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Development of non-woven composites using agro-industrial residue fibre from *Mangifera indica* and analyse its comfort and thermal properties for textile application

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The incorporation of eco-friendly green fibres in the textile industry has become a crucial approach to promoting sustainable production practices. These fibres, particularly those derived from agro-waste and agro-industrial residues, offer a promising alternative to conventional textile raw materials by reducing environmental impact and enhancing the functional and aesthetic properties of textile products. In this study, *Mangifera indica*—a widely consumed seasonal fruit—was selected as a source of green fibre. After pulp extraction in food processing industries, the leftover seed residues, typically discarded as waste, were collected. Subsequently, fibre extraction was carried out using the decortication method. The extracted fibre was then subjected to detailed characterisation to evaluate its morphological, structural, and functional properties. Based on the characterisation results, the fibres were processed into web structures and converted into non-woven sheets using the needle-punching technique. These non-woven materials were further assessed for their thermal insulation and comfort properties to determine their suitability for textile applications. This research investigates the extraction and characterisation of *Mangifera indica* fibre (MIF) and examines the performance of the developed non-woven sheet, demonstrating its potential as a sustainable and functional material for use in protective textiles.

Keywords: Agro-industrial residues, Eco-friendly fibre, Fibre characterisation, Fibre extraction, Needle punching, Sustainability

1 Introduction

Agro-industrial residues are bio-based processed wastes commonly discarded on land or into water bodies, leading to a range of adverse environmental impacts. Repurposing these residues as raw materials or by-products presents a sustainable solution that can significantly support the circular economy while reducing production costs, particularly in the textile sector. The textile industry consumes approximately 113.8 million metric tons of fibres annually, primarily for apparel manufacturing[1–3]. In the domain of technical textile fibres, polyester dominates global production, accounting for approximately 54% due to its low cost and ease of manufacturing. Cotton, although the most widely used natural fibre, contributes only 22% to total production, largely due to its higher cost and the specific agronomic conditions required for its cultivation[4]. In technical textile applications, synthetic fibres are predominantly used due to their high tensile strength, durability, and cost-effectiveness. However, the increasing reliance on synthetic fibres poses significant environmental concerns because of their non-biodegradable nature and long-term ecological impact.

In recent years, there has been growing research interest and practical efforts focused on increasing the application of natural fibres in textile products due to their biodegradability and environmental compatibility[4–6]. However, a significant drawback to the widespread use of natural fibres lies in their labour-intensive cultivation and production processes, which contribute to higher overall costs. To address this challenge, attention has shifted toward the utilisation of agro-residues and agro-industrial/food processing by-products that are typically discarded through environmentally harmful means, such as landfilling, water dumping, or burning. These agro based residuals offer a viable alternative to conventional natural fibres, as they do not require specific cultivation or dedicated farming inputs. Agricultural field waste and food industry by products can be processed to extract fibres at comparatively lower costs, making them an economically and environmentally sustainable raw material. In addition to reducing production expenses, this approach helps mitigate the environmental burden associated with the disposal of agro-waste and

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reduces the demand for virgin fibre resources. Based on this rationale, *Mangifera indica* was selected for the present study. After pulp extraction in the fruit processing industry, the seed coats—often discarded as waste and not used for any commercial or edible application—remain unutilized. These seed coats contain fibre-rich material that can be extracted through boiling water and the stripping method. The presence of fibre in this agro residue, combined with its abundant availability and lack of current utilisation, forms the basis for this research, which focuses on the extraction and characterisation of fibres from *Mangifera indica* seed coats.

Mangifera indica, commonly referred to as mango, is a member of the family *Anacardiaceae* within the kingdom Plantae. It is an evergreen species predominantly cultivated across South and Southeast Asia[7]. Renowned as one of the most widely consumed seasonal fruits, *Mangifera indica* is typically harvested between April and July. Beyond its nutritional value, the plant exhibits a broad spectrum of pharmacological activities, including antibacterial, antifungal, antimicrobial, antiparasitic, antitumor, antiallergic, antipyretic, and gastroprotective properties[8]. Notably, nearly all morphological parts of the tree—leaves, bark, fruit, seeds, and roots—are utilized in traditional and contemporary medicinal applications, underscoring its therapeutic versatility.

India is the world's largest producer of mangoes, accounting for approximately 40% of global mango production (i.e., approximately 22.4 Million metric tons in 2023–24, with an estimate of 22.8 million metric tons in 2024–25, according to the Second Advance Estimates released by the Ministry of Agriculture and Farmers Welfare, India). A significant portion of its pulp, juice, and jam is exported to various countries[9]. During the pulp extraction process, the fruit peel and seeds are removed and discarded in large volumes, often disposed of on land. This massive accumulation of organic waste contributes to microbial contamination, which can lead to air quality degradation and pose serious public health hazards. Importantly, the seed waste generated during processing does not require any cultivation or additional production input, making it an abundant and low-cost raw material. While mango is a seasonal fruit, the scale of its industrial processing ensures a consistent and significant availability of this waste during peak months. The fibre extracted from mango seeds is relatively short and slightly brittle in texture, making it suitable for use in composite material development rather than conventional spinning. The extraction process itself is simple and can be completed within a few days, without the use of harmful chemicals, making it an eco-friendly alternative to traditional fibre sources. To the best of our knowledge, limited or no studies have been reported on the extraction and characterisation of *Mangifera indica* seed fibre (MIF) for textile applications. This study addresses this research gap by detailing the extraction procedure, characterisation of the extracted fibres, development of non-woven fabric structures, and evaluation of their potential suitability in technical textile applications.

2 Materials and Methods

2.1 Seed Collection and Preprocessing for the Extraction Process of *Mangifera Indica* Fibre (MIF)

Mangifera indica seeds were procured from two primary sources: a local fruit market in Erode and the Sri Vari Agro Food Processing Unit in Dindigul, Tamil Nadu, India [Fig. 1 (a)]. Following procurement, the seeds underwent a standardized cleaning protocol involving mechanical rubbing and rinsing to remove surface contaminants, followed by manual sorting based on morphological quality parameters [Fig. 1 (b)&(c)]. This initial decontamination step was critical to minimize the risk of microbial proliferation, particularly bacterial and fungal colonization. Importantly, no chemical disinfectants were employed during the cleaning process. Instead, hot water was utilized as a physical sterilization agent. The application of hot water not only served to reduce microbial load but also facilitated the softening of the fibrous endocarp, decreased surface tackiness, and enhanced the pliability of the fibrous matrix. After washing, the seeds were enveloped in muslin cloth and subjected to solar drying to eliminate residual moisture content [Fig. 1(d)]. Once adequately dried, an iron comb was used to gently brush the seeds, allowing for the efficient separation of the fibres. Final extraction of fibres was performed using a manual stripping method with blades. The extracted fibres were beige in colour, lightweight, slightly brittle, and ranged in length from 1.0 to 2.5 cm, with an average diameter of approximately 0.35 mm. These fibres were subsequently prepared for detailed identification and characterisation to assess their feasibility for textile applications. Alternative extraction techniques, including mechanical processing, chemical retting, and dew retting, were also evaluated; however, they yielded inferior results in terms of fibre

Fig. 1 — The collection and extraction of fibres from *Mangifera indica* seeds (a) using the water boiling and stripping method (b, c) followed by sun dry (d)

quality and quantity, validating the suitability of the adopted method. Specifically, thirty *Mangifera indica* seeds were immersed in 2 litres of water and boiled at 100 °C for 15 min. This thermal treatment effectively loosened the fibrous sheath and aided in the removal of residual mucilaginous pulp adhering to the seed surface.

2.2 Non-Woven Sheet Preparation

Preliminary evaluation of *Mangifera indica* fibres revealed intrinsic limitations for conventional textile applications, including short staple length, moderate brittleness, low elasticity, and a coarse surface texture [Fig. 2 (a)]. These characteristics render the fibres unsuitable for traditional woven or knitted fabric production. However, their structural rigidity and surface morphology are advantageous for non-woven textile fabrication, particularly via mechanical entanglement methods such as needle punching.

To enhance the mechanical integrity of the resulting non-woven structure, *Mangifera indica* fibres (MIF) were blended with Musa paradisiaca fibre (MPF) and Bambusa vulgaris (BVF) in a 70:20:10 ratio. The fibres were carefully mixed to ensure homogeneous blending, which is essential for consistent web formation. Carding, a functional step in web preparation, was employed to separate, clean, and align the fibres into a continuous web structure[10]. During carding, the blended fibres were first layered onto the machine, which facilitated the intermixing and alignment of fibres by passing the web through a series of rollers and drums, during which excess fibre waste was combed out [Fig. 2 (b)]. Repetition of this procedure resulted in a well-formed, evenly distributed fibre web with enhanced mechanical coherence, suitable for subsequent processing via needle punching.

Following the web formation process, the fibre web was consolidated using the needle-punching technique, which involves the repeated penetration of barbed needles through the web to mechanically entangle the fibres and produce a cohesive, fabric-like structure without the use of stitching or chemical adhesives[11]. The prepared fibre web was processed using a TRYTEX needle-punching machine equipped with 38-gauge barbed needles operating at a frequency of 45 punches per minute [Fig. 2 (c), (d)]. The vertical reciprocation of the needles facilitated fibre entanglement along the z-axis, consolidating the web into a cohesive non-woven matrix without the use of thermal or chemical bonding agents. This approach preserved the natural physicochemical properties of the constituent fibres. The resulting material, referred to as the *Mangifera indica* fibre non-woven sheet (MIFNS) [Fig. 2 (e), (f)], was subsequently subjected to comprehensive evaluation of its morphological, thermal, and comfort-related properties. These assessments aim to determine its suitability for technical textile applications, including insulation layers and liner materials.

2.3 Analytical Characterization of *Mangifera Indica* Fibre

To comprehensively evaluate the physicochemical and functional properties of *Mangifera indica* fibre (MIF) for potential textile applications, a suite of analytical techniques was employed. These included Field Emission Scanning Electron Microscopy (FESEM), Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Thermogravimetric Analysis (TGA), Differential Thermal Analysis (DTA),

Fig. 2 — Carding process of MIF and MPF; (a and b) fibres for carding process, (c and d) carded web, and (e and f) *Mangifera indica* fibre non-woven sheet (MIFNS)

chemical composition analysis, and cytotoxicity testing.

Field Emission Scanning Electron Microscopy (FESEM) with a ZEISS instrument was utilized to investigate the surface morphology and microstructural features of the fibres, providing high-resolution imaging and elemental mapping capabilities. The analysis was performed on uncoated fibre samples at various magnifications: 250x at a 100µm scale, 500x at a 25µm scale, and 100x at a 25µm scale. An accelerating voltage of 5.00 kV was applied during imaging to assess the surface morphology and structural integrity of the fibres[12].

The elemental composition of *Mangifera indica* fibre was further investigated using Energy Dispersive X-ray Spectroscopy (EDX), with the resulting spectrum. This analysis quantified both atomic and weight percentages of the elements present in the fibre matrix[12].

FTIR spectroscopy facilitated the identification of functional groups by detecting characteristic vibrational modes within the infrared spectrum, thereby elucidating the chemical constituents of the fibre matrix[13].

XRD analysis was performed to determine the crystallographic structure and quantify the degree of crystallinity, which is critical for understanding the mechanical and thermal behavior of the fibres[14].

The crystallinity index (CI) of MIF was determined to be 46%, calculated using the Segal method.

$$CI = \frac{(I_{200} - I_{am})}{I_{200}} \times 100 \quad \ldots (1)$$

where I200 represents the maximum intensity of the crystalline peak, and Ima denotes the intensity of the amorphous baseline at a specific 2θ angle.

Thermal stability was assessed using TGA, which monitored the mass loss of the fibres as a function of temperature under controlled heating conditions. The fibre sample was placed in an alumina crucible, and the temperature was increased from 30°C to 600°C at a constant heating rate of 10°C/min. The weight of the sample was recorded continuously to assess the stages of thermal degradation.

Differential Scanning Calorimetry (DSC) is a thermos analytical technique used to measure the difference in the amount of heat required to increase the temperature of a sample and a reference material as a function of temperature or time[15], the temperature difference *(ΔT)* can be computed according to the following equation.

$$\Delta T = T_{sample} - T_{reference} \quad \ldots (2)$$

Chemical composition analysis was performed at the South Indian Textile Research Association (SITRA) by calculating the percentages of cellulose content, hemicellulose, lignin content, wax content, ash content (on a dry basis), and pectin. This analysis quantified the relative proportions of cellulose, hemicellulose, lignin, wax, ash, and moisture content following the ISO 1833 series standard. Additionally,

fibre density was measured to support structural and performance evaluations[16].To ensure biocompatibility and safety for potential wearable applications, cytotoxicity testing was conducted to assess the impact of the fibres on living cells and biological tissues[17].

In addition, the thickness of the *Mangifera indica* fibre non-woven sheet (MIFNS) was evaluated using a precision thickness gauge to ensure accurate measurement of the needle-punched non-woven fabric. A thickness gauge equipped with a 25mm diameter presser foot and a standardized pressure of 0.5 kPa was employed.

Areal density was measured by cutting five circular specimens of 10 cm × 10 cm (0.01 m²) using a grams per square meter (GSM) die cutter, ensuring that the fabric was not stretched or compressed during cutting. All samples were conditioned under controlled conditions (20 ± 2°C and 65 ± 4% RH) for 24 hours prior to evaluation. Each specimen was weighed using a high-precision digital analytical balance[18]. For this evaluation, five specimens measuring 10 × 10 cm were cut from various regions of the *Mangifera indica* fibre non-woven sheet (MIFNS) needle-punched fabric to ensure representativeness.

Air permeability is a critical parameter used to assess the breathability of textile materials, defined as the rate of airflow passing perpendicularly through a known surface area under a specified pressure differential. For this evaluation, five specimens measuring 10 × 10 cm were cut from various regions of the *Mangifera indica* fibre composite (MIFC) needle-punched fabric to ensure representativeness. All samples were conditioned under standard atmospheric conditions of 21 ± 1°C and 65 ± 2% relative humidity (RH) for 24 h prior to testing.

To evaluate the air permeability of the samples, the specimens were securely clamped between the upper and lower plates of the test head, and the pressure differential across the fabric was set to 125 Pa, as per standard test conditions. Upon initiating the test, air was drawn through the fabric perpendicularly, and the resulting airflow rate was measured and recorded directly in cubic feet per minute per square foot (CFM/SF).

To evaluate the thermal performance of the needle punched *Mangifera indica* fibre non-woven sheet (MIFNS), thermal conductivity (λ) and thermal resistance (R) analyses were conducted at 35°C using a heat flow meter (HFM) at PSG iTech. This standardized steady-state technique is designed for assessing insulation materials. The HFM software computes thermal conductivity using Fourier's law of heat conduction:

$$q = \lambda \times \frac{\Delta T}{d} \quad \ldots (3)$$

To assess the biocompatibility of MIF fibres, a cytotoxicity evaluation was performed using the MTT assay (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide) with L929 murine fibroblast cells, as presented in Fig. 10. While the MTT assay is a widely accepted method for quantifying cellular metabolic activity and assessing the cytotoxic effects of materials, it is important to acknowledge that MTT itself may exert cytotoxic effects under certain conditions. The intracellular reduction of MTT results in the formation of insoluble formazan crystals, indicating the termination of cell viability, which precludes further biological analyses post-assay. Furthermore, elevated concentrations or prolonged exposure durations may compromise cell integrity and potentially skew viability outcomes.

The liquid absorption capacity test evaluates a fabric's ability to retain fluids, expressed as the percentage increase in weight from the dry to the wet state or as the amount of liquid absorbed per gram of dry fabric. For this study, five specimens measuring 10 × 10 cm were prepared from different locations on the needle-punched fabric and conditioned at 21 ± 1°C and 65 ± 2% RH for 24 h.

Each dry specimen was fully submerged in distilled water at room temperature for 30 mins to ensure saturation. Gentle agitation was applied during submersion to eliminate any trapped air bubbles. After soaking, each sample was removed using forceps and held vertically for 30 secs to allow excess liquid to drain naturally. The wet weight was recorded immediately using a precision analytical balance. This process was repeated for all five replicates, and the average values were used for discussion in the results section.

The absorption capacity was calculated using the following formula:

$$\text{Absorption Capacity \%}, \frac{W_w - W_d}{W_d} \times 100 \quad \ldots (4)$$

3 Results & Discussion

3.1 Field Emission Scanning Electron Microscopic Analysis of MIF

A comprehensive morphological assessment of agro-residue fibres extracted from *Mangifera indica*

was conducted using field emission scanning electron microscopy (FESEM). The micrographs revealed prominent longitudinal striations along the fibre surface, indicative of the presence of cellulosic microfibrils. These features are clearly observable in Fig. 3 at varying resolutions. The extracted fibres exhibited pronounced surface roughness, coiled structures, and voids. These morphological traits significantly contribute to the fibre's highly porous and hydrophilic nature, which, in turn, enhances moisture retention and breathability. Such characteristics are particularly advantageous for applications requiring absorbency and air permeability. Further analysis indicated that the fibres consist of bundled fibrils, a structural arrangement that promotes fibrillation. Fibrillation inherently increases porosity, thereby improving the material's sound absorption capabilities for future applications[2,3]. The roughness of the surface enhances the probability of incidental acoustic waves being attenuated, resulting in superior acoustic damping performance. Additionally, the helical and irregular surface topography of the fibres facilitates the formation of microscopic air pockets. This FESEM image shows similarities to other lignocellulosic materials like *jute*, *flax*, and *sisal*fibres[26]. It also shares structural similarities with the lignocellulosic fibres of *Atriplex halimus*. L and *Mucuna atropurpurea*[27].

A detailed morphological analysis of the *Mangifera indica* fibre non-woven sheet (MIFNS) was conducted using FESEM. This investigation aimed to assess the surface morphology and structural properties of the fibres following the needle-punching process, with images shown in Fig. 4. The FESEM micrographs revealed that the fibres within the composite were generally uniform, smooth, and structurally intact. Notably, distinct fibre entanglement points were observed throughout the composite matrix, indicating effective mechanical interlocking. Such inter-fibre interactions are essential for ensuring structural coherence in non-woven fabric systems.

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

The elemental composition of *Mangifera indica* fibre was further investigated using Energy-Dispersive

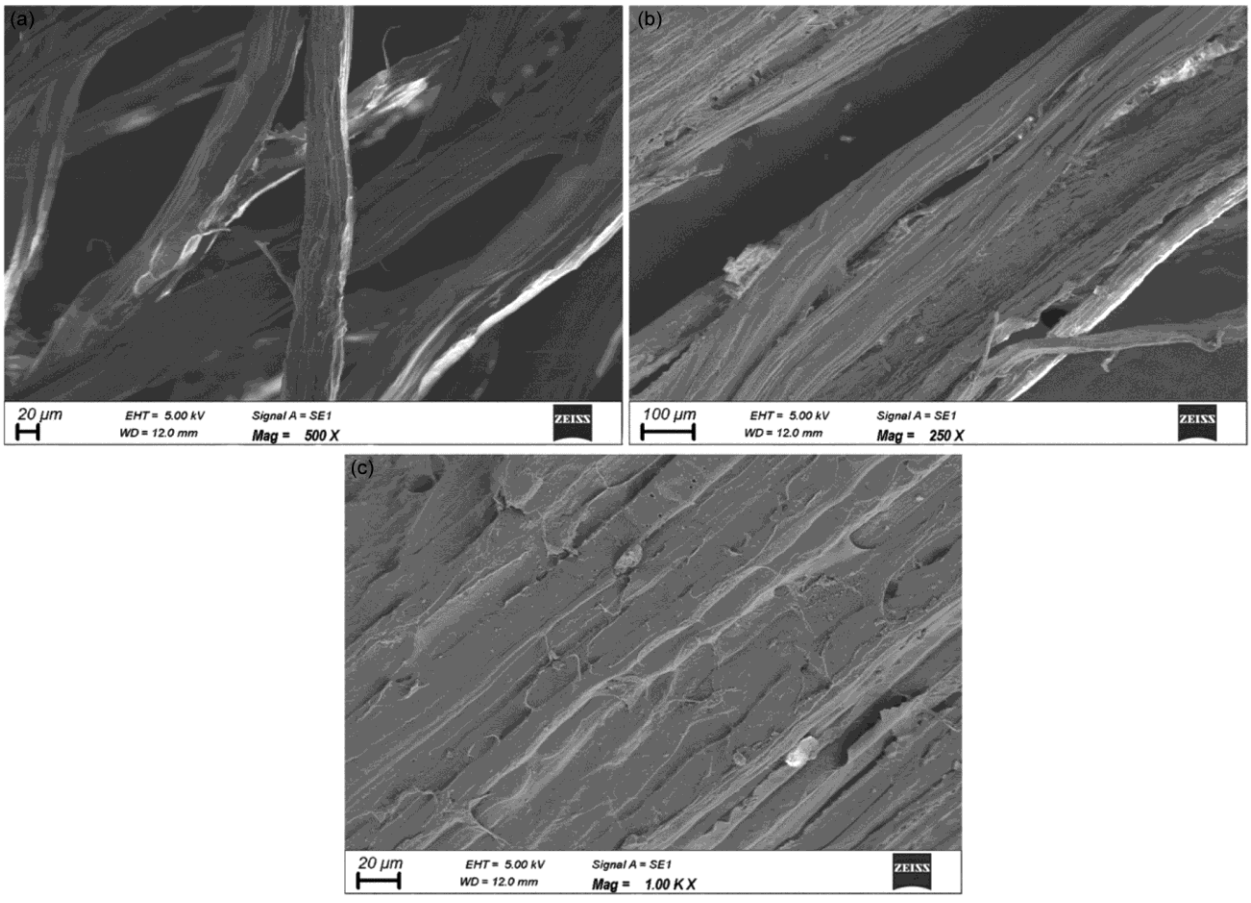

Fig. 3 — Morphological analysis of *Mangifera indica* fibres using FESEM

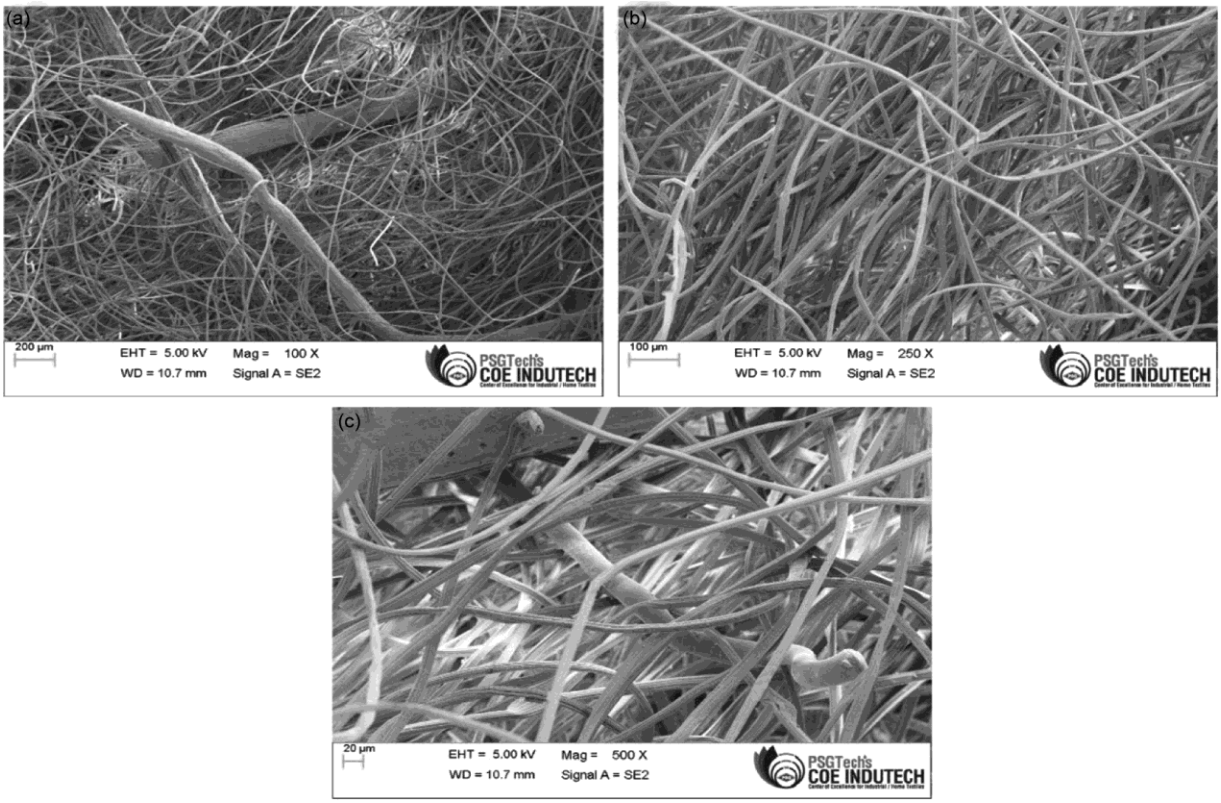

Fig. 4 — Morphological analysis of *Mangifera indica* fibre composite using FESEM

X-ray Spectroscopy (EDX), with the resulting spectrum presented in Fig. 5. This analysis quantified both atomic and weight percentages of the elements present in the fibre matrix[28]. The primary constituents identified were carbon (C) and oxygen (O), with weight percentages of 54.94% and 61.16%, and atomic percentages of 43.09% and 36.06%, respectively. These values confirm the lignocellulosic nature of the fibre, consistent with its origin from plant biomass[29]. In addition to the major elements, trace amounts of fluorine (F: 1.41 wt.%, 1.01 at%), potassium (K: 0.35 wt.%, 0.12 at%), magnesium (Mg: 0.16 wt.%, 0.09 at%), and silicon (Si: 0.05 wt.%, 0.02 at%) were detected. The presence of these inorganic elements, particularly Mg[30], K[31], and Si[32], suggests potential enhancements in thermal stability and moisture regulation. However, the relatively elevated concentrations of certain elements may also indicate surface contamination, possibly introduced during processing or handling. Earlier studies show that other lignocellulosic fibres, such as *Mucuna atropurpurea*, exhibit similar inorganic materials, which are comparatively higher than those found in *Mangifera indica fibre*. Additionally, kenaf bast fibre shows the presence of similar inorganic elements[33]. Overall, the EDX analysis reinforces the lignocellulosic composition of *Mangifera indica* fibre and highlights its potential for use in mineral-enriched, sustainable textile and technical applications.

3.3 FTIR Quantification of the Chemical Composition of MIF

Fourier Transform Infrared Spectroscopy (FTIR) analysis was conducted on *Mangifera indica* fibre (MIF) to identify the functional groups present within the fibre matrix. The spectral data were collected over a wavenumber range of 4000–500 cm–1 at a scanning rate of 2 mm/s, with the results shown in Fig. 6. The resulting FTIR spectrum exhibited nine distinct absorption peaks, each corresponding to specific chemical bonds and functional moieties inherent to lignocellulosic biomass. Prominent absorption bands at 3698 cm–1 and 3568 cm–1 were attributed to free O–H stretching vibrations, indicative of hydroxyl groups commonly found in cellulose, hemicellulose, and polyphenolic compounds. These hydroxyl functionalities are known to enhance the fibre's hydrophilicity and provide active sites for chemical modification or surface interaction. A peak found at 3020 cm–1 is associated with the aromatic or alkene C-H bond. Its presence indicates an unsaturated or

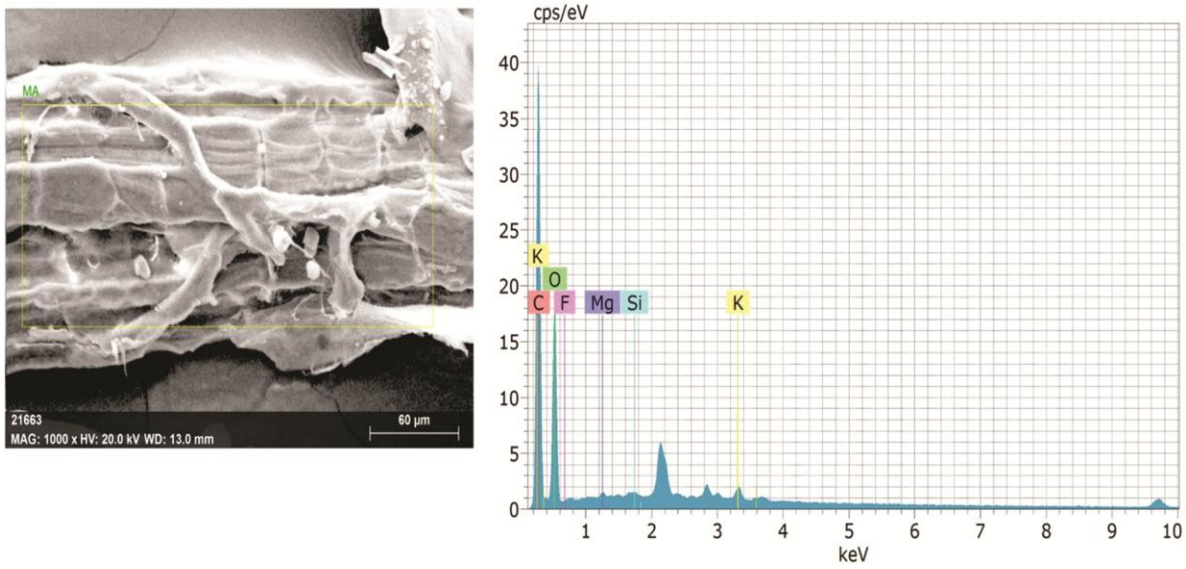

Fig. 5 — EDX spectrum of *Mangifera indica* fibres

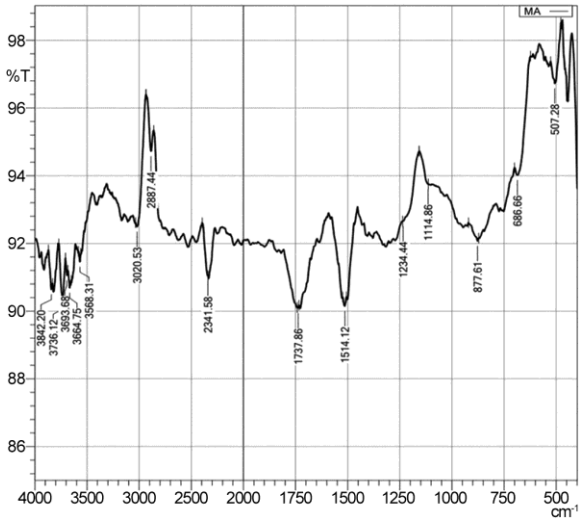

Fig. 6 — FTIR analysis shows the peak points of chemical compounds in MIF

aromatic structure, likely due to lignin, which contains aromatic phenylpropane units conjugated with C=C bonds. A peak at 2341 cm–1 was assigned to C–H stretching vibrations, typically associated with aliphatic chains in cellulose, fatty acids, and surface waxes. The strong absorption at 1737 cm–1 corresponds to C=O stretching vibrations, suggesting the presence of ester, aldehyde, and carboxylic acid group functionalities often linked to pectin, hemicellulose, and residual surface waxes. An aromatic C=C stretching vibration observed at 1514 cm^{-1} confirmed the presence of lignin and other phenolic structures, which contribute to the fibre's rigidity and thermal stability. Peaks at 1234 cm^{-1} and 1141 cm^{-1} were attributed to C–O stretching vibrations, further validating the presence of cellulose, hemicellulose, and lignin. These bands also suggest the presence of ether linkages and glycosidic bonds within the polysaccharide backbone. Additional absorption bands at 877 cm^{-1} and 686 cm^{-1} were associated with polysaccharide skeletal vibrations and aromatic ring deformations, respectively, indicating the presence of saccharide units and aromatic constituents. Collectively, the FTIR spectrum confirms the lignocellulosic nature of *Mangifera indica* fibre, characterized by a complex matrix of cellulose, hemicellulose, lignin, and minor extractives[34]. These peaks show similarity to earlier studies of kenaf stem fibre, which possess similar peaks and functional groups[35] and also to those identified in jack tree fibre[36] and the newly extracted fibre from the Habara Plant Stem[37]. The diversity of functional groups identified suggests that MIF possesses the necessary chemical complexity for a wide range of value-added applications. These include sustainable textiles, bio-composites, and functional inner linings, particularly in contexts requiring moisture management, sweat absorption, and potential anti-odour performance due to the presence of phenolic and carboxylic functionalities.

3.4 XRD Crystallographic Information of MIF

X-ray Diffraction (XRD) analysis was performed to investigate the crystallographic structure of Mangifera indica fibre (MIF), and the result of the

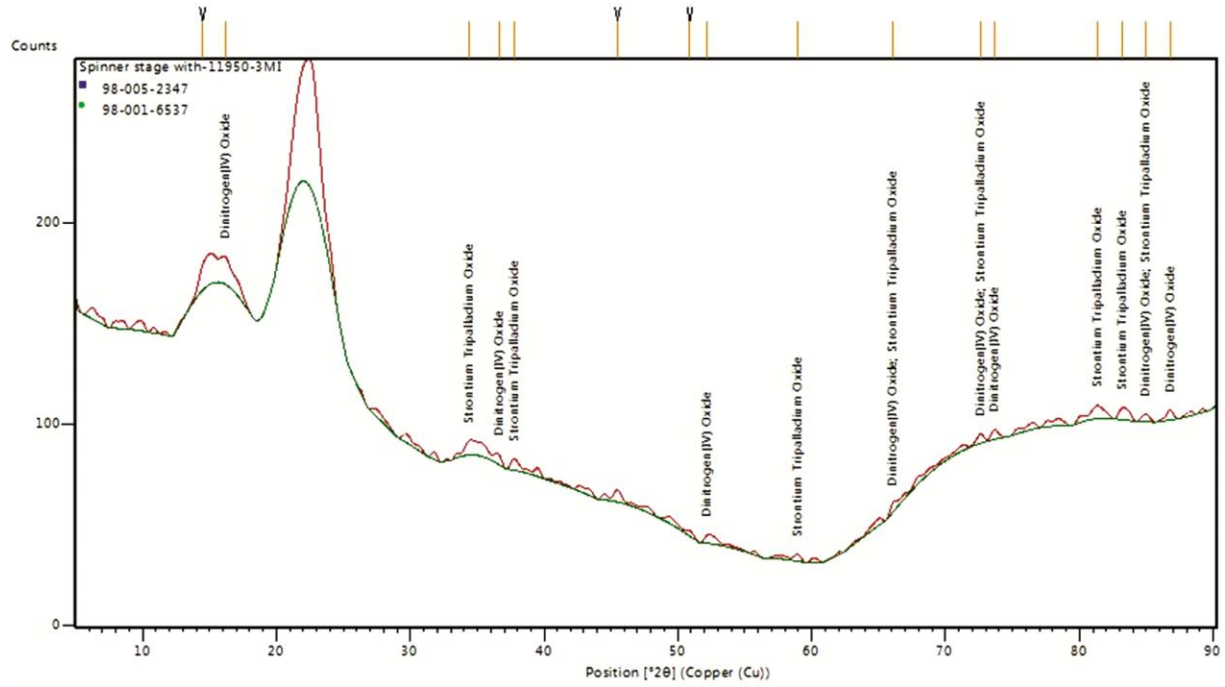

Fig. 7 — XRD analysis: Structure and chemical compounds of MIF

diffraction graph is shown in Fig. 7. The X-rays were directed through the specimens at a wavelength of 1.5460 Å (Cu Kα radiation) under ambient conditions (25°C). The diffraction pattern was recorded over a 2θ range sufficient to capture both crystalline and amorphous features.

A sharp diffraction peak was observed at approximately 22° (2θ), which is characteristic of the (002) plane of cellulose I. This peak indicates a high degree of crystallinity, which is directly associated with enhanced mechanical strength, dimensional stability, and rigidity of the fibre. In addition, a broad halo spanning the 10°–30° (2θ) range was observed, signifying the presence of semi-crystalline or amorphous regions. This dual-phase structure confirms that MIF possesses a partially ordered arrangement typical of natural lignocellulosic fibres.

Interestingly, the XRD pattern also revealed minor peaks corresponding to crystalline compounds such as dinitrogen (IV) oxide and strontium tri-palladium oxide. The presence of these inorganic phases may be attributed to environmental exposure or processing residues and could potentially enhance the fibre's functional characteristics, including thermal stability, flame retardancy, or catalytic activity. The semi-crystalline nature of MIF offers an optimal balance between flexibility and mechanical integrity, making it particularly suitable for applications in composite reinforcement, functional textiles, bio-absorbents, and sustainable engineered fabrics. The crystallinity index (CI) of MIF was found to be higher than that of several other natural fibres, including. *Cymbopogon flexuosus* (lemongrass) root fibre (36.8%), *Mucuna atropurpurea* (purple bush-bean) fibre (24.01%), *Cortaderia selloana* (pampas grass) stem fibre (22%), *Momordica charantia* (bitter gourd) fibre (21.42%), *Cordia dichotoma* (Indian cherry) fibre (12.14%), and *Borassus flabellifer* L. (palmyra palm) fibre (17.13%) were compared. In contrast, common textile fibres such as Banana and Jute exhibit significantly higher crystallinity indices, with Banana fibre at 50.8%, Jute fibre at 63.09%, and cotton fibre at approximately 65%[25].

Despite this, *Mangifera indica* fibre still demonstrates favourable structural properties for eco-friendly and high-performance material applications, including technical textile. The results highlight the promising potential of *Mangifera indica* fibre as a sustainable alternative to conventional fibrous materials, particularly for applications in acoustic damping and thermal insulation. Its performance characteristics suggest suitability in contexts demanding an optimal balance of mechanical strength, structural flexibility, and environmental compatibility.

3.5 TGA assessment of the Thermal Degradation Nature of MIF

Thermogravimetric analysis (TGA) was conducted to evaluate the thermal stability and optimal

processing temperature of *Mangifera indica* fibre (MIF). The fibre sample was subjected to controlled heating under ambient atmospheric conditions, and its weight loss was continuously recorded to monitor thermal degradation behavior. The resulting thermogram is presented in Fig. 8. The thermal decomposition of MIF occurred in four distinct stages:

Stage 1 (30–100 °C): Initial weight loss was observed due to the evaporation of physically bound moisture and volatile components. This stage reflects the fibre's hygroscopic nature and its capacity for moisture absorption.

Stage 2 (100–250 °C): This phase corresponds to the thermal degradation of hemicellulose and partial breakdown of amorphous cellulose. The onset of decomposition in this range indicates the presence of low molecular weight polysaccharides and extractives.

Stage 3 (250–350 °C): Significant mass loss occurred due to the decomposition of crystalline cellulose and lignin. This stage is critical for assessing the fibre's structural integrity under elevated temperatures and contributes to its mechanical performance in composite applications.

Stage 4 (350–600 °C): The final degradation phase involved the formation of char and accumulation of inorganic ash content. A residual mass of 21.74% was recorded at 548°C, indicating substantial thermal resistance and the presence of thermally stable constituents.

The high decomposition temperature and residual mass suggest that *MIF* possesses excellent thermal stability, making it suitable for thermally demanding applications such as flame-resistant textiles, bio composites, and insulation materials. When benchmarked against other natural fibres, *MIF* demonstrated superior thermal stability compared to *Borassus flabellifer*. L. (498.2°C), *Mucuna atropurpurea* (298°C), *Juncus effusus* L. (300°C), *Cissus quadrangularis* root (328.9°C), and banana fibre (348.6°C). Although its thermal resistance is slightly lower than that of jute fibre, which retains a residual mass at 687°C[19], *MIF* still exhibits favorable thermal characteristics for eco-friendly and functional material applications. These findings reinforce the suitability of *Mangifera indica* fibre for use in high performance, sustainable engineering materials where thermal endurance is a critical parameter.

3.6 Differential Scanning Calorimetry of Mangifera Indica Fibre

Differential Scanning Calorimetry (DSC) was conducted to investigate the thermal transitions of

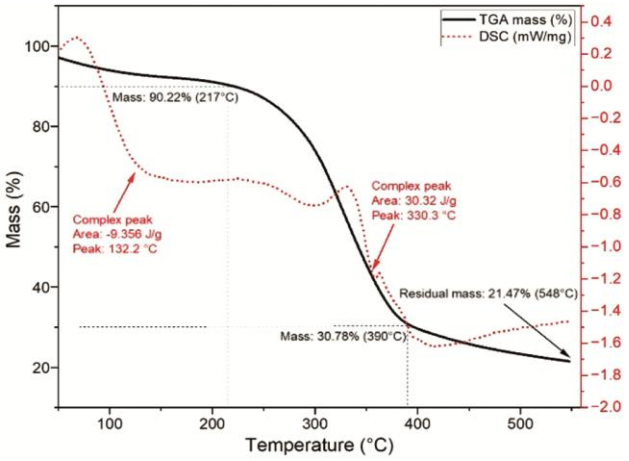

Fig. 8 — TGA and DSCanalysis of MIF

Mangifera indica fibre (MIF), and the result is shown in Fig. 8. The analysis was performed over a temperature range of 30°C to 550°C at a controlled heating rate of 10 K/min under ambient atmospheric conditions. The resulting thermogram revealed several key thermal events that characterize the fibre's thermal behaviour. An endothermic peak at 132°C was observed, corresponding to the evaporation of bound moisture and volatile compounds. This event reflects the fibre's hygroscopic nature and its capacity for moisture retention, which is relevant for applications requiring breathability and absorbency. A glass transition temperature (Tg) was identified between 250–300°C, indicating the onset of polymer chain mobility. This transition marks the softening of the amorphous regions within the fibre matrix and is critical for understanding the thermal processing limits of MIF in composite and textile applications. A strong exothermic peak at 330.3°C was attributed to the thermal degradation of cellulose, signifying the breakdown of the crystalline regions and the onset of structural decomposition. This peak is a key indicator of the fibre's thermal endurance and stability under elevated temperatures. The thermal decomposition profile of MIF demonstrates moderate-to-high thermal resistance, making it suitable for applications in thermally demanding environments. When compared to other natural fibres like *Artocarpus hystrix* (298.8°C), *Juncus effusus* (300°C), and *Cissus quadrangularis* root (328.9°C), MIF exhibits a higher exothermic decomposition temperature. However, it is slightly lower than *Borassus flabellifer. L* (332.9°C), *Agave sisalana* (350°C), Jute fibre (368.8°C), and Banana fibre (481.2°C)[20]. These findings establish *Mangifera indica* fibre as a promising candidate for

aerospace components, thermal-resistant composites, and biodegradable material systems, where thermal stability and controlled degradation are essential performance criteria.

3.7 Assessment of the Toxicity Range of MIF (*In Vitro* Extraction Method)

Fibre extracts were prepared using two solvents, phosphate-buffered saline (PBS) and cottonseed oil, and subsequently incubated with the L929 cell line at 37°C in a humidified CO2 atmosphere. The PBS extract demonstrated a cell viability of 94%, corresponding to 6% cytotoxicity, whereas the cottonseed oil extract yielded 89% viability and 11% cytotoxicity. According to the ISO 10993-5 guidelines, materials exhibiting cell viability above 80% are classified as Grade 1, indicating non-cytotoxic or only slightly cytotoxic behavior. These findings suggest that MIF fibres exhibit minimal cytotoxicity and are thus suitable for applications in technical textiles, particularly in contexts involving prolonged dermal contact or integration into wearable systems.

3.8 Assessment of the Chemical Composition of MIF

The chemical composition analysis of *Mangifera indica* fibre revealed that it contains 68.63% cellulose, 12.24% lignin, 16.87% hemicellulose, 28.24% ash, 5.75% pectin, 2.08% protein, and 1.57% wax. These components contribute to the fibre's enhanced mechanical strength, crystallinity, and biodegradability. These values are comparable to those of other natural fibres, such as:

3.9 Analysis of Physical Properties

3.9.1 Thickness

The thickness of the *Mangifera indica* fibre non-woven sheet (MIFNS) was evaluated using a precision thickness gauge to ensure accurate measurement of the needle-punched non-woven fabric[23]. Measurements were taken at five different locations, and the average thickness of the non-woven MIFNS determined through this method was 4.5mm, 3.9mm, 4.1mm, 4.2mm, and 4.5mm. The Coefficient of Variation (CV%) was calculated using the formula:

$$CV\ (\%) = \frac{SD}{\bar{t}} \times 100 \quad \ldots (5)$$

where SD is standard deviation and ¯t is a mean thickness, it results 6.15 CV%.

3.9.2 Areal Density

The areal densities measured—488.16, 501.22, 506.44, 510.32, and 416.57 g/m²—combined with the calculated average of 502.01 g/m² and a coefficient of variation of 2.83%, reflect strong uniformity and reliability in your composite fabric structure. Areal density is determined using standard methods such as dividing the sample's mass by its area, commonly expressed in grams per square meter (GSM). Ensuring low variation is important for consistent performance, especially where strength-to-weight ratio matters.

Table 1 — chemical composition details of other plant based new fibres

Fibre Name	Cellulose, %	Hemicellulose, %	Lignin, %
Mucuna atropurpurea	58.74	16.31	14.22
Cissusquadrangularis	77.17	11.02	10.45
Cortaderia selloana	53.07	14.43	10.32
Momordica charantia	61.02	17.03	4.08
Cymbopogon flexuosus	74.33	9.76	27.50
Screw pine prop	73.10	12.58	7.11

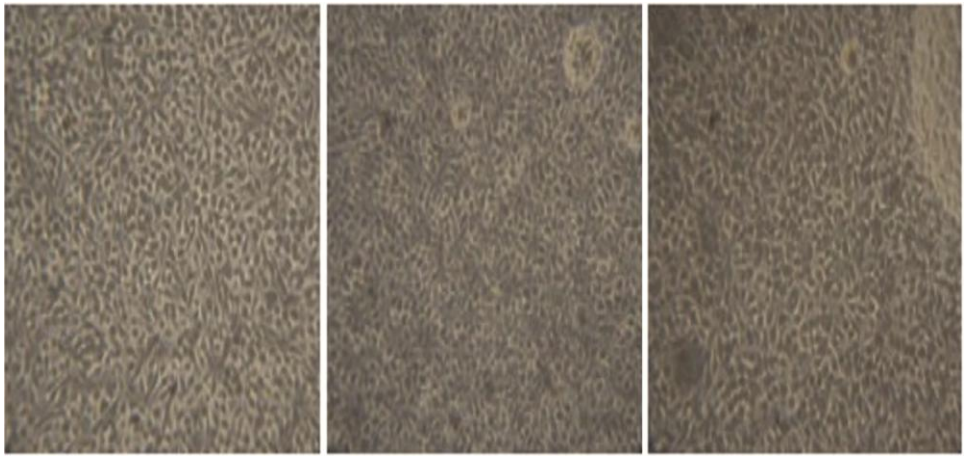

Fig. 9 — Cytotoxicity assay test shows cytotoxicity percentage of MIF; (a) controlled, (b) polar PBS, and (c) non-controlled cotton seed oil

3.9.3 Air Permeability

The specimens were securely clamped between the upper and lower plates of the test head, and the pressure differential across the fabric was set to 125 Pa, as per standard test conditions. Upon initiating the test, air was drawn through the fabric perpendicularly, and the resulting airflow rate was measured and recorded directly in cubic feet per minute per square foot (CFM/SF). Each specimen was tested at three distinct points, and the mean value was calculated to ensure data reliability. The mean air permeability was found to be 114.5 $cm^3/cm^2/s$, indicating excellent breathability[23].

3.9.4 Liquid absorption capacity

The average liquid absorption capacity was determined to be 827.41%, with a standard deviation of ±21.6. This indicates that the MIFNS nonwoven fabric can absorb approximately 8.27 times its dry weight, showcasing exceptional fluid retention properties. Such performance makes the material a promising candidate for sweat-absorbing inner linings, insulation layers, medical textiles, and other applications where high moisture absorption is essential[21].

3.10 Thermal Analysis of MIFNS

Based on the measured parameters, the thermal conductivity of the MIFNS fabric was determined to be 0.043142 W/m·K, indicating a moderate thermal insulation capability. Lower values of thermal conductivity are preferable for insulation, as they denote a reduced rate of heat transfer through the material[24]. This level of conductivity aligns with materials suitable for thermal protection layers. The corresponding thermal resistance was calculated as 0.102785 m^2·K/W, classifying the composite as a medium-grade thermal insulator. Such resistance is appropriate for various protective and insulation applications, including helmet liners, padding in protective gear, thermal clothing, and packaging insulation.

4 Conclusion

This study investigates the extraction, characterization, and composite potential of *Mangifera indica* seed fibre, an underutilized agro residual by product. FESEM analysis showed that the fibres having smooth, compact, and uniform surfaces with visible entanglement points, indicating strong inter fibre bonding ideal for non-woven composites. TGA/DTA results revealed multi-phase degradation like moisture loss, cellulose breakdown, lignin decomposition occurs 21.47% residual mass post degradation. XRD analysis indicated a semi crystalline structure of fibre that results 46% crystallinity, balancing rigidity, and brittleness. Chemical composition showed high cellulose of 68.63%, hemicellulose 16.87%, moderate lignin content of 12.24%. Non-woven composites produced by blending of *Mangifera indica* fibre with bamboo and banana fibres via needle-punching exhibited a thickness of 4.5mm and 6.15 CV%, areal density of 502.01gm/m^2, and a CV of 2.83%. With its favourable thermal, mechanical, absorbency and biological properties, *Mangifera indica* fibre processed sustainably that shows strong potential foe technical textiles such as helmet liners, thermal insulation panels, biodegradable padding, and filtration materials. Overall, *Mangifera indica* fibre presents significant environmental advantages. *Mangifera indica* seed fibre, when processed via sustainable and tis favourable mechanical, thermal, absorbent, and biological properties confirm its viability for use in functional applications such as helmet liners, thermal insulation panels, bio-degradable padding materials, and technical textiles. This research lays the foundation for further exploration into industrial-scale applications, life cycle analysis, and the integration of these fibres into broader bio-composite markets.

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