Nettle fibre for technical applications

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Abstract

Due to greater awareness of environmental and social issues, as well as stricter environmental regulations, there is a rising demand for green materials to replace fossil-based resources and raw materials. With its excellent mechanical properties, biodegradability, and low cost, nettle fibre has the potential to become a sustainable fibre for technical applications. Dyeability, antimicrobial properties, renewability, and wrinkle resistance make this fibre suitable for textile applications. Due to its low density, it may be used in a wide array of applications such as woven and non-woven fabrics, blends, and composite materials. This paper aims to critically review nettle fibre in various textile applications and provide directions for future research.

Keywords: Alkali treatment; building material; non-woven textiles; textile composite; sound absorption; sustainability.

1. INTRODUCTION

Nettle (*Girardinia diversifolia*) fibre is derived from the stems of the nettle plant, a herbaceous plant that belongs to the *Urticaceae* family. The plant is grown as a wild shrub in Asia, Europe, North Africa and North America [1]. The *Urticaceae* family, which includes the nettle genus, comprises approximately 500 species [2-4]. It is a perennial grass species that does not require pesticides and can grow up to 3.6 to 5.5 m. It provides the longest natural fibre and is amenable to yarn formation and fabric manufacturing [5]. When conventional raw materials were less abundant and diverse, nettle played a critical role in the field of textiles. In Europe, people have been using nettle plants to extract fibres since the 12th century, mainly for domestic handicrafts [6]. During the 16th and 17th centuries, Scottish households favoured nettle fibre as their preferred textile for linens [2,7]. Germany was the first country to commercialize the production of nettle fibre. Attempts were made at the cultivation of nettle and the process of extracting fibres from the plant was established at the beginning of the 18th century. Europeans and Americans used nettle plant fibres to make sail cloths, sacks, cordages, and fishing nets [8-10]. Till 1860, nettle fibre was used to make sturdy, durable cloth in Great Britain, but it was discontinued due to low-cost imported materials [7]. During World War I, nettle fibre was used as a substitute for cotton. The German uniforms constituted of 85 % nettle fibre at the beginning of World War II. The British government used 100 tons of nettle plants to extract green dye for camouflage [11-13]. Due to limited scientific research and reliance on extraction traditional methods, the potential of nettle fibre for development into textile-grade products has not been fully explored [14].

2. COMPOSITION, MORPHOLOGY AND PROPERTIES OF NETTLE FIBRE

2. 1. Composition and morphology

The fibres are found in the plant's bast or skin, as shown in Figures 1a, 1b and 1c, and are highly oriented along the fibre axis with a small helix angle [5].

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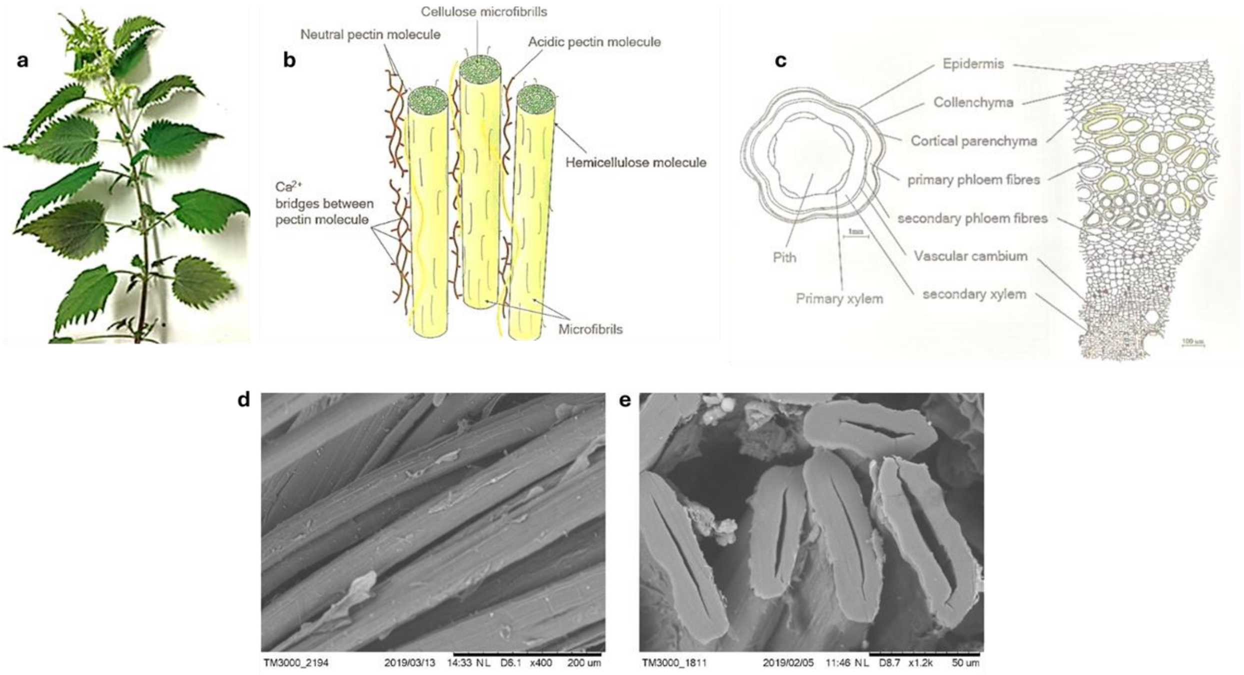

Figure 1. *Nettle fibre: a - photograph of nettle plants; b and c - schematic presentation of the structure of bast fibres in nettle stem, adapted with permission from [5,15] © IJHS 2018; scanning electron micrographs of d - longitudinal and e - cross-sectional view of nettle fibres, reprinted with permission from [16]*

Chemical composition of the nettle plant was reported to vary with the age of the plant with a mean fibre content reported as 11 % [17]. The middle portion of the plant had the highest fibre yield (13 %), with fibres containing the lowest cellulose content (79 ± 2 %) and the highest hemicellulose content (12.5 ± 3 %), compared to the top and bottom portions. Lignin content (4.4±0.4 to 3.5±0.2 %) and fibre diameter (47 to 19µm) decreased from the bottom to the top of the plant, with the longest fibres found at the top. Variability in the diameter, length, and lignin content affects the characteristics of the extracted fibre. The composition of nettle fibre might differ depending on the specific clone variation. Scanning electron microscopy of nettle fibres shows surface characteristics similar to other bast fibres. The longitudinal image of nettle fibres in Figures 1d and e shows a clean surface, free from impurities, voids, and scratch marks. The cross-section of nettle fibre (Figures 1d and e) is annular and has an elliptical rather than circular shape.

2. 2. Physical and mechanical properties

The physical properties of nettle fibre vary depending on the species. Fibre diameter ranges from 20 to 80 µm and varies along its length, while density ranges from 1.4-1.5 g cm^{-3}. The average length of the fibre for *Goirardinia diversifolia*, reported as 478 ± 21 mm, was considerably longer than that reported for *Urtica dioica* (52 ± 2 mm) and other common bast fibres. The moisture content of fibre was reported as 6 % for *Girardinia diversifolia* and 9.4 % for *Urtica dioica* [8,14,18]. The tensile strength of nettle fibre has been reported as 4451 ± 13 MPa, surpassing that of glass fibre. Its Young's modulus was 73 ± 22 GPa with an elongation at break of 6.2 ± 1.3 % [14]. As shown in Table 1, these values are the highest among all bast fibres and even exceed those of some industrial fibres, including glass. Due to their hollow structure and resulting low density, nettle fibres possess superior characteristics compared to most other fibres. However, these properties can vary depending on the plant species and the fibre extraction technique employed [19].

Table 1. *Mechanical and physical characteristics of different fibres**

Fibres	Length, mm	Average diameter, µm	Young's modulus, GPa	Tensile strength, MPa	Strain to failure, %	Density, g cm^{-3}	Ref.
Nettle	478±21	-	73±22	4451±131	6.2±1.3	1.4 to 1.5	[14]
Stinging nettle	52±2	19.9±4.4	87±28	1594±640	2.11±0.81	-	[20]
Flax	207±3	17.8±5.8	58±15	1339±486	3.27±0.4	1.53	[21]
Hemp	20±5	31.2±4.9	19.1±4.3	270±40	0.8±0.1	1.48	[22]

Fibres	Length, mm	Average diameter, µm	Young's modulus, GPa	Tensile strength, MPa	Strain to failure, %	Density, g cm^{-3}	Ref.
Coir	150 to 280	100 to 500	3 to 5	140-225	-	1.2	[23,24]
Jute	-	70-80	26.5	393-723	3.5-4.5	1.3	[25]
Ramie	135±15	34	24.5	560	2.5	1.51	[26]
E-Glass	-	5 to 25	76 to 78	3100-3800	3.4	2.55	[27]

*Among the references, some report values as means with standard deviations (mean ± SD), whereas others present data as ranges to reflect higher variability

In a study of fibre tensile properties [20], a positive association between Young's modulus and the fibre diameter was shown (Figure 2), with the measured values being widely spread. One possible explanation is that as the fibre's diameter increases, the lumen that is the hollow portion, also becomes larger. For this specific nettle, the average diameter was 20±2 µm, and the mean Young's modulus was 87 ±28 GPa [20]. There have been reports of similar effects with flax fibre [28].

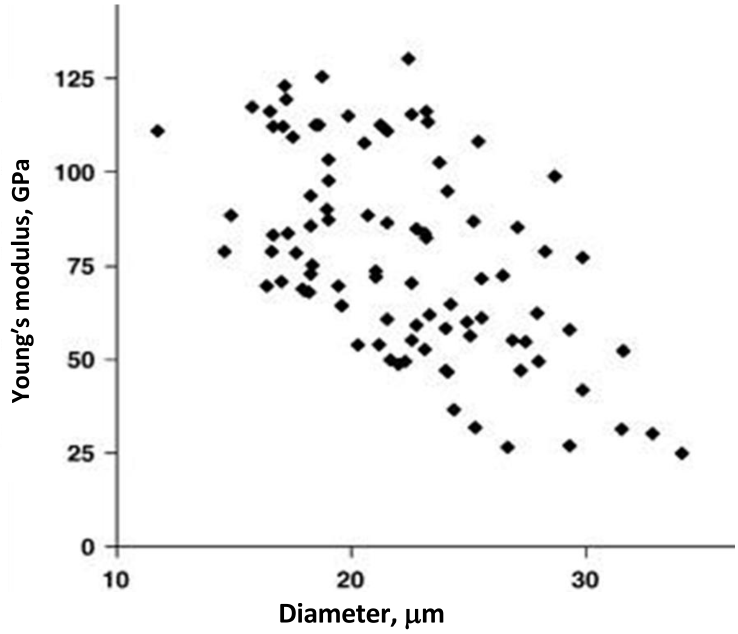

Figure 2. *The relationship between the Young's modulus and the diameter of stinging nettle fibre. Adapted from [29] © 2007 Elsevier*

3. CHARACTERISTICS OF NETTLE FIBRE

Fibres extracted from the nettle plant are pliable, the longest natural fibre known to humans. They are suitable for a variety of spinning techniques in fabric manufacturing. Moreover, this fibre type is stronger and lighter than cotton, the world's most widely used natural fibre [30,31]. Fabric made from nettle fibres is stronger and stiffer than linen and has also shown antimicrobial activity against nine different microorganisms due to compounds such as catechins and epitheca [32]. The fibre has also shown good resistance to wrinkling and pilling, resulting in improved durability and aesthetic properties of the fabric [33]. These properties are dependent on the processes used for fibre extraction [34]. Due to the fibre's hollow core structure, nettle fibre fabric can be tailor-made for both winter and summer seasons. In winter, the hollow core of the nettle fibre entraps air inside, providing the necessary insulation. It helps in keeping the body warm by preventing the transfer of body heat to the environment. In summer fabrics, thermal insulation can be reduced by increasing the twist in the yarn [35]. In addition, the fabric made from this fibre is dyeable yet cost-effective, like other cellulosic fabrics. These properties have increased the acceptability of the nettle fibre in textile applications [36]. From a sustainability point of view, this fibre could be used as a source of cellulose feedstock for regenerated cellulosic products and can also be reused [30,31]. The plant only needs a source of water and can survive a contaminated soil environment [37]. However, the use of nettle fibre is currently restricted to handmade textile products due to its rigid and inextensible characteristics, as shown in Figure 3. Once these drawbacks are overcome through chemical treatments as with other bast fibres, they can be rendered useful in technical applications [13,38,39].

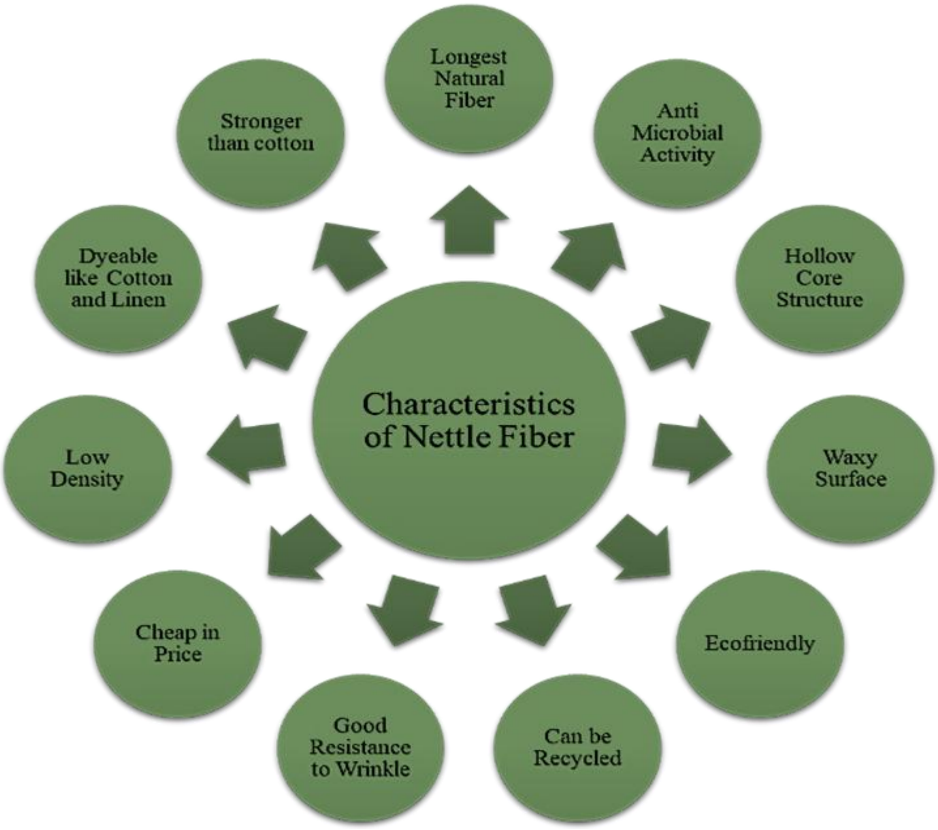

Figure 3. *Technical characteristics of nettle fibre*

4. PROCESSING OF NETTLE FIBRES

Processing of nettle fibre from the plant to the fabric stage consists of various steps. The nettle plant is a perennial crop (life of 10-15 years) and can produce fibres suitable for textile applications for 4-5 years [14,42]. Although the plant is typically ready to harvest in August, the exact timing is determined by various factors such as plant height, the seed-forming stage, and the emergence of new branches from the roots. Nettle plants are harvested with a sharp knife and then retted to extract the fibres. After cleaning and opening by specialized equipment, the fibres may be blended as needed for specific applications. The resulting blend is then carded to produce slivers, preparing it for further textile processing. Alignment and uniformity of the sliver are ensured during the drawing stages. Through opening and twisting, the sliver is converted into roving and then into yarn *via* the spinning process, following the required parameters. Subsequently, the yarn must go through the warping process to prepare a series of parallel yarns ready for weaving. Sizing is applied to the warp sheet to increase its strength, which helps reduce breakages during the weaving stage. Then the fabric is then manufactured on a loom by interlacing the warp and weft yarns perpendicularly. The aesthetic appearance of the fabric can be enhanced through dyeing, if required. Additionally, it can be treated with various chemicals at the finishing stage to add value, if necessary [43].

5. EXTRACTION METHOD

Fibres are separated by removing the gummy substance that binds them together, with a detailed process shown in Figure 4 [44,45]. Various methods can be used to extract fibres from the stem, and their respective advantages and disadvantages are discussed in the following section.

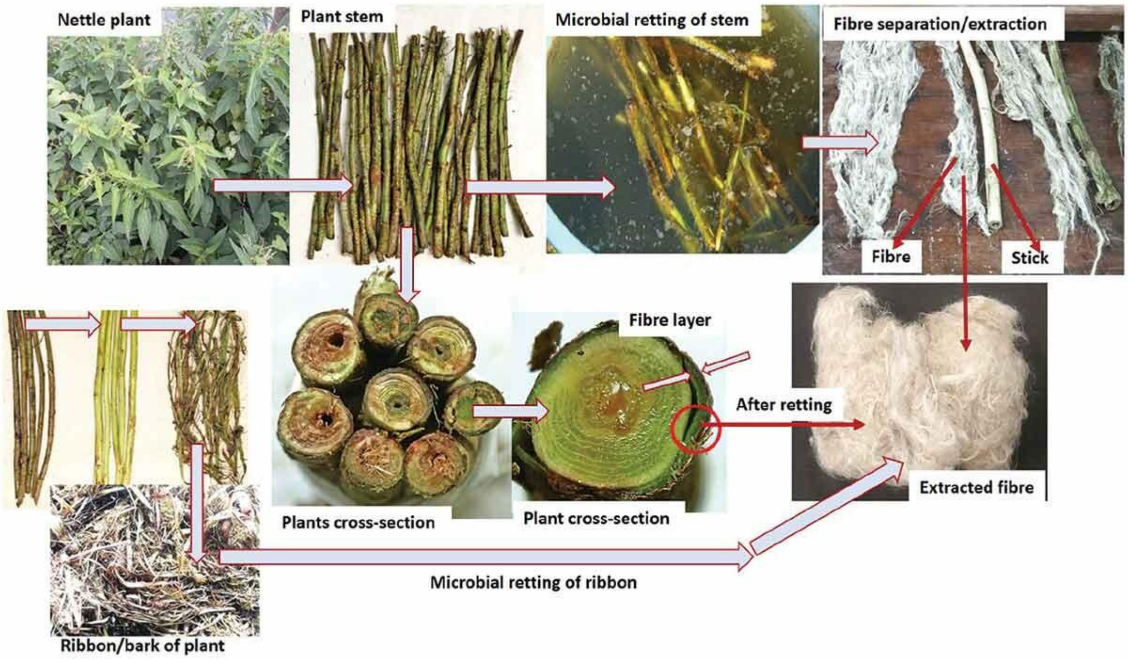

Figure 4. *Extraction process of nettle fibre. Adapted from [46].*

5. 1. Microbiological retting

5. 1. 1 Dew retting

Dew retting, also known as field retting, involves spreading the stalks widely in an open field for up to 10 weeks. During this period, microorganisms present in the soil and on the plants break down non-cellulosic contents, resulting in the removal of pectin and hemicellulose, while leaving the cellulosic fibres intact [44].

5. 1. 2. Water retting

After harvesting, the plant stalks are immersed in water for 2 to 3 weeks, allowing microorganisms to degrade the gummy substances binding the fibres together. This process is cheap but time-consuming [44].

5. 2. Enzymatic retting

Enzymatic retting, also known as the scouring process, is less time-consuming and requires less water. It uses enzymes to degrade the gummy part of the stem at a specific temperature. In terms of time-saving, eco-friendliness and convenience characteristics, this method has shown that it can be a promising substitute for conventional retting techniques [44].

5. 3. Mechanical separation

Mechanical separation is the most conventional method, where fibres are mechanically decorticated to separate them from the woody stem, followed by scutching and hackling. This process is similar to the extraction of banana fibres, as reported previously [47].

Although the process has become automated, the basic steps remain the same and include the following stages:

- Breaking: Extracted stalks are passed through rollers to crush and split the woody core.
- Scutching: Bundles are fed between rollers and beaten by mechanical blades to separate the fibres from the woody stem material.
- Hackling: The fibres are passed through a set of pins to disentangle and align them.

5. 4. Physical retting

5. 4. 1. Steam explosion

The steam explosion procedure utilizes high-pressure saturated steam, followed by rapid depressurization. This sudden change causes the breakdown of lignocellulose, hydrolysis of hemicellulose, depolymerisation of lignin, and separation of the fibres (defibrillation).

5. 4. 2. Hydrothermal methods

In the hydrothermal method, water at high temperature and pressure is used to degrade hemicellulose and lignin.

5. 4. 3. Osmotic degumming

In the osmotic degumming method, degumming occurs through the diffusion of water into the material within the stem. When the tension generated by water penetration exceeds the longitudinal strength of the stem, the epidermis fractures along its length without damaging the fibres. Once pectins get dissolved in water, the fibres can be separated out by filtration. These fibres exhibit high strength and a soft texture [48].

5. 4. 4. Plasma treatment

Plasma treatment involves various forms of gases at atmospheric and high pressures, while generally, oxygen and argon are used [49]. This is a surface modification technique that uses ionized gases under atmospheric or low-pressure conditions to alter the surface properties of materials without affecting their bulk characteristics. In this process, various gases can be used, but oxygen and argon plasmas are most commonly applied to activate and clean the material surface [50]. The energetic plasma species interact with the surface, removing contaminants and introducing functional groups, which improves properties such as wettability, adhesion, and dyeability. Due to its environmentally friendly nature and minimal chemical usage, plasma treatment is widely used in textile processing, polymer modification, and advanced material engineering applications [51].

5. 5. Chemical retting

In chemical retting, chemicals are used to degrade the gummy substances binding the fibres together. This method is often preferred since it yields fibres of uniform quality in a shorter time regardless of weather conditions. Common chemical treatments include alkalization, ammonia treatment, acidic retting, and oxidative delignification [52]. After extraction, the fibres can be processed into different forms, such as yarns, fabrics, or composites, depending on the intended application and specific requirements [53]. Comparison of different methods of retting is given in Table 2.

***Table 2**. Comparison of different retting methods [44,49,54].*

Retting method	Description	Advantage	Disadvantage
Mechanical separation	Fibres are separated mechanically; then post-cleaning and further impurities are filtered.	A high amount of short fibres can be produced in less time.	Low quality of fibre
Water retting	Plant stems are immersed in water. They are regularly tested to check the extent of retting.	Provides highly uniform and high-quality retted fibres.	Severe pollution problem resulting from anaerobic fermentation of bacteria and high cost. Requires intensive wastewater treatment.
Enzymatic retting	Gum and pectins are hydrolysed by enzymes. To optimize retting efficiency, controllable retting conditions are allowed.	Specific properties for various applications can be achieved by adjusting the retting time and the type of enzyme used. It is a cleaner and faster process.	Low strength of fibre
Chemical retting	Hydrogen peroxide, sodium benzoate or sodium hydroxide are commonly used.	Possibility to obtain a smooth and clean surface. Consistency cannot be achieved in less time.	Deterioration in fibre quality for higher chemical concentration, high cost of processing, and adverse colour.

6. NETTLE FIBRES EXPLORED IN VARIOUS TECHNICAL APPLICATIONS

The textile sector has been increasingly focusing on sustainable fibres, as the use of conventional fibres results in excessive waste generation and pollution [55]. Nettle fibre has the potential to replace technical fibres that contribute to environmental pollution [56,57]. It is biodegradable, low-cost and exhibits good mechanical properties including high strength, making it ideal for technical textile applications. In addition, nettle fibre is renewable, abundantly available, and has low density allowing for its use in a broad range of applications [58]. However, its inextensibility has restricted its application primarily to handmade textile products [59]. This characteristic makes it difficult to process nettle fibres on conventional textile machines and converting them into yarn and fabrics for a variety of products has proven to be challenging. Some research studies focused on improving the processability of nettle fibres, introducing modifications to reduce their limitations [40,59]. It was reported that mild alkali treatment (0.5 % NaOH, 30 °C for 30 min) led to improved tensile strength (~36 %) and elongation at break (~40 %) with a slight reduction in initial modulus. In the case of concentrated alkali treatment (10 % conc., 100 °C for 6 h), strength and modulus decreased by ~14 and 21 %, respectively, with a ~8 % gain in elongation. An increase in tensile strength up to 5.5 g den^{-1} was also observed for the treatment with 4 % sodium chlorite for 4 h [60]. However, the treatment optimization has not been done yet for nettle fibres. The summary of fabrication methodologies for different materials, such as composites, woven, non-woven, and blended fabrics, along with the main observations by the researchers, is presented in Table 3.

Several attempts have been made to introduce nettle fibre to textile applications. A detailed review of those attempts is discussed below.

Table 3. *A summary of the reported work of nettle fibre used in various applications.*

Applications	Material	Main observations	Ref.
Composite	Nettle and polypropylene	PP composites reinforced with nettle fibre have comparable mechanical qualities to other lignocellulosic composites. Strong qualities of nettle fibre nucleate crystalline structure formation in the PP matrix.	[61]
	Nettle and poly (lactic acid) fibres	Properties were originally enhanced to 50/50 nettle/PLA fibres. ● Tensile strength - 14.93 times increased ● Elongation at break - 1.45 times increased ● Young's modulus - 48 % decreased ● Flexural strength - 2.05 times increased ● Impact strength - 14 times increased. Properties decreased from nettle/PLA 50/50 to 90/10 ● Tensile strength - 2.15 times decreased ● Elongation at break - 1.2 times decreased ● Young's modulus - 51 % decreased ● Flexural strength - 12.2 times decreased ● Impact strength - 6.2 times decreased	[59]
Hybridized composite	Nettle/wool and polyethylene	Tensile strength increased by 21 % up to 20 % fibre loading, then decreased by 4 % up to 25 % fibre loading. Tensile modulus increased by 161 % from 0 to 25 % fibre loading. Fibre loading enhanced flexural stiffness by 24 % at 20 % fibre loading, then reduced it by 6 % at 25 % fibre loading. With 25 % fibre loading, the tensile modulus rose by 33 %. The NaOH treatment improved mechanical characteristics.	[62]
	Nettle fibre, bauhinia-vahlii fibre and epoxy	Increasing dietary fibre increased the void fraction. The water absorption rate increased with fibre content. Tensile strength improved with composite fibre content. Nettle/epoxy composite is weaker than Bauhinia/epoxy composite. Composite hybrids are stronger than mono-fibre composites.	[63]
Woven fabric	Nettle, cotton, polyester, modal	The highest values of moisture loss of 23 % at 4 h and 47 % at 24 h were observed with nettle fibre. Softness values are not reduced with the utilization of nettle fibre in the production of towels. The towel’s hydrophilicity was not adversely affected using nettle fibres.	[41]

Non-woven fabric	Nettle poly (lactic acid) fibres	Alkali treatment • Increased tensile strength by 27 % • Increased elongation at break by 68 % • Decreased initial modulus by 9 % • Increased coefficient of fibre-to-fibre friction by 9 %. Tensile strength decreased as the proportion of nettle fibre increased. Nettle fibres exhibited superior biodegradability compared to Poly (lactic acid) fibres.	[64]
	Nettle and polypropylene	Needle-punched non-woven fabric absorbs crude and diesel oil best. The highest sorption was found in a 30/70 nettle/PP with lower weight (GSM) and needle punch density. Needle-punched non-woven fabric with 30/70 nettle/PP demonstrates outstanding potential for reusability. It can be effective for oil spill cleaning.	[38]
	Nettle	Nettle non-woven fabric demonstrated comfort properties. 494 % water absorbency and 79 $cm^3/cm^2/s$ air permeability. The thermal conductivity reaches a minimum value of 0.0251 W/m K at a needle penetration depth of 8 mm. Fabric weight - 150 g/m^2 Needle density - 75	[65]
Blended fabric	Nettle and acrylic	As blended fabric contains more nettle fibre, moisture absorption rises. Higher-nettle content fabric offered better thermal insulation.	[65,66]
	Nettle, organic cotton and bamboo	The tensile strength of nettle fabric increased by 14.21 % with organic cotton and 10.23 % with bamboo fibre in the warp direction. The tensile strength of nettle fabric increased by 11.1 % with organic cotton and 10.1 % with bamboo fibre in the weft direction. Elongation at break of nettle fabric increased by 8.26 % with organic cotton and 7.53 % with bamboo fibre in the warp direction. Elongation at break of nettle fabric increased by 28.39 % with organic cotton and 7.25 % with bamboo fibre in the weft direction. Abrasion resistance of nettle fabric increased by 3.1 % with organic cotton and 4.23 % with bamboo fibre.	[67]

6. 1. Composite materials

Nettle fibres can be incorporated into bio-composites as a sustainable reinforcement material for automotive, aerospace, and construction industries.

Utilization of stinging nettle (*Urtica dioca*) in reinforcement of polymers was investigated confirming the usability of these fibres in manufacturing polymer composites [29]. To use nettle fiber for composite reinforcement [61], polypropylene was used as a matrix and nettle (10 wt.%) as a filler. The composite was manufactured through extrusion and subsequently by injection moulding. The properties of the obtained composite were compared with those of other composites containing different fillers. It was found that with the addition of nettle fibre to polypropylene resulted in a slight rise in Young's modulus, but a decrease in other properties such as tensile strength (23 %), elongation at break (12 %), impact strength (20 kJ m^{-2}) and hardness (18 %).

Figure 5 shows tensile strength values for different polypropylene composites with addition of 30 wt.% nettle and other natural fibres. It could be seen that the composites containing banana and kenaf fibres have significantly higher strength than the composite containing nettle fibres. The inherent stiffness of the fibre has been the key reason for such observation [68]. Since different researchers have attempted to work with these various organic fibres, it would be intriguing to understand the reasons behind the observed results in a comparative study.

In another research, a bio composite was manufactured for vehicle dashboard panels by carding and compression moulding process [59]. Significant breakage of nettle fibres was observed upon feeding them to the carding machine. The authors commented that the reason was in high stiffness and low elasticity of the fibres. To improve the processability of the fibres, nettle fibres were treated with a 10% NaOH solution (liquor ratio 1:50) at 61.5 °C for 30 min. The treatment resulted in increased fineness (denier), tensile strength, MPa and elongation at break of 0.4, 30 and 70 %, respectively, but the initial modulus decreased by 6.7 %. After the treatment, nettle and poly (lactic acid) (PLA) fibres were fed to a carding machine and slivers of different proportions were obtained: 10/90, 25/75, 50/50, 75/25, and 90/10 [59].

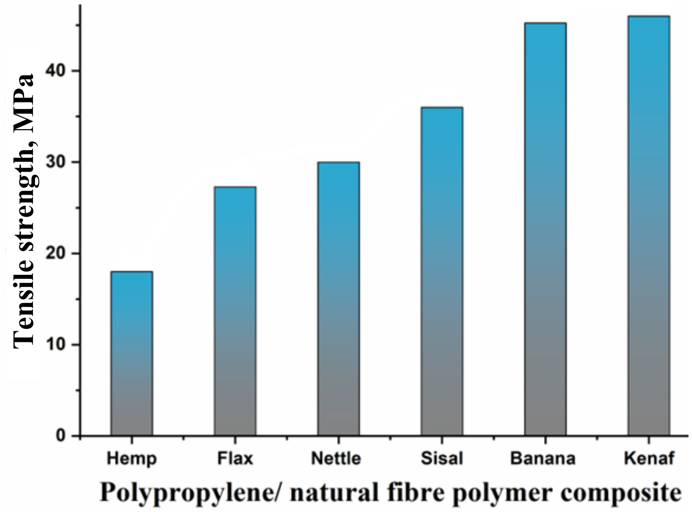

Figure 5. *Tensile strength of polypropylene composites with 30 wt.% fibre. The data is based on studies conducted by [68-70]*

Comparison of the bio composites showed that increasing the proportion of nettle fibre led to a decrease in overall density, owing to the fibre's lower density. As the nettle content is increased, mechanical properties such as tensile strength, elongation at break, Young's modulus, flexural strength, and impact strength improved up to the point where PLA and nettle fibres were present in equal proportions. Beyond this proportion, there was a significant decline in these properties. These results indicate that incorporating nettle fibre as reinforcement can enhance mechanical properties, but only up to an optimal proportion. When the nettle fibre content exceeded 50 % a decrease in mechanical properties was observed as a result of inadequate adhesion between the nettle fibres and the matrix, which led to fibre slippage within the composite [71]. This also caused a reduction in flexural strength. In the case of storage modulus, representing the energy stored in the composite, the nettle/PLA composite with a 50/50 mass ratio showed the highest storage modulus of 4024 MPa, while that of the neat PLA material was 2427 MPa at 35 °C. As shown in Figure 6, the storage modulus of the composite decreased with an increase in temperature. A sudden drop in storage modulus was observed at approximately 70 °C, corresponding to the glass transition temperature of PLA [72].

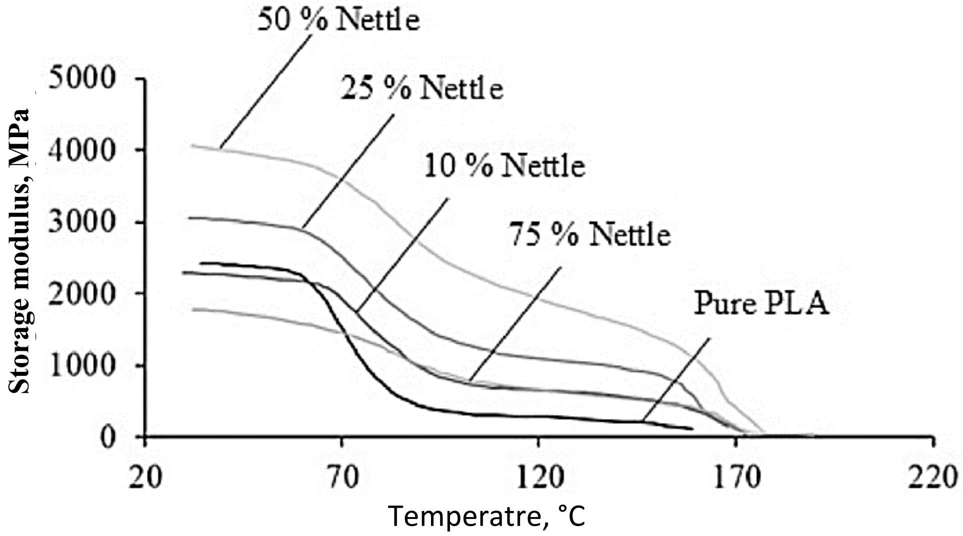

Figure 6. *Variation of storage modulus of nettle/PLA composite. Adapted from [59].*

This composition (nettle/PLA: 50/50) exhibited the best properties among PLA/nettle composites. In comparison to composites with other fibres, the kenaf/PLA composite initially exhibited higher tensile strength than the nettle/PLA composite. However, at higher fibre loadings, the nettle composite subsequently surpassed it due to its superior tensile properties. On the other hand, the nettle/PLA composite showed poorer properties compared to banana/PLA and glass/PLA composites [73]. However, as the fibre loading increases, nettle/PLA composites can surpass kenaf/PLA in tensile properties due to better reinforcement effects at optimal ratios. This trend where mechanical properties increase with fibre content up to an optimum point and then decrease is common among natural fibre-reinforced PLA systems [63,74]. For instance, hybrid PLA composites containing banana or glass fibres have been reported to achieve even greater tensile strengths (up to 79 MPa for PLA/banana/sisal hybrids), attributed largely to superior interfacial bonding and compatibility especially when silane coupling agents are used.

Another study investigated the use of Himalayan nettle (*Girardinia Diversifolia*) as a filler in polyester composites [10,75], examining the influence of fibre loading on physical and mechanical properties. Composite samples with 5, 10, 15 and 20 wt.% fibre were produced using the conventional hand layup method. The results showed that as the fibre loading increased, void fraction and micro spaces within the composite increased up to 75 % when compared to that of the neat polyester sample. The incorporation of natural fibre also increased the hydrophilicity of the composite. Water absorption rose from 0.58 % in neat polyester to 7.04 % in composites with 20 wt.% fibre. Tensile strength improved from 18 MPa in neat polyester to 31 MPa at 15 wt.% fibre loading but decreased to 29 MPa (a 6.45 % reduction) at 20 % fibre content. The authors argued that up to 15 wt.% fibre loading, stress was transferred uniformly throughout the composite. However, beyond this point, the polyester matrix was insufficient to effectively transfer the load, leading to non-uniform stress distribution and a decrease in tensile strength. In terms of hardness, the sample with the highest fibre loading (20 wt.%) exhibited the highest value of 24.91 Hv, whereas the 100 % polyester sample had the lowest value of 17.24 Hv. This indicates that composite hardness increases with the increase in the nettle fibre content, as hardness depends on both the relative weight and the Young's modulus of the fibres. Similarly, impact strength increased with fibre loading up to 15 wt.%, likely because stronger coupling between interlaced fibre bundles requires more energy to break the composite. Beyond 15 wt % fibre loading, impact strength decreased slightly either because of fibre slippage or fiber/matrix pull out [75].

6.1. 1. Hybridized composites

Research has been conducted on hybridized composites [62] utilizing low-density polyethylene (LDPE) as the matrix (density 0.94 g cm^{-3}) with a hybridized woven fabric of wool and nettle serving as a filler. The plain hybridized woven fabric was manufactured by placing alternate wool and nettle fibres in the warp direction and using nettle as the weft. As LDPE is a non-polar substance and the nettle/wool hybridized fabric is a polar material, the resulting composite showed poor interfacial adhesion [10]. To improve the interphase, chemical modification of the hybridized fabric was performed by adding 2 % NaOH, which modified the surface topography resulting in the increase of the fibre's surface roughness. This also resulted in enhanced mechanical interlocking, or the physical connection between the fibres and the matrix material. The treatment further removed surface impurities from the fibre, showing a clean fibre surface. The fibre loading for the composite was kept at 15, 2 and 25 wt.% for both chemically treated and untreated samples. Comparison of the mechanical properties revealed that the tensile strength of the composites increased with fibre loading up to 20 wt.%. This improvement may be due to the higher proportion of the hybridized fabric in the composite. Additionally, a reduction in tensile strength was observed at higher fibre loadings: 4 % in the untreated sample and 5 % in the treated sample. The value of the resultant composite exceeded that of the clean LDPE sample. The decrease in strength with increased fibre loading may be due to weak adhesion between fibre and matrix at higher weight percentages. Higher fibre loading also resulted in interface microcrack formation and non-uniform stress transfer due to matrix-fibre agglomeration [76,77].

Besides, the modulus of the composite and proportion of nettle/wool fibre increased simultaneously. According to the authors, this occurred due to increased rigidity of the composite caused by a greater amount of the total nettle/wool component in the hybridized composite. The increase in the nettle/wool component proportion restricted the matrix mobility in the composite. A group of researchers reported a similar increase in hardness with an increase in fibre loading [78,79]. A comparison of chemical treatment performance showed that at a fibre loading of 20 wt.%, the modulus of the chemically treated sample increased by 1.6 %. Chemical treatment enhanced fibre uniformity and reduced the surface impurities. An analogous pattern was noted for flexural strength, which was found to increase with nettle/wool fibre content up to 20 wt.%, similarly to tensile strength. However, increasing the proportion beyond 20% weakened the composite, leading to a reduction in flexural strength. The researchers considered that this observation may have been due to defects caused by tensile and compressive stresses generated during flexural tests. High stress intensity at the ends of the fibre led to poor matrix adhesion with the nettle/wool hybridized fibre. Still, the flexural strength values were greater than those determined for a neat LDPE sample. Finally, it was concluded that reinforcing with 20 % hybridized fibre resulted in optimal properties of the composite [62].

In one of the studies on hybridized epoxy composites, samples were manufactured using nettle and Bauhinia-vahlii fibres [63]. Mono and hybridized epoxy composites were produced with fibre weight percentages of 2, 4 and 6 %. Both fibre types were treated with a 5 % NaOH solution at room temperature for 6 h. resulting in improved mechanical properties. After the treatment, bidirectional mats were prepared manually. The composites were then fabricated using the hand layup method by alternating layering the fibres and a mixture of epoxy and a hardener (10:1) in a mold. The mold was subsequently kept under a pressure of 12 kg at room temperature for 24 h. Examination of the physical and mechanical characteristics revealed that the void fraction of the composite increased with the increase in the fibre content, which was attributed to the hollow structure of the fibres. However, the water absorption capacities also increased due to the hydrophilic in nature of the fibres. The tensile strength of the composites also increased with the increase in the fibre content. In all three composite types (nettle/epoxy, bauhinia/epoxy, and hybridized composite), the composite with the maximum fibre content exhibited the highest tensile properties. This can be attributed to improved adhesion between the fibre and matrix as the fibre content increases. Bauhinia/epoxy composite was reported to be stronger than nettle/epoxy composite due to the higher surface roughness of the bauhinia fibre. Furthermore, the hybridized (nettle/bauhinia) composite showed higher tensile strength than the mono-fibre composites. The highest tensile strength, 34.04 MPa, was exhibited by the 6% hybridized composite, which was ~55, 33 and 8 % greater than that of neat epoxy, nettle/epoxy and bauhinia/epoxy composites at the same fibre content. A similar trend was observed in the flexural characteristics of the composites [63].

6. 2. TEXTILE INDUSTRY

Nettle fibre can be used to produce eco-friendly fabrics for clothing, upholstery, and other textiles due to its strength, durability, and breathability [80]. Nettle fibre is gaining recognition in the textile industry as a sustainable and eco-friendly alternative to synthetic fibres and conventional natural fibres, such as cotton or flax. Harvested from the stems of the nettle plant (*Urtica dioica*), this fibre has been used historically in fabric production but has seen a resurgence due to its environmental benefits and favourable properties, making it an ideal candidate for a range of textile applications. Fabrics made from nettle fibre are resilient and can withstand wear and tear, making them suitable for long-lasting garments and household items. Upholstery fabrics made from nettle fibre are not only strong but also offer a unique aesthetic and tactile quality, which is ideal for furniture coverings, curtains, and other interior textiles. In addition to its durability, nettle fibre is breathable and thermoregulatory, which makes it particularly suitable for clothing. It allows for good airflow, keeping the wearer cool in warmer conditions and warm in cooler climates. This breathability also contributes to the fabric's ability to wick away moisture, making nettle fibre clothing comfortable for all-day wear [65,66]. Moreover, the production of nettle fibre is inherently sustainable. Furthermore, nettle fibre possesses natural antibacterial properties, making it beneficial for use in textiles that come into direct contact with the skin, such as undergarments and activewear. Its hypoallergenic nature is an added advantage, particularly for sensitive skin [80].

6. 2. 1. Woven fabrics

Nettle fibres have long been incorporated into woven textile materials. Woven fabrics are created by intertwining at least two sets of threads (warp and weft) perpendicular to each other. One notable attempt involved using nettle fibres for towel production, which requires specific characteristics [41]. Fibres intended for towels should ideally possess excellent water absorbency, quick drying, softness, and antibacterial properties. While cotton fibre meets most of these requirements, its slower drying rate can promote microbial growth on the towel. It was reported that blending nettle with cotton fibres can overcome this problem and also provide the benefit of antimicrobial properties [81], as nettle fibre possesses inherent antimicrobial properties [32]. In the study, nettle was blended with cotton in a 70/30 cotton/nettle mass ratio in two different pile yarns (100 % cotton, 50 % cotton + 50 % modal), and the results were compared with samples made of 100 % cotton and polyester/cotton blend. It was observed that samples with nettle blend dried faster compared to the rest of the samples, possibly due to the hollow structure of nettle fibre, which can act as a natural insulator [82,83]. In addition, although nettle fibre is known for its firm texture, the softness values of the fabric were not decreased when the nettle was used in the weft direction. This could be attributed to the pile warp yarns, composed of either 100 % cotton or 50 % cotton + 50 % modal, which enveloped the relatively coarse nettle yarns and maintained a soft feel. The softness of samples made with modal fibre was significantly lower than that of other samples. On the other hand, the towel hydrophilicity was slightly reduced. After 5 washing cycles, a decrease in antibacterial activity was observed against *Staphylococcus aureus* and *Escherichia coli*. The antibacterial activity is probably due to constituents such as neuphytadiene, an antibacterial compound, and flavonoids, which can form complexes with bacterial cell walls, soluble proteins and extracellular proteins [84,92]. In particular, nettle's strong activity against *S. aureus* may be attributed to its rich content of phenolic compounds, including chlorogenic acid, caffeic acid, rosmarinic acid, and rutin [85].

6. 2. 2. Non-woven fabrics

Nettle fibres have also been explored for use non-woven materials. Nonwovens are engineered fibre structures, often flat, that achieve strength and stability through physical and/or chemical processes, without the use of weaving, knitting, or paper-making techniques. In this context, Kumar and Das [86] investigated the use of nettle fibres in non-woven geotextiles for slope stabilization in combination with poly (lactic acid) fibres. They produced the non-woven geotextile fabric by first creating parallel fibre webs using a carding machine, which were then processed into a non-woven fabric through needle-punching. Before the blending stage on the carding machine, the nettle fibre underwent alkali treatment. The untreated nettle fibre surface was uneven, with the presence of impurities, while the alkali treatment cleaned the outer layer of the fibre (Figure 7). The treatment also improved the processability of the fibre and reduced breakages on the carding machine by increasing the fineness, tensile strength, and elongation at break of the nettle fibre. The nettle and PLA fibres were blended in different proportions (0/100, 25/75, 50/50, 75/25 and 100/0).

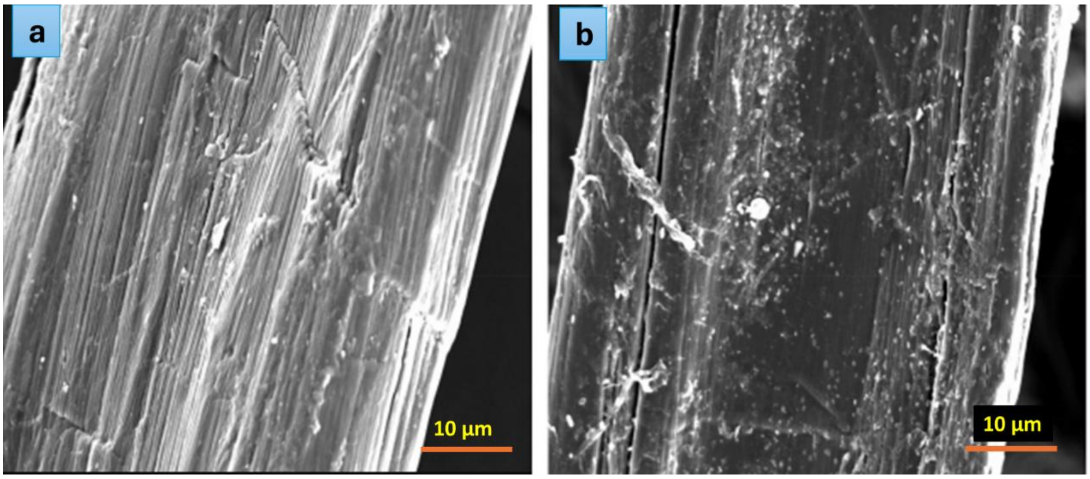

Figure 7. *Scanning electron micrographs of nettle fibre surfaces: A) untreated, B) alkali treated. Adapted from ref. [87] © 2022 Taylor & Francis Group, LLC*

The obtained non-woven geotextiles exhibited a decrease in the tensile strength as the nettle fibre content increased, with the lowest value observed with the 100 % nettle fibre fabric. This is due to the nettle fibre-to-fibre slippage, which increased with the nettle fibre proportion. The resulting fibre-matrix debonding led to the lower tensile strength of the material. Nettle fibre has also shown higher biodegradability than PLA fibres. Also, as the proportion of nettle fibre increased, the residual strength in the non-woven material decreased. For a 100 % nettle sample, only about

11 % of the original strength remained after 40 days and this diminished further after 120 days in the soil burial test. By contrast, 100 % PLA samples retained 70 % of their strength after 40 days and 59 % after 120 days. These results indicate that nettle fibre is significantly more biodegradable than PLA fibres. Overall, the prepared non-woven geotextile showed potential for use in slope stabilization.

Researchers have also developed nettle/polypropylene blended needle-punched non-woven fabrics for oil spill clean-up applications [38]. The study tested these fabrics with crude oil and diesel engine oil of specified viscosities and densities. Nettle fibres were trimmed to a 65 mm staple length, opened and then blended with 60 mm polypropylene fibres using a carding machine; the resulting webs were further needle-punched to produce the non-woven fabric. The study included 15 different samples prepared under varying process parameters: fabric weight (200, 300 and 400 g m^{-2}), punch density (150, 250,and 350 punches cm^{-2}) and nettle/polypropylene blend mass ratio (30:70, 50:50, and 70:30). It was shown that the fabric sorption capacity was affected by density, functional groups, and buoyancy characteristics (fabric's ability to float on a liquid surface) [88]. For both crude and diesel oil, it was found that the nonwoven fabric can be reused multiple times; however, a significant decrease in oil sorption capacity was observed after eight cycles.

In another study, an eco-friendly nettle non-woven sorbent for oil was developed [65]. Nettle fibres were treated with 2 % NaOH at room temperature, aligned on a carding machine and then processed by needle punching to form the non-woven fabric. Samples were prepared with varying needle punch densities (50, 75, 100 punches cm^{-2}), penetration depths (8, 10, 12 mm), and fabric weights (150, 250, 350 g m^{-2}) and were characterised for weight, thickness, and porosity. Results indicated that porosity and thickness were key factors determining the thermal characteristics of the fabric. With an increase in porosity, the volume of the air pocket increased with a consequent increase in thermal insulation. Thus, this led to a reduction in heat and moisture transfer of the clothing system. The water absorption capacity of the non-woven fabric increased with porosity, as greater pore volume allows more water to penetrate the material. Similarly, air permeability rose with an increasing porosity, since permeability is directly related to the amount of open space within the fabric. Among all the samples tested, the highest water absorbency (494 %) and air permeability (79 (cm^3 s^{-1}) cm^{-2}) were obtained with a needle punch density of 75 punches cm^{-2}, penetration depth of 8 mm, and an aerial weight of 150 g m^{-2}. This sample had also shown the highest porosity (0.97) and the lowest thermal conductivity (0.0251 W m^{-1} K^{-1}) [89].

6. 2. 3 Blended fabrics

Researchers have introduced nettle fibre into winter wear clothing [90]. Presently, the market is dominated by wool, an expensive natural fibre. To reduce costs and offer a more affordable solution, acrylic is commonly blended with wool. Replacing these fibres with a sustainable alternative that offers similar properties, such as nettle, presents an attractive option [90,91]. In this study, blends of nettle and acrylic fibres were prepared in different proportions (30/70, 50/50, and 70/30), and yarns of 16^s Ne and 24^s Ne were produced and further characterized for essential properties of winter wear (air permeability, moisture absorption, and thermal insulation). The results showed that increasing the proportion of nettle fibre led to higher air permeability in the blended fabric, as nettle fibre is less bulky than acrylic fibre.

Other researchers [67] have also explored the use of nettle fibre (*Girardina diversifolia*) and its blends. In this study, the extracted fibres were bio-scoured and bio-softened using Scour Zyme L and Celluso ft L enzymes to remove waxes and pectins, thereby making the textile material more hydrophilic. The softening process reduced the flexural rigidity of the fibres by 11 %. The fibres and their blends of a similar count were spun using open-end spinning technology into yarns: 100 % organic cotton, 100 % bamboo, 50/50 nettle/organic cotton, 50/50 nettle/bamboo, which were then used to produce textile fabrics utilizing a handloom. An increase in tensile properties was observed for both nettle/organic cotton (abrasion resistance 3 %, warp strength 4 %, weft strength 11 %, warp elongation 8 %, weft elongation 19 %) and nettle/bamboo blends (abrasion resistance 4 %, warp strength 10 %, weft strength 10 %, warp elongation 7.5 %, weft elongation 7 %). These improvements can be attributed to the higher tensile strength of nettle fibre compared to organic cotton and bamboo fibres [92], while bio-softening of nettles fibre could be the reason for the increase in elongation. The nettle fibre length contributed to the good abrasion resistance of the blended fabric. Based on the observed properties, it was concluded that nettle fibre can be successfully blended with various other fibres and spun in 10^s Ne yarn. Fabrics produced from this yarn are suitable for home textiles and show potential as candidates for technical textile applications.

6. 2. 4. Geotextiles

In environmental applications, nettle fibre can be used to manufacture geotextiles for erosion control, soil stabilization, and plant growth [93]. Geotextiles made from nettle fibre provide natural alternatives to synthetic geotextiles, which are often derived from petroleum-based materials and pose environmental challenges after disposal. One of the main advantages of nettle fibre geotextiles is their biodegradability, which is especially beneficial in temporary applications, such as erosion control during re-vegetation projects. After fulfilling their role, these geotextiles naturally decompose, reducing long-term environmental impact. Their natural strength enables the formation of durable mats that effectively prevent topsoil displacement by wind, rain, or runoff on slopes, riverbanks, and construction sites. The open structure of nettle geotextiles allows water to permeate through while still providing sufficient reinforcement to stabilize soil, thereby reducing the risk of landslides or soil degradation [64,93]. In addition to erosion control, nettle geotextiles provide a robust and permeable layer that reinforces soil structure, making them suitable for applications such as road construction, embankments, and landscaping where controlling soil movement is critical for structural stability. The fibres' natural durability ensures effective performance during the operational period, offering reliable necessary support until vegetation or other long-term reinforcements become established. Additionally, nettle fibre geotextiles can play a significant role in supporting plant growth. Their porous structure allows roots to penetrate easily, facilitating plant establishment and promoting healthy root systems. The fibres also help retain the soil moisture, creating a more favourable environment for seedlings and vegetation. In reclamation projects or areas requiring reforestation or revegetation, nettle geotextiles can increase the success of planting efforts by shielding young plants from erosion while promoting natural growth. Due to their permeability, nettle fibres allow proper drainage of water, reducing the risk of waterlogging or pooling in the soil. This is critical in geotechnical applications where managing water flow is essential for maintaining soil integrity. The ability of nettle geotextiles to filter, allowing water to pass while preventing soil erosion, makes them highly effective in drainage systems, wetland restoration, and stormwater management. These geotextiles also align with sustainability goals in construction and environmental management [64]. Their use in ecological restoration and civil engineering projects supports the growing demand for green solutions that prioritize environmental responsibility.

6. 2. 5. Medical textiles

Natural antimicrobial properties of nettle fibre make it a valuable and sustainable option for use in medical textiles, including wound dressings, bandages, and other healthcare-related fabrics. Its natural ingredients, such as phenolics and flavonoids, which can inhibit the growth of bacteria, fungi, and other pathogens support hygiene, sterility, and patient comfort in medical settings [3]. Antimicrobial activity can lead to improved healing outcomes and fewer complications during patient recovery. Nettle fibre is also breathable and moisture-wicking, which enhances its suitability for wound care. Its ability to allow airflow while absorbing excess moisture creates an optimal environment for healing, helping to keep wounds optimally moist and reducing the risk of bacterial growth. At the same time, its breathability ensures patient comfort by allowing the skin to remain cool and dry, which is especially important for bandages that are worn for extended periods. In addition to its antimicrobial and moisture-wicking properties, nettle fibre is hypoallergenic, making it safe for use on sensitive or damaged skin. Traditional materials such as polyester or nylon used in medical textiles are not biodegradable, contributing to medical waste and environmental pollution. In contrast, nettle-based textiles can decompose naturally after disposal, reducing their ecological footprint. This characteristic aligns with the growing demand for sustainable solutions in healthcare, especially in reducing the environmental impact of disposable medical products [94]. In terms of durability, nettle fibres are strong and long-lasting, ensuring that nettle-based medical textiles maintain their integrity during use. This is crucial for bandages and dressings that must endure movement and regular handling without tearing or losing their effectiveness. Moreover, nettle fibres can be processed into various forms to suit different medical applications, from soft, absorbent fabrics for wound dressings to more durable, woven fabrics for support bandages or compression wraps. This versatility makes nettle fibre a flexible and valuable resource for a wide range of medical textiles [94].

6. 3. Ropes and cords

Due to its natural strength and resilience, nettle fibre is suitable for creating ropes, cords, and twine, especially in applications requiring biodegradable materials [98]. Historically, nettle fibres were used for rope-making in various cultures. Today, with an increasing focus on sustainable materials, nettle fibre is regaining attention as an environmentally friendly alternative to synthetic and non-biodegradable fibres. Unlike synthetic ropes made from plastic-based fibres (such as nylon or polypropylene), which contribute to pollution when discarded, nettle fibre ropes naturally decompose over time, reducing their environmental impact. This makes nettle fibre especially valuable in outdoor applications where ropes might be exposed to the elements and left in nature, such as in forestry, hiking, or conservation efforts. One of the advantages of using nettle fibre in ropes and cords is its durability. The fibres are long, strong, and have a high tensile strength, allowing them to withstand significant stresses and strains. This makes nettle fibre ropes suitable for various demanding applications, such as agricultural use, gardening, marine activities, and construction, where robust and reliable materials are essential. Nettle ropes and twines are also lightweight, which makes them easier to handle, and transport compared to some traditional materials [91],[95]. They are also resistant to damage from UV light and water to a degree, further enhancing their versatility in outdoor settings. Furthermore, nettle fibre's natural resistance to mold and microbial growth is beneficial in humid or wet conditions, where ropes are often prone to degradation. This antimicrobial property helps extend the lifespan of nettle-based ropes, particularly in farming, fishing, or other industries that involve moisture [91].

6. 4. Insulation materials

Nettle fibre can be processed into insulation materials for buildings, providing a renewable, non-toxic and eco-friendly alternative to synthetic products such as fibreglass or mineral wool. Its excellent thermal efficiency helps maintain consistent indoor temperatures by reducing heat loss in winter and minimizing heat gain in summer. This improves energy efficiency lowers heating and cooling costs and supports sustainable construction and green building practices by reducing the building’s carbon footprints [91].

In addition to thermal insulation, nettle fibre also provides sound insulation [95]. Its dense structure can effectively absorb sound, making it ideal for use in interior walls, floors, and ceilings to reduce noise transmission between rooms or from outside sources. This dual functionality, thermal and acoustic insulation, adds to the versatility of nettle fibre in building applications. Affirmative sustainability aspects of nettle fibre make it a more sustainable option than many traditional insulation materials, which often rely on non-renewable resources or energy-intensive manufacturing processes. Nettle fibre insulation is therefore ideal for builders and architects looking to minimize environmental impact and promote sustainable construction practices.

Another important feature of nettle panels is their non-toxicity and absence of harmful chemicals. In contrast, many synthetic insulation products contain substances that can release volatile organic compounds (VOCs) or pose health risks to installers and building occupants. Nettle fibre, as naturally safe, is thus, a healthier choice for indoor environments, particularly for people with sensitivities or allergies. Moreover, nettle fibre naturally regulates moisture, adding valuable functionality as an insulation material. It can absorb and release moisture without compromising its insulation properties, helping to maintain indoor air quality and prevent mold growth. This moisture control contributes to a more comfortable and healthier indoor environment [6].

6. 5. Paper production

Nettle fibres are an excellent resource for producing high-quality paper, particularly for specialty applications such as artistic and archival papers. offering an eco-friendly and sustainable alternative to traditional wood-based paper. The long, strong fibres from the nettle plant (*Urtica dioica*) impart durability, a smooth texture and a fine finish to the final product. This makes nettle paper highly suitable for artistic applications, such as fine art prints, handmade stationery, calligraphy, and bookbinding. The paper's strength also lends itself well to various printing techniques, from screen printing to letterpress, providing a versatile surface for artists and designers [58,96]. Additionally, nettle fibre paper has a distinctive aesthetic, often featuring a natural, slightly textured surface with a pleasant organic appearance, which is especially valued in handmade and specialty papers. The subtle texture and unique look make it a preferred choice for creating high-end products such as luxury packaging, greeting cards, or decorative papers, where a tactile, artisanal quality is desired. Nettle fibre paper is also archivally stable, meaning it resists degradation over time. The fibres are naturally resistant to yellowing and brittleness, making nettle paper suitable for archival purposes, such as preserving documents, artwork, or photographs that need to withstand long-term storage without deteriorating. From an environmental perspective, nettle fibre paper is an appealing option for eco-conscious consumers and industries, looking to reduce the ecological footprint of paper production. Moreover, nettle fibres can be blended with other natural fibres, such as cotton or hemp, to create a range of paper types with different weights, textures, and finishes. This flexibility in processing allows for a wide variety of applications, from delicate, translucent papers for fine art to sturdy, thick papers for packaging or industrial use [6].

6. 6. Sustainable packaging

Nettle fibres offer a promising solution for sustainable packaging, providing a biodegradable and eco-friendly alternative to traditional plastic-based materials [3]. As a demand for environmentally responsible packaging grows [97], nettle fibres are emerging as a versatile renewable resource that can reduce the ecological impact of packaging waste. One of the key advantages of incorporating nettle fibres into packaging materials is their biodegradability. Unlike conventional plastics, which take hundreds of years to decompose and contribute significantly to environmental pollution, nettle-based packaging breaks down naturally over time. This makes it an ideal choice for industries aiming to reduce their reliance on single-use plastics and minimize packaging waste that ends up in landfills or oceans. This makes nettle fibre a more sustainable option compared to packaging materials derived from fossil fuels or intensive agricultural processes. In terms of performance, nettle fibres are known for their strength and durability, which are crucial attributes for packaging materials. Nettle fibre-based packaging can effectively protect products, resisting wear and tear during shipping and handling, while maintaining structural integrity [18]. This makes it suitable for a wide range of applications, from protective packaging for fragile items to flexible wraps for food or consumer goods. Nettle fibre's natural moisture resistance and breathability make it well-suited for packaging applications that require protection from humidity, such as food packaging. These properties help reduce condensation and spoilage, thereby extending the shelf life of perishable goods and providing a natural sustainable solution for the food industry. Furthermore, nettle fibre packaging can be combined with other sustainable materials, such as recycled paper or bio-based films, to create composite packaging solutions that meet specific needs. Whether for rigid containers, flexible wraps, or cushioning materials, nettle fibres can be integrated into various packaging forms, providing versatility and adaptability across sectors [97]. Another advantage of nettle-based packaging is its lightweight nature, which can reduce shipping costs and energy use during transportation. Lightweight yet strong, nettle fibre packaging minimizes the environmental footprint associated with logistics, particularly for companies aiming to optimize their supply chains and reduce carbon emissions. In addition to its practical benefits, nettle fibre packaging is also appealing from a consumer perspective. As awareness of environmental issues grows, consumers are increasingly seeking eco-friendly products and packaging solutions. Packaging made from natural fibres such as nettle not only aligns with consumer preferences for sustainability but also conveys a brand's commitment to reducing its environmental impact.

7. CONCLUSIONS AND FUTURE PERSPECTIVES

This manuscript reviewed the use of nettle fibre in different textile industry sectors. Nettle fibre is notable for its high strength and is a promising material for both apparel and technical textiles. Significant research has demonstrated its potential in woven and non-woven fabrics, as well as composite materials Its combination of length, high tensile strength, and Young's modulus make it suitable for a wide range of applications. Additionally, nettle fibres are relatively inexpensive, derived from renewable resources, and fully biodegradable. However, challenges remain due to inherent rigidity and variability of these fibres, which are influenced by growth conditions and plant maturity.

Further research is needed to expand the applications and improve the properties of nettle fibres. Investigations into fibre treatments could make them softer and more suitable for apparel use. One of the most promising directions is the reinforcement of polymeric composites, particularly through hybridization, which may overcome current limitations and enable high-end applications. Detailed studies of surface modifications could improve interfacial properties in fibre-reinforced composites, while comparative analysis with other natural fibres using the same matrix would be valuable. In addition to mechanical performance, research should also address damping, tribological, and machining properties, as well as biodegradability and thermal insulation. Finally, the potential of nettle fibres as biomaterials for adsorption warrants further exploration.

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Vlakna koprive za tehničke primene

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Izvod

Zbog sve veće svesti o ekološkim i društvenim problemima, kao i strožih ekoloških propisa, raste potražnja za zelenim materijalima koji bi zamenili resurse i sirovine na bazi fosilnih goriva. Sa svojim odličnim mehaničkim svojstvima, biorazgradivošću i niskom cenom, vlakna koprive imaju potencijal da postanu održiva vlakna za tehničke primene. Sposobnost bojenja, antimikrobna svojstva, obnovljivost i otpornost na gužvanje čine ova vlakna pogodnim za tekstilne primene. Zbog svoje niske gustine, mogu se koristiti u širokom spektru primena kao što su tkane i netkane tkanine, mešani i kompozitni materijali. Ovaj rad ima za cilj da kritički razmotri primenu vlakna koprive u različitim oblastima tekstilne industrije i da pruži smernice za buduća istraživanja.

Ključne reči: Tretman alkalijama; građevinski materijal; netkani tekstil; tekstilni kompoziti; apsorpcija zvuka; održivost.