

A Review on Plant Root Fibre Extraction, Characterization, And Composite Development

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Abstract—Plant root fibres are biodegradable, affordable, available, and renewable in nature, which has made them viable substitutes for synthetic fibres in composites. Despite their abundance and renewability, root fibres remain underdeveloped compared to stem and leaf fibres, yet they offer distinct advantages such as low density, biodegradability, and availability from agricultural residues. This review explores the extraction methods and provides a comprehensive analysis of the physical, chemical, mechanical, thermal, and morphological characteristics of plant root fibres. Plant root fibres are further analyzed after developing composite products. The relationship between fibre composition, structure, and properties is highlighted, with particular focus on how treatments and modifications enhance fibre–matrix compatibility. Root fibres exhibit potential for producing lightweight, durable, and cost-effective materials suitable for applications in packaging, automotive, construction, biomedical, and geotextile sectors. By consolidating current research, this article underscores the importance of root fibres as a sustainable reinforcement resource and identifies opportunities for advancing their use in high-performance composite products.

Index Terms—Chemical Composition; Composite Development; Mechanical Properties; Physical Properties; Plant Root Fibre Extraction; Thermal Properties

I. INTRODUCTION

Sustainability, biodegradability, and the need to replace synthetic fibres in a variety of industries, including automotive, construction, packaging, and aerospace, are the main drivers of demand for natural fibre composites[1]. While root fibres are still mostly unexplored despite their enormous potential [2], natural fibres generated from stems and leaves have been thoroughly researched and used [3]. Root fibres

provide several special benefits, such as low density, a large range of morphologies that can be customized for certain composite application [4], [5], and easy access from agricultural leftovers and by-products. The techniques employed to extract the fibres, as well as their inherent physical and chemical characteristics, have a significant impact on the performance of root fibre-reinforced composites. Important factors that affect the mechanical and thermal behaviour of the final composites include cellulose content, lignin and hemicellulose composition, fibre diameter, lumen structure, and surface roughness. Additionally, the fibre's stiffness, strength, and moisture absorption properties—all of which are crucial for engineering application and that influenced by the degree of cellulose crystallinity. Developments in analytical methods, including Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and thermo gravimetric analysis (TGA), have made it possible to characterize root fibres in great detail and provide information about their structural, chemical, and thermal characteristics. The fibres derived from particular plant roots are the focus of this paper, which also discusses their extraction techniques, morphological and chemical characteristics, and possible uses in polymer composites. By contrasting these root fibres with more widely used plant fibres, the review identifies ways to create high-performance, sustainable composite while lowering dependency on non-renewable resources.

II. ROOT FIBRE EXTRACTION

The extraction of plant root fibres typically involves uprooting or collecting roots, followed by thorough washing to remove soil, bark, and other impurities

After the roots have been cleansed and let to air or sun dry, the fibres are separated either mechanically through decortication or manually by peeling and combing[6]. In certain situations, binding elements like pectin, hemicellulose, and lignin are loosened by retting procedures like water or enzymatic retting[7],[8], which facilitates fibre separation. In order to improve fibrillation, strength, and interfacial interaction with matrix, fibres are frequently treated with alkali processing, bleaching, or surface changes after extraction. To guarantee stability, the fibres are lastly dried under carefully monitored circumstances. These standard procedures produce lightweight, biodegradable, and adaptable root fibres that are used in a range of textile, composite, biological, and building applications.

III. ROOT- BASED NATURAL FIBRES

3.1 *Zea mays* (Corn Root Fibres)

Corn root fibres are extracted by carefully digging out roots. Hydroponically grown ZM root fibres are used as the study's subject[9]. The roots are washed to remove soil and then dried in the sun. Manual peeling and combing are applied for fibre separation, while mechanical decortication can be used for large-scale recovery. Alkali treatment with NaOH (2–5%) improves fibre roughness, removes hemicellulose, and increases crystallinity. Bleaching may also be carried out to enhance brightness and bonding with polymer matrices. Corn root fibres, whether raw or treated, may be able to interlock well with polymer matrices like natural rubber or epoxy. These fibres are lightweight and suitable for packaging and automotive panel composites[10].

3.2 *Ficus retusa* (Aerial Root Fibres)

Aerial roots of *Ficus retusa* are peeled and repeatedly washed to remove bark and impurities. Fibres are separated using combing and then sun-dried. Mild NaOH treatment enhances tensile strength and fibre–matrix adhesion, while enzymatic retting is sometimes employed to soften fibres naturally. These fibres are traditionally used in ropes and mats, and their flexibility makes them promising for composites requiring pliability[11].

3.3 *Cymbopogon flexuosus* (Lemongrass Root Fibres)

Lemongrass root fibres are obtained as waste after harvesting. Roots are washed, sun-dried, and mechanically peeled to separate fibres. Treatment

with 5% NaOH reduces lignin content (~20%) and enhances fibre–matrix bonding, while silane treatment improves water resistance. These fibres provide rigidity and are well suited for construction boards, packaging sheets, and rigid composites[12].

3.4 *Ficus benghalensis* (Banyan Aerial Root Fibres)

Banyan aerial roots are harvested, washed, and peeled manually. The separated fibres are combed and dried before use[13]. Alkali treatment with NaOH improves fibre crystallinity, while bleaching and acetylation reduce hydrophilicity. These fibres are flexible yet durable, making them ideal for eco-furniture, mats, panels, and interior decorative composites[14].

3.5 *Acalypha indica* Root Fibres

The roots of *Acalypha indica* are uprooted, washed, and air-dried, followed by manual separation and light beating to isolate fibres. NaOH treatment (2–4%) enhances strength, and bleaching improves purity, particularly for biomedical applications. These fibres are absorbent and lightweight, showing potential in biomedical textiles, mats, and biodegradable composite fillers[15].

3.6 *Vetiver* (*Chrysopogon zizanioides*) Root Fibres

Vetiver roots are dug out, cleaned, and sun-dried, with fibres separated through combing or decortication. Often, oil extraction is performed first, leaving roots available for fibre use. Alkali treatment reduces lignin (~25%) and improves flexibility. Vetiver fibres are strong, durable, and applied in geotextiles, mats, ropes, and reinforced composites for construction[16].

3.7 *Cissus quadrangularis* root fibres

The cellulose nature and availability of *Cissus quadrangularis* root fibres led to their selection as the raw material. Before being chopped into manageable lengths for extraction, the roots were carefully cleansed to get rid of any dirt, dust, or clinging contaminants. The roots were steeped in water for a few days as part of a water-retting procedure to break down the binding agents, which included hemicellulose, pectin, and waxy materials. After retting, the fibres were manually separated through peeling and combing to ensure the removal of residual impurities. They were then thoroughly washed multiple times and finally sun-dried for several days to eliminate moisture. The fibres were alkali treated with sodium hydroxide (NaOH) to increase interfacial compatibility and purity for

composite applications. This successfully eliminated any leftover hemicellulose. This successfully eliminated the last of the lignin and hemicellulose. The cleaned and fibrillated *Cissus quadrangularis* root fibres that were prepared for characterization were then obtained by oven-drying the treated fibres after they had been cleaned with distilled water until a pH of neutral was reached[17].

3.8 Screw pine (*Pandanus odorifer*)

A new source of root fibre for composite applications has been discovered recently: fragrant screw pine (*Pandanus odorifer*), a tropical plant that is abundantly found along the shore. Fibres were taken from the plant's prop roots, which operate as structures for support in the air, for the [18] investigation. Water retting was a step in the extraction process that entailed soaking roots to break down and soften the hemicellulose and pectin that

hold the fibre bundles together. The fibres were hand separated, properly cleaned, and sun-dried to eliminate moisture after retting. The fibres were treated with an alkali solution (NaOH) to further clean and improve their surface characteristics. The process successfully eliminated lignin, wax, and leftover hemicellulose, among other non-cellulosic components. The procedure produced clean, fibrillated screw pine root fibres with enhanced interfacial properties that were appropriate for reinforcement in polymer composites after neutralization with distilled water and regulated oven drying[18].

IV. PHYSICAL, CHEMICAL, THERMAL, AND MECHANICAL PROPERTIES OF ROOT FIBRES

4.1 Physical Properties of Root Fibres

Table.1 Physical Properties of Root Fibres

Fibre Source	Diameter (µm)	Density	References
<i>Zea mays</i> root	345	0.64 g/cc	[9],[19]
<i>Ficus retusa</i> root	495	1376 kg/m ³	[20]
<i>Cymbopogon flexuosus</i> root	460	1330 kg/m ³	[21]
<i>F. benjamina L. aerial</i> root	492.94 ± 9.40	1175 kg/m ³	[14], [2]
<i>Acalypha indica</i> root	–	1.356 g/cm ³	[15]
<i>Chrysopogon zizanioides</i> root	–	1.18 g/cc	[16]
<i>C. quadrangularis</i> root	610–725	1510 kg/m ³	[17]
<i>Screw pine</i> root	27–280	1.3852 g/cm ³	[18]

4.2 Chemical Properties of Root Fibres

Table.2 Chemical Properties of Root Fibres

Fibre Source	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Wax (%)	Moisture (%)	Ash (%)	References
<i>Zea mays</i> root	58.74	29.53	19.04	1.37	11.86	3.47	[9], [19]
<i>Ficus retusa</i> root	64.12	–	–	0.33	–	–	[20]
<i>Cymbopogon flexuosus</i> root	74.33	9.76	27.50	0.42	8.70	4.91	[21]
<i>F. benjamina L. aerial</i> root	64.48	11.56	9.33	8.31	5.63	0.69	[14],[2]
<i>Acalypha indica</i>	67.86	0.24	18.75	0.86	10.16	2.13	[15]
<i>Chrysopogon zizanioides</i> root	63.70	30.95	16.08	0.91	8.79	4.13	[16]
<i>C. quadrangulari</i>	77.17	11.02	10.45	0.14	7.30	–	[17].

<i>s root</i>							
<i>Screw pine</i>	73.10	12.58	7.11	0.35	8.28	–	[18]

4.3 Thermal Properties of Root Fibres
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Fibre Source	Thermal Stability (°C)	Max Degradation Temperature (°C)	References
<i>Zea mays root</i>	345–525	700	[9], [19]
<i>Ficus retusa root</i>	342	527	[20]
<i>Cymbopogon flexuosus root</i>	272.31	309	[21]
<i>F. benjamina L. aerial root</i>	330	470	[14], [2]
<i>Acalypha indica root</i>	225	–	[15]
<i>Chrysopogon zizanioides root</i>	–	–	[16]
<i>C. quadrangularis root</i>	230	328	[17].
<i>Screw pine</i>	235	800	[18]

4.4 Mechanical Properties of Root Fibres
Table.4 Mechanical Properties of Root Fibres

Fibre Source	Tensile Strength (MPa)	Young’s Modulus	Elongation at Break (%)	Micro fibril Angle (°)	References
<i>Zea mays root</i>	10.74	467.13 MPa	2.3	12.17	[9], [19]
<i>Ficus retusa root</i>	331.22–465.45	3.33–5.81 GPa	–	–	[20]
<i>Cymbopogon flexuosus</i>	315.22 ± 61.72	4.77 ± 0.34 GPa	6.6 ± 2.7	4.3 ± 0.21	[21]
<i>F. benjamina L. aerial root</i>	292.66 ± 12.32	7.95 ± 5.42 GPa	1.31 ± 0.09	8.30 ± 0.26	[14], [2]
<i>Acalypha indica root</i>	–	–	–	–	[15]
<i>Chrysopogon zizanioides root</i>	–	–	–	–	[16]
<i>C. quadrangularis root</i>	1857–5330	68–203 GPa	3.57–8.37	5.89 ± 0.27	[17]
<i>Screw pine root</i>	915 ± 195	33 ± 12 GPa	3.36–8.85	–	[18]

4.5 Comparative Explanation

Throughout the fibres, there are substantial differences in their structural, chemical, thermal, and mechanical characteristics. In terms of physical properties, the root fibres of *Zea mays* are the lightest at a density of 0.64 g/cc, whereas *C. quadrangularis* exhibits the highest density at 1510 kg/m³ along with a thicker diameter, imparting significant structural rigidity. Chemically, *C. quadrangularis* leads with the most cellulose at 77.17%, followed by screw pine at 73.10% and *C. flexuosus* at 74.33%, indicating

considerable reinforcing capabilities. Conversely, *Acalypha indica* possesses a very low hemicellulose content of 0.24%, which limits its flexibility. In terms of thermal properties, *Zea mays* and screw pine exhibit excellent stability, with degradation temperatures between 700–800 °C, while *Acalypha indica* and *C. flexuosus* demonstrate poor thermal stability, degrading below 300 °C. Mechanically, *C. quadrangularis* exhibits outstanding tensile strength reaching up to 5330 MPa and stiffness of 203 GPa, with screw pine following at 915 MPa and 33 GPa.

In contrast, *Zea mays* display the weakest tensile strength at 10.74 MPa, which restricts its use in high-load composite applications but makes it appropriate for lightweight items. The micro fibril angle greatly affects fibre stiffness and strength. *Zea mays* shows a higher angle (12.17°) linked to lower strength, while *C. flexuosus* (4.3°), *F. benjamina* (8.30°), and *C. quadrangularis* (5.89°) exhibit lower angles with higher modulus values. Thus, smaller MFAs generally enhance mechanical performance of root fibres. In summary screw pine and *C. quadrangularis* present the most favorable reinforcing options due to their high strength, modulus, and cellulose content, while lighter fibres such as *Zea mays* are ideal for low-density, biodegradable uses. [9], [19], [20], [22], [21], [14], [2], [15],[16] ,[17], [18].

V. COMPOSITE DEVELOPMENT

Plant root fibres present considerable opportunities for the creation of eco-friendly composites due to their renewable characteristics, ability to decompose, and favorable mechanical features. The interest in utilizing plant fibres in composite materials is increasing as a response to ecological issues and the demand for sustainable options[23] [24]. Research is investigating plant fibres, particularly root fibres, as supportive materials within polymer matrices to create composites that are lightweight, economical, and beneficial for the environment. These natural fibres frequently substitute synthetic fibres in composite uses due to their availability and simple extraction processes[25]. The attraction of these fibres rests in their capacity to enhance the mechanical traits of composites, making them appropriate for a wide array of industrial uses, including automobile parts and building materials[26] [27]. One key benefit of incorporating plant root fibres in composites is their inherent bonding qualities, which can be enhanced through chemical processes. Such treatments improve the connection between the fibre and the matrix, resulting in better overall performance of the composite material produced[28] . The mechanical attributes of these composites can be adjusted by varying the fibre content, length, and surface treatments, enabling precise management of properties like rigidity, strength, and thermal resilience [29]; [30]. Despite the advantages, issues such as water absorption and

the deterioration of plant fibre composites over time persist. Absorbing moisture can significantly weaken the mechanical properties of the composite material[31], particularly in damp conditions. Consequently, on-going research is directed at developing various treatments to reduce water uptake and extend the durability of these composites [32]. Nonetheless, the progress and implementation of composites made from plant root fibres provide encouraging solutions for the advancement of sustainable materials. They open pathways for decreasing dependency on finite resources, fostering environmental protection, and generating new possibilities across several sectors, such as automotive, packaging, and construction [33]. Continued research and creative advancements in this field emphasize the substantial promise of plant root fibres to transform the composite materials sector and aid in achieving sustainability objectives[34].

VI. CONCLUSION

Root fibres such as *Zea mays*, *Ficus retusa*, *Cymbopogon flexuosus*, *Ficus benghalensis*, *Acalypha indica*, *Chrysopogon zizanioides* root, *Cissus quadrangularis* and *Screw pine* are valuable renewable reinforcements for polymer composites. Extraction and treatments, particularly alkaline processes, significantly improve their mechanical, thermal, and crystallinity properties. SEM confirms enhanced surface roughness; TGA demonstrates improved thermal stability and tensile tests show strength gains. While stem fibres currently dominate industrial applications, root fibres offer unique opportunities in lightweight, rigid, and eco-friendly composites, with applications spanning automotive, construction, packaging, and geotextiles. Future research should focus on optimizing extraction and hybrid treatments to unlock the full potential of these underexplored natural fibres.

Data availability

The datasets generated during the current study can be requested from the corresponding author upon reasonable request.

Declaration of competing of interests

The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics declarations

Ethics approval

Not applicable

Consent for publication

All the authors agreed to publish the paper

Credit authorship contribution statement

Vaikarai Lakshmannan: Writing- original draft,

Investigation, conceptualization

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Supervision, formal analysis

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