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ORIGINAL ARTICLE

Mechanical Properties of Banana Peduncle Fiber Ropes

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ABSTRACT – Banana plants are utilized in almost all parts except for the peduncle due to their hardness and the presence of gum. This research, aimed at evaluating the mechanical properties of banana peduncle fiber, particularly its tensile strength, is significant in exploring the potential of this underutilized part of the plant. The tensile test followed the SNI 12-0064-1987 standard to assess and compare Manila and sisal ropes. Six types of fiber were tested: bleached peduncle fiber, unbleached peduncle fiber, abaca (Manila) fiber, coir fiber, marketed abaca fiber, and marketed coir. The highest average maximum load was found in marketed abaca rope, which measured 346.7 kg. However, this is still below the minimum load standard required by SNI, which is 480 kg. The results of the marketed abaca differ from those of abaca ropes spun using a foot spindle, indicating that the spinning and twisting techniques significantly influence tensile test outcomes. The test also shows that the bleaching process weakens the fiber strength because the unbleached banana peduncle ropes reach a higher average maximum load (92.9 kg) than the bleached banana peduncle ropes (45.2 kg). Moreover, the tensile strength tests revealed that the average breaking load of banana peduncle fiber rope was 92.9 kg, comparable to abaca fiber at 93.7 kg and coir fiber at 92.8 kg. This comparison was based on similar variables: a diameter of 8 millimeters, similar spinning techniques using a foot spindle, and no prior bleaching process. These findings underscore the potential of underutilized banana peduncle fiber ropes as a promising alternative to abaca or coir due to their load-bearing capabilities. It is important to note that the results of this tensile test are comparative rather than absolute.

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INTRODUCTION

Bananas are one of the famous herbaceous plants worldwide, including in tropical countries such as Indonesia. In 2021, Indonesia had hundreds of banana cultivars in 115,915.41 ha planting area, with the most significant harvest areas being in East Java (22,519.69 ha), West Java (22,162.61 ha), and Lampung (12,491.59 ha), respectively [1]. Furthermore, the entire planting area in Indonesia produced up to 8.7 million tons of bananas in the same year [1]. Indonesia has consistently been one of the largest banana-producing countries supplying their domestic markets [2].

The banana plant is an herb that only produces fruit once, and then it will die after the growing season. Several parts of this plant, the corm, pseudo-stem, leaves, and fruits, can still be used after the harvest for various needs. About 13% of the biomass comprises peduncles detached from the cluster and disposed of as organic waste [3]. Nevertheless, the farmers usually dump the peduncle because it contains gum, which is too complicated even for livestock to consume. The peduncle is the stalk supporting inflorescence [4], whose female flowers will develop into fruits [5]. A portion of the floral stem emerges from the rhizome's meristem and passes through the pseudo-stem's center to emerge at the top of the plant [5]. The peduncle has various lengths, diameters, and weights affected by the variety of banana plants, the amount of fruit, the soil fertility, the irrigation, the fertilizer, and other determining factors.

The researcher observed the banana peduncle Raja Bulu variety *(Musa paradisiaca)* using a microscope with magnification 100 times and safranin as a counterstain (Figure 1). The microscopic observation revealed that the peduncle consists of simple tissues (parenchyma, sclerenchyma) and complex tissues (phloem and xylem, which are often referred to as vascular bundles). Two forms of sclerenchyma cells occur: fibers and sclereids. These sclerenchyma fibers are often extracted and used [6]. There are also Sclerenchyma cells in the xylem tissues. Xylem tissues account for transporting minerals and water to flowers and fruit. The banana peduncle *(Musa paradisiaca)* contained 19.06% ash with a wealth of minerals such as potassium, calcium, and silica [5]. Besides, the peduncle also contains other main ingredients: alpha-cellulose (31.59%) and lignin (13.65%) [5]. The alpha-cellulose indicates that the peduncle has a considerable amount of fiber.

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Nevertheless, Palit et al. [6] affirmed that high-quality fibers such as cotton, ramie, flax, and hemp contain less than 5% lignin. In contrast, jute, kenaf, and roselle generally contain 10-20% lignin, making them inferior for delicate fabrics. Because of the high amount of lignin, the peduncle fiber is also less suitable for textile material.

Another research of the use of banana peduncle is a reinforced mixture of polymer composite [7], organic fertilizer [8], burger patties [9], composites epoxy [10], biochar [11], and biofuel [12]. Further, banana peduncle fiber can still be utilized for various uses, such as other fibers. Generally, the fiber plant is used as a textile material and as cordage and tying, brushes, filling, plaiting and weaving, thatching, paper, building and construction, and miscellaneous uses [6].

Given the abundant supply of banana peduncles in Indonesia and the significant amount of fiber they contain, it is crucial to find ways to utilize this resource effectively. Research on natural fibers suggests that they could serve as a sustainable alternative in various industries, such as light load automotive components, construction equipment, under floor protection panels, textiles, paper, and packaging [13], [14], [15], [16]. Moreover, banana peduncles are a renewable and biodegradable resource, making them an attractive option for sustainable materials in an ever-evolving materials research landscape.

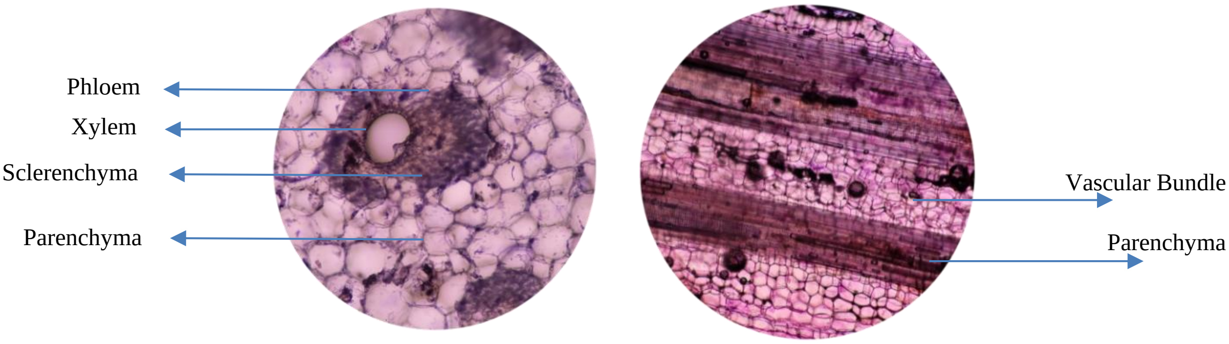

Figure 1. (a) Cross Section and (b) Longitudinal Section of Banana Peduncle Variety Raja Bulu

EXPERIMENTAL METHOD

Materials and Instruments

Six types of rope fiber were tested in this research: bleached peduncle fiber, unbleached peduncle fiber, abaca (manila) fiber, coir fiber (these four fibers were spanned with the same dynamo-foot spindle), marketed abaca (manila) fiber, and marketed coir. The samples of marketed abaca and coir fiber ropes were purchased from local shops. In addition, this marketed abaca and coir fiber was also spanned using a high-technology spindle machine that can only be accessed in big factories. Meanwhile, the bleaching for the banana peduncle fiber was using hydrogen peroxide (H_2O_2) and water glass (Na_2SiO_3) as stabilizers.

All the banana peduncle fiber in these samples was harvested through mechanical decortication and biological retting processes (Figure 2), utilizing waste generated by the household industry's processing of banana chips and cakes in the Klaten area of Central Java. While retting and decortication machine is primarily used to extract banana pseudo-stem fiber [17], [18], a significant finding from the study indicated that anaerobic digestion is more effective for processing banana peduncle biomass [19]. In this research, the average dry yield of banana peduncle fiber obtained through the biological retting process is 7.6%, which notably surpasses the 3.1% yield achieved with a decorticator.

However, several factors can affect the outcomes of fiber decomposition when using a decorticator, including the operator's proficiency, the condition of the machine, and the settings employed. In this study, the decorticator used was originally designed for decomposing pineapple leaf fibers, leading to less-than-optimum results for banana peduncles. A key issue was the excessive distance between the beating rod and the feeding area, which resulted in significant fiber loss. To improve efficiency, it is recommended that the decorticator intended for processing banana peduncles should be modified to better suit their distinct physical properties compared to pineapple leaves.

Figure 2. Banana Peduncle Fiber Decomposition Process

The use of several fiber types in this study has at least three purposes. First, comparing the mechanical properties of banana peduncle fiber to abaca and coir fiber, which are widely known earlier as intense and widespread rope fibers [20], [21]. The result will be beneficial in positioning the strength of banana peduncle rope as an unpopular fiber and, second, knowing whether different spinning machines affect the tensile strength of samples. Third, find out whether the bleaching process influences the tensile strength of samples since the fibers that have undergone the bleaching process appear brighter and thinner.

Cellulose fiber, such as in banana peduncle, has a limited length (about 30-100 cm). Accordingly, it should be spanned into yarn or rope to gain unlimited length like other popular fibers such as abaca (manila) and coir, which are widely used for miscellaneous needs. The banana peduncle fiber in this study was spanned into a three strands rope using a foot spindle, which is frequently used by local craftspeople. This foot spindle is driven by a petite dynamo with a maximum speed of 6000 rpm. Afterward, the rope that will be tested should be formed as a lasso on both ends so it can be looped on the hooks of the testing machine. This research was also using a scale from Libror (EB-4000 HU series) with 4000.00 g capacity, an airtight container to keep the specimens, a moisture meter from Extech (Mo260 series), and a thermo-hygrometer from Corona (Figure 3).

Figure 3. Tools for measuring the weight and the moisture content of the specimen

Method and Procedure

The mechanical properties of banana peduncle fiber ropes in this research are the determination of their tensile strength. The tensile test is adapted from SNI (National Standard of Indonesia) 12-0064-1987, a method to qualify and test Manila Rope and Sisal Rope [22]. The use of SNI 12-0064-1987 as a reference in this tensile test is necessary because of the limited availability standard of testing standards for fiber ropes. Only one of the standards was published in 1987 and has not yet been updated. The other argument for using this standard is that abaca or manila *(Musa textilis)* fiber is also classified in a similar genus *(Musa)* to edible banana *(Musa paradisiaca)*. Besides, abaca (manila) fiber rope also belongs to the most important cordage fiber [23] and has good mechanical properties [20]. Thus, it is expected to be used as a guide for approaching the issue. Hence, the abaca (manila) fiber is also used in this tensile test as a reference.

The Universal Testing Machine (UTM) obtained this research's tensile strength data. According to the referenced standard, each specimen was pulled at 150 mm/minute speed until it ruptured completely or maximum load (Figure 4). The testing is considered valid if the rope is broken at the center rather than at the end near the eye of the rope. Before the test was conducted, the weight density and moisture specimens of each specimen (Figure 3) and the temperature and humidity of the location were checked to inform us of the situation and condition when this test was conducted. The complete data is described in Table 1.

Table 1 Sample data information for tensile strength of fiber ropes

Standard	SNI 12-0064-1987 Tali Manila dan Tali Sisal, Mutu dan Cara Uji
Location	Structural Engineering and Materials Laboratory, Civil Engineering Study Program, Institut Teknologi Bandung
Instrument	*Universal Testing Machine* (*Iebertest, Eurotest – 200 series, Made in Spain)*
Speed	150 mm/minute
Humidity	54 - 61%.
Temperature	$25,2^0$ - $25,7^0$ C
Amount of Specimen	Five ropes each
Total valid specimen	30 pcs

Figure 4. Tensile Test

RESULT AND DISCUSSION

Comparing the tensile strength of marketed abaca ropes (code A1-A5) and abaca ropes spanned using a foot spindle (code A13-18) demonstrates that the spinning and twisting techniques play a crucial role in influencing the tensile test result (Figure 5). For instance, the marketed abaca ropes (code A1-A5) and the abaca ropes spun using a foot-spindle machine (code A13-18) are both made of abaca fiber, but the tools used to spin and twist the ropes differ. This difference not only affects the texture but also the density of the ropes. Therefore, it is of utmost importance to consider spinning and twisting techniques when working with fibers. For further utilization, it is strongly recommended that the banana peduncle fiber be spun and twisted using the same tools as the marketed abaca, which is generally used in the ropes industry to obtain the best result.

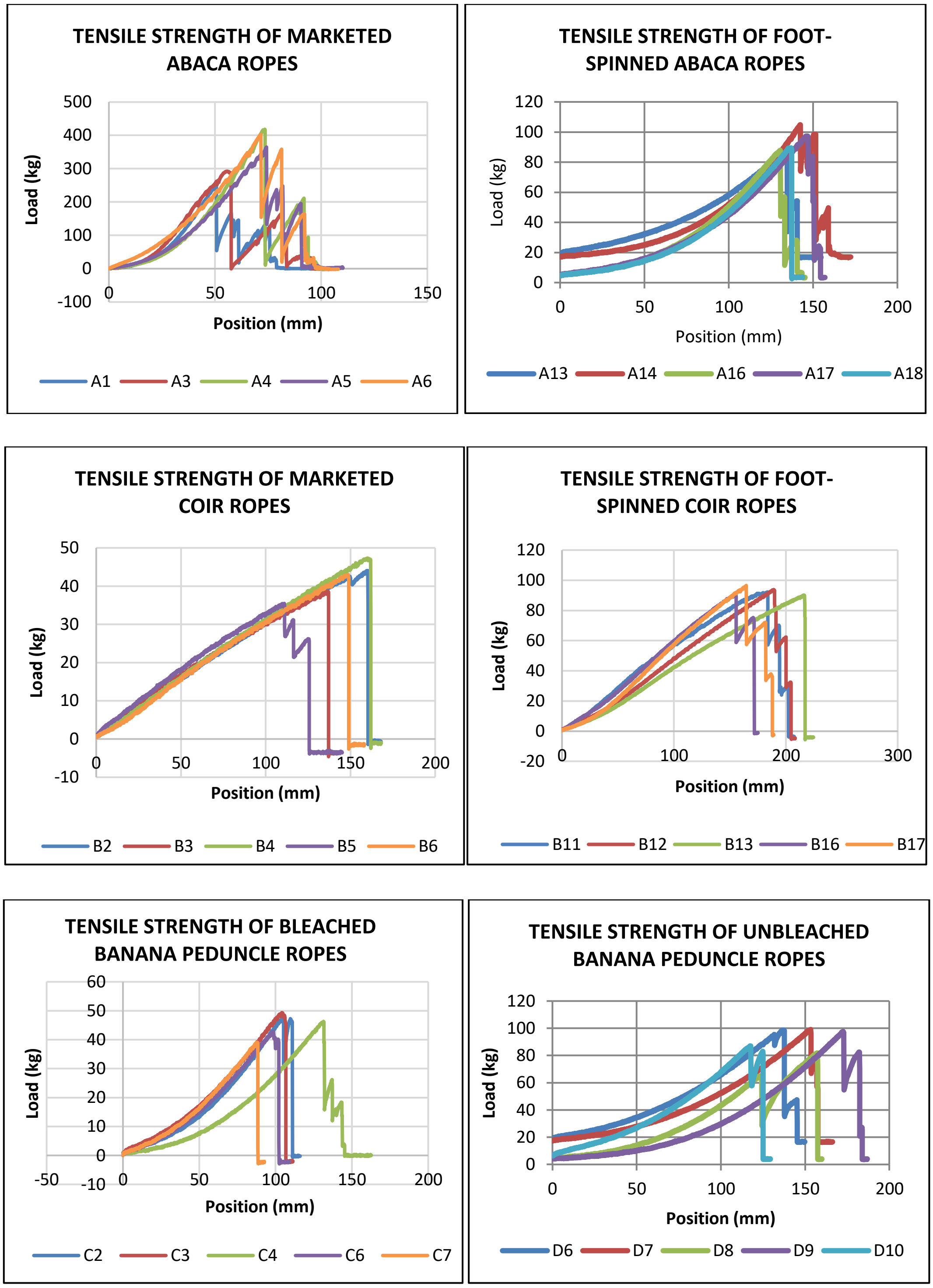

Figure 5. Tensile strength testing result of Abaca, Coir, and Banana Peduncle Ropes

The comparative tensile strength of fiber ropes was conducted by comparing the abaca rope (specimen B1-B5), coir rope (specimen D1-5), and unbleached banana peduncle fiber rope (specimen F1-5) in similar variables: diameter (8 mm), spindle tools (using foot-spindle), and without bleaching process (Figure 5). The average results of those three fiber types are 93.7 kg, 92.8 kg, and 92.9 kg, respectively (Table 2). Therefore, it is recommended that banana peduncle fiber ropes can be considered as a viable alternative to abaca or coir, particularly in their ability to withstand loads.

Table 2 Sample data information for tensile strength of fiber ropes

Fiber	Specimen	Moisture (%)	Weight (gr)	Maximum Load (kg)	Average of Maximum Load (kg)
Marketed Abaca Ropes	A1	18,7	59,9	255,1	**346,7**
	A3		58,7	292,3	
	A4		67,4	418,6	
	A5		70,1	365,0	
	A6		65,5	402,5	
Foot-Spanned Abaca Ropes	A13	19,6	33,4	88,1	**93,7**
	A14		40,2	105,3	
	A16		41,6	88,1	
	A17		43,8	97,6	
	A18		41,3	89,4	
Marketed Coir Ropes	B2	18,5	21,7	44,3	**42,1**
	B3		21,1	39,9	
	B4		22,0	47,5	
	B5		21,6	35,5	
	B6		20,9	43,2	
Foot-Spanned Coir Ropes	B11	18,7	47,2	92,2	**92,8**
	B12		46,9	93,9	
	B13		48,2	90,2	
	B16		33,7	90,8	
	B17		35,2	96,7	
Bleached Banana Peduncle Ropes	C2	19,1	39,1	47,9	**45,2**
	C3		48,8	49,5	
	C4		39,3	46,4	
	C6		39,9	42,9	
	C7		36,4	39,4	
Unbleached Banana Peduncle Ropes	D6	20,2	48,5	98,7	**92,9**
	D7		48,2	99,2	
	D8		45,9	82,0	
	D9		47,1	97,6	
	D10		40,7	87,1	

Besides, it is also known that the weight of each specimen is not directly proportional to fire rope strength in holding the load until it breaks. It could have happened because the weight of the ropes does not ensure that the rope is dense or binding to each other. It is clearly shown on the test of abaca ropes (B1-B5), coir fiber ropes (D1-D5), and unbleached banana peduncle ropes (F1-F5). Although abaca ropes have a minimum average Weight (40.1 gr) compared to the average Weight of coir ropes (42.2 gr) and banana peduncle ropes (46.1 gr), abaca fiber ropes have the highest average tensile strength among those three ropes. Specifically, it is also shown on several tests that the specific weight rope does not affect the maximum load, e.g., specimen A3 to specimen A4, specimen B2 to specimen B4, specimen C2 to C5.

The results of the test demonstrate that unbleached banana peduncle ropes can support a significantly higher average maximum load of 92.9 kg, in contrast to bleached banana peduncle ropes, which exhibit a maximum load of only 45.2 kg. The bleaching process, which includes boiling, is likely to contribute to the dissolution of chemical compounds such as hydrogen peroxide (H_2O_2) and sodium metasilicate (Na_2SiO_3). Bleached banana peduncle fibers exhibit a strikingly clean and brilliant appearance, with a vivid white hue that catches the eye. However, this aesthetic comes at a cost, as these fibers are considerably thinner and possess a brittleness that compromises their durability. Furthermore, the subsequent drying process adversely impacts the tensile strength of the fibers. Consequently, it is strongly recommended that the implications of the bleaching process be thoroughly evaluated in future applications of banana peduncle fiber, particularly in relation to the coloring process that employs natural colorants.

Based on the result of tensile strength, as shown in Table 2, the highest average maximum load of marketed abaca (manila) rope is 346.7 kg. This number is still far from the minimum load standard of the diameter of 8 millimeters abaca (manila) ropes, as required by SNI, which is 480 kg. This difference is due to the difficulty of pursuing ideal conditions in the test, as stated in the SNI requirement. The limitations imposed by equipment constraints, specifically the restricted drag space of the Universal Testing Machine, limited apparatus availability, and the confined length of specimens, hinder the accurate measurement of tensile strength. Therefore, it is essential to address these testing limitations to ensure compliance with established standards and improve the reliability of abaca rope performance assessments. Further research and development may be necessary to enhance testing methodologies and equipment accessibility. Assuming that the ideal testing condition can be accomplished, thus the maximum load of each specimen will undoubtedly increase. Hence, the results of this tensile test are comparative, not absolute. Comparing the result of the banana peduncle fiber rope with the abaca rope and the coir rope will describe the position of the banana peduncle fiber rope as viewed from its mechanical properties.

CONCLUSION

The tensile strength evaluation of marketed abaca (manila) ropes indicates that the highest average maximum load recorded is 346.7 kg, which is below the SNI minimum requirement of 480 kg for 8-millimeter diameters. This shortfall underscores the difficulties in meeting ideal testing conditions specified by SNI. The comparison between commercially produced abaca ropes and those fabricated with a foot spindle reveals significant differences in tensile strength, with commercial ropes averaging 346.7 kg and spindle-produced ropes at 93.7 kg. This disparity emphasizes the critical impact of spinning and twisting methodologies on the mechanical properties of fibers. Variations in equipment and technique not only influence the texture and density of the ropes but also their tensile performance. Thus, to optimize the tensile strength and overall quality of banana peduncle fiber, it is essential to adopt the spinning and twisting techniques used in the commercial abaca rope industry.

Further analysis of unbleached and bleached banana peduncle ropes shows that unbleached ropes significantly outperform bleached ones in tensile strength, suggesting that the bleaching process weakens the fibers by dissolving important chemical agents. This finding calls for more research into the effects of bleaching on the structural integrity of banana peduncle fibers and the interaction between bleaching and natural colorants in future applications.

Future studies should reconsider bleaching processes to enhance the utility of banana peduncle fibers across various industries. Our research reveals that the average breaking load of banana peduncle fiber rope (92.9 kg) is comparable to that of abaca (93.7 kg) and coir fiber (92.8 kg). This similarity suggests the potential of banana bunch fiber as a viable alternative to traditional fibers, particularly due to its load-bearing capabilities. By comparing the mechanical properties of banana peduncle fiber with those of abaca and coir, we highlight the promising position of banana peduncle fibers in the spectrum of mechanical performance. Despite being viewed as agricultural waste, banana peduncles possess significant untapped potential. Their availability, ease of decomposition, and renewability make them an important area for further research and exploration.

REFERENCES

[1] Kementerian Pertanian Republik Indonesia, "Luas Panen Pisang 1 Tahun Terakhir (Dalam Ha)," 2021. [Online]. Available: https://bdsp2.pertanian.go.id/bdsp/id/home.html

[2] V. Voora, S. Bermúdez, J. J. Farrell, C. Larrea, and E. Luna, "Global market report: Banana prices and sustainability," 2023. [Online]. Available: https://www.iisd.org/system/files/2023-03/2023-global-market-report-banana.pdf

[3] H. Azaizeh, H. N. A. Tayeh, R. Schneider, A. Klongklaew, and J. Venus, "Sugarcane Lignocellulose Biomass," *Molecules*, vol. 25, p. 2956, 2020.

[4] D. W. Turner, D. J. Gibbs, W. Ocimati, and G. Blomme, "A Functional Analysis of Inflorescence Architecture in Musa (Musaceae)," 2024, doi: 10.1002/fes3.70010.

[5] M. M. Rahman, T. Islam, J. Nayeem, and S. Jahan, "Variation of chemical and morphological properties of different parts of banana plant (Musa paradisica) and their effects on pulping," *Int. J. Lignocellul. Prod. Int. J. Lignocellul. Prod. Int. J. Lignocellul. Prod.*, vol. 1, no. 12, pp. 93–103, 2014, [Online]. Available: http://ijlp.gau.ac.ir

[6] M. Brink and R. P. Escobin, *Plant Resources of South-East Asia No. 17 Fibre Plants*. Leiden: Backhuys Publishers, 2003.

[7] P. Nagarajan Durai and K. Viswalingam, "Study on mechanical properties of banana peduncle fiber reinforcement antique polymer composite," *Mater. Today Proc.*, vol. 64, pp. 895–899, Jan. 2022, doi: 10.1016/J.MATPR.2022.05.403.

[8] S. Syarifinnur, Y. Nuraini, B. Prasetya, and E. Handayanto, "Comparing compost and vermicompost produced from market organic waste," *Int. J. Recycl. Org. Waste Agric.*, vol. 12, no. 3, pp. 279–289, 2023, doi: 10.30486/ijrowa.2022.1944251.1368.

[9] C. M. Bueno, S. A. Sedano, E. D. Beltran, A. B. Sapin, and M. Tavanlar, "Chemical, cooking and sensory characteristics of burger patties with different levels of banana peduncle powder," *Philipp. J. Vet. Anim. Sci.*, vol. 38, no. 1, 2012, [Online]. Available: http://www.pjvas.org/index.php/pjvas/article/view/52%0Ahttps://www.pjvas.org/index.php/pjvas/article/download/52/47

[10] S. Sridhar, R. Patil, A. Ashfaq, H. Vardhan, and A. Kumar, "A Study on The Effect of Sic on Mechanical Properties of Carbon/Banana Peduncle Fiber Reinforced Epoxy Composites," *J. Appl. Agric. Sci. Technol.*, vol. 3, no. 2, pp. 179–188, 2019, doi: 10.32530/jaast.v3i2.105.

[11] A. Karim, M. Kumar, S. Mohapatra, C. Panda, and A. Singh, "Banana Peduncle Biochar: Characteristics and Adsorption of Hexavalent Chromium from Aqueous Solution," *Int. Res. J. Pure Appl. Chem.*, vol. 7, no. 1, pp. 1–10, 2015, doi: 10.9734/irjpac/2015/16163.

[12] M. Pazmiño-Hernandez, C. M. Moreira, and P. Pullammanappallil, "Feasibility assessment of waste banana peduncle as feedstock for biofuel production," *Biofuels*, vol. 10, no. 4, pp. 473–484, 2019, doi: 10.1080/17597269.2017.1323321.

[13] S. Palanisamy, K. Vijayananth, T. M. Murugesan, M. Palaniappan, and C. Santulli, "The prospects of natural fiber composites: A brief review," *Int. J. Light. Mater. Manuf.*, vol. 7, no. 4, pp. 496–506, 2024, doi: 10.1016/j.ijlmm.2024.01.003.

[14] O. Suparno, “Potensi Dan Masa Depan Serat Alam Indonesia Sebagai Bahan Baku Aneka Industri,” *J. Teknol. Ind. Pertan.*, vol. 30, no. 2, pp. 221–227, 2020, doi: 10.24961/j.tek.ind.pert.2020.30.2.221.

[15] A. S. Afkari, R. A. Pratama, A. L. Juwono, and S. Roseno, “Mechanical Properties of Pineapple Leaf Fiber / Epoxy Composites with 0 ° / 0 ° / 0 ° / 0 °,” vol. 23, no. 2, pp. 83–89, 2022.

[16] P. Manimaran, G. P. Pillai, V. Vignesh, and M. Prithiviraj, “Characterization of natural cellulosic fibers from Nendran Banana Peduncle plants,” *Int. J. Biol. Macromol.*, vol. 162, pp. 1807–1815, 2020, doi: 10.1016/j.ijbiomac.2020.08.111.

[17] D. Saikia, N. Gogoi, S. Bhuyan, and L. Soraisham, “Evaluation of physical properties of mechanically extracted Musa acuminate Fibre,” *Pharma Innov.*, vol. 12, no. 11, pp. 01–04, 2023, doi: 10.22271/tpi.2023.v12.i11a.23941.

[18] S. Singh, N. Naik, N. Sooriyaperakasam, T. Iyer, and C. Agarwal, “A Comprehensive Review of Banana Fiber-Reinforced Composites : Properties , Processing and Applications Banana Fibers Physical structure and chemical composition,” *J. Comput. Mech. Manag.*, vol. 1, no. 2, pp. 22–33, 2022, doi: 10.57159/gadl.jcmm.1.2.23011.22.

[19] F. A. Wobiwo *et al.*, “Recovery of fibers and biomethane from banana peduncles biomass through anaerobic digestion,” *Energy Sustain. Dev.*, vol. 37, pp. 60–65, 2017, doi: 10.1016/j.esd.2017.01.005.

[20] N. Kumar *et al.*, “An investigation of various properties of hybrid bricks using Natural fibers and waste fiber-based materials,” *J. Eng. Fiber. Fabr.*, vol. 19, no. 1, pp. 1–23, 2024, doi: 10.1177/15589250241240073.

[21] L. Le Gué, P. Davies, M. Arhant, B. Vincent, and B. Parnaudeau, “Coir ropes as a low-tech circular alternative to synthetic ropes in French Polynesia pearl farming,” *Clean. Circ. Bioeconomy*, vol. 9, p. 100111, Dec. 2024, doi: 10.1016/J.CLCB.2024.100111.

[22] Badan Standarisasi Nasional, “Standar Nasional Indonesia (SNI) 12-0064-1987 Tali Manila dan Tali Sisal, Mutu dan Cara Uji,” Standar, Indonesia, 1987.

[23] E. A. Simbaña, P. E. Ordóñez, Y. F. Ordóñez, V. H. Guerrero, M. C. Mera, and E. A. Carvajal, “Abaca: cultivation, obtaining fibre and potential uses,” *Handb. Nat. Fibres Second Ed.*, vol. 1, pp. 197–218, Jan. 2020, doi: 10.1016/B978-0-12-818398-4.00008-6.