PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 6 No. 2 (2025) 268-275
https://publisher.uthm.edu.my/periodicals/index.php/peat

Mechanical Propertes of Nonwoven Needle Punching Machine for Vegan Leather Application

Muhammad Nabil Najmi Yusjah[1], **Mohd Nazrul Roslan**[1]*

[1] *Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA*

*Corresponding Author: nazrul@uthm.edu.my

DOI: https://doi.org/10.30880/peat.2025.06.02.029

Article Info

Received: 26 June 2025
Accepted: 11 August 2025
Available online: 30 October 2025

Keywords

Sustainable fibers, Agricultural waste Needle punching technology, Vegan leather Eco-friendly composites, Plant-based materials

Abstract

Mechanical characteristics of non-woven textiles made from plant fibers, such as pineapple, bamboo, and banana stems, employing needle punching technology to promote environmentally friendly textile industry practices. Fiber extraction, mixing with cotton and polyester, and processing into non-woven composites are all methodically examined in this study. Thorough mechanical and physical testing is then conducted. The findings emphasize the impact of fiber type and blend composition on performance, showing that pineapple-polyester blends have the highest tearing resistance, while banana-cotton composites have the best tensile strength and elongation. The results demonstrate that these plant-based non-wovens have promising durability and structural integrity, which makes them suitable substitutes for vegan leather and other uses. This encourages waste valorization and environmental sustainability in the production process.

1. Introduction

Deforestation and the burning of fossil fuels are two examples of human actions that have irreversibly altered Earth's climate. These activities increase greenhouse gases, which trap heat and raise global temperatures. Serious effects result from this, including ecological changes, harsh weather, and rising sea levels. As a result, sustainability and the use of renewable resources, such as agricultural waste, are gaining popularity. Modern technology has made it possible to turn waste materials like pineapple leaves, bamboo, and banana stems into sustainable fiber that helps achieve environmental goals. Banana pseudo-stems, for instance, are frequently thrown away after harvest but are high in cellulose and may be turned into biodegradable textile fiber, giving farmers additional revenue. Bamboo is helpful for numerous items because it grows rapidly, can be collected responsibly, and has strong, antibacterial fiber. Typically regarded as trash, pineapple leaves may be processed into durable, adaptable fiber for textiles and biodegradable products. Utilizing these agricultural wastes presents a significant chance for Malaysia to produce renewable fiber, cut waste, and boost regional economies [1].

Several processes involved beginning from the extraction of fiber until the non-woven processing from banana stems, bamboo, and pineapple leaves, converting agricultural waste into sustainable resources. Fiber extraction machines mechanically separate the fiber from the source while processing banana stems, producing high-quality fiber in an efficient manner. In a similar manner, the fibrous substance of bamboo is accessed by removing its outer layers, a process known as decortication [2]. These natural fibers are removed, dried, and ready to further process in non-woven punching machines. These machines create fabrics that are flexible enough to be used in medical supplies, hygiene items, and environmentally friendly packaging, including vegan leather product by bonding or entangling the fiber together without the need for traditional weaving procedures. Industries may manufacture superior non-woven materials while encouraging sustainability and reducing waste by employing these procedures [3].

The aim of this research is to systematically examine end test the extraction of fiber from banana stems, bamboo, and pineapple leaves turn it into non-woven needle punching fabrics by conducting a series of experiments, focusing on factors such as tensile strength, durability, and overall performance [4]. The research involved optimizing various parameters of the needle punching process, including needle density and porosity, to determine the ideal conditions for each type of fiber. Through rigorous testing and analysis, this study seeks to contribute valuable insights into the potential applications of these natural fibers in sustainable manufacturing, ultimately promoting innovative solutions for waste reduction and resource utilization in Malaysia's agricultural sector [5].

2. Material and method

Natural fibers from pineapple leaves, bamboo, and banana stems were employed in this study. These fibers were obtained, cleaned, and cut to standard lengths before being blended with cotton and polyester fibers to maximize the composite's qualities. A non-woven needle punching machine was used to mechanically entangle the fibers and create non-woven textiles after the prepared fiber mixes were opened, carded, and web formed. To ensure a trustworthy evaluation of the composites' structural integrity and suitability for sustainable applications, mechanical performance, including tensile and tearing strength, was assessed using a Universal Testing Machine in accordance with ISO 13934 and ASTM D2261 standards, while physical properties like thickness, density, and porosity were measured using standardized equipment.

2.1 Materials

Natural fibers from pineapple leaves, bamboo, and banana stems were chosen for their biodegradable and renewable qualities. To guarantee consistency and quality for further production, this raw fiber underwent preliminary processing, which included washing, drying, and cutting to defined lengths. According to the experimental design, the natural fiber was mixed with polyester and cotton fiber in precise ratios to improve the mechanical qualities and optimize the structure of the resultant non-woven composites. A non-woven needle punching machine was then used to treat the fiber mixes, physically entangling the fibers to create cohesive fabric structures appropriate for uses like vegan leather substitutes. Figure 1 shows three types of fibers used for this research.

(a) Bamboo fiber (b) Banana stem fiber (c) Pineapple leaf fiber

(d) Polyester fiber (e) Cotton fiber

Fig. 1 *Type of fiber*

2.2 Fiber blending

To obtain the required mechanical and physical qualities in the non-woven composites, polyester and cotton fibers are combined with natural fibers taken from pineapple leaves, bamboo, and banana stems. Using customized equipment with brad inclined apron, stripping roller, and fiber adjustment roller, the blending process started by feeding the opened fibers from storage onto a feeding apron. The equipment ran at 3 kW power and had a 60–160 kg/h capacity. A 13.25 kW carding machine that produced 100–200 kg/h then teased and blended the fibers into a homogeneous, loose fiber web. Before the needle punching procedure, this phase made sure that the fiber was homogeneous and aligned properly. To maximize the composite's structural integrity and performance for sustainable textile applications, several mix ratios were created both manually and mechanically. For example, 75% natural fiber with 25% polyester or cotton. Table 1 shows the blending material used on the needle punching machine.

Table 1 *Sample identification*

Specimen	Fiber sample				
	Banana stem fiber	Pineapple fiber	Bamboo fiber	Polyester fiber	Cotton fiber
BC			75%		25%
BP			75%	25%	
PC		75%			25%
PP		75%		25%	
NC	75%				25%
NP	75%			25%	

2.3 Needle punching machine

Needle punching is a mechanical method of producing non-woven fabrics that uses barbed, typically triangular, needles to tangle threads. These needles pierce a web of fiber in an upward and downward motion, producing a thick, cohesive fabric without the need of chemicals or adhesives. Frictional forces induce the fibers to interlock as a result. The method may alter the properties of the fabric by varying elements such as web thickness, penetration depth, and needle density. With a needle frequency of 500–650 strokes per minute, it typically yields fabric thicknesses of 3-8 mm. The YKKS Non-woven Machine at Pagoh Campus of University Tun Hussein Onn Malaysia is used in this project to create non-woven textiles using the fiber of pineapple, bamboo, and banana stems. To guarantee ideal fiber alignment and distribution before needle punching, these fiber go through standardized preparation procedures such cleaning, length-specific cutting, and carding for web development. This fiber made from agricultural waste were chosen for their mechanical strength, sustainability, and biodegradability, making them good options for vegan leather substitutes. Figure 2 shows the non-woven needle punching machine to contribute to the process of this research.

Fig. 2 *Non-woven needle punching machine*

2.4 Physical test analysis

Using mechanical thickness gauges, thickness measurement provides accurate information on the separation between two surfaces, which is crucial for guaranteeing the quality and structural soundness of non-woven composites. Mechanical methods for measuring thickness are thickness gauges devices as shows at Figure 3. A precise measurement of thickness aids in defect detection, product uniformity, and material optimization all of which are essential for production performance and safety. In addition, density testing measures the mass-to-volume ratio of the non-woven fiber samples in a controlled setting utilizing a centimeter-calibrated ruler and weighing scale. Density, which provides important information about the physical properties of bamboo, banana, and pineapple fiber composites, is measured in grams per cubic meter (g/m^3) by dividing the sample's mass by its volume. To further aid in thorough material characterisation, samples measuring 10 cm x 10 cm were used to calculate mass per unit area in accordance with ASTM D3776.

$$Density = \frac{weight\,(g)}{Area} \tag{1}$$

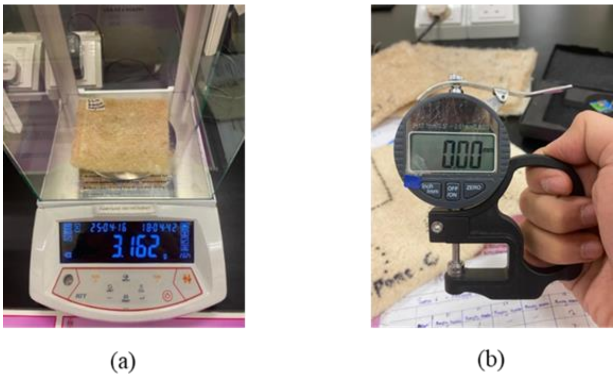

(a) (b)

Fig. 3 *(a)Weight balance and (b) thickness gauge*

2.5 Porosity measurement

A300 series Profile Projector set up at 20× magnification was used to analyse the porosity of non-woven fabric samples to look at micro-structural characteristics. This made it possible to precisely measure the number and area of pores using the machine's digital XY counter, producing two-dimensional pictures for thorough structural analysis. Porosity (P), which provides important information about the material's architectural characteristics and functional potential, was computed as P=As/Ap, where Ap stands for pore area and as for observed surface area. The porosity test on the non-woven fabric waste samples was conducted with the help of an A300 series Profile Projector machine, as illustrated in Figure 4.

$$\text{percentage of pore (\%)} = As/Ap \times 100\% \tag{2}$$

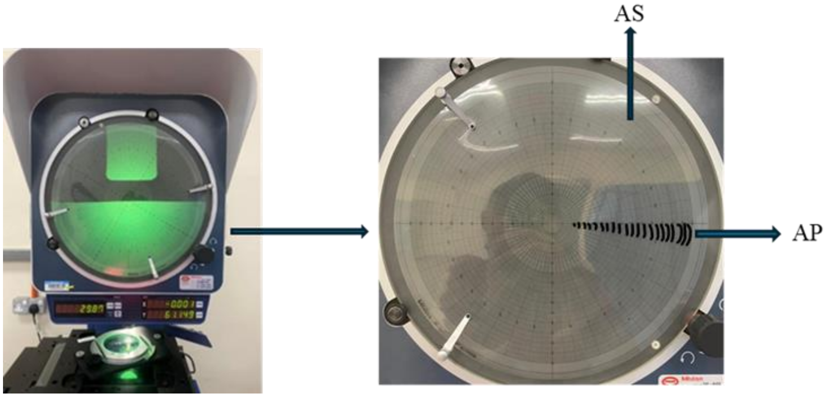


Fig. 4 *Profile projector PJ- A300 series*

2.6 Tensile and tearing test

Using a Universal Testing Machine (UTM) in accordance with ISO 13934-1 strip method standards, the tensile assessment of waste non-woven geotextile fabric was carried out. 15 cm × 2.5 cm specimens were subjected to uni-axial stress at a cross-head speed of 100 mm/min until they ruptured, at which point the highest breaking force and elongation were noted. To prevent slippage and guarantee measurement accuracy, a 100 N load-capacity UTM with pneumatic grips was used for testing at room temperature. This procedure measured the material's flexibility and tensile strength, which are essential for evaluating the structural performance of geotechnical applications as show in Figure 5. For the tearing resistance of non-woven geotextile fabrics was evaluated in accordance with ASTM D2261 using a Universal Testing Machine (UTM). Specimens were conditioned as per ASTM D1776 and cut to dimensions of 16 cm × 4 cm, with a 10 cm gauge length for gripping. Testing was performed at a cross-head speed of 100 mm/min, applying a tensile load until rupture to measure the force required to propagate a tear. Tearing strength (T) was calculated as T=F/A, where F is the maximum force (N) and A is the specimen width (m), providing a standardized metric for material durability in geotechnical applications.

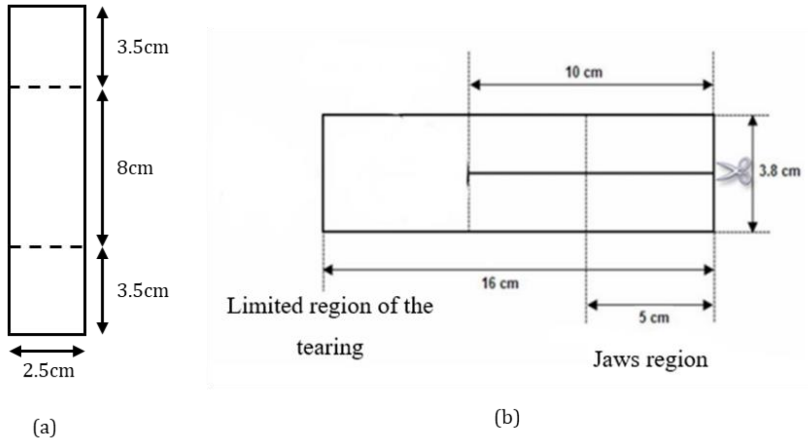


Fig. 5 *(a) Tensile sample (b) tearing sample*

3. Result and analysis

Six different non-woven fabric composites were subjected to thorough physical and mechanical characterization in this study: bamboo-cotton (BC), pineapple cotton (PC), banana-cotton (NC), bamboo-polyester (BP), pineapple polyester (PP), and banana-polyester (NP). Structural qualities, physical variables such as thickness, porosity, and mass per unit area were rigorously assessed and analyzed. Porosity, thickness, tensile behavior, and tearing resistance were the four main research groups whose data were assessed after mechanical performance was measured using tensile and tearing tests. To enable direct performance comparisons between the fiber-blend combinations, experimental data was collated into comparative tables and figures.

3.1 Physical analysis

Data for six non-woven fiber composites, showing notable differences in structural characteristics depending on the blend composition and fiber type. Measurements of thickness showed that bamboo cotton (BC) had the lowest average thickness at 1.68 mm (SD = 0.40 mm, CV% = 23.96), while banana cotton (NC) had the highest average thickness at 2.64 mm (SD = 0.81 mm, CV% = 30.84), followed by bamboo polyester (BP) at 2.20 mm (SD = 0.86 mm, CV% = 38.80). Banana polyester (NP) was 1.90 mm thick, while pineapple cotton (PC) and pineapple polyester (PP) were 2.08 mm and 2.02 mm thick, respectively. In comparison to bamboo-based composites, where BC recorded the lowest density at 236.3 g/m^2, density analysis showed that cotton-based composites, especially pineapple cotton (PC) and banana cotton (NC), displayed superior density values at 436 g/m^2 and 435.3 g/m^2, respectively. The results show that blends of cotton fiber consistently outperform blends of polyester in terms of density, indicating improved fiber packing and structural integrity in cotton-based non-woven composites. However, the coefficient of variation data shows that bamboo polyester (BP) showed the highest structural variability (CV% = 38.80%).

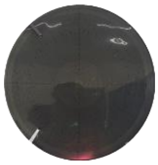
Porosity values varying from 0.16% to 6.83% across various fiber-matrix combinations, the porosity analysis showed notable structural differences among the six non-woven fiber composites as shows in Table 3 and 4. With coefficients of variation of 0.18% and 0.21%, respectively, bamboo polyester (BP) and banana cotton

(NC) showed outstanding measurement consistency, indicating superior structural uniformity and manufacturing reproducibility. On the other hand, pineapple cotton (PC) had the lowest porosity of 0.16% with remarkable consistency across samples, while banana polyester (NP) had the highest porosity at 6.83% with the highest measurement variability. The intermediate porosity values of 4.41% for bamboo cotton (BC), 4.98% for bamboo polyester (BP), and 3.81% for pineapple polyester (PP) showed moderate structural variability, with coefficients of variation ranging from 0.54% to 0.87%.

Table 3 *Thickness and porosity performance*

Designation Name	Thickness (mm)			Density (g/m2)	Porosity		
	Average	SD	CV.%		Average	SD	CV.%
BC	1.68	0.40	23.96	236.3	4.41	2.76	0.63
BP	2.20	0.86	38.80	250.6	4.98	0.92	0.18
PC	2.08	0.42	20.37	436	0.16	0.14	0.87
PP	2.02	0.49	24.36	395.6	3.81	2.16	0.57
NC	2.64	0.81	30.84	435.3	2.31	0.49	0.21
NP	1.90	0.45	23.59	316.2	6.83	3.72	0.54

Table 4 Porosity visual of different type sample

SAMPLE	BC	BP	PP	PC	NC	NP
Figure						

3.2 Tensile test

Tensile testing showed that the two composites had very different mechanical properties. Bamboo cotton (BC) broke when it reached a peak load of 2.9N at 19mm of displacement, while banana cotton (NC) was much more ductile, withstanding an 18N peak load at 23mm before slowly breaking. Pineapple cotton (PC) was moderately tough, with a peak at 2N at 13mm, but it wasn't very strong. Bamboo polyester (BP) reached a peak of 1.2N at 29mm with moderate ductility, banana polyester (NP) reached a peak of 2.1N at 27mm before breaking suddenly at 36mm, and pineapple polyester (PP) showed residual strength up to 3N at 42mm. Banana cotton did better than polyester cotton (18N vs. 2.1N peak load), and pineapple polyester did better than pineapple cotton in both peak load (3N vs. 2N) and elongation. Table 5 shows the tensile test performance.

Banana cotton (NC) showed better tensile performance, with a peak load of about 14N and a tensile stress of 220 Pa. However, both numbers varied a lot (error bars going up to 280 Pa). On the other hand, bamboo cotton (BC) and banana polyester (NP) had moderate tensile stresses of 60 Pa and 50 Pa, respectively. Pineapple cotton (PC), pineapple polyester (PP), and bamboo polyester (BP) had the lowest stresses (20–30 Pa) with little variation. Strain analysis showed that bamboo cotton (BC) and pineapple polyester (PP) were the most extensible composites, with strains over 50%. However, BC had a lot of variation, with strains ranging from 20% to 80%. Banana polyester (NP) and bamboo polyester (BP) had intermediate strain values of about 40%, while banana cotton (NC) and pineapple cotton (PC) were the least extensible at about 20% strain, with more consistency. These results in Figure 6 show that NC has very high tensile strength but not always strong structural integrity. They also show that BC and PP can stretch more when stressed.

Table 5 *Tensile test performance*

TENSILE	LOAD (N)		STRESS (Pa)		STRAIN@MAX	
	Mean	SD	Mean	SD	Mean	SD
BC	2.07	0.89	49.34	21.25	47.11	30.59
BP	1.12	0.28	20.30	5.06	40.65	19.73
PC	1.32	0.08	25.25	1.49	24.50	12.13
PP	1.47	0.17	28.69	3.25	49.63	8.81
NC	14.45	4.35	219.15	65.90	20.70	17.64
NP	3.10	0.87	65.05	18.27	41.76	11.58

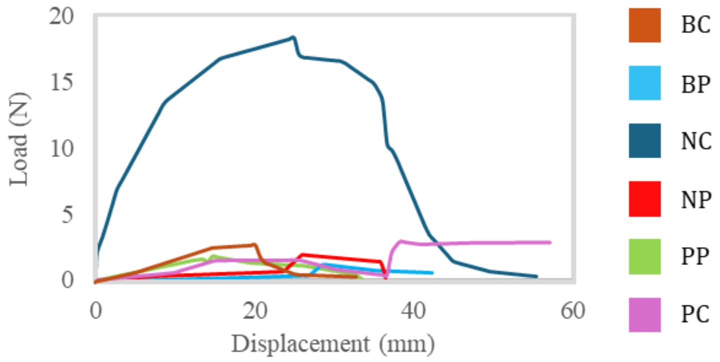


Fig. 6 *Load vs Displacement tensile test*

3.3 Tearing Test

Tearing tests showed that the composites performed differently as shows in Table 6. Banana cotton (NC) showed poorer resilience (3.2N peak at 60mm) with irregular deformation, while bamboo cotton (BC) showed strong tear resistance with a peak load of 6N at 40mm displacement but abrupt failure. Pineapple cotton (PC) demonstrated instability under stress but moderate resistance (4.2N at 40mm). At 65mm displacement, bamboo polyester (BP) and banana polyester (NP) recorded lower peak loads of 4.5N and 5.2N, respectively, for polyester-based composites, with NP exhibiting superior energy absorption. Pineapple polyester (PP) stood out with a peak load of 16.5N at 45mm, showing that it is better at resisting tears and breaking in a ductile way because of better fiber-matrix adhesion. The tearing tests showed that the composites behaved differently when they were pulled apart. Pineapple polyester (PP) had the best tear resistance, with a peak load of 20 N (error bar ±5 N) and a tearing stress of 400 Pa (error bar ±100 Pa), but it was very variable. Banana cotton (NC) had the highest strain at 143%, which was much higher than that of other composites before they broke. On the other hand, bamboo polyester (BP) and pineapple cotton (PC) had very little tearing resistance, with loads under 2 N and stresses around 10 Pa. Bamboo cotton (BC: 60 Pa stress), banana polyester (NP: 80 Pa stress, 82% strain), and pineapple polyester (PP: 80% strain) all had average performance, PC had the lowest strain (48%). Figure 7 shows Load vs Displacement tearing test.

Table 6 *Tearing test performance*

TEARING	LOAD (N)		STRESS (Pa)		STRAIN@MAX	
	Mean	SD	Mean	SD	Mean	SD
BC	2.77	0.90	66.08	21.42	76.17	13.48
BP	1.37	0.41	24.94	7.52	78.86	15.04
PC	0.98	0.75	11.24	14.47	48.00	31.39
PP	20.51	5.25	401.57	102.75	80.58	12.85
NC	2.63	0.55	39.88	8.28	144.68	45.74
NP	3.94	1.24	82.88	26.09	83.64	7.25

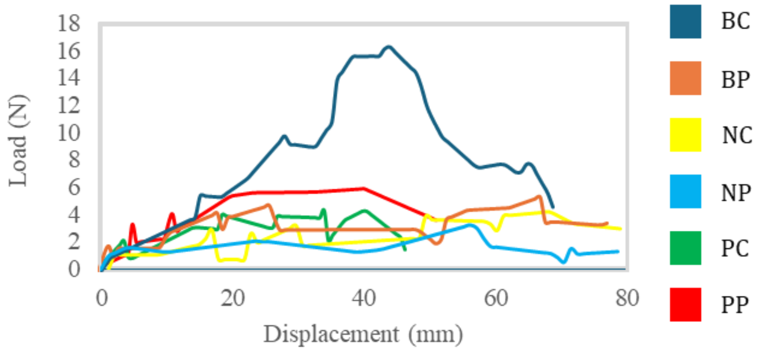


Fig. 7 *Load vs Displacement tearing test*

4. Conclusion

The great potential of non-woven textiles made from agricultural waste fiber, particularly pineapple leaves, bamboo, and banana stems, for sustainable material applications, such as vegan leather has been. The study successfully created composite materials and assessed their mechanical and physical characteristics by methodically extracting them, combining them with cotton and polyester, and then processing them using needle punching technology. The results highlight the significance of fiber selection and blend ratios in reaching desired performance characteristics, demonstrating that pineapple-polyester blends offer the highest tearing resistance and banana-cotton composites excel in tensile strength and elongation.

Cotton-based composites, especially those containing banana and pineapple fiber, have higher density and thickness, which are correlated with better mechanical properties, according to physical characterization. Significant variations in structural homogeneity were found by porosity analysis, with some blends displaying a constant pore distribution and others displaying more fluctuation. These results highlight how the type of fiber and processing parameters affect the final material's structure and suitability for different uses.

That non-woven composites made from plants can be a practical and environmentally responsible substitute for leather and traditional synthetic fabrics. The needle punching method facilitates scalable, chemical-free manufacturing in addition to the effective use of agricultural waste. To further advance the use of sustainable materials in the textile industry, future research should concentrate on improving fiber treatments and increasing the range of applications.

Acknowledgement

The research facilities and support required to conduct this study were provided by University Tun Hussein Onn Malaysia, for which the authors are truly grateful. Additionally, the authors would like to thank Bambusoideae Tech. Sdn. Bhd. for kindly providing the raw materials needed for this study.

References

[1] Syazana, N., Halem, A., Azween, M., Arbain, M., Syamira Binti Noryazid, I., Binti, A., & Musa, H. (2023a). Ideas Unleashed: The Ultimate Innovation Challenge INVENTOPIA 2023: FBM-Seremban International Innovation Competition

[2] Kopitar, D., Marasovic, P., Jugov, N., & Schwarz, I. (2022). Biodegradable Nonwoven Agrotextile and Films A Review. In Polymers (Vol. 14, Issue 11). MDPI. https://doi.org/10.3390/polym14112272.

[3] Poh Jing, T., & Hana Nasir, S. (2021). A Review Study on the Effect of Needle Punching Machine Parameters on the Filtration Efficiency of Non-woven Fabric used for Development of Face Mask. Progress in Engineering Application and Technology, 2(1), 769–778. https://doi.org/10.30880/peat.2021.02.01.073.

[4] Gonzalez, V., Lou, X., & Chi, T. (2023). Evaluating environmental impact of natural and synthetic fibers: A life cycle assessment approach. Sustainability, 15(9). https://doi.org/10.3390/su15097670

[5] Ministry of Plantation and Commodities. (2023). National Biomass Action Plan. Ministry of Plantation and Commodities.