Determining the tensile strength, tear resistance, and stiffness of *Adonidia merrillii* (Manila palm tree) leaf sheaths

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Abstract

Use of natural plant fibers has increased in the past decades from uses such as ropes, textiles, paper-making, to reinforcement for polymer composites due to its advantages over hazardous synthetic fibers with comparable strength. *Adonidia merrillii*, commonly known as Manila palm tree, have not yet been fully explored of its fibrous properties. Its leaf sheaths, a fiber sheet-like material, has no known uses aside from being used as burning fuel. The research aimed to profile the mechanical properties of *A.merrillii* leaf sheaths such as the tensile strength, stiffness, and tear resistance, in comparison to the commercially available textile, canvas. Raw leaf sheaths were first tested to see if it can compare to textile, before applying any treatments. The leaf sheaths were washed, cut, and dried before testing. Due to limitations of the study, only the tensile and tear test yielded results. It was found out that the leaf sheath had a higher average tensile strength and stiffness than that of canvas. The leaf sheaths however were found to have weaker tearing force along the ridges. The leaf sheaths can be an alternative textile in the market.

Keywords: *fiber sheet, textile, canvas, mechanical properties, testing*

Introduction. Use and interest for natural plant fibers from the research community have increased for the past decades. Natural plant fibers have been used as substitute to hazardous synthetic fibers like glass and carbon fibers, with comparable or better mechanical strength, lower density, low cost, lighter, and renewable [1]. It is also biodegradable, which gives an advantage of being eco-friendly and also having low-resin consumption. Other than that, it also has disadvantages such as being susceptible to weathering and insects; and degrades over time due to microorganisms [2]. Examples of fibers that have been studied and used as reinforcement are date palm, kenaf, jute, hemp, sisal, flax, bamboo, etc [3]. It is mostly used in applications involving low to medium strength. Natural plant fibers are used for ropes, textiles, paper-making, and reinforcement for polymer composites.

None of the previous research studies have examined the leaf sheaths of *Adonidia merrillii*. It has little to no research, mainly focused on the biology of the tree, its seeds, and the viruses that affect palm trees. *A. merrillii*, more commonly known as Christmas Palm or Manila Palm Tree, is commonly found in the Philippines, and can also be found in Sabah, Malaysia. It has only been used for ornamental purposes on roads, houses, and buildings, and it is not cultivated. Its leaf sheaths are textile-like and is found at the crown of the plant, where it turns brown in color before falling off the tree. The leaves and the leaf sheaths are regarded as waste material and are usually used as fuel for burning due to its lack of use. Research on indigenous materials is important as it can be an alternative to those common in the market, and it expands the sources of raw materials.

The leaf sheaths of *A. merrillii* could be a good source of raw material or fiber and could be cultivated and collected for good uses.

On textile application, the processed leaf sheaths can be used as a fabric that can have several uses. Ancient technology provided some civilization to use leaves, barks of trees and other parts of a plant as clothing and other accessories. Even today, this kind of tradition of using different kinds of organic material still exists on display in flea markets, furniture shops, and souvenirs shops where hand woven bags, mats, bags, dresses are sold and purchased. Consequently, current research studies focus more on greener and cleaner aspect attaining sustainability and efficient use of organic materials.

Many materials have been used as raw material for textile applications such as bags, furniture, etc. These materials can be natural or synthetic. Natural materials have been widely used due to its renewability, disposability, and is environment-friendly. Cellulosic materials and fibers provide those characteristics and have similar and even better strength [2-4].

Canvas is a type of a textile from natural fibers. Historically, canvas was made from Cannabis sativa (hemp). Modern canvas is manufactured from Gossypium (cotton) and *Linum usitatissimum* (flax). It is mainly used for painting surface or material in manufacturing reusable bags. It is also used for making sails, tents, marquees, backpacks, and other items for which sturdiness is required since it is extremely durable plain-woven fabric. In comparison to the leaf sheath, observationally, canvas is the nearest in terms of thickness and rigidity.

Textile materials have important characteristics to be suitable material for applications. One important characteristic or property is tensile strength, which is the material's resistance to rupture under tension. Materials with high tensile strength are better, as it can bear heavier loads and strain.

Another property is stiffness, which is the material's resistance to deformation. It depends on the specific application of the material [5]. The last property is tear resistance, which is the resistance of the textile material from rupture when an initial tear is present. Higher tear resistance is better as it indicates better durability [6].

The material should also be consistently strong in all directions throughout the material, like woven textiles that are strong in the directions of the fibers but are relatively weaker "on the bias" [5]. In the study of Penava et al. last 2009[7], the experimental painting canvas exhibited lower breaking force on the directions between 0°(warp) and 45°, and between 45° and 90°(weft) of the fibers in the woven fabric. It is one of the main components of the durability of materials.

The tensile strength, stiffness, tear resistance, puncture resistance, and abrasion resistance are the mechanical properties chosen by this study that are important specifically for textiles and bag-making[8].

The properties and applications of this plant are still left undiscovered; thus, this study aimed to profile and compare the mechanical properties of *A. merrillii* leaf sheaths with canvas.

This study aimed to profile the mechanical properties of *A. merrillii* leaf sheaths in comparison with canvas. This research specifically aimed to:

(i) Determine the tensile properties of *A.merrillii* leaf sheath and canvas from a Tensile test using Universal Testing Machine (UTM).

(ii) Determine the stiffness of *A. merrillii* leaf sheath and canvas by calculating the Young's Modulus from the Tensile Test.

(iii) Determine the tear resistance of *A.merrillii* leaf sheath and canvas from a Tear test using Elmendorf Model 60-100 Tear Tester.

(iv) Compare the mechanical properties of *A.merrillii* leaf sheath with canvas.

The leaf sheaths were tested as is; without treatment and other changes on its physical components. Also, it will be tested as a sheet, instead of singular fibers, to determine its feasibility as raw material for the textile industry. This study will pioneer the topic regarding the leaf sheath of *A. merrillii*, since there is little to no research on this topic. Limitations include the age of the leaf sheaths, the age of the tree source, and the set location of *A. merrillii*. The source of the palm trees will be limited to those that are growing in Jaro, Iloilo City, Philippines, since there is no definite cultivation or sample site for *A. merrillii*, and it is only commonly used for ornamental purposes for houses, roads, etc.

Only a non-parametric test (Mann Whitney U Test) was used for the statistical analysis of the data due to the small sample size for the testing. This is due to the restrictions to budget and time constraints. The statistical analysis used may not have been as accurate and reliable than what a parametric test could have offered.

Methods. The leaf sheaths were collected and profiled through different tests which includes the use of Universal Testing Machine (UTM) for tensile test and Elmendorf Model 60-100 Tear Tester for tear test. It was then compared to canvas which mechanical properties were derived from the testing. Dried leaf sheaths that are brown in color and are still attached to the tree was collected and stored in a sealed container. Two parameter groups will be tested: "along the leaf sheaths' ridges", and "perpendicular to the leaf sheaths' ridges". The canvas was bought from a randomly picked textile shop among several textile shops in City Proper, Iloilo City, Philippines. Samples were cut from the leaf sheaths and canvas according to the ASTM standards used in each testing machine. For each test, random sampling on the leaf sheaths was used to select the samples that were sent to the Packaging Laboratory in Central Philippine University (CPU) where the samples were then tested of its mechanical properties. The independent variables are the *A. merrillii* leaf sheaths and canvas, while the dependent variables are the mechanical properties such as tensile strength, stiffness or Young's Modulus, and tear resistance.

Collection of leaf sheaths. The *A. merrillii* leaf sheaths collected were standardized. The criteria of the leaf sheaths that were collected was dried, brown in color and was still attached to the tree since those that were already on the ground may have been affected by other external factors. Another criterion was the dimension of the leaf sheath. It should have a minimum height of 18 inches and minimum width of 12 inches. In addition to that, the palm tree should be bearing fruit as a sign of maturity, and planted singularly and not in clusters, as planting the plant in clusters leads to a noticeable decrease in size and diameter of the plant. Convenient sampling was used to decide the source of the leaf sheath among different areas in Jaro, Iloilo City.

Cutting of Samples. Dimensions of the leaf sheath samples were cut according to the ASTM standards used in each of the testing machines used. The samples were taken from the sides of the leaf sheath, as the middle part is thick and stiffer, thus, was removed. Only the flexible parts were used, which were measured qualitatively by bending the leaf sheath from the side to the center until it does not bend over anymore, and then cut that leaf sheath from that point.

The leaf sheaths had two test groups: "Along the ridges" and "perpendicular to the ridges". The leaf sheaths have noticeable ridges along its length, which was why the two test groups were developed.

The definition of terms for both test groups are as follows:

"Along the ridges"- refers to leaf sheath samples cut parallel to its ridges.

"Perpendicular to the ridges"- refers to the leaf sheath samples cut perpendicular to its ridges.

Rinsing and Drying of leaf sheaths. The leaf sheaths were rinsed with water to remove dirt and other visible impurities before cutting. After the cutting of the samples, the leaf sheaths were then dried. To determine if the sheaths are fully dried, the weight was recorded with an interval of 12 hours right after washing using an electronic weighing machine. All of the samples underwent the same length of time on air drying and the weight of the leaf sheaths decreased, signifying the loss of water content.

Procurement of Canvas. The commercially available canvas was bought from a randomly picked textile shop located along City Proper, Iloilo City, Philippines.

Testing of mechanical properties. The mechanical properties of the fiber sheets extracted from leaf sheaths and canvas were tested using different testing machines at the Packaging Laboratory in Central Philippine University (CPU), Iloilo.

Tensile Test. This test determined the tensile strength, Young's modulus, and percent elongation at break of the samples. The tensile test was performed using the Universal Testing Machine (UTM) Instron Model 1000 by pulling the samples under tension until breakage. When the material breaks, the machine calculates and gives the maximum load in kilogram-force of the sample material before breakage, and the elongation in millimeters. The data for the results were then calculated and derived using the maximum force and extension at break displayed by the machine.

The standard used was ASTM D828-97(2002): Test Method for Tensile Properties of Paper and Paper Board Using Constant-Rate-of-Elongation Apparatus [9], using Instron Model 1000 Universal Testing Machine (UTM). This standard was used as procedure reference only for the test and not a specific test standard for leaf sheaths or canvas. Test conditions were consistent throughout the test, at 26.7°C and 44% relative humidity. The sample width was 25.4mm or one inch, and the sample length or jaw distance was 180 mm or 7.1 inches.

The tensile strength of the material was calculated using the formula below (From the ASTM Standards used by the laboratory):

$$\frac{Max\ Force}{Cross-Sectional\ Area} = Tensile\ Strength\ in\ Pascals\ or\ \frac{N}{m^2}$$

The Young's Modulus is a measure of a material's stiffness in pascals. The formula in solving for the Young's modulus is as follows:

$$\frac{tensile\ stress}{tensile\ strain} = \frac{tensile\ strength}{\%\ elongation} = Young's\ Modulus$$

Percent elongation does not have any unit, as it is the material's extension in divided by the test material's original length.

$$\frac{Extension}{Original\ Length} \times 100\% = percent\ elongation$$

Tear Test. For the tear test, the machine used was Elmendorf Model 60-100 Tear Tester, and the standards used were ASTM D689-"Test Method of Internal Tearing Resistance of Paper"[10] and TAPPI T414-"Internal Tearing Resistance of Paper (Elmendorf Type)[11]. The standards were used as procedure reference only and not a specific standard test for leaf sheaths or canvas. The test conditions were consistent throughout the test, with 26.7°C at 44% relative humidity. The sample dimensions were 3 by 2.5 inches. The average tearing force in grams was calculated by multiplying 16 the scale reading of the machine, and then dividing by the number of plies (from the ASTM and TAPPI standards used), which in this case the samples were tested as one-ply. The samples tested were along the ridges and perpendicular to the ridges of the leaf sheaths, and canvas. The equation in solving for the tearing force is as follows:

$$\frac{16\ \times scale\ reading}{number\ of\ plies} = Tearing\ force\ in\ grams$$

Data Analysis. The results from the test determined if the mechanical properties of *A. merrillii* leaf sheaths are comparable to that of the commercially available canvas. If the values from the test were identified to be significantly different depending on the analysis of the test from the commercially available textiles, then it should be followed by treatment(s) that will improve its properties to make up for the desired value. If comparable results are attained, then the leaf sheaths are suitable for textile application, can skip the treatment phases, and proceed to application as a substitute for canvas.

Due to the small sample size for the tests, the study used Mann-Whitney U Test to compare the means of the canvas to the leaf sheaths, with a significance level of α=0.05. Additionally, as the research focuses more on the material used for the final product, the researchers would propose *A. merrillii* leaf sheath as possible material for other accessories other than the bag.

Safety Procedure. Use of personal protective equipment and following laboratory safety protocols is important in the testing laboratory to avoid injury and damage to the machines. Safety precautions are prioritized when collecting leaf sheaths from the palm tree to avoid injury from falling or animal attacks.

Results and Discussion. The thick and stiff middle part of the leaf sheaths was removed after rinsing. The extracted leaf sheath samples varied from 3-4 inches in width and 15-20 inches in length. The noticeable ridges of the leaf sheaths were along the length of the extracted samples.

Results of the tensile test show the leaf sheath samples having greater average thickness than that of canvas. The leaf sheaths also have a higher average maximum load and tensile strength than canvas. The average percent elongation of the leaf sheaths was lower than that of canvas. However, the average Young's modulus of the leaf sheaths was higher than that of canvas.

Table 1. Tensile Test Results

Material	Leaf Sheaths (along the ridges)	Canvas
Thickness (mm)	0.755	0.543
Maximum Load (kgf)	28.767	11.267
Tensile Strength (kPa)	14,796.367	8,008.100
Percent Elongation (%)	3.980	11.940
Young's Modulus(MPa)	644.883	67.142

According to the Mann-Whitney U test, the mean rank score for tensile strength and Young's Modulus of the leaf sheaths were higher than that of the canvas, which means that the leaf sheaths had a higher average tensile strength and Young's Modulus than that of canvas. The p-value from the test was 0.050, which means that the tested leaf sheaths does not significantly differ from the commercial canvas in terms of tensile strength and Young's Modulus.

The tensile test results show that the leaf sheaths require more force to break under tension. Therefore, it is a stronger material than the commercially-available canvas in terms of tensile strength. Since the material is not lacking in this mechanical property and does not statistically differ, application of treatments is not necessary to improve on this mechanical property.

The canvas had higher average percent elongation than the leaf sheaths, which means that the canvas elongates more under tension before breakage, which is true for most textiles [12]. However, the leaf sheaths have low percent elongation which shows that the material almost breaks instantly before breakage. The leaf sheaths exhibited higher average Young's modulus, which indicates that it is stiffer than that of the commercial canvas [13]. Since the leaf sheaths have higher Young's modulus, it is more resistant to deformation. Since it is found in the Mann-Whitney U test that the two materials do not significantly differ in terms of Young's modulus, applying treatments is not necessary for this mechanical property.

Only the leaf sheaths were able to yield results both from along the ridges and perpendicular to the ridges. The canvas was not able to yield results because the machine was unable to fully tear the canvas material into two separate pieces, which is required for a valid tear test.

The average tearing force of the perpendicular to the ridges samples were higher than that of along the ridges samples of leaf sheaths, with an average tearing force of 85.33g and 48g respectively.

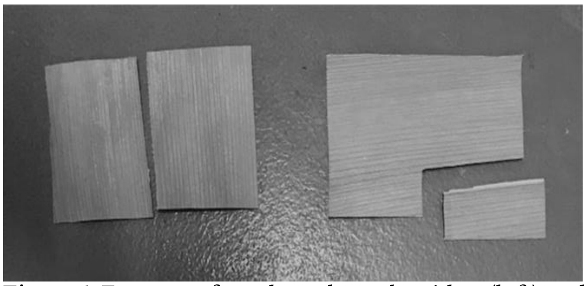

Figure 1. Fractures found on along the ridges(left) and perpendicular to the ridges(right) leaf sheath samples after the tear test.

Looking into the fractures of the leaf sheath samples, both the perpendicular to the ridges and along the ridges samples teared along the ridges. In the perpendicular to the ridges samples, the material teared sideways after the initial cut, and the tear was in line with the ridges. Therefore, the perpendicular to the ridges samples tearing force should be higher than the value given by the machine. As found in the Mann-Whitney U test results, the mean rank score of the perpendicular of the ridges leaf sheaths samples is higher than that of the along the ridges, which means that the leaf sheaths have a higher tearing force perpendicularly than along its ridges. The significance level is α=0.05, and the p-value from the test is 0.034. Since the p-value is not less than the significance level, it can be concluded that the leaf sheaths have significantly higher tear resistance perpendicularly than along the ridges.

The tear test for canvas was not able to obtain a result since to its tearing force was too high for the equipment used to record its value. The material did not fully tear into two pieces whereas supposedly it should for the equipment to show a valid result. This is due to processed nature of canvas which was formed through mechanical weaving of fibers [12]. For the leaf sheath samples, since the perpendicular to the ridges samples average tearing force was statistically higher than that of the along the ridges samples, it is necessary to apply treatments. Simple mechanical treatments can be applied: An example is weaving, where the process is creating an interlace of the material to form a sheet or mat with uniform strength in all sides [14]. Another mechanical treatment that can be applied is the process of stacking, which is the process of folding or stacking in perpendicular pattern then pressing the material to also produce a form of sheet or mat with uniform strength in all sides[15]. Extracting the fibers of the leaf sheaths can be performed, where it can be processed into a continuous thread and into a textile afterwards.

Error Analysis. Since the study used only 3 samples per test, so it may not have represented the population well. Due to this, the study also utilized the Mann-Whitney U Test, a non-parametric test, so the result of the statistical analysis may not be reliable and accurate.

Conclusion. Manila Palm Tree or *Adonidia merrillii* raw leaf sheaths can be an alternative textile in the market. The tested leaf sheaths have higher average tensile strength than the commercial canvas.

It was found that the leaf sheaths were statistically comparable with commercial canvas in terms of tensile strength and stiffness.

It was also found that the leaf sheaths are significantly stronger in the direction perpendicular to the ridges of the fibers. This means that the material tears along the ridges easily. Treatments are needed to fix this weakness of the raw leaf sheath material.

Recommendations. A processing or treatment can be done to fix the weaknesses of the leaf sheath material along its ridges/main fibers. Weaving can be a method to fix this problem of the material, where strips of leaf sheaths (along the ridges) is weaved together to form a mat to be strong on both directions. Another method is stacking the leaf sheaths, where one layer is perpendicular to the other with adhesive applied between each sheet toppled. This can make the produced material strong in both directions.

Further research in extracting fibers from the leaf sheaths of *A. merrillii* may be implemented. Processing the leaf sheath material to become a continuous sheet, where its fibers can be extracted and formed into a thread which can be manufactured into a textile.

A problem encountered in this study was the variation of thickness on the different parts of the leaf sheath especially the middle part where it is perceived as thicker than the sides. It is recommended to do processing on the inequality of the thickness so that the whole leaf sheath can be utilized. Extraction of fibers is another option in making use of the middle thick part of the leaf sheaths. It is also recommended to extract the raw natural fibers from the leaf sheaths of *A. merrillii.* The extracted fibers can be a new source of raw natural fibers. The fibers can be utilized in many uses such as textile/cloth-making, and fiber reinforcement or natural fiber composites.

This research used a non-parametric test (Mann-Whitney U Test) due to the small sample size for the tests. It is recommended to have a larger sample size to perform parametric tests instead, for more reliable results and analysis than what non-parametric tests offers.

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References

[1] Obi Reddy K, Obi Reddy S, Maheswari U, Rajulu V, Rao M. 2010. Structural Characterization of Coconut Tree Leaf Sheath Fiber Reinforcement. Journal of Forestry Research 21 (1): 53-58. DOI: 10.1007/s11676-010-0008-0

[2] Pickering KL, Aruan Efendy MG, Le TM. 2015, A review of recent developments in natural fibre composites and their mechanical performance. Composites: Part A. 83: 98-112. DOI: https://doi.org/10.1016/j.compositesa.2015.08.038

[3] Pradeep P, Edwin Raja Dhas J. 2015. Characterization of Chemical and Physical Properties of Palm Fibers. Advances in Materials Science and Engineering: An International Journal. 2: 4: 1-6. DOI: 10.5121/msej.2015.2401

[4] Akil HM, Omar MF, Mazuki AAM, Safiee S, Ishak ZAM, Abu Bakar A. 2011. Kenaf fiber reinforced composites: A review. Materials and Design. 32:4107–4121. DOI: 10.1016/j.matdes.2011.04.008

[5] Lovatt A, Shercliff H, Johnson K, 2002. Bags. Material Selection and Processing. Department of Engineering, University of Cambridge, UK. http://wwwmaterials.eng.cam.ac.uk/mpsite/short/OCR/bags/default.html

[6] Basu SK, Dalal M. 2008. Canvas fabric from high tenacity air-textured synthetic filament. Nonwoven & Techinical Textiles: The Indian Textile Journal: November 2008 Issue. http://www.indiantextilejournal.com/articles/FAdetails.asp?id=1672

[7] Penava Ž, Peneva D, Tkalec M. 2009. Experimental Analysis of the Tensile Properties of Painting Canvas. AUTEX Research Journal: 182-196. Doi: 10.1515/aut-2015-0023

[8] Kiron MI. 2012. Properties of Fiber | Properties of Textile Fiber. Textile Learner. https://textilelearner.blogspot.com/2012/02/properties-of-fiber-properties-of.html

[9] ASTM D828-97, Standard Test Method for Tensile Properties of Paper and Paperboard Using Constant-Rate-of-Elongation Apparatus, ASTM International, West Conshohocken, PA, 1997,http://www.astm.org/cgi-bin/resolver.cgi?D828-97 DOI: 10.1520/D0828-97

[10] ASTM D689-17, Standard Test Method for Internal Tearing Resistance of Paper, ASTM International, West Conshohocken, PA, 2017, http://www.astm.org/cgi-bin/resolver.cgi?D689-17 DOI: 10.1520/D0689-17

[11] Tappi T414, Internal tearing resistance of paper (Elmendorf-type method), Tag and Label Manufacturers Institute, Inc. (TLMI), 1998, https://www.tappi.org/80749/

[12] Eryuruk SH, Kalaoğlu F. 2015. The Effect of Weave Construction on Tear Strength of Woven Fabrics: 207-214, DOI: 10.1515/aut-2015-0004

[13] Schneider A, Francuis G, Obeid R, Schwinté P, Hemmerlé J, Frisch B, Schaaf P, Voegel JC, Senger B, Picart C. 2006. Polyelectrolyte Multilayers with a Tunable Young's Modulus: Influence of Film Stiffness on Cell Adhesion. American Chemical Society. 22: 1193-1200. DOI: https://doi.org/10.1021/la0521802

[14] Faqua M, Huo S, Ulven C. 2012. Natural Fiber Reinforced Composites, Polymer Reviews, 52:3, 259-320, DOI: 10.1080/15583724.2012.705409

[15] Smimizu SS, Tanaka MT, Ohara NO, Inoue FT. 1990 Nov. 6. Laminated Material Made of Annual Lignocellulosic Stalks. United States Patents US 4968549.