INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

OPEN ACCESS

Received: 18-11-2024

Accepted: 18-12-2024

Published: 10-01-2025

Citation: Sasikala M, Sangeetha K, Kumar BS (2025) Investigation of the Characterisation Variances of Blended Non-woven Textiles: Banana, Flax and Recycled Cotton. Indian Journal of Science and Technology 18(1): 23-36. https://doi.org/10.17485/IJST/v18i1.3732

* **Corresponding author**.

hanuman2389@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Investigation of the Characterisation Variances of Blended Non-woven Textiles: Banana, Flax and Recycled Cotton

M Sasikala[1]*, K Sangeetha[2], B Senthil Kumar[3]

1 Research scholar, Department of Textiles and Apparel Design, Bharathiar University, Coimbatore, Tamil Nadu, India
2 Professor and Head, Department of Textiles and Apparel Design, Bharathiar University, Coimbatore, Tamil Nadu, India
3 Assistant professor, Department of Rural Industries and Management, Gandhi gram rural Institute (Deemed to be University), Dindigul, Tamil Nadu, India

Abstract

Objectives: The study examines natural fibers' mechanical and thermal properties, specifically cellulose-based flax and banana fibers. Flax fibers are noted for their low density, high tensile strength, and rigidity, while banana fibers are recognized for their flexural strength and damping properties. However, treatments applied to these composites can negatively affect mechanical performance and surface integrity. The objectives of the research include comparing the properties of both fiber types, enhancing tensile strength through recycled cotton blends, evaluating the micro-structural characteristics of non-woven textiles for potential applications and sustainability, analyzing the elemental composition of nanomaterials, and investigating air permeability in relation to pore structure. **Methods:** The Energy-dispersive X-ray spectroscopy detector is incorporated into both transmission electron microscopy (TEM) and scanning electron microscopy (SEM) systems, which are employed for high-energy measurements. The analysis of the air permeability was carried out to evaluate how the pore structure affects its capacity to allow the passage of air/vapours. A testing analysis conducted by SITRA-South Indian Textile Research Association, Coimbatore utilized the Tex-test FX-3300-III, S/n:1198 Air permeability tester, following the guidelines of ASTM D 737-04 (2016) and IS 11056:2013, indicating that the static air permeability strength was notably enhanced. **Findings:** To determine if nanoparticles were present in the non-woven textiles, the microstructure of the non-wovens was examined at different EDS locations. Various elements were identified at each EDS site within the blended non-woven webs, along with variations in the elements' relative weights, atom counts, and K ratios. In an air permeability test, non-woven-1, made from banana-recycled cotton, exhibited higher values compared to non woven-2, which consisted of flax-recycled cotton. **Novelty and applications:**

This research focuses on creating sustainable textiles by blending varying proportions of banana, flax, and recycled cotton, presenting an alternative to traditional single-fiber textiles. The study also introduces textile waste regeneration as a novel concept. Through the EDS Spots system, elements are identified and compared, offering valuable insights for potential technical applications. Permeability analysis evaluates the pore structure of the composite nonwoven materials, which are recognized as superior substitutes for synthetic glass fibers due to their elevated cellulose content. Their outstanding mechanical and thermal properties make them highly suitable for technical applications in the construction and automobile sectors.

Keywords: Banana/flax fibers; Recycled cotton; Energy-dispersive X-ray spectroscopy; Air permeability; SEM-Scanning electron microscopy

1 Introduction

In comparison to synthetic fibers, natural fibers provide a number of advantages, including cheaper costs, lower densities, greater flexibility, higher impact resistance, less equipment abrasion, low specific gravities, process friendliness, fewer health risks, lower greenhouse gas emissions, CO_2 neutrality, and re-cyclability[1].

Natural fibers are more frequently accepted in the technical sector than other synthetic fibers since they are less expensive, biodegradable, recyclable, and have been demonstrated to have low elongation at break along with strong tensile and flexural strengths[2]. However, studies on the practicality of natural fibers have shown problems with their durability. Moreover, there is a dearth of studies on the application of various natural fibers, such as those present in bananas, sisal, hemp, coconut, jute, and bananas[3].

Bananas are a potential crop because it is simple to harvest banana fibers from pseudostems, which are often left to decay on fields as agricultural waste.

Studies on banana fibers have revealed that they are affordable, easily accessible, with respectable performance characteristics, and environmentally friendly[4]. They therefore have the potential to improve the mechanical properties of non-woven textiles. Apart from yielding a diverse range of jute goods, the appropriate method for creating needle-punched non-woven jute also contributes to its value[5]. For carpets and floor coverings, jute-mixed needle-punched non-woven fabric can be used with good results. Our fabrics mixing technology combines the practical and aesthetic aspects that the technical textile sector demands from its materials. The main advantage is that, although jute products perform somewhat lower than woollen things, they are significantly less expensive than woollen fabrics[6].

The digitized ED spectrum is displayed with the X-ray energy (often in channels 10 or 20 eV wide) on the x-axis and the number of counts per channel on the y-axis. The response of the system expands a Gaussian-profiled X-ray line composed primarily of mono-energetic photons. Energy resolution is defined as the full width of the peak at half maximum height (FWHM). This is commonly characterized for the Mn Kα peak at 5.89 keV. Ge detectors may detect as low as 115 eV, whereas Si(Li) and SDD detectors often produce readings between 130 and 150 eV. The EDS resolution is adequate to differentiate between the K lines of nearby components while being just somewhat better than a WDS[7]. Since the ED spectrometer can quickly offer a whole spectrum, it is very useful for qualitative investigations. There are identification aids, such as the option to overlay the line positions of an element so that it may be compared to the recorded spectrum. Nano materials' elemental composition and distribution (mapping) are investigated using energy-dispersive X-ray spectroscopy (EDS). The findings of this work will contribute to a better understanding of the properties and presence of nanoparticles in non-woven materials through the application of energy-dispersive X-ray spectroscopy (EDS)[8]. Energy dispersive X-ray spectroscopy was used to perform qualitative and quantitative assessments, elemental distribution mapping, and chemical state studies on the non-woven materials. X-rays are released when a high-energy beam is reflected off the surface. Since each element has its own characteristic energy, the fingerprint spectrum, also known as the signature spectrum, may be compared to reference spectra[9]. Consequently, this study's main goal was to examine the micro-structural properties of non-wovens manufactured from recycled cotton mixed with banana and flax fibers. In addition, the influence of the micro pores of the non-woven in air permeability is examined by analysis of the SEM and EDS characterization.

Alternative formulations for single fiber applications were identified as the primary benefit of this research. While there has been considerable past research, single fiber applications have mainly been utilized in the textile sector. Banana, flax, and recycled cotton fibers were selected for this study in order to utilize the agricultural crop residue and its regeneration. Whereas flax's microstructure has a high ratio of cellulose, lignin, and pectin, banana wastes include significant levels of cellulose and hemicellulose, two substances of critical economic relevance. This cellulose increases the composites' mechanical strength, which makes them better suited for technical functions, particularly in the automobile sector. The capacity of fibers to absorb moisture and permeate is another significant factor. Both bast fibers' hollow structures are notable for their remarkable moisture absorption and air permeability, which renders them more appropriate for applications in automotive and healthcare applications. Although recycled formulations and synthetic alteration are in high demand, further research is required for better utilization of plant fibers. Therefore, this study will assist in identifying advantages and also in evaluating and improving current textile formulations.

2 Methodology

2.1 Materials and methods

Table 1. Materials and methods

S.No	Materials	Methods	Properties
1	**Textile fibers** i. Banana fibre+Recycle cotton ii. Flax+Recycle cotton	Needle punching technology	Blended fibers into non-woven fabrics
2	**Non woven fabrics** Web-1 and Web 2	Characterization analysis using SEM and EDS.	Micro-structural and chemical composition of the nonwoven fabrics
3	**Non woven fabrics** Web-1 and Web-2	Air permeability analysis using Tex-test FX-3300-III, S/n:1198 Air permeability tester in accordance with ASTM D 737-04 (2016) and IS 11056:2013	Analyze the ability to permeate natural air and vapors.

The experimental investigation in this section was carried out in multiple phases, including the following: i. Development of non woven web. ii. Characterization analysis using SEM and EDS techniques. iii. Analysis of the non-woven fabric air permeability.

2.2 Phase I-formation of non-woven fabrics

The needle punching method is used to generate non-woven fabrics, and the results are these two webs: (a) Web 1: 70:30 recycled cotton-banana blend, feed rate at 25 mm stroke, parallel-laid web, 50 punches per minute. (b) Web 2: 50/50 feed rate at 35 mm stroke, parallel-laid web, recycled cotton-flax mix, 40 punches per minute. The rate of processing was 10 m/min.

Tensile strength of Banana fibres-355-754 MPa while Flax fibers-1500 MPa[10]. In nature, flax fibers possess greater tensile strength than banana fibers. As a consequence, repurposed cotton made up 50:50 of the mixture. 30% banana fibers and 70% recycled cotton compose web-2, which increases the web's weight and tensile strength. The processed fibers used to produce non-woven textiles are presented in Figure 1.

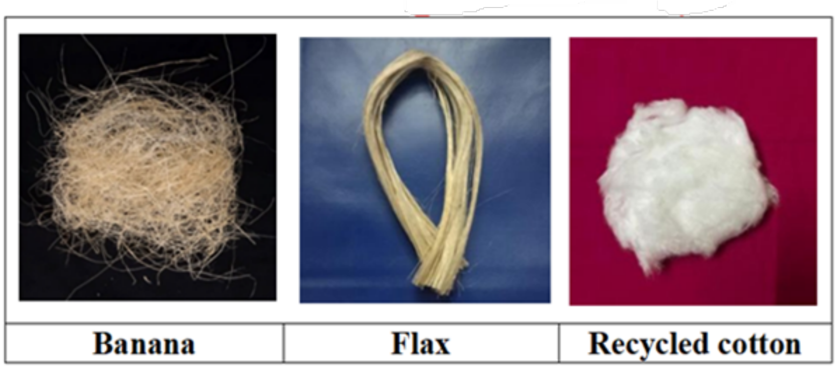


Fig 1. Processed textile fibers

2.3 Phase-II scanning electron microscopy analysis(SEM and energy dispersive x-ray spectroscopy (EDS)

2.3.1 Scanning electron microscopy analysis-SEM

This study aimed to assess the visual characteristics of textile fibers when blended with other fibers to produce non-woven textiles, as well as inquire into the morphology of the fibers by acquiring SEM images of the fiber ends. Two varieties of non-woven samples—banana and flax combined with recycled cotton—are studied using a high-resolution power scanning electron microscope (SEM) from the University Science Instrumentation Centre (USIC), Bharathidasan University, Tiruchirapalli. SEM-HV (high voltage) was used on both samples, and the range of voltage was 25.0 kV. The field of view (FOV) and working distance (WD) were adjusted according to the 10–500 micron SEM image magnification range. Comprehensive pictures of the surface topography of a fabric sample are obtained, and sub-micron-scale features of non-woven fabric samples are observed and assessed. Figure 2 displays the high-resolution SEM images of the non-woven materials.

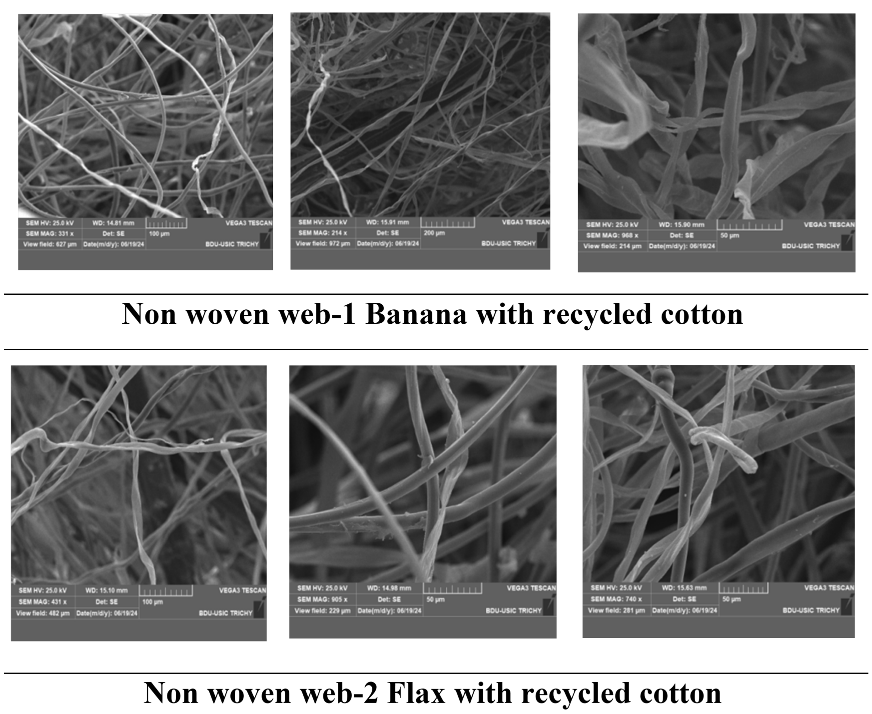


Fig 2. High resolution SEM images of Non woven samples

2.3.2 Energy Dispersive X-Ray Spectroscopy (EDS)

This study utilizes energy dispersive X-ray spectroscopy to investigate the effects of incorporating organic banana and flax fibers with recycled cotton on the micro-structural characteristics of non-woven textiles. A common approach for analysing the elemental composition and distribution (mapping) of nano-materials is energy-dispersive X-ray spectroscopy or EDS. The blended non-woven textiles' individual EDS spots revealed the presence of several elements together with variations in their proportion of weight, atoms, and K ratios. High energy measurements are performed at the University Science Instrumentation Centre (USIC) of Bharathidasan University, Tiruchirapalli, using the EDS detector integrated into both TEM and SEM equipment.

The EDS characterization of non-woven materials may be divided into three phases:

i. Line Identification

ii. Energy resolution

iii. Using spectrum overlay for qualitative ED analysis

2.3.3 Line Identification

Finding the lines in the X-ray spectra and utilizing energy or wavelength statistics to determine the components of the non-woven material are the goals of qualitative analysis. Occasionally, difficulties can develop, and they may always be resolved through analysing both the primary and supporting lines. The line identification analysis was carried out in compliance with Table 2 standards. Figure 3 shows the line identification graph of the non-woven webs composed of recycled cotton and flax.

Table 2. L ine Identification Analysis

S.No	Conditions	Value
1	kV	24
2	Mag	325
3	Take-off	25
4	Live Time(s)	90
5	Amp Time(s)	3.89
6	Resolution:(eV)	128.5

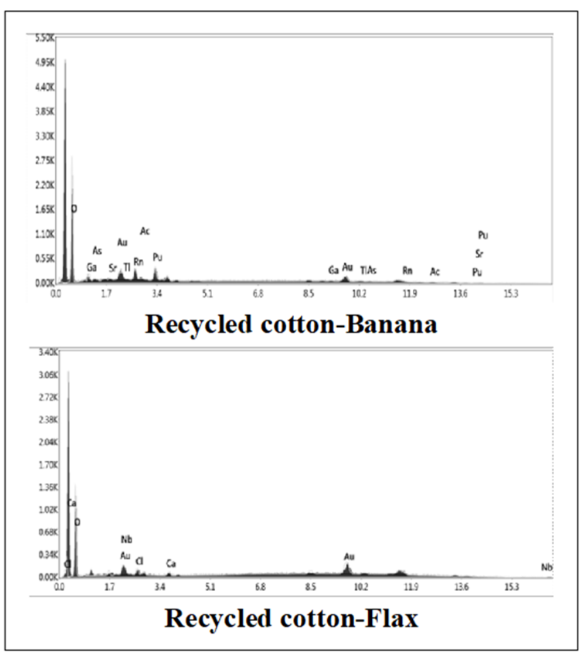


Fig 3. Line identification graph

2.3.4 Energy Resolution

The ED spectrometer is extremely beneficial for qualitative research since it provides a whole spectrum. Identification aids include the capability to overlay an element's line spots so that they can be easily recognized by comparing them to the recorded spectrum. With energy-dispersive X-ray spectroscopy (EDS), the elemental composition and distribution (mapping) of nanomaterials are studied. Energy-dispersive X-ray spectroscopy (EDS) was employed in this study to investigate the characteristics and existence of nano-particles in non-woven materials. Throughout the non-woven web-1 recycled cotton banana and web-2 recycled cotton flax synthesis process. Three different sites were shown in an EDX-energy resolution analysis in Figure 4.

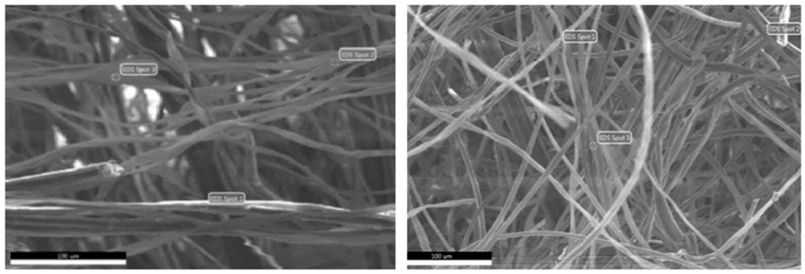


Fig 4. EDX-energy resolution of Non woven webs

2.3.5 Qualitative ED Analysis in Spectrum Overlay

The X-ray energy (often in channels 10 or 20 eV wide) and the number of counts per channel are shown on the x and y axes, respectively, in the digitalized ED spectrum. The system's response expands an X-ray line with a Gaussian distribution that is mainly made up of mono-energetic photons. The full width of the peak at half maximum height (FWHM) is the definition of energy resolution. This is frequently referred to for the 5.89 keV Mn Kα peak. While Si(Li) and SDD detectors typically offer values between 130 and 150 eV, Ge detectors have the ability to detect as low as 115 eV. The EDS resolution is just significantly greater than a WDS, yet it is sufficient to distinguish between the K lines of adjoining components. Consequently, the spectrum overlay for the whole graph of the three EDS spots is displayed in Figure 5.

2.3.6 Air permeability

All non-woven materials undertake static air permeability examination using the Tex test FX3300-III static air permeability analyzer with standard test parameters of 125 Pa test pressure and 38 cm^2 test area. The nominal range of flow and its CV (coefficient of flow) are important characteristics in an air permeability study. Table 3 shows the test range from the minimum value to the maximum value used to test the permeability of non-woven samples. The non-woven's airflow range graph is shown in Figure 6.

Table 3. T est range of air permeability analysis

S.No	Sample code	Air permeability (cm^3/cm^2 /s)
1	B-RC-1	14.9
2	B-RC-2	16.0
3	B-RC-3	16.7
4	B-RC-4	16.5
5	B-RC-5	15.5
6	B-RC-6	15.5
7	F-RC-1	14.9
8	F-RC-2	13.2
9	F-RC-3	13.9
10	F-RC-4	12.1
11	F-RC-5	15.3
12	F-RC-6	15.7
13	F-RC-7	13.9
14	F-RC-8	13.4

B-RC: Banana-Recycle cotton* F-RC: Flax-Recycle cotton*
Relative Humidity: 65%$\pm$2%, Temperature: 21^{o}C$\pm$1^{o}C

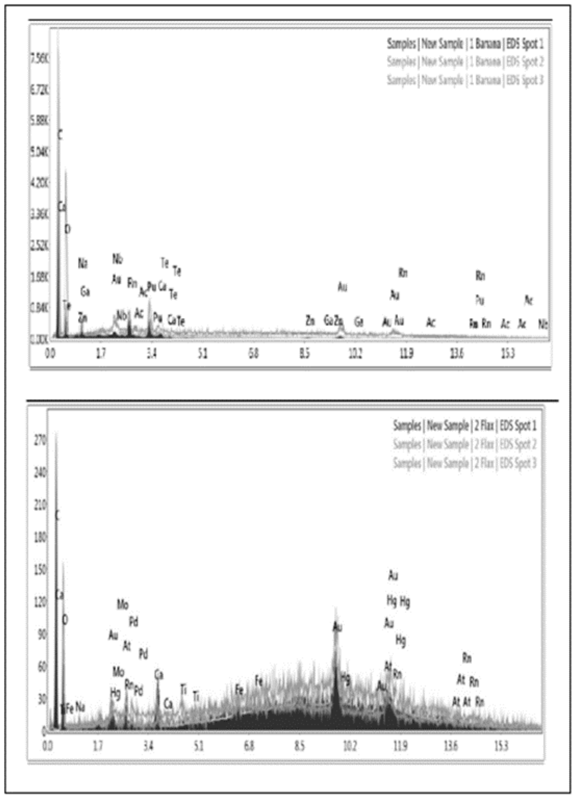


Fig 5. Spectrum overlay of non woven fabrics

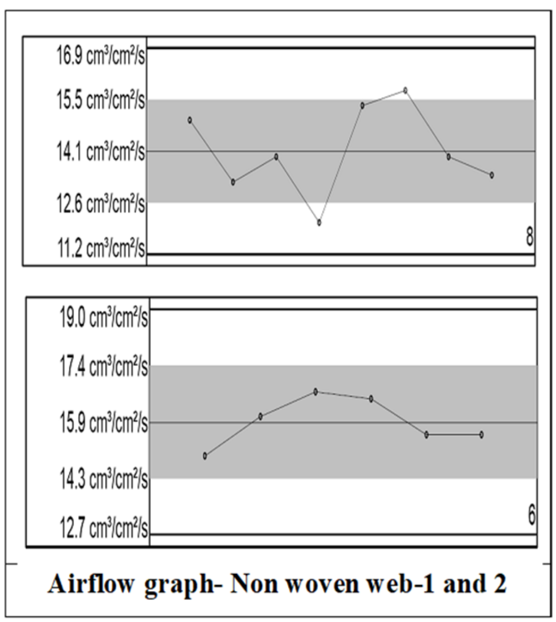


Fig 6. Air permeability analysis for non-woven webs

3 Results and Discussion

3.1 Phase I

Banana and flax fibers greatly increase the tensile strength of recycled cotton at fiber concentrations of up to 0.25% across all fiber lengths. The mass per unit area(g/m2) of the nonwoven fabrics was divided by the measured thickness and bulk (cm3/g) to determine and compare the density (kg/m3) of the nonwoven samples. Mass per unit area, thickness, bulk and density are considered as an important factor for the relaxation of textile fibres and porosity. Table 4 shows the comparison values of the nonwoven webs. Compared to the banana web, the flax blend shows higher density based on its mass per unit area. Hence the higher density of the flax web results in better fibre flexibility and higher porosity than compared to banana web. Density is a vital physical property of composite reinforcements, playing a significant role in engineering design calculations. Accurately measuring the density of reinforcing fibers is essential, as it influences mechanical performance evaluations and is crucial for determining the fibers' viability in lightweight construction applications[11]. Figure 7 depicts developed non-woven webs.

Table 4. Comparison value of Nonwoven webs

S.No	Test Parameter	Web-1	Web-2
1	Mass per unit area (g/m2)	65 ± 1	67 ± 1
2	Fabric thickness (μm)	310 ± 20	400 ± 30
3	Fabric bulkness (cm3/g)	4.8 ± 0.1	6.0 ± 0.3
4	Density(kg/m3)	210 ± 3	167 ± 7

Web-1 Banana-R.Cotton Web 2-Flax-R.Cotton

Fig 7. Non woven fabrics

3.2 Phase-II Scanning electron microscopy analysis (SEM) and energy dispersive x-ray spectroscopy (EDS)

Scanning electron microscopy analysis was used to reveal the micropores of blended non-woven materials as well as the presence of cellulose, wax and ash content. The morphological analysis of these micro-particles, which ranged in size from 20 to 500 μm, revealed clearly identifiable structures. By using cross-sectional views, the structure of the biological polymer, fracture behavior, bonding capacity of the fiber and recycling matrix are analyzed.

The study indicated that the tensile strength of the banana fiber is enhanced by its diametric cross-section and elliptical shape, slightly surpassing that of the flax web. The diameter of the banana fiber showed variation, with web-1 (banana fiber blended with recycled cotton) exhibiting a greater diameter than web-2. Additionally, the surface composition of the non-woven blended webs revealed notable levels of hemicellulose, lignin, and pectin. A comparison of mechanical properties highlighted that banana-recycled cotton and flax webs are influenced by their low micro-fibril angle and high cellulose content; specifically, flax demonstrated higher cellulose content, while the banana blend had elevated ash content.

3.3 Line Identification Analysis

The analysis of web-1 banana fibers showed higher line values for various components compared to web-2 flax fibers, as indicated by smart quantum results. The study presented metrics such as K ratio, atomic value, and weight percent for each element, highlighting the presence of oxygen-potassium (OK) and (AuL)-Gold-Lanthanum in both non-woven samples.

Notably, the weight of (AuL)-Gold-Lanthanum in the Web-1 Banana Blend was recorded at 50.21%. The element oxygen-potassium demonstrated maximum values of 0.1929 for the K ratio and 95.28% for atomic percentage, while (AuL)-Gold-Lanthanum in the non-woven flax showed an average weight of 48.39% and a K ratio of 0.3653. The atomic value of oxygen-potassium reached 89.04%. The line identification of the different constituents found in the banana and flax non-woven fabric samples is displayed in Table 5.

Table 5. Line identification values of Banana and Flax blend

Recycled cotton-Banana				
Element	**Weight %**	**Atomic %**	**Net Int.**	**K ratio**
O K	50.21	95.28	204.06	0.1929
AsK	3.14	0.35	1.24	0.0081
SrL	0.90	0.31	7.45	0.0089
GaK	0.70	0.42	3.72	0.0172
AcM	2.41	0.24	6.17	0.0202
TIL	3.81	0.46	5.31	0.0116
RnM	8.72	0.89	30.89	0.0559
AuL	25.52	4.91	25.43	0.1740
PuM	10.30	3.45	42.31	0.0927
Recycled cotton-Flax				
Element	**Weight %**	**Atomic %**	**Net Int.**	**K ratio**
O K	46.43	89.04	101.62	0.1347
NbL	1.72	0.57	6.82	0.0138
CIK	2.11	1.83	11.09	0.0116
CaK	1.34	1.03	6.91	0.0100
AuL	48.39	7.54	43.91	0.3653

The line identification results indicate that the banana blend exhibited a higher count of elements but a lower percentage. In contrast, the flax blend showed lower counts but higher elemental weight percentages. Common elements, such as oxygen-potassium (OK) and (AuL)-Gold-Lanthanum, were identified in both non-woven webs, albeit with different weights. Figure 8 illustrates the common elements found in both non-woven webs, highlighting the variations in their respective values.

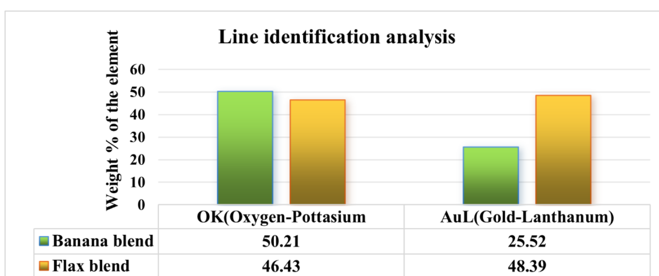


Fig 8. Elements in both non woven webs with different values

3.4 EDX-Energy resolution and spectrum lay analysis

The energy resolution of various elements in non-woven materials, specifically web 1 and web-2, is analyzed through an EDX-energy resolution study. Notably, the elements in non-woven web-1 exhibiting the highest percentage errors include actinium-molybdenum (AtM), mercury-lanthanum (HgL), molybdenum-lanthanum (MoL), and palladium-lanthanum (PdL). For non-woven web-2, the elements with the greatest percentage errors are calcium-potassium (CaK), zinc-potassium (ZnK), and gold-lanthanum (AuL). Additionally, Table 6 includes a comprehensive display of the elements present in the non-woven materials under spectrum overlay.

Table 6. Spectrum overlay of non-wovens

Banana-EDS-SPOT-1				Flax EDS-SPOT-1			
Element	**Weight%**	**Atomic%**	**Error%**	**Element**	**Weight%**	**Atomic%**	**Error%**
RnM	3.98	0.41	10.69	O K	18.05	71.28	13.93
PuM	8.10	0.49	10.98	AtM	0.7	0.21	66.98
O K	15.67	14.67	15.86	RnM	6.22	1.77	18.79
NaK	4.56	3.51	9.89	FeK	3.39	3.84	18.08
C K	53.91	89.03	5.34	AuL	56.36	18.08	25.9
ZnK	0.53	0.5	35.61	HgL	15.29	4.82	44.27
AuL	4.81	0.7	31.97				
CaK	0.72	0.34	16.25				
EDS-SPOT-2				**EDS-SPOT-2**			
Element	**Weight%**	**Atomic%**	**Error%**	**Element**	**Weight%**	**Atomic%**	**Error%**
TeL	2.57	0.29	35.93	O K	29.04	78.57	11.42
GaK	2.35	0.38	41.20	NaK	1.08	2.04	31.05
AuL	8.21	0.7	32.07	MoL	1.45	0.66	40.65
O K	38.26	35.51	13.06	RnM	5.53	1.08	26.7
RnM	4.18	0.23	18.89	PdL	2.1	0.85	46.76
PuM	7.41	0.56	18.52	CaK	2.12	2.29	28.1
C K	40.32	60.04	7.41	TiK	2.37	2.14	20.24
CaK	0.76	0.31	19.61	AuL	56.3	12.37	16.95
EDS-SPOT-3				**EDS-SPOT-3**			
Element	**Weight%**	**Atomic%**	**Error%**	**Element**	**Weight%**	**Atomic%**	**Error%**
NaK	4.32	5.32	15.54	CK	32.27	67.51	10.11
NbL	3.6	0.67	13.20	OK	16.53	25.96	14.06
PuM	9.01	0.67	15.51	AuL	51.19	6.53	19.84
O K	51.2	83.24	10.61				
CaK	2.03	0.78	23.34				
AuL	32.54	5.31	16.20				
RnM	5.67	0.90	14.54				
AcM	1.28	0.43	35.56				

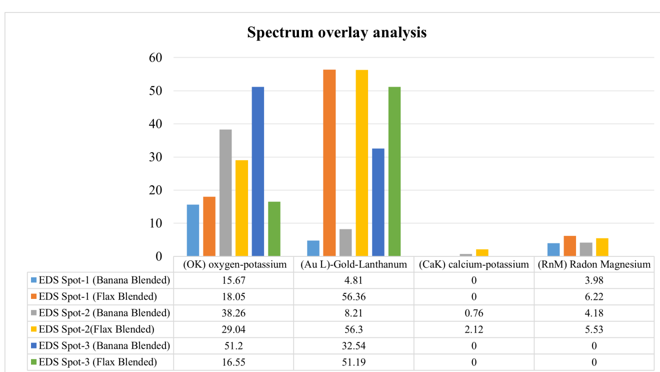
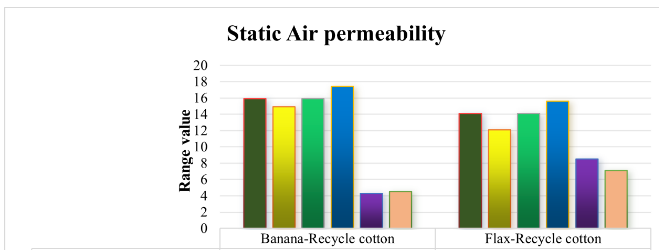


Fig 9. Presence of elements in spectrum overlay spots

In a comparative study of the spectrum overlay of non-woven webs, the EDS spots of the banana blend exhibited higher elemental counts than those of the flax blend. Common elements identified in both fabric blends, varying by weight percentage, included oxygen-potassium (OK), gold-lanthanum (AuL), calcium-potassium (CaK), and radon-magnesium (RnM). The results of the spectrum overlay are illustrated in Figure 9.

3.5 Air permeability analysis of the non woven fabrics

The density of non-woven fabrics exhibits significant variation in relation to changes in porosity, with a negative correlation between the two. Experimental findings indicate that the air permeability of non-woven materials decreases with increasing thickness. Specifically, for non-woven textiles made from recycled cotton (web-1), projected air permeability values were substantially higher than those obtained experimentally. Conversely, air permeability improves with increased porosity. The web-1 experiment's values for recycled cotton bananas exceeded those of the web-2 experiment involving recycled cotton and flax, particularly under rising porosity and pressure gradients. However, the complexity of flow rate dependence on channel characteristics undermines the establishment of a straightforward relationship between permeability and porosity. Although porosity can be seen as a replacement for density, density is not deemed crucial. Notably, the air permeability range for banana fibers surpassed that of the flax blend, attributed to their lightweight, hollow cell structure and lower density, which collectively enhance the air permeability of non-woven web-2. The findings on the air permeability value range for different non-woven webs are illustrated in Figure 10.



	Banana-Recycle cotton	Flax-Recycle cotton
Average value(cm3/cm2/s)	15.9	14.1
Minimum Value(cm3/cm2/s)	14.9	12.1
Nominal value(cm3/cm2/s)	15.9	14.1
Maximum value(cm3/cm2/s)	17.4	15.6
CV%	4.3	8.5
CI%	4.5	7.1

Fig 10. Air permeability value range of non woven webs

3.6 Comparative analysis of the study

In comparison to earlier studies, the blended fabric made from banana, flax, and recycled cotton demonstrates a greater density due to its mass per unit area. The increased density of these blended fibers enhances their flexibility and porosity. As a result, the suitability and technical applications of blended fabrics significantly surpass those of single-fiber formulations. The longitudinal examination of blended fibers using scanning electron microscopy (SEM) is crucial for understanding their surface morphology, identification, and the influence on the tensile properties of fabrics. SEM analysis reveals notable differences in the longitudinal view of banana and flax fiber blends, which are linked to variations in their microstructures. Specifically, non-woven web-1 exhibits a high ratio of twisted flat ribbon recycled cotton fibers integrated with a smaller proportion of cylindrical banana fibers that display surface irregularities. In contrast, non-woven web-2 is characterized by a blend of tubular flax and rounded fibers alongside flat ribbon structure fibers.

The identification of elements and their influence on blended textiles has been thoroughly investigated in this study. The newly explored relationship between the presence of elements and thermal textile applications contributes to the development of more sustainable and functional textiles for the future. While numerous experiments and studies have addressed the wearability and flexibility of single-fiber textiles, the unique formula of blended textiles-which involves waste regeneration-has demonstrated improved textile porosity and density. The pore structure of blended textiles results in variations in air permeability values when compared to prior research outcomes.

4 Discussion

Natural fibers like flax and banana composites contribute to the conservation of rapidly diminishing non-renewable resources and move materials closer to green composites for the future because of their fully or partially biodegradable properties. Cellulosic natural fibers such as banana and flax are more environmentally friendly and are plentiful for reinforcing polymers. They are regarded as a viable substitute for synthetic fibers like glass, carbon, and other materials. The lightweight banana fiber composites can aid in enhancing fuel efficiency and lowering emissions during the usage phase of the component, particularly in automotive applications. Cotton garment recycling is an essential idea in contemporary waste management and the reprocessing of discarded cotton materials into new or reusable items. Despite the fact that a significant amount of recycled cotton fiber is utilized in low-value products, the creation of new, higher-value items from recycled cotton fibers will promote the use of these fibers, thereby contributing to the sustainability of the textile industry's future.

Enhancing the utilization of raw materials has emerged as the most crucial challenge confronted by the scientific and industrial community. As a result, the rising need for textiles and the extensive production of clothing are driven not only by the demand from a growing population but also by evolving fashion trends.

4.1 Limitations of the study

- **Sample size:** In SEM analysis, the dimensions and layers of nonwoven webs must be reduced because of the limited space in the SEM chambers, resulting in a loss of important information. Therefore, it is not very feasible to use nonwoven fabrics that have a greater number of layers. Due to the heavy layers of non-woven fabrics, evaluating dense materials will decrease the accuracy of the air permeability assessments.
- **Sample type:** Only dry samples of non-woven webs are examined in the SEM chamber. Imaging non-woven webs in a wet state would be more beneficial for analyzing their swelling and water repellency characteristics, which provides clearer insights for technical and engineering applications.
- **Characteristics of sample:** Even though banana, flax, and recycled cotton are inherently soft materials, the low surface roughness of the web sample impacts the outcomes in the EDS technique.

4.2 Potential challenges

- The challenges surrounding textile production largely stem from the need for organic non-woven textiles to meet the functional and practical expectations set by consumers who are accustomed to synthetic fibers. Although these eco-friendly alternatives face criticism for their durability, ongoing advancements in material engineering aim to address these limitations. While conventional 100% synthetic and mixed fabrics are widely available, the acceptance of innovative non-woven textiles as the next generation of biotextiles poses difficulties, particularly due to a lack of awareness regarding their benefits and applications. This gap in understanding may impede the transition from traditional fabric usage to embracing these new materials.
- Researchers predict that the development of nonwoven materials from natural fibers will involve modifying these fibers and incorporating waste materials or reinforcements. The variety of natural waste materials, often with complex structures, necessitates diverse nonwoven manufacturing methods, leading to fabrics with distinct properties. The potential for creating unique nonwoven fabrics arises from the effective combination of waste fibers from various sources. However, considerations regarding fiber availability, cost, safety, consumer attitudes, and environmental impact are crucial. Promoting slow fashion and engaging in recycling and upcycling initiatives can encourage responsible consumer behavior. By utilizing technological advancements and sustainable practices while addressing these challenges, the textile industry can offer innovative solutions that align with consumer needs and preferences.

5 Conclusion

This research highlights several key points: This research highlights several key points: In this investigation, organic textile items were produced utilizing various combinations of commercial textile fibers, bananas, and flax. An additional important element of this study is the incorporation of textile waste for product regeneration, such as recycled cotton. The primary finding of this research revealed that the needle-punched nonwoven fabrics demonstrated medium to high levels of physical-mechanical properties, including mass per unit area, bulk, and density.

The SEM technique was utilized to analyze the pore size and structure of the nonwoven materials, providing valuable insights into the produced products and their suitability for various technical applications. The functional applications are also significantly influenced by the blended ratio, fiber type, and blending method. Among the tested samples, the combination of banana fibers and recycled cotton showed the highest air permeability. The samples made from flax and recycled cotton also displayed good air permeability; however, the airflow passage was somewhat affected by the samples' thickness. It is crucial for researchers to further explore underutilized plant fibers in order to expand their uses in technical textiles.

The Energy Dispersive X-ray (EDX) method was applied to evaluate the elemental composition of the nonwoven webs, uncovering a range of elements present in the samples. This analysis yields both semi-qualitative and semi-quantitative data about the nano-particles, which could improve the therapeutic efficacy of nonwoven materials in healthcare applications. The lightweight characteristics of natural composite materials are achieved through the use of low-density, hollow-structured fibers. These materials are essential in the design of medical textiles, including surgical caps, masks, and ultra-absorbent bandages, due to their critical properties such as moisture vapor permeability, air permeability, and thermal comfort, which are vital for healthcare and hygiene applications.

Hence, there exists a significant amount of research regarding the natural fibers. There is a considerable demand for organic materials in the textile sector, which is vital for promoting a sustainable future. Selection of fibers, blending of composites are consider as the important factor in this new generation products. Natural fibers are highly utilized in combination with synthetic fibers. Presently, many technical and engineering applications involve synthetic blended textiles (Example: recycled cotton mixed with polyester employed for sound-absorbing and insulation purposes). The identification of appropriate fibers and the creation of 100% natural composites for technical uses has been minimally addressed in the existing research. Yet, many types of natural fibers are solely applied for aesthetic purposes. Sectors like automotive and medical require increased contributions from textile research, and it has now become a highly relevant topic. Therefore, further research is required for the sustainable future of the textile industry. With ongoing improvements and processing techniques, this research aims to facilitate the future application of eco-friendly textile fibers.

Acknowledgement

I am grateful to Dr. K. Sangeetha for her invaluable support in accomplishing this research report. I am grateful to Dr. M. H. N. Badhusha for his support and enlightening feedback, which were significant in completing this work. I express my gratitude to the entire faculty of Jamal Mohamed College, Trichy for their kind collaboration and assistance during my study research.

Data availability statement

The sample production, test analysis, results, and their associated data have been developed and are owned by the corresponding authors from different institutions, including SITRA-South Indian Textile Research Association in Coimbatore, Bharathiar University, and Bharathidasan University.

Details of ethical clearance

All procedures and experimental research conducted in this study adhered to ethical guidelines.

References

1) Navaratnam S, Selvaranjan K, Jayasooriya D, Rajeev P, Sanjayan J. Applications of natural and synthetic fiber reinforced polymer in infrastructure: A suitability assessment. *Journal of Building Engineering*. 2023;66. Available from: https://dx.doi.org/10.1016/j.jobe.2023.105835.
2) Karimah A, Ridho MR, Munawar SS, Adi DS, Ismadi, Damayanti R, et al. A review on natural fibers for development of eco-friendly bio-composite: characteristics, and utilizations. *Journal of Materials Research and Technology*. 2021;13:2442–2458. Available from: https://doi.org/10.1016/j.jmrt.2021.06.014.
3) Waraczewski R, Sołowiej BG. Potential Valorization of Banana Production Waste in Developing Countries: Bio-Engineering Aspects. *Fibers*. 2024;12(9). Available from: https://dx.doi.org/10.3390/fib12090072.
4) Selmi S, Habibi M, Laperrière L, Kelouwani S. Characterisation of Natural Flax Fibers Honeycomb: Compression Damage Analysis Using Acoustic Emission. *Journal of Natural Fibers*. 2022;19(3):1084–1093. Available from: https://doi.org/10.1080/15440478.2020.1789531.
5) Elfaleh I, Abbassi F, Habibi M, Ahmad F, Guedri M, Nasri M, et al. A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials. *Results in Engineering*. 2023;19. Available from: https://dx.doi.org/10.1016/j.rineng.2023.101271.
6) Costa C, Azoia NG, Silva C, Marques EF. Textile Industry in a Changing World: Challenges of Sustainable Development. *U Porto Journal of Engineering*. 2020;6(2):86–97. Available from: https://www.researchgate.net/publication/346420826_Textile_Industry_in_a_Changing_World_Challenges_of_Sustainable_Development.
7) Chung SY, Kim JS, Stephan D, Han TS. Overview of the use of micro-computed tomography (micro-CT) to investigate the relation between the material characteristics and properties of cement-based materials. *Construction and Building Materials*. 2019;229. Available from: https://dx.doi.org/10.1016/j.conbuildmat.2019.116843.
8) Quadri TW, Fayemi OE, Olasunkanmi LO, Ebenso EE. Chapter 15 - Survey of different electrochemical and analytical techniques for corrosion measurements. *Electrochemical and Analytical Techniques for Sustainable Corrosion Monitoring-Advances, Challenges and Opportunities*. 2023;p. 293–323. Available from: https://doi.org/10.1016/B978-0-443-15783-7.00012-8.

9) Shojaei TR, Soltani S, Derakhshani M. Chapter 6 - Synthesis, properties, and biomedical applications of inorganic bio nano materials. *Fundamentals of Bionanomaterials-Micro and Nano Technologies*. 2022;p. 139–174. Available from: https://doi.org/10.1016/B978-0-12-824147-9.00006-6.
10) Karimah A, Ridho MR, Munawar SS, Adi DS, Ismadi, Damayanti R, et al. A review on natural fibers for development of eco-friendly bio-composite: characteristics, and utilizations. *Journal of Materials Research and Technology*. 2021;13:2442–2458. Available from: https://dx.doi.org/10.1016/j.jmrt.2021.06.014.
11) Amiri A, Triplett Z, Moreira A, Brezinka N, Alcock M, Ulven CA. Standard density measurement method development for flax fiber. *Industrial Crops and Products*. 2017;96:196–202. Available from: https://dx.doi.org/10.1016/j.indcrop.2016.11.060.