International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 6, 2025
https://theaspd.com/index.php

Extraction And Physiochemical Characterization Of Fibre From An Agro-Residue: *Curcuma Longa* Root For Eco-Textile Development

Ramya.N[1], Dr.J. Banu Priya[2]
[1]Ph.D- Research Scholar,[2]Research Supervisor and Assistant Professor
[1,2]Department of Costume Design& Fashion, PSG College of Arts & Science, Coimbatore, India.
E-Mail id: n.ramyacdf@gmail.com,[1] banupriya_j@psgcas.ac.in [2]

Abstract
Globally, the textile industry is experiencing demand for manufacturing eco-friendly products that meet customers' requirements and concerns about environmental conditions. The demand for sustainable fibres results in the development of novel fibres from plants and their residuals to reduce the usage of usual natural fibres and harmful synthetic fibres, and to incorporate them for various technical textile applications. Based on this concept, an agro-residue, Curcuma Longa root fibres, was selected for this study and was collected from local fields of Erode. Fibres were sorted and subjected to the extraction process using the water retting method. The extracted fibres were then evaluated to assess their properties, including fibre identification, structural features, and elemental composition, which were examined through FESEM and EDX analyses. The presence of specific chemical groups and their respective compositions were identified using FTIR spectroscopy and chemical composition testing. XRD analysis revealed a distinct peak at 22θ position, indicating a crystallinity index of 51.1%. Thermal stability and melting capacity were evaluated via TGA and DTA, with the fibres displaying a residual mass of 30.00% and a melting point of 428.8^{0}C respectively. This study evaluates the structural, thermal, mechanical and biocompatibility to assess its potential suitability for sustainable technical textile use.
Keywords: *Agro-residue fibres, fibre extraction, fibre characterisation study, non-wovens, thermal stability analysis, sustainable textile fibre*

1. INTRODUCTION

Plants and crops serve as the primary source of livelihood for humankind. Leftovers from harvested crop residues and processed residues from food processing industries generate a substantial amount of waste. Most of this waste is discarded in landfills, while some is disposed of in water bodies, leading to significant health hazards and severe environmental pollution. However, these underutilised resources present opportunities for sustainable valorisation into by-products that contribute to the growing global consumer interest in recycled products, supporting environmental protection [1]. Following the food industry, the textile industry is also one of the largest sectors with a substantial consumer base and an annual fibre consumption of approximately 113.8 million metric tons, requiring considerable resources and incurring high costs [2]. Utilising agro-residuals as raw materials can support the textile industry by reducing disposal volumes and lowering fibre production costs. Recent research in the textile field has focused on numerous vegan sources for fibre extraction; however, these processes often require substantial resources, resulting in high production costs. In contrast, the utilisation of agro-residuals generally involves only sorting and extraction processes, which don't require extensive resources [3].

In this study, we selected an agro-residue of *Curcuma longa* roots, which are discarded as waste after the cultivation process and are typically dumped into the soil or burned. To extract fibres from these roots, the discarded material was collected from the fields and sorted based on its strength and length. The roots were then prepared for the extraction process using the water-retting method, which is known to yield higher-quality fibres. The extracted fibres were subjected to characterisation analyses to assess their potential for textile applications. Several factors motivated this investigation of *Curcuma longa* roots for extraction and to analyse its properties. The plant's rhizomes are a key ingredient in the food industry, valued as a flavouring agent, food colourant, and for their antimicrobial properties. They are also used extensively in traditional Ayurvedic and home remedies. In contrast, the roots have no current application, making them an underutilised by-product. The roots are relatively short, brittle in texture, and contain antimicrobial compounds, making them a promising and sustainable candidate for the development of natural textile fibres.

The extraction method is relatively simple and can be completed within a few days. As a green fibre, it offers an eco-friendly alternative to conventional textile raw materials. This study describes the extraction process and presents a comprehensive characterisation of the fibre, including its morphology examined via FESEM, and chemical composition evaluated through FTIR. The crystallographic structure was assessed using XRD, while thermal properties such as melting point and thermal stability were analysed by DTA and TGA, respectively [4]. The results of the extracted fibres were compared with those of other plant-derived fibres-including *Cymbopogon flexuosus* root, *Mirabilis jalapa, cortaderia selloana* grass stem fibre, *Momordica charantia* fibre, *Cordia dichotoma, Borassus flabellufer L.* fibre, *Juncus effusus L.*, and *Cissus quadrangularis* root fibre-which have been studied extensively by various researchers. The significance of this work lies in utilising an agro-residue to introduce and incorporate it as an eco-friendly textile fibre, thereby advancing sustainable materials for the textile industry.[3]

1.1. About *Curcuma Longa*

Curcuma longa, commonly known as turmeric, belongs to the *Zingiberaceae* family.[5] It is a perennial herb extensively cultivated in tropical regions of Asia; its underground rhizomes contain fat-soluble curcuminoids, which impart the characteristic bright yellow colour used as a food colourant in many Indian dishes, earning a popular name, Indian saffron.[6] It is a herbaceous plant that grows to a height of approximately 60-90cm, with short, tufted leaves. Its flowers are yellow, measuring about 10-15cm in length. The rhizomes range from approximately 2.5-7.0cm long and about 2.5cm in diameter, while its roots can grow 6-12cm long and 0,5-1.5cm wide, appearing elongated, indistinctly ringed, and simple or sparsely branched.[7] Traditionally, turmeric has been used for its medicinal properties to treat cough, cold, fever, nausea, stomach ailments, blood purification, liver disorders, inflammation, biliousness, jaundice, muscular and biliary conditions, anorexia, diabetic wounds, hepatic ailments, rheumatism, sinusitis, and various other illnesses [8]. In addition, it serves as a beautifying agent, a cooking spice and a natural dye in textile industries. It has bioactive properties that include antidiabetic, antibacterial, anti-inflammatory, antifungal, and antiviral activities.[9]

2. METHODOLOGY

2.1. Extraction process of *Curcuma Longa* fibre (CLF)

Curcuma longa roots were collected from local agricultural fields in and around Erode, India. Shredded leftover root sections were sourced from various forms were sorted based on quality, and subjected to the water retting process for fibre extraction. This method of water retting extraction yields better quality of fibres.[10] Mechanical decortication fails to preserve fibre strength effectively, while chemical retting, although more efficient, compromises the medicinal properties of the plant, and it is not environmentally sustainable. In this study, water retting was employed over 10-14 days in an open chamber, allowing for microbial activity and anaerobic reactions that reduce the lignin content in the fibre. Extended retting durations can weaken the structure, whereas insufficient retting time results in inadequate lignin breakdown, producing weak and uneven fibres [11].

For this process, one litre of water at room temperature was placed in a vessel, and 50 g of *Curcuma longa* were immersed in an open chamber under the ambient conditions to facilitate microbial activity.[12] After the retting process, the roots were removed and thoroughly washed with running water.[13] During this stage, the swollen outer layer of *Curcuma longa* roots was removed, exposing the thin, fibrous inner portion. The extracted fibres were shade-dried at room temperature to eliminate excess moisture, yielding thin, lightweight, beige brown colour fibres. These fibres were then prepared for identification and characterisation studies to assess their suitability for textile applications. Alternative extraction methods, including mechanical, chemical, and water-boiling techniques, did not produce fibres of satisfactory quality or quantity.[4]

Fig.2.1. Extraction of fibres from *Curcuma longa* roots by using the water retting method

2.2. Characterization studies

A range of analytical techniques -including FESEM, FTIR, XRD, TGA, DTA and chemical composition testing were employed to evaluate the *Curcuma longa* fibre's (CLF) properties and determine its potential for textile applications. Field Emission Scanning Electron Microscopy (FESEM) was used to investigate the surface morphology and elemental composition of fibres [14]. Fourier Transform Infrared Spectroscopy (FTIR) facilitate the identification of functional groups in various fibre components based on characteristic absorption peaks in the infrared spectrum [15]. X-ray Diffraction (XRD) analysis was conducted to examine the crystallographic structure, physical characteristics, and chemical composition of the fibre sample [16]. Thermogravimetric Analysis (TGA) was applied to assess thermal stability and to quantify volatile content by monitoring weight loss under controlled heating conditions [17]. Differential Thermal Analysis (DTA) measures temperature changes and heat flow associated with thermal transitions in the material [18]. Chemical composition analysis was carried out to determine the content of cellulose, hemicellulose, lignin, ash, wax, moisture, and the fibre's density range.[4]

3. RESULTS & DISCUSSION

Characterization Studies

3.1. Field Emission Scanning Electron Microscopic Analysis of CLF

Fig.3.1. FESEM analysis shows structural morphology of CLF

A morphological study of *Curcuma longa* agro-residue fibre was conducted using Field Emission Scanning Electron Microscopy (FESEM) with a ZEISS instrument. Uncoated fibre samples were examined at magnifications of 100x at a 200μm scale, 1.00Kx at a 20μm scale and 5.00Kx at 2μm scale with an accelerating voltage of 5.00kV applied to evaluate the fibre's morphology and elemental composition. The FESEM images revealed pitted zones, flaky or crust-like layers on fibre surfaces, which indicates the presence of surface impurities or natural waxes. The rough texture suggests an untreated lignocellulosic origin of the fibre. Despite the surface roughness, the core fibre structure remains intact, suggesting a degree of rigidity or toughness. This FESEM analysis suggests that the fibre structure supports more for composite applications like eco-friendly bio-composites, thermal insulations, high moisture retention and absorbent material.

3.2. Energy-Dispersive X-ray Spectroscopic (EDX) Analysis of CLF

The elemental composition of *Curcuma longa* fibre was further evaluated using Energy-Dispersive X-ray Spectroscopy (EDX), and the resulting spectrum is presented in Fig.4. The analysis quantified both atomic and weight percentages of elements present in the fibre. The Primary constituents detected were Carbon (C) and oxygen (O), with weight percentages of 52.56% and 41.42% and atomic percentages of 61.25%

and 31.36%, respectively, confirming the lignocellulosic nature of the fibre. In addition, trace elements such as calcium (Ca) 4.47. wt% and 1.56.at% Fluorine (F) 0.72. wt%, 0.5 at%, potassium (K) 0.18%. wt%, 0.06.at%, Magnesium (Mg) 0.14. wt%, 0.08 at%, and silicon (Si) 0.15. wt%, 0.07.at%, Aluminium (Al) 0.14. wt% 0.07.at%, Sodium (Na) 0.22. wt% and 0.13 at% were also detected.

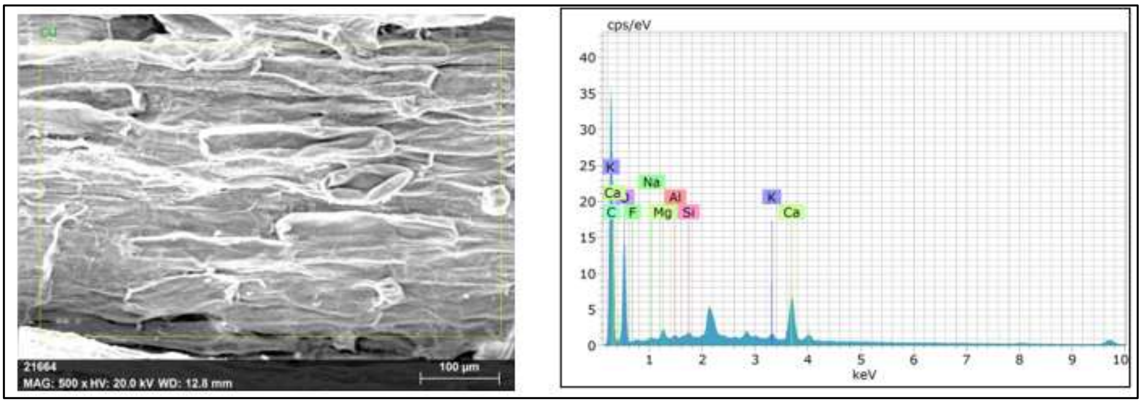


Fig.3.2.EDX analysis shows elemental composition of CLF

3.3. Quantification of the chemical composition of CLF

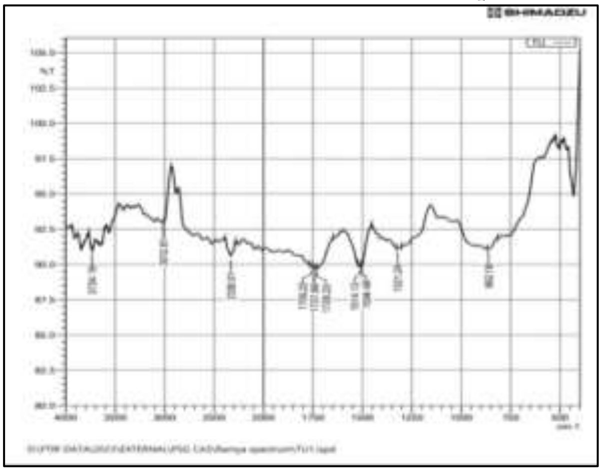


Fig.3.3. FTIR analysis shows the peak points of chemical compounds in CLF

The figure above presents the Fourier Transform Infrared Spectroscopy (FTIR) analysis of *curcuma longa* fibres, conducted using a SHIMADZU spectrometer. Infrared light was transmitted through the disc containing the CLF sample, with a wavelength range of 4000 to 500 cm^{-1}. The scanning rate was maintained at 2mm/s. The FTIR spectrum revealed ten distinct peaks, indicating the presence of various chemical compounds.[19] The identified functional groups include: free O-H stretching (free hydroxyl group): Present at 3730 cm^{-1}, indicating the presence of carboxyl and polyphenols and may also imply surface active sites. =C-H stretching Bonds: Stretching observed at 3012.81cm^{-1}, representing characteristics of aromatic rings like lignin and phenolic structures. C≡N or CO_2 Presence confirmed at 2330.01cm^{-1} represents the nitrile group and suggests proteinous residues. C=O (ester, aldehyde, and carboxylic group) present at 1755.22cm^{-1},1737.86cm^{-1},1728.22cm^{-1}, represents the presence of pectin, hemicellulose, or waxes. C=C bond (Aromatic stretching) absorbed at 1514.12cm^{-1}, 1504.48cm^{-1} represents a typical lignin or phenolitic compound that confirms aromatic structure in fibre. O-H or CO_2 Symmetric stretch absorbed at 1321.24cm^{-1} represents the phenolic O-H bending responsible for antioxidant presence in fibre. C-H bond present at 862.18cm^{-1} represents aromatic substitutions that imply mono or para-aromatic benzene rings. These results confirm the presence of multiple functional groups, indicating that CLF fibres contain significant chemical compounds suitable for various applications like anti-odour, anti-microbial, bio-active composites, insulations, and medical and technical textile applications.

3.4. Crystallographic Information of CLF

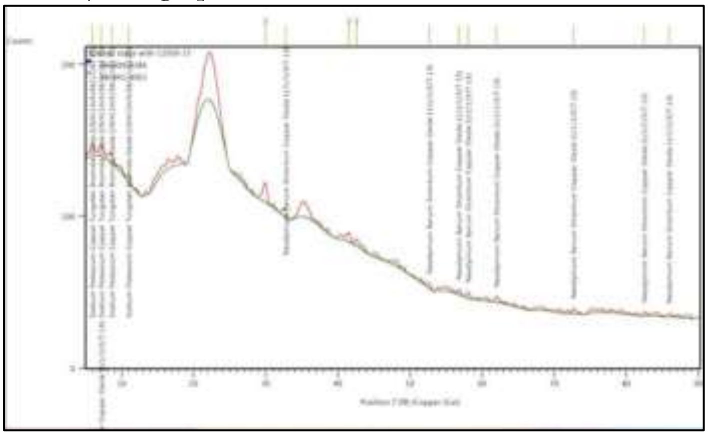


Fig.3.4.XRD analysis Structure and chemical compounds of CLF

X-ray diffraction (XRD) analysis was performed to determine the crystallographic structure of CLF using a SHIMADZU analyser. In this analysis, fibre samples were placed in a sample holder, and X-rays were passed through the sample at a wavelength of 1.54060Å at a temperature of 25°C. A strong peak appeared at the range of 22° 2ɵ shows high crystallinity contributing to mechanical strength and stiffness. A broad peak appears at 15-18 ^{0} 2ɵ that represents amorphous cellulosic or hemi-cellulosic regions. The XRD analysis revealed the presence of the following chemical compounds in CLF: Neodymium Barium Strontium Copper Oxide, which represents an orthorhombic structure, and Sodium Potassium Copper Tungsten Bromide Oxide represents a monoclinic structure. The crystallographic investigation of CLF demonstrated a significant decomposition rate with a crystalline index of 51.1% calculated with the formula $CI = Ic - Ia/I_c \times 100$= Intensity of the crystalline peak, where Ia = Intensity of the amorphous region. Ic = Intensity of the crystalline peak, and these results indicate that CLF primarily exhibits a semi-crystalline cellulosic structure, which provides a balance between strength and flexibility. Through this analysis, we came to know that CLF is suitable for protective textile layers, bioactive composites, and moisture-wicking materials. When compared to other cellulosic fibres, Ach has a crystalline index percentage similar to *Cymbopogon flexuosus* root fibre (36.8%) and a higher crystallinity index than *M. autopurpurea* fibre (24.01%), *Cortaderia selloana* grass stem fibre (22%), *Momordica charantia* fibre (21.42%), *Cordia dichotoma* fibre (12.14%), and *Borassus flabellifer* L. (17.13%). Additionally, its relative intensity percentage is comparable to that of *Borassus flabellifer* L. (24.17%). In contrast, common textile fibres such as Banana and Jute exhibit significantly higher crystallinity indices, with Banana fibre at 50.8%. [20]

3.5. Assessment of the thermal degradation nature of CLF

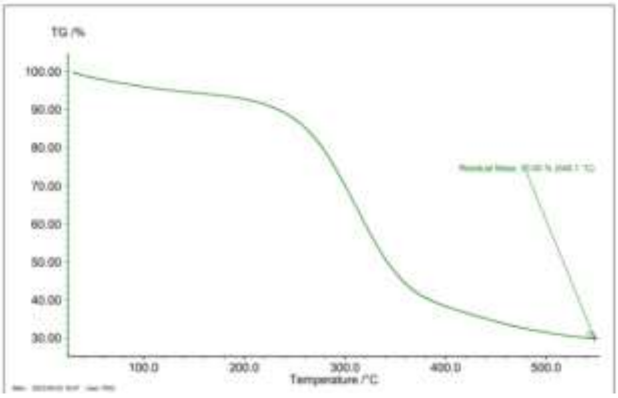


Fig.3.5.TGA analysis shows residual mass of CLF subjected to thermal contact.

Thermogravimetric analysis (TGA) was conducted to determine the optimal processing temperature for plant-based fibres. For CLF sample, TGA was performed using a NETZSCH STA 449 F3 instrument. This analysis supports the findings of the chemical structures of hemicellulose, cellulose, and lignin. Initially, an CLF sample was placed on an alumina pan, and the temperature was set to 30°C. the temperature was then gradually increased to 600°C at a heating rate of 10°C/min. At each interval, the mass of the sample was recorded. The TGA analysis revealed that fibre decomposition occurs in four distinct stages: Stage 1

(30-100°C): weight loss due to the release of absorbed moisture and water content. Stage 2 (100–250°C): weight loss due to the decomposition of cellulose. Stage 3 (250–350°C): Decomposition of lignin content. Stage 4 (350–600°C): Increase in ash content. In this thermogravimetric analysis, the residual mass of CLF was recorded as 30.00% at 548.01°C, which shows a maximum safe processing temperature and good range of thermal stability of fibre; and bio-degradable in nature, that suggest CLF is more suitable for flame resistance, thermal resistance and bio-active composites and high durability textiles. This TGA range of CLF is better than *Borassus flabellifer* L. (498.2°C), *Mucuna atropurpurea* (298.0°C), *Juncus effusus* L. (300.0°C), *Cissus quadrangularis* root (328.9°C), and Banana fibre (348.6°C). However, it is lower than Jute fibre, which has a residual mass recorded at 687°C under thermal contact conditions.[21]

3.6. Assessment of the Melting Point of CLF Subjected to Thermal Contact

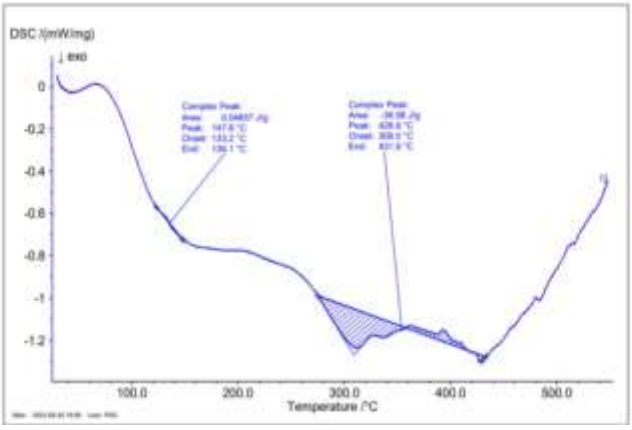


Fig.3.6.DTA analysis shows the melting point of CLF subjected to thermal contact.

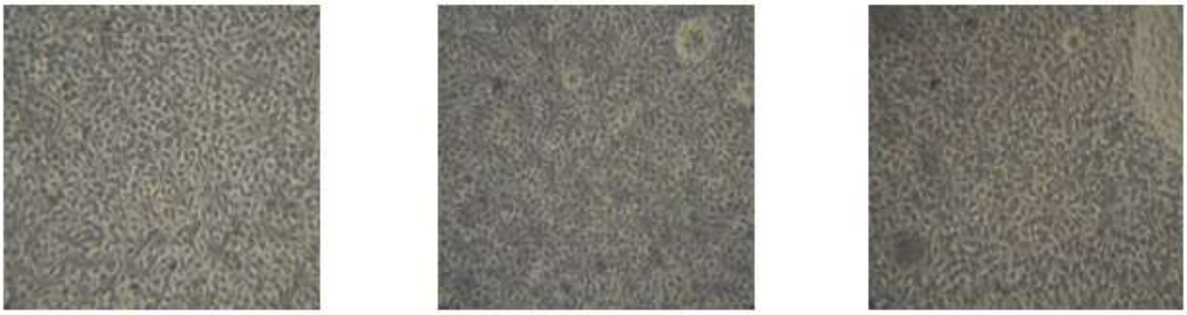
Differential Thermal Analysis (DTA) is a technique used to measure temperature changes and heat flow in a fibre material during thermal transitions. The DTA analysis of CLF was conducted using the NETZSCH STA 449 F3 analyser to measure its exothermic heat range. The temperature range started at 30°C and increased to 550°C at a heating rate of 10/K min. During DTA analysis, heat transmission was gradually applied to the CLF sample, leading to structural changes in the fibre. The graphical representation of the analysis displays thermal variations in the form of curves. In this analysis, an endothermic peak at 147.8°C was recorded, indicating moisture vaporisation from the fibre surface. A glass transition was observed in the range 250-300°C, as the heat transition increased. The exothermic peak at 428.8°C was attributed to cellulose degradation in the CLF sample.[18] This DTA graph shows exothermic decomposition, and the fibre can withstand moderate to high temperature before degradation. It is suitable for aerospace, thermal resistance, and bio-degradable composite applications. When compared to other fibres, the exothermic degradation peak of CLF (428.8°C) was higher than *Borassus flabellifer* L. (332.9°C), *Agave sisalana* (350°C), and Jute fibre (368.8°C), but lower than Banana fibre (481.2°C).[1]

3.7. Assessment of the Chemical Composition of CLF

The chemical composition analysis of *Curcuma longa* fibre revealed that it contains 51.09% cellulose, 39.91% lignin, 16.87% hemicellulose, 14.44% ash, 8.11% pectin, and 0.66% wax which resulting the better mechanical strength, crystallinity, and bio-degradability of the fibre. These values are comparable to other natural fibres, such as: Banana fibre: Cellulose (60–70%), Hemicellulose (10–30%), Lignin (5–12%) Jute fibre: Cellulose (50–70%), Hemicellulose (10–20%), Lignin (7–21%) [22], *Mucuna atropurpurea*: Cellulose (58.74%), Hemicellulose (16.31%), Lignin (14.22%), *Cissus quadrangularis* root: Cellulose (77.17%), Hemicellulose (11.02%), Lignin (10.45%), *Cortaderia selloana* grass stem fibre: Cellulose (53.7%), Hemicellulose (14.43%), Lignin (10.32%), *Momordica charantia* fibre: Cellulose (61.2%), Hemicellulose (17.3%), Lignin (4.8%), *Cymbopogon flexuosus*: Cellulose (74.33%), Hemicellulose (9.76%), Lignin (27.50%), *Screw pine prop* root: Cellulose (73.10%), Hemicellulose (12.58%), Lignin (7.11%) [3]

3.8. Assessment of the Toxicity Range of CLF (In Vitro Extraction Method)

To evaluate the biocompatibility of CLF, an MTT cytotoxicity assay was conducted using L929 fibroblast cells. Fibre extracts were prepared using both Phosphate Buffered Saline (PBS) and cottonseed oil, and the samples were incubated with the cell line at 37°C in a CO_2 incubator. PBS extract shows 94% cell viability and 6% cytotoxicity. Cottonseed oil extract shows 89% cell viability and 11% cytotoxicity. According to ISO 10993-5 standards, cell viability above 80% classifies the sample as Grade 1 (non-toxic or slightly toxic). Therefore, CLF fibres exhibit minimal cytotoxicity and are safe for use in technical textiles, especially those with prolonged skin contact or for wearable applications.



Controlled ***Polar PBS*** ***Non-controlled cottonseed oil***

Fig.3.7. Cytotoxicity assay test shows the cytotoxicity percentage of CLF

4. CONCLUSION

This study aimed to investigate the effects of fibre extraction and analyse the surface structure and chemical properties of *Curcuma longa* roots. Classified as agro-residuals, these roots were collected from fields and subjected to water retting for fibre extraction. The extracted fibres were beige to light brown, slightly brittle, flexible, and strong enough to withstand pressure.

Surface morphology analysis revealed pitted zones, flaky or crust-like layers on fibre surfaces, which indicates the presence of surface impurities or natural waxes. The rough texture suggests an untreated lignocellulosic origin of the fibre. Despite the surface roughness, the core fibre structure remains intact, suggesting a degree of rigidity or toughness. Elemental analysis through Energy Dispersive X-ray Spectroscopy (EDX) confirmed the presence of carbon with 52.56 wt.% and oxygen with 41.42 wt% as dominant elements, with minor contributions from fluorine, potassium, magnesium, Aluminium, Calcium, and silicon. These elemental compositions provide insight into the fibre's functional behaviour, especially regarding its thermal response and potential compatibility with other bio-based materials. This composition contributes to the fibre's compact structure and low internal transmission. TGA analysis showed that significant weight loss occurs in four stages: 30–100°C: Initial weight loss due to the release of absorbed moisture. 100–250°C: Decomposition of cellulose materials. 250–350°C: Decomposition of heavy components such as lignin. 350–600°C: Increase in ash content. At the final stage, CLF retains a residual mass of 30.00% at 548.01 ^{0}C after thermal degradation.

DTA analysis revealed an endothermic peak at 147.8°C, indicating moisture vaporisation from the fibre surface. A glass transition was observed between 250°C and 300°C, and an exothermic peak at 428.8°C was attributed to cellulose degradation. X-ray diffraction (XRD) analysis indicated that CLF has a crystalline structure, which contributes to its brittle nature. The material also demonstrated a significant decomposition rate, with a crystalline index of 51.1%. The chemical composition analysis of *Curcuma longa* fibre revealed that it contains 51.09% cellulose, 39.91% lignin, 16.87% hemicellulose, 14.44% ash, 8.11% pectin, and 0.66% wax. Biocompatibility assessments using cytotoxicity testing confirmed that *Curcuma longa* fibre exhibits minimal toxicity. The fibre retained over 94% cell viability in PBS extract and 89% in cottonseed oil extract, both falling under the ISO Grade 1 cytotoxicity classification, indicating no or negligible cytotoxic effects.

Compared to traditional textile fibres such as cotton, silk, and polyester, *Curcuma longa* fibre has minimal environmental impact. Since it is a plant-based fibre extracted from residual parts, its extraction process does not involve any chemical treatments, unlike traditional fibres, which often require chemical processing. Furthermore, the water used in the retting process can be recycled and reused, making this method sustainable for large-scale production. Based on the characterisation, physical, chemical and toxicity analyses, *Curcuma longa* residual fibre demonstrates favourable properties and is well-suited for the production of non-woven sheet composite materials for technical textile applications rather than for woven or knitted fabric production.

Competing Interests

The authors declare that they have no competing interests relevant to the content of this article.

Acknowledgments & Funding

This research was financially supported by PSG College of Arts & Science, Coimbatore.
Author[1] Ramya. N received research support from PSG College of Arts & Science, Coimbatore.

Authors' Contributions

Conceptualisation, experimental design, data collection, data analysis, and manuscript writing: Ramya. N
Research supervision, editing, and review: Dr. J. Banu Priya

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