Giarto Giarto,[1] Wiah Wardiningsih,[1] Aurilia Ika Wulandari,[1] Witri Aini Salis,[1] Resty Mayseptheny Hernawati,[1] Muhammad Iqbal Siregar,[2] Didin Wahidin[1]
[1] Politeknik STTT Bandung (Bandung Polytechnic of Textile Technology), Jalan Jakarta No. 31, Bandung 40272, West Java, Indonesia
[2] Politeknik Teknologi Kimia Industri Medan, Medan, North Sumatera, Indonesia

Development of Biodegradable Nonwoven Fabrics from *Alpinia purpurata* Pseudo-Stem Fibres Using Poly Lactic Acid Binder

Razvoj biorazgradljivih vlaknovin iz vlaken, pridobljenih iz navideznega stebla rastline Alpinia purpurata, in polimlečne kisline kot veziva

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 11–2024 • Accepted/*Sprejeto* 3–2025

Corresponding author/*Korespondenčna avtorica:*
Wiah Wardiningsih
E-mail: wiahwards@gmail.com
ORCID iD: 0000-0001-6767-3355

Abstract

This study investigates the development of biodegradable nonwoven fabrics utilizing *Alpinia purpurata* pseudo-stem fibres, bonded with poly lactic acid (PLA) through a thermal bonding process. Given the underutilization of *Alpinia purpurata* fibres, this research explores their potential for sustainable textile applications. The fibres were extracted via decortication and blended with PLA at varying mass ratios (90/10, 80/20, 70/30), followed by comprehensive characterization. Evaluations included fabric mass per unit area, thickness, air permeability, tensile strength, elongation, wetting time, moisture regain and surface morphology. The results indicate that increasing PLA content enhances tensile strength but reduces air permeability and water absorption. Conversely, a higher proportion of *Alpinia purpurata* fibres improves breathability and moisture regain. These findings demonstrate that *Alpinia purpurata* fibres, in combination with PLA, can produce nonwoven fabrics with tunable properties, offering promising potential for environmentally friendly textile applications.
Keywords: nonwoven fabrics, Alpinia purpurata pseudo-stem fibres, poly lactic acid, biodegradable binder, thermal bonding method

Izvleček

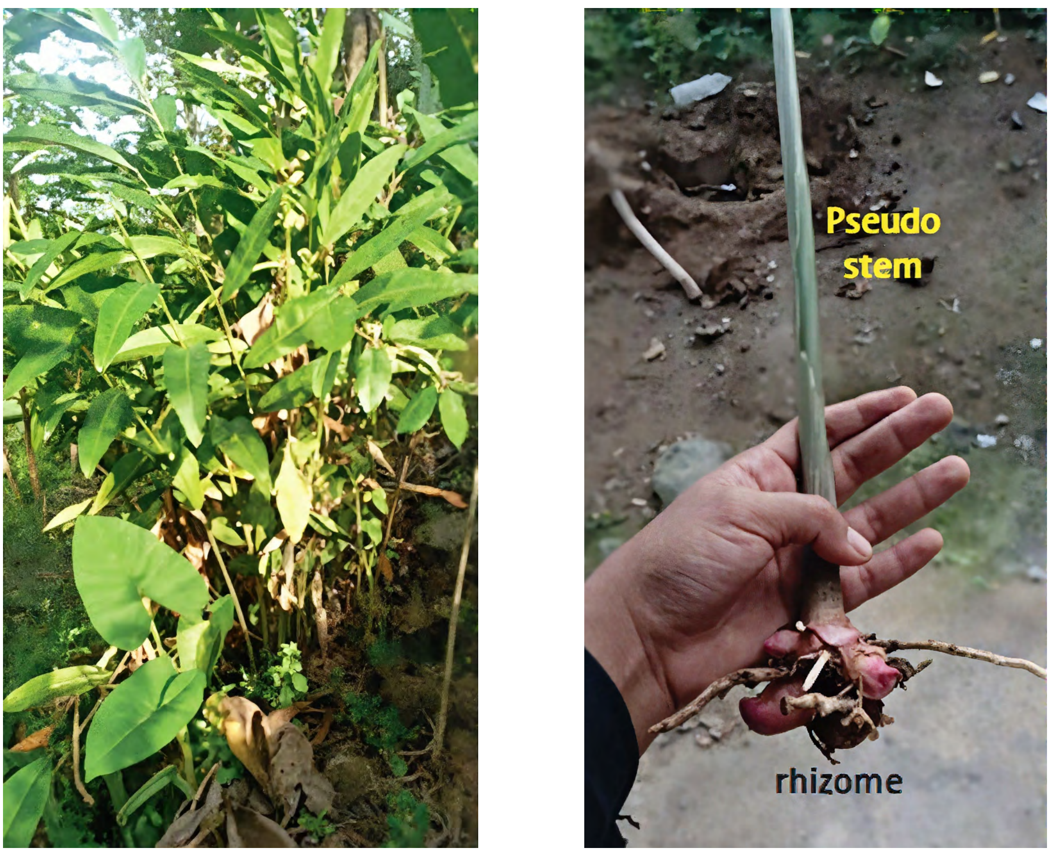
Študija zajema razvoj biorazgradljivih vlaknovin z uporabo vlaken iz navideznega stebla rdečega ingverja (Alpinia purpurata), termično utrjenih s polimlečno kislino (PLA). Glede na slabo izkoriščenost vlaken rdečega ingverja je bila v tej raziskavi proučevana možnost uporabe teh vlaken za trajnostne tekstilije. Vlakna so bila strojno ekstrahirana iz navideznega stebla in mešana v različnih masnih razmerjih s PLA (90/10, 80/20, 70/30), čemur sta sledili termična obdelava in celovita karakterizacija. Ocene so vključevale ploščinsko maso vlaknovine, debelino, zračno prepustnost, natezno

trdnost/raztezek, čas omočenja, vsebnost vlage in morfologijo površine. Rezultati kažejo, da povečanje vsebnosti PLA izboljša natezno trdnost, vendar poslabša zračno prepustnost in absorpcijo vode. Nasprotno pa večji delež vlaken Alpinia purpurata izboljša zračnost in vsebnost vlage. Ugotovitve kažejo, da iz vlaken Alpinia purpurata v kombinaciji s PLA lahko izdelajo vlaknovine načrtovanih lastnosti, kar je velik potencial za razvoj okolju prijaznih tekstilij.
Ključne besede: netkane tkanine, polilaktid, biorazgradljivo vezivo, metoda toplotnega utrjevanja

1 Introduction

The textile industry continually seeks innovative materials that provide environmental benefits along with novel functional properties. Natural fibres have become increasingly popular due to their biodegradability and sustainable nature, aligning with global trends towards environmentally friendly products [1]. Among various natural sources, pseudo-stem fibres from plants such as *Alpinia purpurata* present a promising avenue for exploration. *Alpinia purpurata* (Figure 1a) is primarily cultivated for its rhizome [2, 3]. However, the pseudo-stem, which is considered agricultural waste, remains underutilized (Figure 1b) and represents potential as a raw material for fibre production. Previous studies have successfully utilized pseudo-stem fibres from similar species in textile applications, indicating the feasibility of this approach [4].

Previous research has shown that fibres extracted from *Alpinia purpurata* pseudo-stems possess properties suitable for textile applications [5]. Tradi-



a) b)

Figure 1: a) Alpinia purpurata plant, b) rhizome and pseudo stem of Alpinia purpurata

tionally, these fibres were extracted using the water retting method, a time-consuming and labour-intensive process where plant stems are soaked in water to loosen the fibres. To improve efficiency, this study focuses on using decortication—a mechanical method that separates fibrous material from non-fibrous components—thereby enhancing the extraction process. Decorticators play a crucial role in fibre production by improving the efficiency and quality of extracted fibres. This mechanical method, widely applied to other fibres such as flax and hemp, allows for efficient fibre extraction without the need for the labour-intensive retting processes [6].

The development of nonwoven fabrics using natural fibres is an area of significant interest due to their wide range of applications, from geotextiles to hygiene products [7-9]. Nonwoven fabrics are preferred for certain applications due to their adaptability, cost-effectiveness, and high-speed manufacturing compared to traditional woven fabrics. The integration of bio-based polymers such as poly lactic acid (PLA) in nonwoven fabric production further enhances their environmental appeal, as PLA is known for its biodegradability and is derived from renewable resources [10-13].

The conversion of agricultural byproducts such as *Alpinia purpurata* pseudo-stems into useful materials aligns with sustainable development principles, particularly reduction, reuse and recycling [14]. Natural fibres from agricultural waste, such as banana stems, pineapple leaves and coconut coir, are increasingly recognized for their mechanical properties, low density and renewability [15].

Recent advancements in sustainable textile production have explored non-traditional fibrous plants, leading to the development of innovative textile products. For example, fibres from plants such as *Furcraea foetida, Cordyline australis,* and *Etlingera elatior* have shown potential in creating new raw material for textiles [16-18]. Similarly, *Alpinia purpurata* pseudo-stem fibres could be utilized as a sustainable raw material, thereby contributing to the reduction of environmental impacts.

The production of nonwoven fabrics, known for their versatility and cost-effectiveness, often involves thermal bonding techniques. Thermal bonding involves the application of heat to a thermoplastic component, which can exist in the form of fibres, powders, films or melts. The heat causes the thermoplastic material to become viscous or melt, enabling it to flow to fibre crossover points where bonding regions are formed and solidify upon cooling. These bonds, primarily mechanical or adhesive, arise from physical interactions at the interface between different materials. The resulting thermally bonded fabrics can be composed entirely of thermoplastic materials or blends that include non-thermoplastic fibres [19]. The binder, typically representing 5–50% of the total weight, significantly affects a fabric's properties, such as tensile strength, flexibility and biodegradability. The remaining 50–95% consists of base fibres, which are crucial in determining a fabric's final characteristics. Commonly used base fibres include natural fibres, synthetic fibres and mineral fibres. Thermal bonding is preferred for its economic and environmental benefits, and for its ability to produce recyclable and sustainable textile products [19].

The research problem centres on the utilization of *Alpinia purpurata* pseudo-stem fibres for nonwoven fabric production, a domain that has not been extensively studied. The primary challenge is determining the mechanical and physical properties of these fibres and understanding their behaviour when combined with a thermal bonding method using PLA as a binder. The hypothesis suggests that nonwoven fabrics can be developed from decorticated *Alpinia purpurata* pseudo-stem fibres that meet the functional requirements for textile applications, necessitating a thorough investigation of fibre characteristics and fabric performance [5, 20].

The general solution involves a novel approach using the thermal bonding technique to create nonwoven fabrics. Thermal bonding is widely recognized for its effectiveness in bonding fibres through heat application, eliminating the need for additional weaving or knitting processes [19]. This method is particularly suitable for preserving the structural integrity of delicate pseudo-stem fibres, as it minimizes mechanical stress that could degrade their physical properties. The selection of PLA as a biodegradable binder further enhances the sustainability of a fabric, aligning with previous studies that highlight its role in improving fibre cohesion while maintaining biodegradability [20]. Consequently, the combination of thermal bonding and PLA offers a promising pathway for developing environmentally friendly nonwoven fabrics with potential applications in the textile industry [20].

Thermal bonding is a well-established method in nonwoven fabric production, and is particularly advantageous for blending synthetic and natural fibres [19, 21]. It involves the application of heat and pressure to bond fibre webs, often using biopolymers such as PLA as binders [19, 21]. This method is ideal for *Alpinia purpurata* fibres, as it preserves their natural properties while ensuring adequate bonding and structural integrity [20].

Although extensive research has been conducted on nonwoven fabrics derived from natural fibres such as banana and hemp, a significant gap remains in studies specifically examining *Alpinia purpurata* pseudo-stem fibres. While previous literature has highlighted the potential of various pseudo-stem fibres for nonwoven fabric applications, the unique properties and performance of *Alpinia purpurata* fibres in this context remain unexplored. This gap in research limits the understanding of how these fibres interact with biodegradable binders such as PLA during the thermal bonding process. Addressing this knowledge gap is crucial to expanding scientific insights into the feasibility, structural characteristics and sustainability of *Alpinia purpurata*-based nonwoven fabrics, thereby unlocking new opportunities for eco-friendly textile applications.

Despite the promising potential of *Alpinia purpurata* fibres, research regarding their application in nonwoven fabric production remains scarce, particularly in combination with biodegradable binders such as PLA. To date, no scholarly studies have explored the development of nonwoven fabrics using decorticated *Alpinia purpurata* fibres, or evaluated their structural and mechanical properties. This study seeks to fill this gap by investigating the feasibility of utilizing *Alpinia purpurata* fibres in nonwoven fabric applications using the thermal bonding method.

This study aims to bridge the research gap by examining the properties of nonwoven fabrics produced from *Alpinia purpurata* pseudo-stem fibres, utilizing the thermal bonding method with PLA as a biodegradable binder. Unlike previous studies that have focused on other natural fibres such as banana and hemp, no prior research has specifically investigated *Alpinia purpurata* fibres for nonwoven applications. The novelty of this research lies in the introduction of *Alpinia purpurata* as a new natural fibre source in textile technology, thereby contributing to the development of sustainable and eco-friendly textile products.

2 Materials and methods

The production and characterization of nonwoven fabrics from *Alpinia purpurata* fibres and PLA involve several key steps, as illustrated in Figure 2. These steps include the harvesting of the stems, fibre decortication, fibre drying, PLA powder preparation and the blending of PLA with the fibres. The fabricated nonwoven fabrics were then subjected to various characterization tests to evaluate their mass per unit area, thickness, air permeability, tensile strength, wetting time and moisture regain. The process flow highlighted in Figure 2 provides a comprehensive overview of the methodology used to develop these fabrics and assess their performance characteristics.

2.1 Materials

Alpinia purpurata stems (Figure 3a) were harvested from Bogor city, West Java, Indonesia. These stems were approximately 10–12 months old and had reached a height of 1–2 meters. Polylactic acid

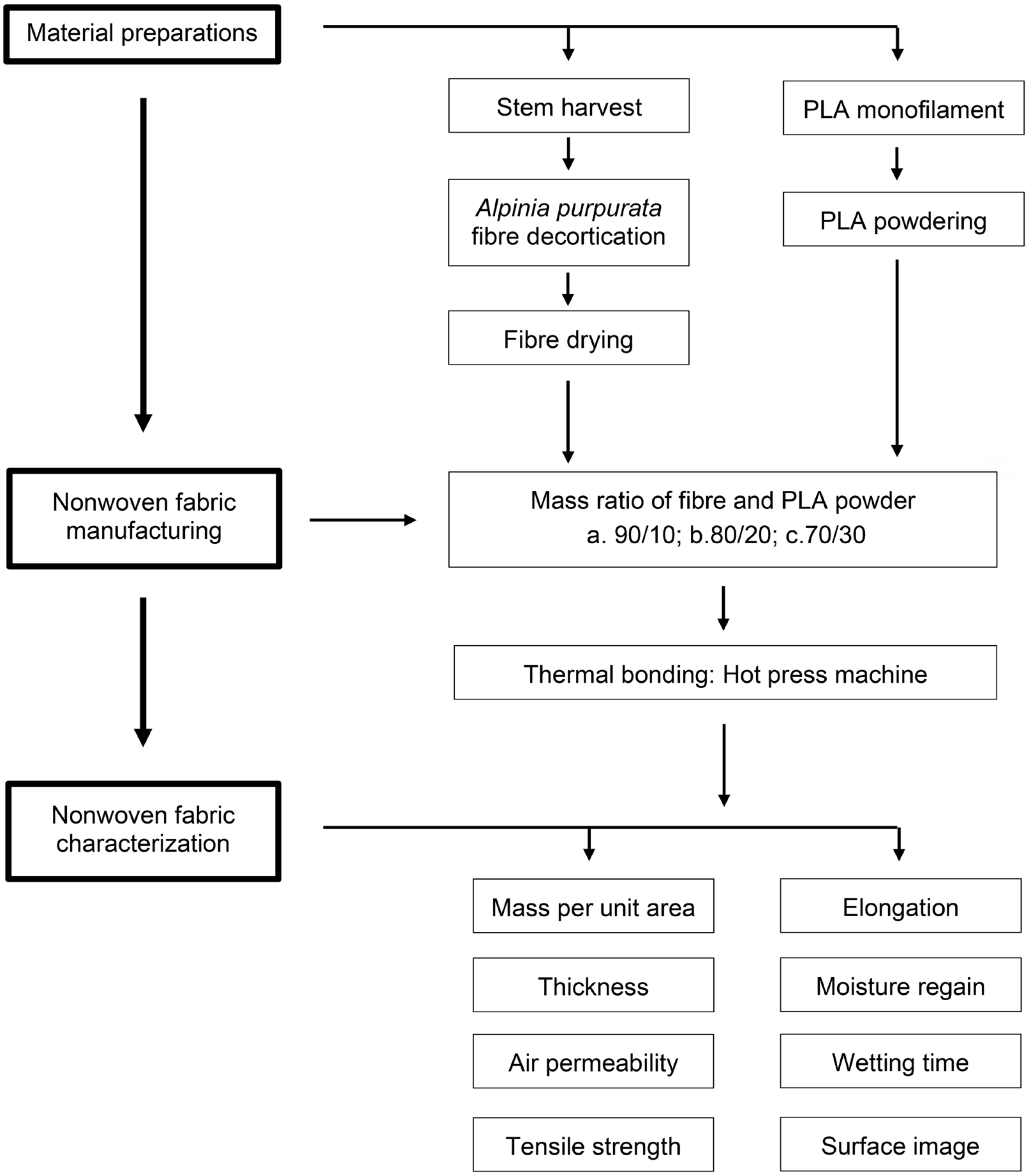


Figure 2: Process steps in the fabrication and characterization of nonwoven fabrics made from Alpinia purpurata fibres and PLA

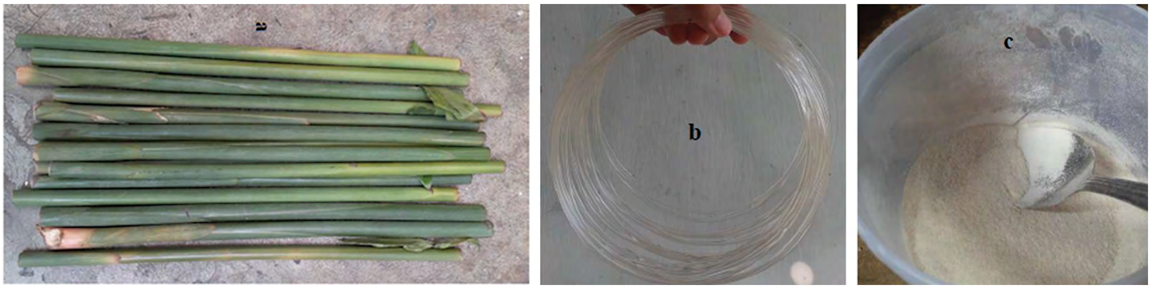
(PLA) powder was used as the binding agent due to its biodegradable properties and compatibility with natural fibres. The PLA powder (Figure 3c) was derived from 100% polylactic acid monofilament fibres (Figure 3b), which were powdered using a blender.

2.2 Methods

2.2.1 Fibre extraction

Alpinia purpurata fibres were extracted from the plant's stems through the decortication process, which involves different methods with decortication being a common mechanical process used for this purpose. Decortication helps separate valuable bast fibres from plant stems by breaking down components such as pectin, lignin, and hemicellulose [6]. This process is essential for obtaining high-quality raw materials for further processing [22].

Fibre extraction was performed using a decorticator machine, as shown in Figure 4. The minimum fibre length to be processed using the decorticator



a) b) c)

Figure 3: a) Alpinia purpurata pseudo stem, b) poly lactic acid monofilament, c) poly lactic acid powder

machine is 60 cm. Therefore, after harvesting, the stems were cut into 60–80 cm lengths. After decortication, the fibres were dried in the shade by aerating them and turning them upside down to ensure they dried quickly and evenly without exposure to direct sunlight. The dried fibres were then ready to be processed into nonwoven fabric.

Figure 4: Fibre extraction process using decorticator

2.2.2 Nonwoven fabric production

The nonwoven fabric was produced using a hot press machine (Figure 5a) under the following conditions: a temperature of 190ºC, a pressure of 40 psi, a pressing time of 30 s and a sample size of 30 cm x 30 cm. The fabric was produced by varying the fibre composition and PLA powder content. The mass ratios of *Alpinia purpurata* fibres to PLA powder used were 90/10, 80/20 and 70/30. This study focused on the production of nonwoven fabric rather than composite materials. According to the literature [19], materials with a binder content of less than 50% are classified as nonwoven fabrics, while those with a binder content exceeding 50% are considered composites. In this study, the binder content was maintained below 50%, ensuring that the final product was categorized as nonwoven fabric.

Nonwoven fabric production involved planning the fabric mass per area, taking into account fibre availability. PLA powder was prepared as the binding material, and the fibres and PLA powder were weighed according to predetermined weights. The fibres were sprayed with water to maintain the position of the PLA powder and prevent it from falling to the bottom layer when sprinkled. The PLA powder was evenly distributed on the bottom, middle and top layers of the fibres. This mixture was placed on a 30 cm x 30 cm baking tray (Figure 5b) lined with Teflon paper to prevent sticking to the tray and the top press plate. The temperatures of the top and bottom plates were set to 190 °C. The pressing pressure was adjusted to 40 psi, while the pressing time was set to 30 s. After pressing, the Teflon paper containing the nonwoven fabric was removed and the fabric sample was cooled at room temperature. This process was repeated for subsequent samples. Finally, the nonwoven fabric was ready for testing (Figure 6).

2.2.3 Characterization of nonwoven fabrics

Fabric mass testing: The fabric mass test complied with the Indonesian National Standard SNI ISO 3801:2010 (Testing Method for Fabric Mass per Unit Length and Area).

Fabric thickness testing: This testing adhered to the Indonesian National Standard SNI ISO 5084:2010

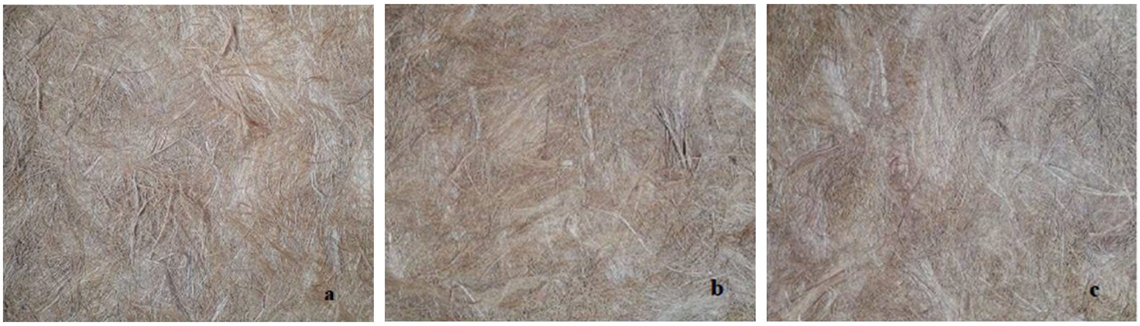
a) b) c)

Figure 5: a) Hot press machine, b) preparation of Alpinia purpurata fibre and PLA powder in baking tray, c) pressing process

(Testing Method for Textile and Textile Product Thickness). The fabric thickness was measured using a thickness gauge tester.

Air permeability testing: Air permeability testing was conducted according to Indonesian National Standard SNI 7648:2010 (equivalent to ISO 9237 1995 - Textiles — Determination of the permeability of fabrics to air) using the Textest FX 3300 air permeability tester. Test samples with a surface area of 20 cm² were evaluated under a pressure drop of 100 Pa. The results were expressed in mm/s.

Tensile strength and elongation testing: Tensile strength and elongation testing were performed using a Tensolab tensile strength tester, following Indonesian National Standard SNI 08-0276:2009 (Testing Method for Tensile Strength and Elongation of Fabrics). The test sample, measuring 10 cm x 20 cm, was mounted on the machine with a grip distance of 7.5 cm between two clamps. The procedure for the tensile and elongation strength test was as follows: First, the test sample was prepared. Next, the sample was mounted on the machine, ensuring a grip distance of 7.5 cm. The pulling speed was set to 300 mm/min. The machine was then operated to pull the test sample, while the test was stopped by pressing the OFF button once the pulling process was completed. The sample was released from the clamps by pressing the pressure pedal to open the clamps.



a) b) c)

Figure 6: Experimental nonwoven fabric with different ratios of Alpinia purpurata fibre and PLA powder: A) 90/10, B) 80/20, C) 70/30

The results of the tensile and elongation strength test were displayed on the Tensolab software, which was connected to a computer linked to the tensile strength tester.

Moisture regain testing: Moisture regain testing followed the Indonesian National Standard SNI 8100:2015 (Testing Method for Moisture Content and Moisture Regain) protocol. The procedure involved heating a weighing bottle in an oven at 110 °C, cooling it in a desiccator and then weighing it. The sample was subsequently heated and weighed to determine the air-dry and oven-dry weights. Actual moisture regain was determined using equation 1 and theoretical moisture regain was determine using equation 2 [23].

$$Moisture\ regain\ (MR) = \frac{W}{D}\ x\ 100\ (\%) \quad (1),$$

where W represents the mass of water present in the material and D represents the oven dry mass of material.

$$Moisture\ regain\ of\ blended\ fabric = \frac{(\%A)(Ra)+(\%B)(Rb)+\ ...}{\%A+\%B+\ ...}(\%) \quad (2),$$

where %A represents a percentage of fibre A in dry state in the blended fabric, %B represents a percentage of fibre B in dry state in the blended fabric, *Ra* represents moisture regain of fibre A (%) and R_b represents moisture regain fibre B (%).

Wetting time testing (relevant to water absorption): Water absorption testing was conducted using the water drop method, in accordance with Indonesian National Standard SNI 0279:2013 (Testing method for water absorption of textile materials). The procedure began with the preparation of the nonwoven fabric sample to be tested, which was then conditioned in a standard testing room. Next, the burette was filled with water and a stand or three-legged support was positioned beneath the burette. The fabric sample was placed on top of the support at a distance of (10 ± 1) mm from the burette. One drop of water was then released onto the surface of the stretched fabric sample and the stopwatch was started as soon as the water drop touched the sample. The recorded time was the duration it took for the reflection of the water drop on the fabric to disappear, known as the wetting time. If the reflection remained after 60 s, the wetting time was considered to be greater than 60 s.

Surface image: The images of nonwoven fabrics were obtained using a Phenom ProX G6 Desktop SEM at a magnification of 800× and an accelerating voltage of 15 kV.

Statistical analysis: Statistical analysis was performed using one-way analysis of variance (ANOVA) to identify significant differences between the mean values of various fabric samples. The significance level was set at 0.05, followed by a post hoc test.

3 Results and discussion

3.1 Fabric mass

Figure 7 illustrates the mass per unit area (g/m²) of three types of experimental nonwoven fabrics (A, B and C). Each fabric type exhibits similar mass values, averaging approximately 550 g/m². The chart indicates that variations among the groups are minimal. This observation is further supported by the ANOVA test results, which yielded a p-value of 0.99. This p-value confirms that there is no statistically significant difference in mass per unit area among the three fabric groups (A, B and C) at a 5% significance level ($\alpha = 0.05$).

The analysis from both the bar chart and ANOVA test results suggests that the composition of *Alpinia purpurata* fibres and PLA powder as a binder (A: 90/10, B: 80/20 and C: 70/30) does not significantly impact the mass per unit area of the nonwoven fabrics. Furthermore, the predetermined target mass of approximately 550 g/m² was consistently achieved across all three compositions. These findings indicate that the blending process successfully maintained uniform fabric mass, regardless of the variations in the fibre-to-binder ratio. This consistency can be attributed to the fact that the mass per unit area was pre-established and the mass ratio of fibre to PLA was carefully controlled and predetermined. Additionally, the manufacturing process strictly followed established protocol, ensuring that the target mass per unit area and fibre-to-binder ratio were adhered to with minimal variation. Moreover, precise control over the amounts of fibres and PLA powder during the preparation phase likely contributed to the uniformity in the final fabric weight. The lack of significant differences in mass per unit area further suggests that the thermal bonding process applied during manufacturing did not cause any significant changes to the overall fabric weight, even with varying compositions of fibres and binder.

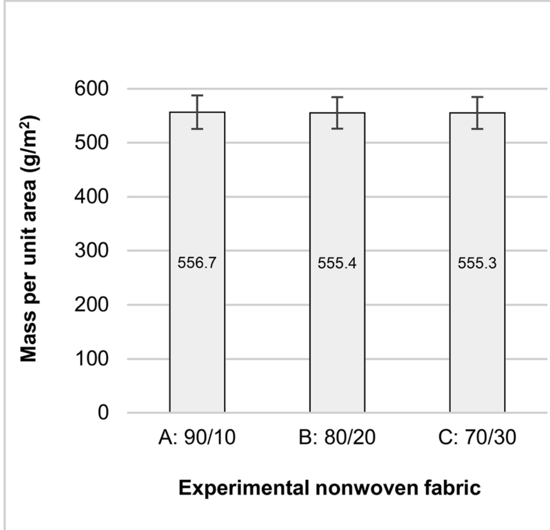


Figure 7: Mass of experimental nonwoven fabric with different ratio of Alpinia purpurata fibre and PLA powder: A) 90/10, B) 80/20, C) 70/30

3.2 Fabric thickness

Figure 8 illustrates the thickness of nonwoven fabrics composed of *Alpinia purpurata* fibres and PLA powder. The ANOVA test results indicate that there are no statistically significant differences in fabric thickness, as the p-value is greater than the 0.05 significance level. These results suggest that variations in the composition of *Alpinia purpurata* fibres and PLA do not significantly influence the thickness of the nonwoven fabrics. Despite differences in fibre composition, the thickness measurements remain relatively consistent across all fabric types. This consistency can be attributed to the fact that the fabrication process used the same pressing pressure (40 psi) for all samples. As the pressure is uniform across all compositions, the resulting thickness is likely to be consistent, as the mechanical force applied during the pressing process is equal for all fabric types. Additionally, the thermal bonding process does not significantly alter the fabric's thickness, as it serves primarily to bond the fibres together without causing substantial compression. The pre-established target mass per unit area and the fixed fibre-to-binder ratio also play a role in maintaining consistent thickness, as these parameters guide the fabric formation without significantly influencing thickness variations.

The study demonstrates that the thickness of nonwoven fabrics composed of *Alpinia purpurata* and PLA remains uniform, regardless of the specific blend ratios tested. This finding is particularly important for applications requiring consistent fabric thickness and provides valuable insight into the structural characteristics of nonwoven fabrics with different fibre compositions.

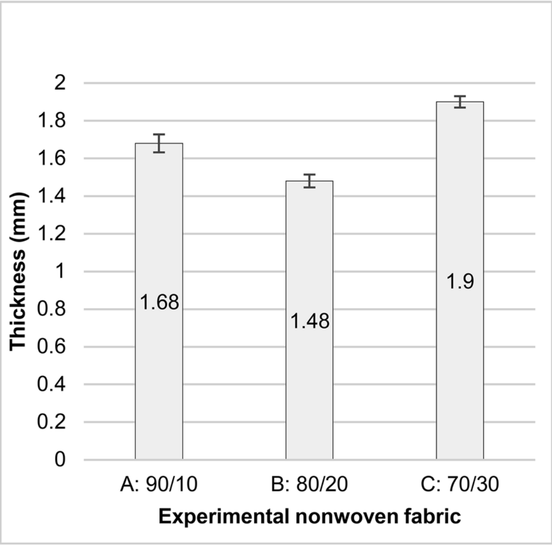


Figure 8: Thickness of experimental nonwoven fabric with different ratio of Alpinia purpurata fibre and PLA powder: A) 90/10, B) 80/20, C) 70/30

3.3 Air permeability

Figure 9 illustrates the air permeability of nonwoven fabrics composed of *Alpinia purpurata* fibres and PLA powder. Significant differences in air permeability were observed among the three fabric compositions, with Fabric A (90/10) showing the highest air permeability, followed by Fabric B (80/20) and Fabric C (70/30). Specifically, the mean air permeability for Fabric A was approximately 200 mm/s, around 180 mm/s for Fabric B and about 160 mm/s for Fabric C. These results suggest that fabrics with higher proportions of *Alpinia purpurata* fibres allow air to pass through more effectively.

The ANOVA test yielded an F-statistic of approximately 5.948 and a p-value of 0.0062, confirming that the differences in air permeability among the three fabric types are statistically significant at a 0.05 significance level. This indicates that the observed variation in air permeability is due to differences in the fabric composition, particularly the relative proportions of *Alpinia purpurata* fibres and PLA powder.

These findings suggest that Fabric A, with its 90/10 composition, is the most breathable among the three, while Fabric C (70/30) is the least breathable. This trend can be attributed to the role of PLA in the fabric formation process. As the proportion of PLA increases, air permeability decreases. This is likely due to the melting of PLA during the manufacturing process, which forms a denser structure that obstructs airflow. PLA, being hydrophobic and prone to melting under heat, fills the gaps between fibres more extensively, reducing the overall porosity of the fabric and, thus, its ability to allow air to pass through.

These results underscore the significant impact of fibre composition on the breathability of nonwoven fabrics. A higher proportion of *Alpinia purpurata* fibres maintains more open spaces between fibres, facilitating air flow, while increased PLA content creates more compact and less permeable structures. These insights provide a valuable foundation for optimizing fabric compositions to achieve specific breathability characteristics tailored to particular applications, especially in textiles where air permeability is a crucial factor.

3.4 Tensile Strength

Figure 10 illustrates the tensile strength of nonwoven fabrics composed of *Alpinia purpurata* fibres and PLA powder. Significant differences in tensile strength were observed among the three fabric compositions. Specifically, Fabric C (70/30) exhibited the highest tensile strength, followed by Fabric B (80/20) and Fabric A (90/10). The mean tensile strength for Fabric C was approximately 500 N, around 400 N for Fabric B and about 300 N for Fabric A. These results suggest that fabrics with higher PLA content possess greater tensile strength.

The ANOVA test yielded a p-value of 0.000131, confirming that the differences in tensile strength

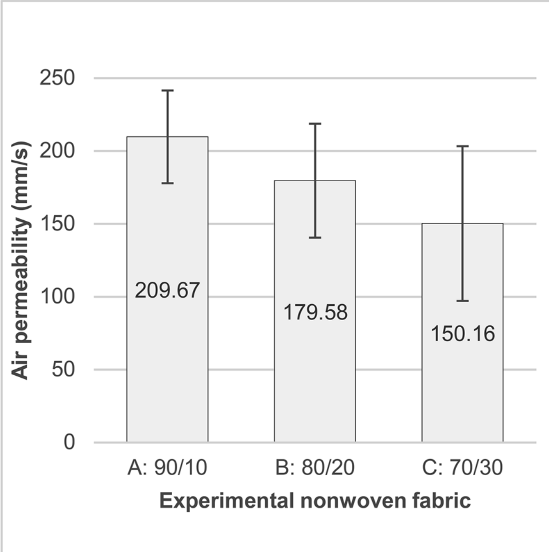


Figure 9: Air permeability of experimental nonwoven fabric with different ratio of Alpinia purpurata fibre and PLA powder: A) 90/10, B) 80/20, C) 70/30

among the fabric types were statistically significant at a 0.05 significance level. This indicates that the variations in fabric composition (specifically the proportion of PLA) have a meaningful impact on the fabric's mechanical properties. This trend can be attributed to the role of PLA in the fabric formation process. PLA is a thermoplastic material, meaning it melts under heat. During the manufacturing process, PLA melts and forms stronger bonds with the fibres, reinforcing the structure of the fabric. As the proportion of PLA increases, more bonding sites are available, which increases the overall strength of the fabric. This process of bonding through thermal fusion leads to improved cohesion between the fibres, resulting in a fabric that can withstand greater forces before breaking. Consequently, fabrics with higher PLA content, such as Fabric C (70/30), exhibit superior tensile strength.

These findings clearly demonstrate how the varying compositions of *Alpinia purpurata* fibres and PLA powder affect the tensile strength of the nonwoven fabrics. A higher proportion of PLA enhances tensile strength by increasing inter-fibre bonding, while an increased proportion of *Alpinia purpurata* fibres leads to lower tensile strength. This is likely due to the reduced bonding strength between the fibres when there is less PLA present to act as a binder, making the fabric more prone to failure under stress.

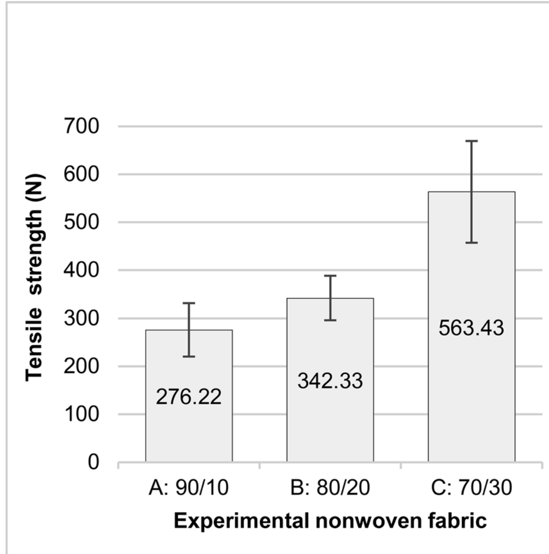


Figure 10: Tensile strength of experimental nonwoven fabric with different ratio of Alpinia purpurata fibre and PLA powder: A) 90/10, B) 80/20, C) 70/30

3.5 Elongation

Figure 11 illustrates the elongation of nonwoven fabrics composed of *Alpinia purpurata* fibres and PLA powder. Based on the graph and ANOVA test results, no significant differences in elongation were observed among the three fabric compositions. The mean elongation percentages for the fabrics were approximately 3.2% for Fabric A, 3.1% for Fabric B and 3.4% for Fabric C.

The ANOVA test results, with a p-value of 0.26, confirm that the differences in elongation among the fabric types are not statistically significant at a 0.05 significance level. Additionally, the post-hoc Tukey HSD test showed no significant differences between any pairs of fabric groups, reinforcing the conclusion that variations in fibre-to-PLA composition do not substantially affect elongation. This suggests that factors such as the ratio of *Alpinia purpurata* fibres to PLA powder do not significantly alter the fabric's ability to stretch under stress.

This uniformity in elongation can be attributed to the fact that elongation is largely dependent on the overall fibre network structure and the mechanical properties of the fibres themselves, rather than on the composition of the binder. PLA, being a thermoplastic polymer, provides some flexibility when bonded with the fibres. However, since the thermal bonding process is controlled and the PLA content does not vary drastically between the fabric types, the overall elongation behaviour remains relatively unchanged. The consistent fibre network created during the manufacturing process likely allows for similar stretchability across the different fabric compositions, despite variations in the fibre-to-PLA ratio.

These results indicate that the elongation properties of the fabrics remain consistent regardless of the specific ratio of fibres to PLA in the composition. This uniformity in elongation is beneficial in applications where consistent stretchability is required, such as in certain medical or protective textiles, as the fabric will perform similarly regardless of slight variations in the fibre and binder composition.

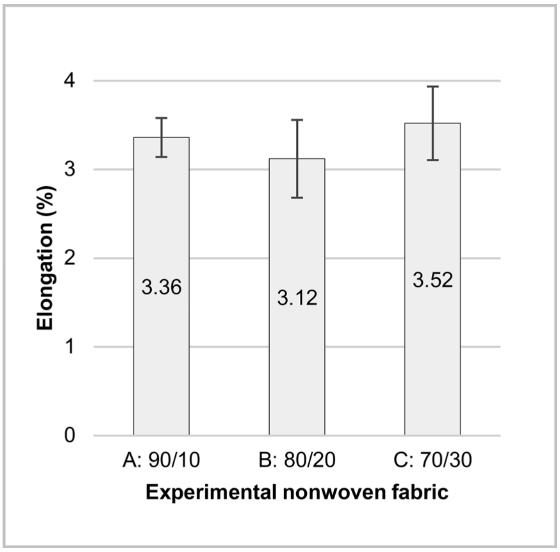


Figure 11: Elongation of experimental nonwoven fabric with different ratio of Alpinia purpurata fibre and PLA powder: A) 90/10, B) 80/20, C) 70/30

3.6 Wetting time

Figure 12 illustrates the wetting time of nonwoven fabrics composed of *Alpinia purpurata* fibres and PLA powder. Significant differences in wetting time were observed among the three fabric compositions. Fabric C (70/30) exhibited the longest wetting time, followed by Fabric B (80/20) and Fabric A (90/10). Specifically, the mean wetting time for Fabric C was approximately 90 s, for Fabric B around 80 s, and for Fabric A about 70 s. These results suggest that fabrics with higher PLA content require more time to wet. The ANOVA test yielded a p-value of 0.0499, confirming that the differences in wetting time among the three fabric types are statistically significant at a 0.05 significance level.

The trend observed can be attributed to the hydrophobic nature of PLA. PLA is a hydrophobic material, meaning it repels water rather than absorbing it. As the proportion of PLA in the fabric increases, the fabric's ability to absorb water decreases, leading to a longer wetting time. This resistance to wetting is particularly evident in Fabric C (70/30), which has the highest proportion of PLA and thus demonstrates the slowest water absorption. Conversely, Fabric A (90/10), with a higher proportion of *Alpinia purpurata* fibres, is more hydrophilic, allowing water to be absorbed more quickly, resulting in a shorter wetting time. The *Alpinia purpurata* fibres, being more water-absorbent than PLA, allow for quicker wetting and faster water absorption.

This study highlights the significant influence of fibre composition on the wetting properties of nonwoven fabrics. As the proportion of PLA increases, the fabric becomes more hydrophobic, leading to longer wetting times. On the other hand, increasing the proportion of *Alpinia purpurata* fibres enhances the fabric's hydrophilicity, resulting in shorter wetting times. These insights are valuable for optimizing fabric compositions to achieve specific wetting characteristics required for various applications.

3.7 Moisture regain

Figure 13 illustrates the moisture regain of nonwoven fabrics composed of *Alpinia purpurata* fibres

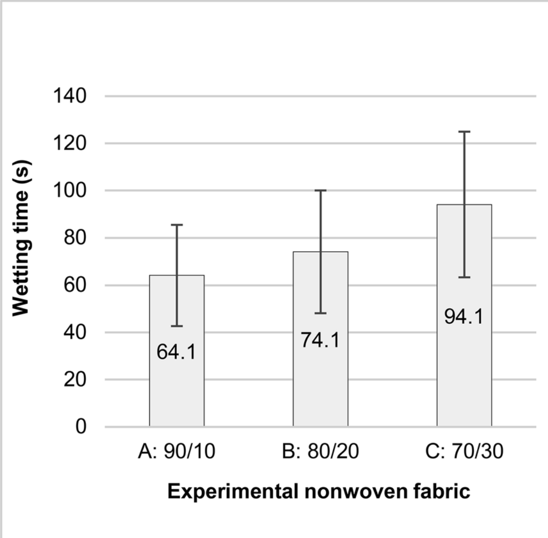


Figure 12: Wetting time of experimental nonwoven fabric with different ratio of Alpinia purpurata fibre and PLA powder: A) 90/10, B) 80/20, C) 70/30

and PLA powder. The moisture regain properties were analysed based on both experimental results and theoretical calculations. The graph presents laboratory-measured and theoretically calculated moisture regain values for three fabric compositions: Fabric A (90/10), Fabric B (80/20) and Fabric C (70/30). The results show strong correlation between experimental and theoretical values, particularly for Fabrics A and B. Fabric A, with the highest proportion of *Alpinia purpurata* fibres, exhibited the highest moisture regain, while Fabric C, with the highest PLA content, demonstrated the lowest moisture regain.

The theoretical calculations were performed using a formula that accounts for the individual moisture regain properties of *Alpinia purpurata* (11.97%) and PLA (0.4%), weighted by their respective proportions in the fabric. The close correlation between theoretical and experimental results for Fabrics A and B validates the reliability of this formula in predicting the moisture regain behaviour of these blended fabrics.

However, a slight discrepancy was observed in Fabric C, where the laboratory-measured moisture regain was marginally lower than the theoretical prediction. This variation can be attributed to several factors, such as experimental uncertainties, differences in fibre interactions at higher PLA concentrations or potential variations in measurement conditions. For example, PLA, being hydrophobic, may not interact as effectively with water as *Alpinia purpurata* fibres, leading to slightly less moisture absorption than expected in the fabric with a higher PLA ratio. Additionally, the high PLA content may result in a less open structure and fewer spaces for water absorption.

Despite this minor deviation, the overall trend remains clear: fabrics with higher *Alpinia purpurata* content show greater moisture regain, while those with higher PLA content exhibit lower moisture regain. This is due to the higher water-absorbing capacity of *Alpinia purpurata* fibres compared to PLA, which resists water absorption due to its hydrophobic nature. Therefore, fabrics with a higher proportion of *Alpinia purpurata* fibres tend to absorb more moisture.

These findings highlight the significant influence of fibre composition on the moisture regain properties of nonwoven fabrics. The strong correlation between theoretical and experimental data provides a solid framework for predicting the moisture regain characteristics of these materials.

3.8 Surface image

Figure 14 presents SEM images of the experimental nonwoven fabric at 800× magnification, captured from two distinct locations. In Figure 13a, the fibres and the PLA binder, which has melted and re-solidified on the fibres, are visible. Initially in powder form, the PLA melts and subsequently bonds the fibres together. Due to the low binder content—comprising 10% PLA and 90% fibres—the presence of PLA melt is minimal in Figure 14a.

In contrast, Figure 14b exhibits a slightly greater amount of PLA melt compared to Figure 13a, corresponding to an increased PLA composition of 20%, while the fibres remain discernible. Finally, Figure 14c shows a substantial increase in PLA melt, nearly

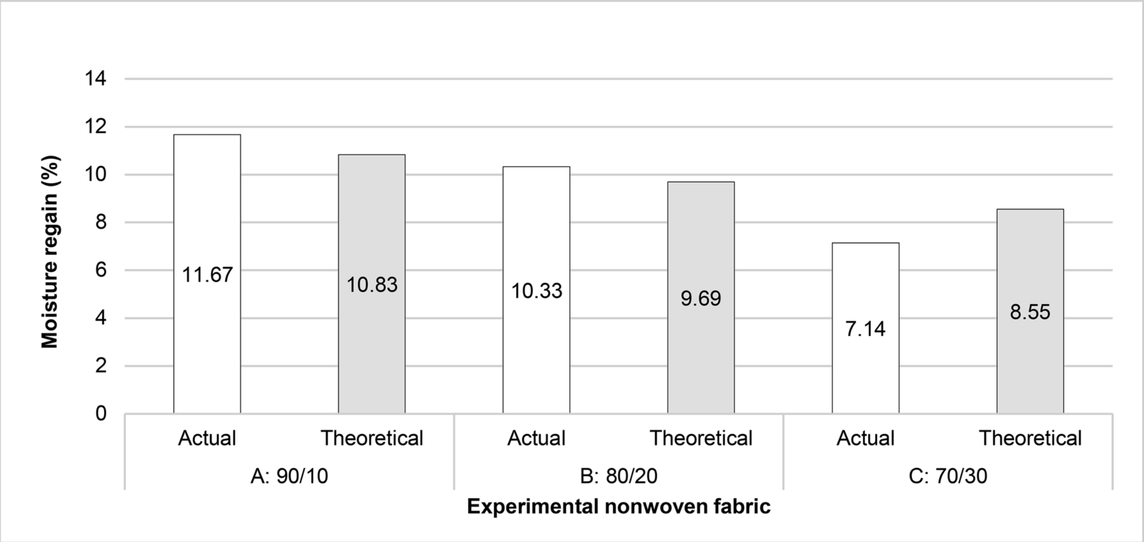


Figure 13: Moisture regain of experimental nonwoven fabric with different ratio of Alpinia purpurata fibre and PLA powder: A) 90/10, B) 80/20, C) 70/30

covering the entire surface at 800× magnification, with only a small fraction of the fibres remaining visible. This is attributed to the highest PLA content among the samples, at 30%.

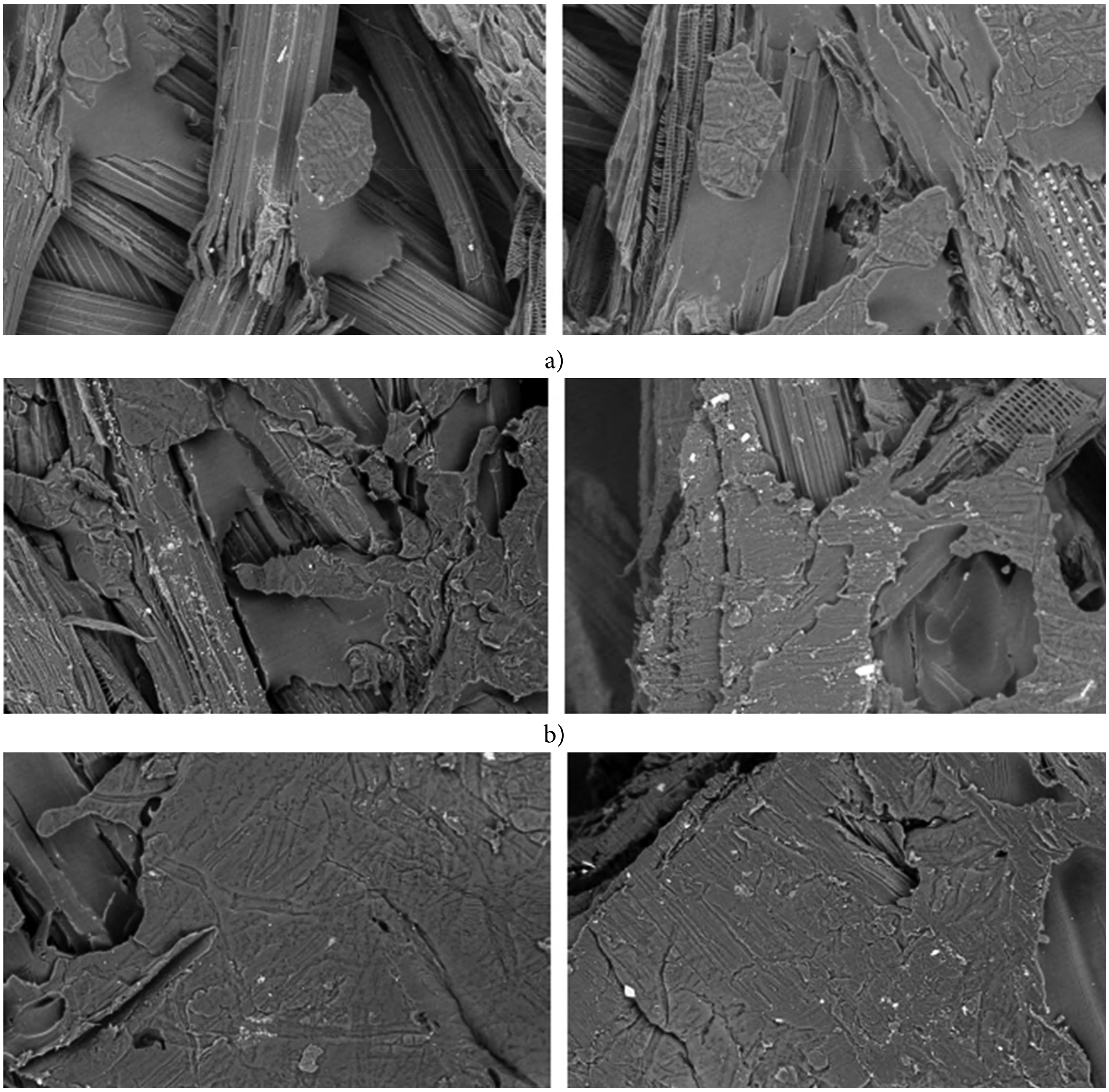
This progression demonstrates that as the PLA binder content increases, fibre bonding becomes more extensive, leading to a more pronounced PLA melt. These observations align with the tensile strength test results, which indicate that the melting PLA binds the fibres and solidifies upon cooling. Consequently, fabrics with higher PLA content exhibit stronger fibre bonding, resulting in enhanced tensile strength.

3.9 Limitations

This study serves as a preliminary investigation, as no prior research has explored the use of *Alpinia purpurata* fibres in nonwoven fabric production. Due to the limited availability of fibres from the decortication process, only a limited quantity of nonwoven fabric was produced, which constrained the range of characterization tests that could be conducted. Additionally, the available laboratory equipment limited the scope of testing to physical and mechanical characterization.

3.10 Future research recommendation

This study provides initial insights into the potential of *Alpinia purpurata* fibres for nonwoven fabric applications using thermal bonding with PLA. However, further research is required to enhance the understanding of fibre properties and material performance. Future studies should focus on comprehensive chemical characterization, including differential scanning calorimetry (DSC) to assess thermal transitions, thermogravimetric analysis (TGA) to evaluate thermal stability and degradation, and Fourier transform infrared spectroscopy (FTIR) to analyse chemical interactions between *Alpinia purpurata* fibres and PLA. Additionally, extended mechanical and structural performance tests, such as compression and recovery tests, stiffness and fabric handle evaluation, and durability tests (tear strength, burst strength and abrasion resistance), are essential to assess fabric resilience and long-term usability. Porosity and fluid management properties, including water permeability testing and analysis of porosity, pore size and distribution, should also be investigated to evaluate liquid absorption, transport characteristics, filtration potential and breathability. These future investigations will provide a more



c)

Figure 14: Experimental nonwoven fabric with three different fibre and binder compositions at 800x magnification, shown at two different locations: (a) 90/10, (b) 80/20 and (c) 70/30

comprehensive understanding of the structural, chemical and mechanical properties of *Alpinia purpurata*-based nonwoven fabrics, further establishing their suitability for sustainable textile applications.

4 Conclusion

This study explored the development of biodegradable nonwoven fabrics using *Alpinia purpurata* pseudo-stem fibres and poly lactic acid (PLA) as a binder using the thermal bonding method. The findings demonstrate that the fibre-to-binder ratio significantly influences fabric properties, with higher PLA content enhancing tensile strength but reducing air permeability and water absorption, while a greater proportion of *Alpinia purpurata* fibres improves breathability and moisture regain. The successful integration of these natural fibres into nonwoven fabric structures highlights their potential for sustainable textile applications. However, limitations such as the lack of chemical and thermal analyses, indicate the need for further research. Future studies should focus on optimizing processing conditions, evaluating long-term environmental impact and exploring industrial feasibility to fully harness the benefits of *Alpinia purpurata*-based nonwoven fabrics. This research provides a foundation for advancing eco-friendly textile materials while contributing to the broader goal of sustainability in the textile industry.

Data availability statement: Since 4 November 2025, the research data have been available at https://doi.org/10.5281/zenodo.17518726.

References

1. SUBAGYO, A., CHAFIDZ, A. Banana pseudo-stem fibre: preparation, characteristics, and applications. In *Banana Nutrition - Function and Processing Kinetics*. London : IntechOpen, 2020, doi: 10.5772/intechopen.82204.
2. CHAN, E.W.C., WONG, S.K. Phytochemistry and pharmacology of ornamental gingers, *Hedychium coronarium* and *Alpinia purpurata*: a review. *Journal of Integrative Medicine*, 2015, **13**(6), 368–379, doi: 10.1016/S2095-4964(15)60208-4.
3. SANTOS, G.K., DUTRA, K.A., BARROS, R.A., DA CÂMARA, C.A., LIRA, D.D., GUSMÃO, N.B., NAVARRO, D.M. Essential oils from *Alpinia purpurata* (*Zingiberaceae*): chemical composition, oviposition deterrence, larvicidal and antibacterial activity. *Industrial Crops and Products*, 2012, **40**, 254–260, doi: 10.1016/j.indcrop.2012.03.020.
4. WARDININGSIH, W., SYAUQI PRADANTA, F.A., RUDY, R., HERNAWATI, R.M., SUGIYANA, D. Characterization of decorticated fibres from agricultural waste of the *Curcuma longa* plant and their nonwoven fabric properties. *Research Journal of Textile and Apparel*, 2025, **29**(2), 427–443, doi: 10.1108/RJTA-09-2023-0090.
5. WARDININGSIH, W., SYAHPUTRA, I.P., RUDY, R., MULYANI, R.W.E., PRADANA, S.M., PUDJIATI, P., SUMIHARTATI, A. Exploring eco-friendly pseudo stem fiber from the agricultural byproducts of the *Alpinia purpurata* plant. *Bioresource Technology Reports*, 2024, **27**, 1–12, doi: 10.1016/j.biteb.2024.101947.
6. ZIMNIEWSKA, M. Hemp fibre properties and processing target textile: a review. *Materials (Basel)*, 2022, **15**(5), 1–29, doi: 10.3390/ma15051901.
7. SHARMA, M., SINGH, G., VAISH, R. Diesel soot coated nonwoven fabric for oil-water separation and adsorption applications. *Scientific Reports*, 2019, **9**(1), 1–11, doi: 10.1038/s41598-019-44920-x.
8. DIAO, Z., WANG, L., YU, P., FENG, H., ZHAO, L., ZHOU, W., FU, H. Super-stable nonwoven fabric-based membrane as a high-efficiency oil/water separator in full pH range. *RSC Advances*, 2017, **7**(32), 19764–19770, doi: 10.1039/C7RA01603D.
9. SAWHNEY, A.P.S., CONDON, B., REYNOLDS, M., SLOPEK, R., HUI, D. Advent of greige cotton nonwovens made using a hydro-entanglement process. *Textile Research Journal*, 2010, **80**(15), 1540–1549, doi: 10.1177/0040517510363194.
10. AU, H.T., PHAM, L.N., VU, T.H.T., PARK, J.S. Fabrication of an antibacterial nonwoven mat of a poly(lactic acid)/chitosan blend by electrospinning. *Macromolecular Research*, 2012, **20**(1), 51–58, doi: 10.1007/s13233-012-0010-9.
11. OSTAFINSKA, A., FORTELNY, I., NEVORALOVA, M., HODAN, J., KREDATUSOVA, J., SLOUF, M. Synergistic effects in mechanical properties of PLA/PCL blends with optimized composition, processing, and morphology. *RSC Advances*, 2015, **5**(120), 98971–98982, doi: 10.1039/C5RA21178F.
12. ZHAI, S., LIU, Q., ZHAO, Y., SUN, H., YANG, B., WENG, Y. A review: research progress in modification of poly(lactic acid) by lignin and cellulose. *Polymers (Basel)*, 2021, **13**(5), 1–15, doi: 10.3390/polym13050776.

13. BOONLUKSIRI, Y., PRAPAGDEE, B., SOMBATSOMPOP, N. Effect of poly(D-lactic acid) and cooling temperature on heat resistance and antibacterial performance of stereocomplex poly(L-lactic acid). *Journal of Applied Polymer Science*, 2020, **137**(33), 48970, doi: 10.1002/app.48970.
14. DUQUE-ACEVEDO, M., BELMONTE-UREÑA, L.J., CORTÉS-GARCÍA, F.J., CAMACHO-FERRE, F. Agricultural waste: review of the evolution, approaches and perspectives on alternative uses. *Global Ecology and Conservation*, 2020, **22**, 1–23, doi: 10.1016/j.gecco.2020.e00902.
15. JAWAID, M., KHALIL, H.P.S.A. Effect of layering pattern on the dynamic mechanical properties and thermal degradation of oil palm-jute fibres reinforced epoxy hybrid composite. *BioResources*, 2011, **6**(3), 2309–2322.
16. TOTONG, T., WARDININGSIH, W., AL-AYYUBY, M., WANTI, R., RUDY, R. Extraction and characterization of natural fibre from *Furcraea foetida* leaves as an alternative material for textile applications. *Journal of Natural Fibres*, 2022, **19**(13), 6044–6055, doi: 10.1080/15440478.2021.1904477.
17. SUMIHARTATI, A., WARDININGSIH, W., AL KAUTSAR, N., PERMANA, M., PRADANA, S., RUDY, R. Natural cellulosic fibre from *Cordyline Australis* leaves for textile application: extraction and characterization. *Research Journal of Textile and Apparel*, 2022, **26**(3), 276–290, doi: 10.1108/RJTA-04-2021-0049.
18. WARDININGSIH, W., SOPYAN, M., PRADANA, S., PUDJIATI, P., RUDY, R. Characterization of natural fibre extracted from *Etlingera elatior* stalk for textile applications. *Journal of Natural Fibres*, 2022, **19**(14), 9384–9395, doi: 10.1080/15440478.2021.1982828.
19. RUSSELL, S.J. *Handbook of Nonwovens*. Cambridge : Woodhead Publishing, 2022.
20. WARDININGSIH, W., RUDY, R., SALIS, W.A., APRILIA, R., JANNAH, R.W., MULYANI, R.W.E. Study on the properties of water-retted *Cymbopogon citratus* pseudostem fibres and their nonwoven fabric characteristics. *Research Journal of Textile and Apparel*, 2024, ahead-of-print, doi: 10.1108/RJTA-06-2024-0089.
21. KARTHIK, T., PRABHA KARAN, C. RATHINAMOORTHY, R. *Nonwovens: Process, Structure, Properties and Applications*. New York : WPI Publishing, 2017.
22. FERNANDO, D., THYGESEN, A., MEYER, A.S., DANIEL, G. Elucidating field retting mechanisms of hemp fibres for biocomposites: effects of microbial actions and interactions on the cellular micro-morphology and ultrastructure of hemp stems and bast fibres. *BioResources*, 2019, **14**(2), 4047–4084, doi: 10.15376/biores.14.2.4047-4084.
23. DAS, A. *Testing of Textile and Fibrous Materials*. Boca Raton : CRC Press, 2024.
24. WARDININGSIH, W. Alpinia Purpurata non woven data. Zenodo, 4. november 2025, https://doi.org/10.5281/zenodo.17518726.