consume water or cause pollution, making it a sustainable, "green" method for fibre production (Ayekpam 2016; Zimniewska 2022).

Fig. 2 : Dew Retting

Water Retting: Water retting is a method used to extract bast fibres from plant stems by immersing in the slow-moving rivers, ponds, dams or tanks (Tahir *et al.* 2011). It involves submerging plant stems in water, where microbial activity breaks down pectin substances and separating the fibres. Fungi and bacteria play crucial roles in retting process as water retting primarily attributed to bacterial activity. Both aerobic and anaerobic bacteria contribute to this process, with aerobic bacteria present in the early stages and replaced by anaerobic bacteria when dissolved oxygen depletes (Angulu and Gusovius 2024).

Fig. 3 : Water Retting

The retting period varies based on environmental conditions, in tanks' lasting up to 4 to 6 days and in rivers and ponds up to 14 days depending on water temperature. The water depth, with a minimum plant material-to-water ratio of 1:20, should be sufficient to allow the stem bundles to float. As the retting process progresses, the straw softens and becomes coated with a layer of green slime, which indicates the breakdown of the plant material. It is important to avoid reusing retting tanks or ditches if the water becomes too polluted. Water retting produces strong and good quality fibres however, the process causes water pollution and releases a foul odour as the plant material decomposes, making it environmentally and socially undesirable (Ayekpam 2016).

Mechanical Retting: Mechanical retting, also known as vat retting, involves submerging woody bark in warm water, typically between 75 and 90°F. The warm water accelerates the breakdown and decomposed bark is crushed by rollers, while clean water is used to wash away impurities, reducing the time needed for retting (Ayekpam 2016). The jute fibre extractor is a lightweight machine weighing 50 kg, designed for field use. It extracts green ribbons from freshly harvested plants, using foot pressure and manual pulling back the cane (CRIJAF 2011). The machine can extract 25 kg of dry jute fibre per hour, compared to the traditional manual method of 5 kg per hour. This equipment is affordable, easy to operate, saves time and requires less water. It produces higher quality fibre and significantly reduces transportation and labour costs compared to traditional methods (Sarkar and Sengupta 2015).

Fig. 4 : Mechanical Retting

Mechanical fibre separation can also be achieved through decorticating machines and the tilby process, which separates sugarcane into its skin, rind and pith. The rind is used for paper, panels and boards, while the pith is utilized in fibre boards and fillers. This method is also applicable to other lignocellulosic plants like corn and sorghum. Cellulosicfibres extracted from wheat straw and sugarcane rind being suitable for textiles, paper and composites (Bavan and Kumar 2011).

Chemical Retting: Chemical retting is a method that offers shorter processing time and better control over fibre quality compared to traditional water retting method. It degrades noncellulosic materials like lignin, pectin and hemicellulose in the plant stalk, but over-retting can degrade the cellulosic part of fibre. Factors determining the quality of chemically extracted fibres include the concentration of chemicals, temperature and duration of treatment.

Fig. 5 : Chemical Retting

Commonly used chemicals for retting include alkalis like sodium hydroxide (NaOH) and hydrogen peroxide (H_2O_2), which are effective in breaking down the plant matrix. Other agents like mild acids, enzymes, salts (e.g., sodium benzoate) and combinations of acids (such as sulphuric and oxalic acid) with detergents have also been used (Sadrmanesh and Chen 2019; Mushtaq *et al.* 2023). However, chemical retting has higher costs and environmental concerns. To address these issues, wastewater from the chemical retting process can be reused, reducing costs and environmental impact (Lee *et al.* 2020).

Enzymatic Retting: Enzymatic retting, also known as bio-retting, is a method that uses enzymes like cellulases, pectinases and xylanases to break down plant polymers, particularly lignin, the toughest polymer in the plant cell wall. White-rot fungi are often used for lignin degradation due to their ability to produce extracellular lignin-modifying enzymes such as laccases and peroxidases (lignin peroxidases and manganese peroxidases). Synthetic peroxidase enzymes are recently been added to retting water to enhance efficiency (Ayekpam 2016; Sachdeva 2018). Enzymatic retting is more environmental friendly, as it is faster, more targeted and requires milder conditions. However, enzymatic retting can cause darkening of fibres due to the redeposition of hydrolyzed hemicelluloses (Pandey 2016). It reduces costs by using reaction residue for enzyme production. Reusing retting water containing bacterial enzymes aids in fibre degumming and reduces water consumption, making it a cost-effective and eco-friendly method (Stanescu 2023). Enzymatic retting is faster, cleaner and results in high-quality Fibres compared to other methods. Combining chemical and enzymatic retting is the most effective approach for fibre extraction (Tahir *et al.* 2011).

Physical Retting: Physical retting or semi- physical retting is a method that involves physical disruption of plant structure to loosen fibres from its woody core. It involves two main types: physical processes requiring chemical or biological treatments and physical interactions in an aqueous solution with chemical reagents, enzymes or microorganisms. Examples include steam explosion,radio frequency, microwave energy assistance, cryogenic treatment and ultrasonic or supercritical carbon dioxide treatments. A combined process is often necessary to achieve desired fibre properties (Lyu *et al.* 2021; Angulu and Gusovius 2024).

Steam explosion is an environmentally friendly biomass processing method, originally proposed in 1927 for cellulose nanowhiskers and adapted in 1998 for flax fibre extraction. It involves heating material with high-pressure saturated steam, then rapidly releasing pressure, causing explosive decompression. This process penetrates fibrous tissues and cells, breaking down the fibre matrix, making it suitable for large-scale applications (Dong *et al.* 2014; Lyu *et al.* 2021).

Radio frequency method has also been utilized by the researchers to enhance the retting process of bast fibre stalks, aiming to improve water retting efficiency or support enzymatic retting of flax stems. Factors like pre-soaking, power levels, application duration and water temperature should be adjustedto optimize the process and enhance the fibre properties (Angulu and Gusovius 2024).

In microwave energy assistance, microwaves are electromagnetic waves with frequencies ranging from 300 MHz to 3000 GHz, typically operating at 2.54 GHz. They are used to extract bast fibres by soaking them in water to ensure moisture molecules penetrate the gum structure. Moisture absorbs microwave energy and converts it into heat, unlike cellulose and gums which have lower dielectric loss. Process parameters like pre-soaking, microwave power, temperature and time influence the breakdown of non-cellulosic polysaccharides, which act as binding agents in the fibres (Lyu *et al.* 2021; Angulu and Gusovius 2024).

Cryogenic treatment is a process that manipulates or changes a material's structure by adjusting the differences in thermal expansion within a material during cooling to low temperatures. In hemp fibre, the fibre's coefficient of thermal expansion (CET) differs from the gum components in the matrix. When exposed to cryogenic conditions, residual thermal stresses develop, intensifying as temperature decreases and exposure duration increases. These stresses can damage the matrix or fibre-matrix interface, leading to micropore production or microcracking, loosening hemp fibre bundles (Liu *et al.* 2018).

Ultrasonic treatment uses sound waves with frequencies above 20,000 Hz, transmitted as mechanical vibrations to cause liquid bubbles to collapse impulsively, a process called acoustic cavitation. The process releases 10-100 kJ mol^{-1} of energy.This energy breaks hydrogen bonds, forming micro-bubbles that erode and strip the cellulose surface, leading to fibrillation and the formation of nanofibres (Bang and Suslick 2010; Syafri *et al.* 2019).

Retting of Some Unconventional Bast Fibres

Unconventional fibres derived from bark include significant quantities of lignified cellulose, making them harsh, hard and coarse. These fibres must be processed to remove impurities and improve appearance. Impurities can be removed and performance can be improved by using techniques such as retting, scouring, bleaching and softening. These fibres can be employed as nonwoven materials or spun into yarn for woven and knitted items. With rising ecological consciousness and limited area for fibre farming, researchers are looking at underutilized and novel natural resources for textile fibres (Arya *et al.* 2016; Negi 2017). This paper describes about the retting process of several unconventional fibres and its applications in the textile industry. In addition, influence of retting procedure on physical properties and chemical composition of fibres is explained.

(1) Ashoka

Ashoka tree, also known as *Polyalthia longifolia*, is a perennial plant with woody characteristics. It grows symmetrically in a pyramidal shape, reaching heights over 30 feet. Stems of the tree are erect and develop surface cracks over time (Kumar *et al.* 2023). To maintain its tall, straight trunk, pruning is necessary before winter, generating significant plant waste. Huge amounts of plant waste are being disposed-off in an unethical manner, which is posing numerous risks to the environment and ultimately public health (Rani, 2018).

Fig. 6 : Ashoka Stems

Rani and Brar (2020) extracted fibre from ashoka tree waste using chemical retting method. The ribbons of ashoka stems were treated with 3 percent sodium hydroxide solution for 2.5 hours, neutralized with acetic acid, bleached with sodium hypochlorite and dried. Silicone emulsion was used to improve softness and pliability for spinning. Yarns were developed from 100 percent ashoka fibre and 50:50 blend with wool. It was found that ashoka fibres, extracted chemically, were ideal for creating heavyweight fabrics suitable for home textiles and clothing items like blazers, jackets, and stoles.

(2) China rose

There are about 300 tropical and subtropical species in the genus Hibiscus, which belongs to the Malvaceae family and includes trees, shrubs and herbs. Numerous commercial applications exist for these species, including those in food, medicine, cosmetics, fibres and ornamentals (Cabarrubias *et al.* 2017; dos Santos *et al.* 2024). Typically propagated by cuttings from mature wood, methods like layering, grafting and budding are also effective (Jadhav *et al.* 2009).

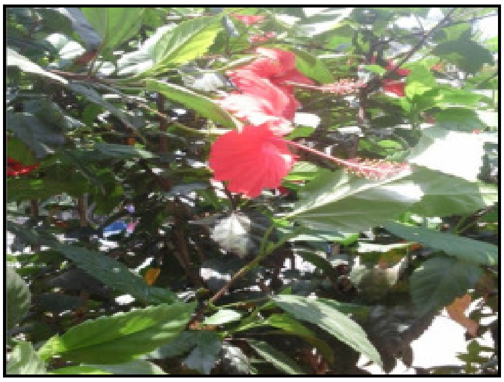

Fig. 7 : China Rose

Strong bast fibres found in the bark of *Hibiscus rosa-sinensis*, also known as China rose, support the phloem of the plant. Chemical retting was used to extract the fibre from fresh China-rose stems. Stems were treated with 3 percent sodium hydroxide solution for 2.5 hours after being cleaned with distilled water. After the treatment, the residue was completely rinsed and neutralized with 5 percent acetic acid. In order to make the fibres more pliable for spinning, they were then softened at room temperature using a silicone emulsion (0.5% by weight of fibres). Two varieties of yarns were developed by hand spinning by blending 50:50 ratio of cotton and China rose fibres and a 100 percent China rose yarn.When compared with pure China rose yarn, the blended yarn exhibited greater strength and elongation at break. The yarn's increased mechanical qualities suggested that it can be used to create heavyweight textiles for clothing and home decor (Rani 2018).

(3) Cluster fig tree

Cluster fig tree also known as *Ficus glomerata* or *Goolar*, is a medicinal plant native to India, cultivated in various regions including Uttarakhand, Punjab, Nagpur, Kolkata, Bihar, Odisha, Rajasthan and parts of South India. The tree typically grows to a height of 10-16 meters, with a bark thickness ranging from 0.5 to 1.8 cm. Most parts of the plant, including bark, leaves, fruits and roots are used for medicinal purposes, with the bark being particularly useful for treating urological disorders and diabetes. Other parts of the plant exhibit wound-healing, analgesic, antifungal and anti-inflammatory properties (Aaditaa and Jahan 2018).

Fig. 8 : Cluster Fig (*Goolar*)

Fibre extraction from *F. glomerata* stems was performed using the water retting method, followed by scouring with sodium hydroxide (NaOH) to enhance their suitability for product development. The optimal treatment was found to be 3 percent sodium hydroxide concentration and one hour treatment time, resulting in improved fibre quality. Nonwoven fabrics were developed from the extracted fibre for items like letter holders, file bags, table runners, carpet slippers and handbags. This fibre offers a promising source of raw material for producing natural products like carrier bags, baskets, belts and handicrafts (Aaditaa 2015).

(4) Cotton stalk

Cotton, a soft, fluffy fibre, is a natural form of crystalline cellulose derived from the seeds of Gossypium plants. It grows in tropical to semi-arid regions and produces around hundred million tonnes of dry stalks annually. These stalks are either incorporated into the soil or burned in the field to prevent pests like the pink bollworm from breeding. However, burning these stalks releases harmful greenhouse gases, contributing to environmental pollution. Therefore, the traditional method of incorporating the stalks into the soil or burning them in the field is not sustainable.Therefore, using cotton stalks for fibre added value for farmers by turning waste into a profitable resource, reducing disposal issues and providing extra income (Yzombard *et al.* 2014; Nkomo *et al.* 2022).

Fig. 9 : Cotton

Reddy and Yang (2009) used chemical methods to extract bast fibres from cotton stalks and studied their chemical composition, crystallinity and mechanical properties. Nkomo *et al.* (2022) used a three-week water retting procedure to extract fibres from the cotton stalk's top, bottom and root parts, which were then cleaned manually using decortication, hackling, and scutching. The top part has the longest fibres (9.4 cm), followed by the bottom (8.07 cm) and the root (7.04 cm). The bottom portion fibres exhibited the highest tenacity, measuring 56.3cN/tex. In addition, fibre bundles for composite manufacturing were removed mechanically and processed into non-woven matting using air-laying methods (Yzombard *et al.* 2014). Dong *et al.* (2014) extracted fibres from cotton stalk bark using steam explosion, potassium hydroxide and peroxide treatments. It was found that these fibres were superior to rice and wheat straws in mechanical properties. The extracted fibres were used to reinforce thermoplastic composites but couldn't be spun into yarns due to their higher fineness. Cotton stalks have various other applications, including newsprint paper, particle boards, pulp and paper, hardboards, corrugated boxes and for edible mushroom cultivation (Nkomo *et al.* 2022).

(5) *Dhaincha*

Dhaincha (*Sesbania aculeata*) is one of the fast growing and prominent annually available agricultural crops of India, present as agro-waste in large volumes. It is an annual shrub which grows to 2 m in height. The fibrous, pithy stems with long leaves, bears purple-spotted yellow flowers (Islam *et al.* 2013). *Dhaincha* is an ideal green manure crop and also grown for animal feed and fodder, ground cover, wood, firewood and other purposes in traditional agro-forestry systems. Stem and leaves of the plant serve as a source of organic matter for soil by crushing entire plant at young stage in agricultural fields. The stem of this plant is used to extract fibres and prepare eco-friendly and biodegradable products to be used in different applications. It is a non-wood lingo-cellulosic material whose stem contains 27.4 percent total lignin, 48.7 percent α-cellulose and 23.1 percent pentosan, average length (0.77 mm) and width (20.3 µm) values of its fibre being comparable to those of hardwood. The *dhaincha* fibres are harsh, coarse and shiny in appearance but lack elasticity. Extracted *dhaincha* fibres are used for making ropes, cordages, fish nets, sackcloth, sailcloth, carpets, paper pulp and also suitable for construction of non-woven fabric (Singh and Rani 2014; Chanda *et al.* 2018).

Fig. 10 : *Dhaincha*

Dhaincha fibres were extracted using biological and chemical retting processes; it was inferred biological retting produced higher yield. The fibres were scoured with Na_2CO_3 and NaOH to improve tenacity, elongation, fineness, moisture content and whiteness index. After scouring, proportion of cellulose component in *dhaincha* fibres increased from 42.2 to 62.9 percent whereas hemicellulose content decreased from 30.9 to 19.8 percent, lignin content decreased from 21.94 to 11.85 percent and ash content reduced from 2.15 to 1.75 percent. This decrease might be due to the removal of non-cellulosic components *viz.,* hemicelluloses, lignin, fat, wax and ash from fibres after treatment. The fibres were softened using cationic, nonionic, silicon and oil-based emulsions. The treated fibres were spun into twisted and spun yarns for woven and nonwoven textiles, providing viable alternatives to jute and coir geotextiles for soil erosion prevention and road reinforcement (Negi, 2017). Singh and Rani (2013) determined that fibres extracted through 15 days of tank retting were scoured and bleached with 1% KOH and 1% H_2O_2, yielding fibres suitable for nonwoven fabric in geotextile. *Dhaincha* fibres may be dyed with direct, azoic and reactive synthetic dyes for nonwoven fabric production, resulting in goods such as hand fans, magazine holders, and table mats (Arya *et al.* 2016). Gangwar *et al.* (2022) studied woven fabrics constructed from *dhaincha*/jute-blended yarns, emphasizing novel uses for *dhaincha* fibre in textiles for UV protection and thermal comfort.

(6) *Marorphali* shrub

Helicteres isora, also known as *Marorphali* in Hindi, is a shrub or small tree found in India's tropical Western Ghats and forest areas. It grows to 5 to 15 feet and has a trunk diameter of up to 3 inches. The plant thrives in rich humus soil and areas with 120 inches or more annual rainfall. Fruits, bark, leaves and roots of plants have been used for medicinal purposes, but the stems are often discarded or used as fuel. However, these fibres have low commercial value and are obtained by submerging the bark in water for 20 to 25 days. The fibre obtained from thick, grey bark is used in rope-making and other products (Joshy *et al.* 2006; Kesarwani *et al.* 2019; Acharya *et al.* 2023).

Fig. 11 : *Marorphali*

A number of retting methods have been explored to extract fibres from *Helicteres isora* with a focus on chemical and water retting. After analysing the two methods, Kesarwani (2012) found that water retting required cutting and bundling *marorphali* stems before submerging them in stagnant water for a period of 21 days. Pectin and mucilage were degraded by microorganisms in the water, which made fibre separation easier. The stems were cleaned, hammered to break the fibres and allowed to dry after retting. In chemical retting, sodium hydroxide (NaOH), potassium hydroxide (KOH), and sodium carbonate (Na_2CO_3) solutions in 5 percent concentrations were used to boil the stems. After boiling, the fibres were washed and neutralized with acetic acid. Fibres obtained with sodium hydroxide treatment have good tenacity and fineness compare to water retting. It was found that water retting for 21 days was most effective, eco-friendly and economical method for fibre extraction producing high-quality fibres suitable for union and nonwoven fabrics.

(7) Nettle:

The perennial stinging nettle, also known as Nilgiri nettle (*Girardinia diversifolia*), is a herbaceous plant found in various locations, including gardens and forest edges. It belongs to the Urticaceae family, which contains over 500 species. The plant, which grows to a height of 3-7 feet, thrives in Sub-Himalayan regions such as the Uttarakhand hills, Himachal Pradesh, Jammu and Kashmir and Nepal. Its leaves resemble spinach and are covered with hairs, which can induce painful stings and transient swelling as a result of substances such as histamines and acetylcholine. Nettle tea, brewed from fresh or dried leaves is commercially available and highly regarded for its therapeutic benefits. The plant is used for animal feed and vegetables as well as produces a lot of fibre, which is being used to make garments, mats and carpets (Deepa *et al.* 2023; Joshi 2023).

Fig. 12 : Nettle

The extraction of natural Fibres from nettle involves various methods, including water retting, dew retting, chemical extraction and microorganisms (fungi and enzymes) (Deepa *et al.,* 2023). The process involves degrading lignin and pectin, increasing cellulose content and focusing on fibre ribbons compared to whole stems due to their lower water and chemical requirements. The fibres are blended with cotton and bamboo to produce yarns with better abrasion resistance, air permeability, and functional properties. The 65:35 nettle-cotton and 65:35 nettle-bamboo blends had excellent properties, making them suitable for protective clothing (Singh 2021). To improve physical and mechanical properties, nettle fibres can be treated with sodium hydroxide at varying concentrations (Samanta *et al.* 2021). The growing popularity of nettle fibre has led to produce nettle jeans and jackets, with the material being favored for sustainable textiles, fibre composites and handmade goods (Mohan 2023).

(8) Okra

Okra (*Abelmoschus esculentus*), a vegetable crop from the Malvaceae family, is primarily grown in tropical and subtropical regions, with India being the largest producer. It is cultivated for its green non-fibrous immature fruit mostly consumed as a vegetable. Its seeds are a source of oil and protein, comparable to soybean. Okra stalks, often considered agricultural waste, yield 1.8 to 10 percent fibre, depending on species, agronomy practices and retting methods (Gupta *et al.* 2021).

Fig. 13 : Okra

Various retting methods for extraction of fibre from okra have been explored such as water retting, compost culture retting, urea treatment and dew-retting. Vanishree (2016) found that urea treatment and compost treatment enhanced retting efficiency and quality, while Vasugi *et al.* (2019) observed improvements in okra fibre brightness and dyeing potential after scouring and bleaching. Water-retted fibres exhibited superior strength, elongation and lower density compared to dew retting (Stawski *et al.* 2020). Yilmaz *et al.* (2016) highlighted that chemical and enzymatic treatments further enhanced the physical, mechanical and thermal properties of okra fibres.

Okra bast fibre has been used in various textiles and related products, contributing to sustainability by recycling agricultural waste and repurposing inedible plant parts. Hometech products like drapery, *diwan* sets, and table runners have been designed using okra fibre (Vanishree 2016). Other products include brushes, ropes and nonwoven fabrics (Gogoi *et al.* 2017). Okra fibre's high diameter and fineness make it suitable for blending with other fibres for home textiles and technical applications like sound insulation. Other applications include yarn, paper-fibre composites, handmade paper, polymer composites and cellulose nanocrystals. Okra fibre's versatility and ability to blend with other fibres make it an eco-friendly alternative to traditional fibres (Gupta *et al.* 2021).

(9) *Phalsa*

Grewia asiatica is a drought-tolerant plant native to the Tiliaceae family, commonly known as *Falsa* in Pakistan, *Phalsa* in Bengali and Gujarati, and *Dhamin* and *Shukri* in Hindi. It grows as an intercropping plant in fruit orchards, producing purple fruit with long, slender branches. It is a multipurpose plant whose parts are used medicinally to treat various illnesses, including blood, heart, and respiratory conditions. Bark is also used to extract fibres using scotching or retting methods. The presence of non-cellulosic materials like lignin, pectin and hemicellulose in the fibres impacts their characteristics in yarn and fabric (Blackburn 2005; Paul 2015; Upreti 2017).

Fig. 14 : *Phalsa*

Upreti (2017) extracted *Grewia asiatica* fibre from the phalsa plant through water retting and scoured it with sodium hydroxide and ammonium oxalate. The fibres were softened with cationic softener to improve their quality. The scoured fibres had increased elongation value, fineness and decreased tenacity due to the removal of non-cellulosic materials like fat, waxes, lignin and hemicellulose. After extraction of fibres from *phalsa* plant yarn, union and nonwoven fabrics were developed. Union fabric was produced using herringbone weave on handloom, resulting in a heavy, strong, and elongated fabric with good abrasion resistance and drapeability. Nonwoven fabric was made using needle punching method, resulting in a thick, lightweight, thermally insulated and moisture absorption fabric. These nonwoven fabrics can be used in various applications, includingmulching, bio-composites, floor coverings, carpets, handicrafts and home furnishing products.

(10) Sugarcane bagasse

Sugarcane (*Saccharum officinarum*) is a plant that belongs to the Gramineae family. It is a key crop in tropical and subtropical regions and primarily grown in Brazil and India, with India being the second largest producer (Alokika *et al.* 2021). It is mainly used for the production of sugar, alcohol, jagery manufacturing, juice extraction and vinegar. However, 30 percent of its pulpy fibrous waste remains after processing in mill, called bagasse which is a major agricultural byproduct. Bagasse is composed of cellulose, hemicellulose, lignin, wax and other components and used in the paper industry as a feedstock and biofuel (Abd El-Baky *et al.* 2019; Singh and Singh 2020; Mahmud and Anannya 2021).

Fig. 15 : Sugarcane Bagasse

These fibres can be extracted using mechanical, chemical, enzymatic or steam explosion methods. Mechanical extraction results in small fibres unsuitable for technical applications. The rind portion of bagasse can be pre-treated in hot water at 90°C for 60 minutes to remove colouring matter and sugar traces. Mechanical extraction yields are recorded at 0.9 percent manually and 8.69 percent through mechanical extraction. Chemical treatment involves pre-treating the stalks in water and then with NaOH (Sakthivel *et al.* 2021). Cellulosic fibres can be extracted using an alkaline delignification process, which is effective for lignin removal while enzymatic treatment can improve the fineness of fibre. Ring spinning of sugarcane-viscose yarns shows higher tenacity and elongation than sugarcane-cotton yarn. These fibres are used in various textile applications, such as spun yarn, woven fabrics, fibrous handicrafts, coarse foot mats, tufted foot mats and low-cost absorbent sanitary napkins (Michel *et al.* 2013; Sachdeva *et al.* 2018).

Table 1 describes various retting methods, their duration and the resulting fibre qualities of different unconventional plant fibres, including okra, ashoka, cluster fig, China rose, *marorphali*, *phalsa*, cotton stalk, sugarcane bagasse, nettle and *dhaincha*. The retting processes included water retting, accelerated water retting, chemical retting or treatment and enzymatic retting. Each method had a varying impact on fibre tenacity, elongation, fineness, and yield. Accelerated water retting for okraand enzymatic treatment for *dhaincha* were considered the best and most sustainable methods due to their reduced retting time, lower chemical use and improved fibre quality. Chemical retting, though effective in increasing tenacity, especially for ashoka and China rose, may not be as environment friendly due to chemical waste production. Chemical retting could have been environment friendly, if the chemicals were reused or used in smaller amounts.

Table 1: Physical properties of unconventional bast fibres obtained with various retting methods

Fibres	**Retting methods**	**Retting time**	**Tenacity**	**Elongation (%)**	**Fineness / Diameter**	**Fibre yield (%)**	**Reference**
Ashoka	Chemical	2.5 hours	24.75 g/tex	5.78	76.45 denier	-	Rani, 2018
China Rose	Chemical	2.5hours	22.50 g/tex	2.90	69.12 denier	-	Rani, 2018
Cluster fig tree	Water	21days	4.28 g/d	2.33	31.40 denier	-	Aaditaa, 2015
	Water + chemical scouring	21 days+ 1 hour scouring time	3.24 g/d	2.78	21.19 denier	-	
Cotton stalk	Water	21 days					Nkomo *et al.* 2022
	Root		-	-	0.29 mm	22.50	
	Bottom		56.3 cN/tex	1.35	0.23 mm	20.76	
	Top		39.8 cN/tex	1.17	0.18 mm	22.50	
Dhaincha	Unprocessed fibre (Water)	15 days	5.43 g/d	3.4	35.30 denier	-	Negi, 2017
	Water + Chemical scoured (Na_2CO_3)	15 days + 0.50 hour	4.67 g/d	3.9	32.60 denier	-	
	Water + Chemical + Enzymatic scoured (Xylanase +Pectinase)	15 days + 0.50 hour + 1 hour	4.25 g/d	4.1	32.90 denier	-	
Marorphali	Water	21 days	4.30 g/d	1.21	28.04 denier	-	Kesarwani *et al.* 2019
	Chemical retting (NaOH)	1 hour	3.15 g/d	2.17	25.79 denier	-	

Nettle	Water	8 days	3.84 g/d	2.09	15.12 denier	-	Singh, 2021
	Chemical delignification	4 hours	5.04 g/d	3.19	12.08 denier	-	
Okra	Water	8 days	9.8 g/tex	0.40	10.82 denier	1.80	Vanishree, 2016
	Accelerated water retting with urea	5 days	12.50 g/tex	0.50	10.70 denier	2.34	
	Accelerated water retting with compost culture	6 days	11.10 g/tex	0.40	10.80 denier	2.17	
Phalsa	Water	21days	3.53 g/d	2.02	21.59 denier	5.21	Upreti, 2017
	Water + Chemical processing	21days + 1 hours	3.29 g/d	2.59	19.25 denier	5.43	
Sugarcane bagasse	Alkali delignified fibre	1.50 hours	2.07 g/d	-	121 denier	34.30	Sachdeva, 2018
	Alkali and Enzyme delignified fibre	(1.50 + 1.50) hours	2.08 g/d	-	89 denier	-	
	Alkali + Enzyme + Bleached fibre	(1.50 + 1.50 + 0.50) hours	2.05 g/d	2.2-2.5	81 denier	-	

In Table 2, water retting yielded moderate cellulose content, whereas chemical retting increased cellulose levels in fibres. Chemical retting reduced lignin content, which influenced fibre stiffness and coarseness. Fat and wax levels were consistently low across all fibres and retting processes. Chemical retting removed non-cellulosic components, resulting in cleaner, higher-quality fibres with improved mechanical properties, making them suitable for textile applications.

Table 2: Chemical compositions of unconventional fibres obtained with various retting methods

Fibres	**Retting methods**	**Cellulose** (%)	**Hemicellulose** (%)	**Lignin** (%)	**Fat & Waxes** (%)	**Ash** (%)	**Reference**
Cluster fig tree	Water retting	58.20	22.40	17.00	1.5	0.9	Aaditaa, 2015
	Water + chemical scouring	56.44	17.75	16.00	1.02	0.5	
Cotton stalk	Raw stalk	36.56	23.34	21.58	0.96	-	Li and Zhao, 2015
Dhaincha	Unprocessed fibre (Water retting)	42.22	30.90	21.94	1.34	2.15	Negi, 2017
	Chemical scoured (Na_2CO_3)	62.90	19.80	11.85	0.97	1.75	
Marorphali	Water retting	56.29	19.52	14.45	6.34	0.9	Kesarwani, 2012
	Chemical retting (NaOH)	72.37	16.30	5.86	3.07	0.5	
Nettle	Water Retting	68	13.96	9.54	-	2.83	Singh, 2021
	Chemical delignification	73	8	3.32	-	1	
Okra	Water	53.30	25	11.20	1.60	1.20	Vanishree, 2016
	Accelerated water retting with urea	50.90	22.10	10.90	1.50	1.20	
	Accelerated water retting with compost culture	52.40	24.60	11.00	1.60	1.30	
Phalsa	Water	75.57	9.99	16.22	5.48	-	Upreti, 2017
	Water + Chemical	78.68	9.46	15.16	4.23	-	

	processing						
Sugarcane bagasse	Depithed sugarcane rind	48.58	22.35	24.59	-	-	Sachdeva, 2018
	Alkali delignified fibre	59.97	18.21	17.32	-	-	
	Alkali and Enzyme delignified fibre	73.12	11.29	10.05	-	-	
	Bleached fibre	81.56	5.31	8.26	-	-	

Conclusion

Unconventional bast fibres extracted from diverse plants have the potential to convert agricultural waste into valuable textiles. These fibres are frequently discarded because of their biodegradability and environmental friendliness. With growing customer demand for sustainable practices, the textile industry is focusing on underutilizedfibres to reduce its environmental impact. Dew retting, water retting, mechanical retting, chemical retting, physical retting, and enzymatic retting all contribute to the quality and properties of fibres. Each method has distinct benefits and disadvantages that influence extraction quality and environmental effect. Unconventional bast fibres may be utilized in a variety of products, including garments, home textiles, and automobile interiors, encouraging creativity in sustainable designs. As research and development continue, the textile sector is positioned to make substantial steps towards sustainability, utilizing unconventional bast fibres to suit customer expectations while reducing environmental impact.

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