

Tensile Strength Variation Among Abaca (*Musa textilis* Née) Cultivars in Aklan, Province, Philippines

Gene T. Señeris¹, Franz Marielle N. Garcia^{1,2*}, Rosemarie T. Tapic¹, Ariel G. Mactal¹, Fernan T. Fiegalan³, and Anna Maria Lourdes S. Latonio⁴

¹Department of Crop Science, College of Agriculture, Central Luzon State University (CLSU), Science City of Muñoz, Nueva Ecija, 3120, Philippines; ²Crops and Resources Research and Development Center, CLSU, Science City of Muñoz, Nueva Ecija, 3120, Philippines; ³Department of Soil Science, College of Agriculture, CLSU, Science City of Muñoz, Nueva Ecija, 3120, Philippines; ⁴Department of Statistics, College of Science, CLSU, Science City of Muñoz, Nueva Ecija, 3120, Philippines. *Corresponding author, fmcnogoy@clsu.edu.ph

Abaca (*Musa textilis* Née), also known as Manila hemp, is a vital natural fiber-producing plant in the Philippines, mainly cultivated for its highly durable fibers. Five locally described Abaca cultivars found in Aklan province: *Bisaya*, *Agbayanon*, *Tabukanon*, *Totoo*, and *Negro*, which are widely cultivated for fiber production. However, limited research has been conducted to classify their fiber grades, lack comprehensive characterization, and comparison of fiber tensile strength between pseudostem layers (inner and outer) and across cultivars. This hinders the full utilization of Abaca fibers and guides for cultivar-specific production that produces high-quality Abaca fibers. This study investigated the tensile strength of Abaca cultivars in Aklan using one-way ANOVA and other statistical tests to confirm differences within the group. Results showed *Agbayanon*, *Bisaya*, and *Tabukanon* produced S3 (outer) and S2 (inner), while *Totoo* also produces an S2 (outer) and EF fiber (inner). In contrast, *Negro* provides JK fiber grade for both layers. Among cultivars, *Totoo* demonstrated the lowest values in gram force (outer = 2,714; inner = 2,858), but high tensile strength in terms of MPa (outer = 848; inner = 892) and kilogram force (outer = 57.52; inner = 60.65), the only fiber/cultivar exceeding PNS standards (35 to 55 kg/g.m) recommended for fiber production and textile. In contrast, *Negro* showed high gram force (outer = 7782; inner = 4121) but was weakest in MPa (outer = 389; inner = 206), suited for industrial applications. Meanwhile, *Agbayanon* had the gram force (outer = 7,888; inner = 6,437) and ranked second in MPa (outer = 616; inner = 503), suited for versatile applications. *Bisaya* and *Tabukanon*, on the other hand, demonstrated consistent mid-to-high tensile values suitable for moderate strength processing. The study's findings provide valuable information for developing cultivar-specific production policies that encourage farmers, producers, and stakeholders to plant cultivars that produce high-value and export-quality Abaca fibers that meet the Philippine National Standards.

Keywords: natural fiber, *Musa*, Manila hemp, mechanical properties

INTRODUCTION

Natural fibers are now in high demand and increasingly popular in industrial applications due to their environmental benefits, including biodegradability, renewable energy sources, and reduced waste. Abaca fibers are well-known for their exceptional durability and high tensile strength (Sabri et al. 2022). Abaca is a natural fiber-producing crop that is commonly grown in the Philippines, as it is endemic to the country. According to the Philippine Statistics Authority, there are 136.96 thousand hectares area planted with Abaca in the Philippines as of 2023. Among the fiber-producing crops, Abaca is the most important fiber crop in the Philippines, accounting for 86% of the world's Abaca fiber demand. Among all crops in the Philippines, Abaca is the country's top dollar earner, with growing demand globally (Tapado, 2022), making the Philippines the world's leading exporter of Abaca. Abaca fiber demand is increasing in the pulp and paper industry to manufacture disposable products, including tea bags,

coffee sachets, cigarette filters, meat casings, and other specialized paper products (Waller and Wilsby, 2019). Despite the increasing demand, the Abaca fiber industry in the Philippines faces several challenges, including poor fiber yield, declining fiber mechanical properties, a lack of high-yielding varieties, and inadequate research, agricultural practices, and technologies, which result in a decline in overall production and may not keep pace with global demand. According to the Precedence Research in 2023, it was reported that Abaca production in the country declined 5.7% to 63,640.61 metric tons (MT) in 2022.

Due to its durability, flexibility, mechanical properties, and efficiency in seawater, it is commonly used in materials for naval and marine cordage, automotive arena, industrial applications, and polymer reinforcement (Barba et al. 2020; Paglicawan et al. 2022; Seculi et al. 2023; Bledzki et al. 2015; Kurien et

al, 2023; Liu, 2013). It is more durable than man-made fibers such as nylon and rayon (Richter et al. 2013). One of the factors that influences the structural strength of fibers is their single fiber strand strength; the stronger the individual fiber strength, the stronger the overall structural composite (Bledzki and Gassan, 1999). A study showed that abaca fibers exhibit varied tensile strengths due to factors such as the extraction process, variety, non-uniformity in fiber width, length, diameter, and cross-sectional area, geographical location, climate, and agroclimatic conditions (Dabet et al. 2018). Moreover, limited studies have been conducted to characterize the fiber strength of abaca fibers from different varieties and to compare the pseudostem layers. By doing so, it aims to help identify high-quality producing varieties, enhance breeding programs, and optimize fiber production in the Philippines, thereby meeting the increasing demand for high-quality fibers in various industries and applications.

The province of Aklan is one of the prime producers in the Philippines and is ranked among the top Abaca-producing provinces in the Philippines. There are five locally described Abaca cultivars used in the province in the production of Abaca fibers: *Tabukanon*, *Bisaya*, *Agbayanon*, *Negro*, and *Totoo*. However, despite its economic significance and widespread use, limited research has been conducted to classify their fiber grades, and there is a lack of comprehensive characterization and comparison of the fiber tensile strength between pseudostem layers and across cultivars. This hinders the full utilization of Abaca fibers and guides for cultivar-specific production, aiming to produce high-quality Abaca fibers that meet both local and global demand. By performing tensile strength tests on these Abaca fibers and comparing them with existing data will provide new insights into the fiber strength in the Abaca industry. Hence, the study aims to provide comprehensive information by assessing the tensile strength characteristics and classifying the fiber grades of Abaca cultivars, which are crucial for improving production, enhancing economic variability, and optimizing the fiber use. The study will provide relevant information that can inform cultivar-specific production policies, encouraging and guiding farmers to plant cultivars that produce high-value, export-quality fibers that meet the Philippine National Standards (PNS).

MATERIALS AND METHODS

Research Design

The study used a comparative observational research design to determine, assess, and evaluate the fiber grades and tensile strength of the five Abaca cultivars used in the province of Aklan. Thirty (30) randomly selected mature (exhibiting flag leaves) sample plants per cultivar (a total of 150 sample plants) were conducted on site (Figure 1). Moreover, no experimental treatments were applied in the study, relying instead on the naturally occurring agroclimatic conditions of the sampling sites.

Study Site

The extraction of fibers for the tensile strength of the Abaca cultivars was carried out in the municipality of

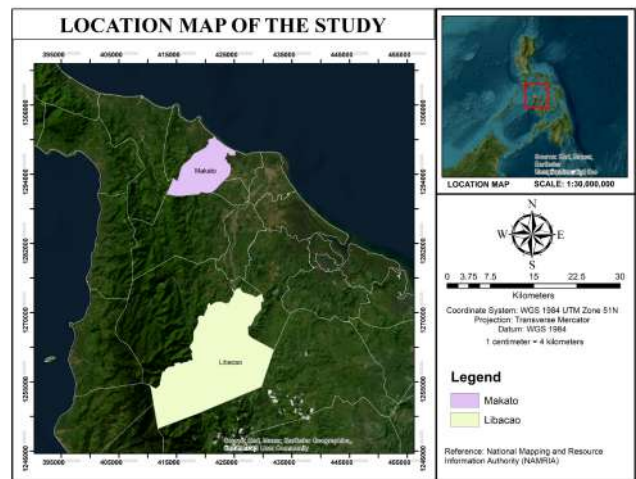


Figure 1. Location map of the study sites where fibers were extracted for analysis

Libacao where fibers from the *Tabukanon*, *Bisaya*, *Agbayanon*, and *Negro* cultivars were prevalent, as these cultivars were grown in the 1st District of the Province of Aklan. Meanwhile, the *Totoo* cultivar was obtained and extracted from the Municipality of Makato, where it is exclusively grown in the 2nd District of Aklan (Figure 1).

Harvesting and Sample Collection

Data on the different fibers extracted from the five Abaca cultivars were harvested on-site using the prescribed measurement procedures. The extraction of fibers was carried out from thirty (30) disease-free, and mature Abaca stalks exhibiting flag leaves (an indication of maturity and readiness for harvest) from each cultivar. Overgrown abaca plants showing yellowing of fruits, overly extended male buds, decaying floral traits, and senescence stage are automatically disregarded as sample plants. The thirty 30 sample plants were derived from ten (10) sample plants replicated three (3) times within the municipality, to ensure a representative sample for the evaluation of the tensile strength across Abaca cultivars. One fiber was collected from each sample plant, resulting in a total of thirty (30) fibers per cultivar, which were subjected to tensile strength analysis.

Tuxying

To extract the fibers from the leaf sheath of each cultivar, the locnit tuxying method was conducted to separate fibers from the leaf sheath using a tuxy knife. The tuxy is separated and pulled off (2-3 sections and 2-3 inches wide) depending on the size and shape (curvature) of the leaf sheath (PhilFIDA, 2016). Frequently, the outer sheath contains a darker color in fibers, while the inner leaf sheath possesses an ivory color (PhilFIDA, 2002; Göltenboth and Mühlbauer, 2010; Waller and Wilsby, 2019).

Hand Stripping

Extraction of fibers were conducted using manual stripping method, a traditional way extracting fibers from the leaf sheath. The tuxies are positioned between a blade and a weighted block that causes the tuxy to press against the knife's cutting edge (Waller and Wilsby, 2019). Moreover, all the modified

Abaca stripping knives (MASK) used in the study were provided by PhilFIDA to the farmers, with a measurement of zero or no serrations (teeth) for *Tabukanon*, *Bisaya*, *Agbayanon*, and *Totoo*, while 18 teeth per inch were used for *Negro*.

Drying of Fibers

The freshly extracted fibers were evenly distributed on a hanger with a proper label and sun-dried for 2–3 days (8 hours/day) to optimize sun exposure at a temperature of 25°C to 28°C. The fibers were hung separately by plant/cultivar and carefully turned to ensure uniform drying and prevent the growth of microbial fungi, thereby reducing fiber quality.

Classifying and Grading

After drying, the Abaca fibers were graded into different classes according to the Philippine National Standards (PNS) for Abaca fiber. This is done by a classifier who has successfully passed PhilFIDA's practical tests on fiber classification. Since no instruments were used, the classification is based on a qualitative evaluation based on visual inspection. The dried bundles were visually sorted into grades (color, texture, and stripping quality) based on the classifier's assessment (Waller and Wilsby, 2019). However, the fibers for tensile strength were measured using a digital caliper (mm) to confirm the size of the fiber strands and grade-specific reference values of the PNS standards. Regardless of the fiber grades, all fibers were subjected to tensile strength analysis according to where the fibers were extracted (inner and outer layer). Hence, the fiber grades were not used as a selection criterion or as a variable in the analysis and the data collection. Moreover, the comparison of tensile strength was based on the source of fibers (inner and outer) and not fiber grades. While the fiber grades were not used as a variable in the analysis, grade-specific reference values (EF = 0.1 – 0.2 mm; S2 and S3 = 0.2 – 0.5 mm; and JK = 0.1 – 1.5 mm) of fiber diameter were used to compute the cross-sectional area for tensile strength.

Data Gathered

Agroclimatic conditions

Data on agroclimatic conditions in Makato and Libacao Aklan, such as soil type and pH, climate, land cover, and topography, were gathered from various government agencies and legitimate sources. Average rainfall data, temperature, and humidity were sourced from the Agromet Station of Aklan State University and the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) at the identified sites. Soil data, including soil type and pH, were obtained from the Bureau of Soil and Water Management. In addition, the data on land cover, elevation, and slope acquired from National Mapping and Resource Information Authority (NAMRIA)

Tensile Strength

The tensile strength analysis of all the collected fiber samples was conducted at the Research Regional Center, University of the Philippines, Miagao, Iloilo Province. One fiber was collected from each sample plant, resulting in a total of thirty (30) single strand

fibers per cultivar, which were subjected to tensile strength analysis. The diameters of the single-strand Abaca fibers were measured using a digital caliper prior to tensile strength testing, with reference values based on their corresponding fiber grades (EF = 0.1 – 0.2 mm; S2 and S3 = 0.2 – 0.5 mm; and JK = 0.1 – 1.5 mm). Fiber tensile strength was determined by utilizing the Ametek Brookfield CT3 Texture Analyzer equipped with a TA-DGA dual grip fixture. The TA-DGA fixture is appropriate for holding fine natural fibers (Abaca, cotton, and pineapple). The study was conducted in a controlled and standardized testing environment, following the American Standard Test Method (ASTM D3822M-14, 2020) for the Tensile Properties of Single Textile Fibers. Furthermore, the Ametek Brookfield CT3 Texture Analyzer was fixed for test type tension, the test target was set to a distance between grips of 60 mm, trigger load was set to a minimum load of 10 gram-force (gf) with a test speed of 1.00 mm/s, in order to reduce sudden shocks, and maximize accurate measurement. Tensile properties of single textile Fibers were calculated using the formula expressed in gram force per square millimeter (gf/mm²):

$$T = \frac{F}{A}$$

Where:

T = tensile strength (gf/mm² or MPa)

F = force to failure (gf or N); and

A = fiber cross-sectional area at fracture plane (normal to fiber axis) (mm²)

Abaca fibers are also used in various engineering and reinforced fiber applications, as well as other industrial contexts, where strength is quantified in megapascals (MPa). The tensile strength results from Ametek Brookfield CT3 Texture Analyzer, expressed as gram force per square millimeter (gf/mm²), were converted to megapascals (MPa) through the use of the formula:

$$T(\text{MPa}) = T(\text{gf/mm}^2) \times 0.00981$$

Where:

1 gf = 0.00981 N

1 MPa = 1 N/mm²

For comparison with the Philippine National Standards (PNS) for the classification and grading of Abaca fibers, expressed in kilogram force per gram meter (kgf/g·m), the tensile strength for the Abaca fibers, which were originally measured in gram force (gf), was converted using the following equation:

Where:

$$\text{Tensile Strength} \left(\frac{\text{kgf}}{\text{g} \cdot \text{m}} \right) = \frac{\frac{\text{gf}}{1000}}{\text{mass (g)} \times \text{length (0.1)}}$$

Where:

(kgf/g·m) = standardized tensile strength;

gf = measured tensile force in gram force;

1000 = gf to kgf conversion factor (1 kgf = 1000 gf);

mass (g) = fiber strand mass in grams;

length (mm) = 0.1 m (equivalent to 100 mm fiber length used)

Statistical Analysis

One-way ANOVA was used to determine if there were significant differences in tensile strength between the cultivars of abaca fiber, with an Alpha level of 0.05. Before this, assumptions of normality and homogeneity of variances were checked. Normality was evaluated using the Shapiro–Wilk test and checking Q-Q plots to visually see the normal distribution of data. Levene’s test, which is robust to violations of normality, was used to evaluate the homogeneity of the covariates across the fiber varieties. If both assumptions were met, a standard one-way ANOVA was applied. If the assumption of equal variance was not met, Welch’s ANOVA was performed and used instead. If normality was violated, the Kruskal–Wallis was used as a nonparametric alternative. When determining that there was a statistically significant overall difference, post hoc tests were conducted when applicable and based on the distributional properties and variance structure of the data: Equality of variances and normally distributed data Tukey’s Honestly Significant Difference (HSD) test, if variances were unequal the Games–Howell test, or Dunn’s test with bonferroni correction if the data was non-parametric. All statistical procedures were carried out using R software version 4.5.1.

RESULTS AND DISCUSSION

Agroclimatic Condition of the Sample Sites

All four cultivars—*Bisaya*, *Tabukanon*, *Agbayanon*, and *Negro*, were extracted and collected in Libacao, Aklan. It appears that the cultivars are well adapted to mostly gently sloping terrain (8–18%), acidic to slightly alkaline soils (pH 4.5–7.5), high rainfall (243.85 mm/month), moderate temperatures (25.6–28.35°C), and moderate humidity (79–85%). These cultivars can occur in both upland and lowland but were more abundant and better suited in upland areas, particularly the municipalities of Libacao, Aklan because of the moderate elevation (90.8 to 135.8 masl), cooler climates, and the abundance of vegetation cover (Forested uplands e.g., brush, shrub, open forest) providing suitable shade to the Abaca. Meanwhile, *Totoo* is cultivated in the Western part (1st District) of Aklan and thrives very well and is prevalent in Makato, Aklan, due to its favorable agroclimatic conditions such as elevation (155 – 288 masl), slope (8 –18% gently sloping), and high perennial cropland use intercropped with other crops and agroforestry. This cultivar highly prefers acidic to slightly acid-slightly alkaline (4.0 - 7.5 pH) (common in Makato), humidity (77 – 84%), rainfall (166.77 mm/month), and moderately high temperatures (25.4 - 27.98°C), supporting the growth requirements of *Totoo*.

According to the PhilFIDA (2016), Abaca is well suited in areas with well-drained soils such as clay loam soils, temperatures between 22°C and 28°C, consistent rainfall (1800–2500 mm annually), high relative humidity (78–85%), and can still be productive in areas above 1000 masl. Aklan’s total annual rainfall in 2024 was 2,001.27 mm, with average temperature ranges of 26.41 °C (minimum) up to 31.9 °C (maximum) and average relative humidity of 81.58%

Table 1. Summary of statistical tests for tensile strength parameters of Abaca fiber across cultivars

Source of Variation	Test Statistic	p-value
Outer Layer		
Tensile Strength (gf)		
Cultivars	F(4, 20.502)=72.79 ^b	p<0.001 **
Tensile Strength (MPa)		
Cultivars	F(4,45)=26.7 ^a	p<0.001 **
Inner Layer		
Tensile Strength (gf)		
Cultivars	H(4)=24.3 ^c	p<0.001**
Tensile Strength (MPa)		
Cultivars	H(4)=35.803 ^c	p<0.001**

^aOne-way ANOVA assuming equal variances was used;

^bWelch ANOVA was used due to unequal variances among the cultivars.

^cKruskal–Wallis test (H) was used for non-normal data.

(PAGASA). Based on these requirements, the agroclimatic and edaphic conditions of the study areas are suited for Abaca cultivation, fiber extraction, and data analysis.

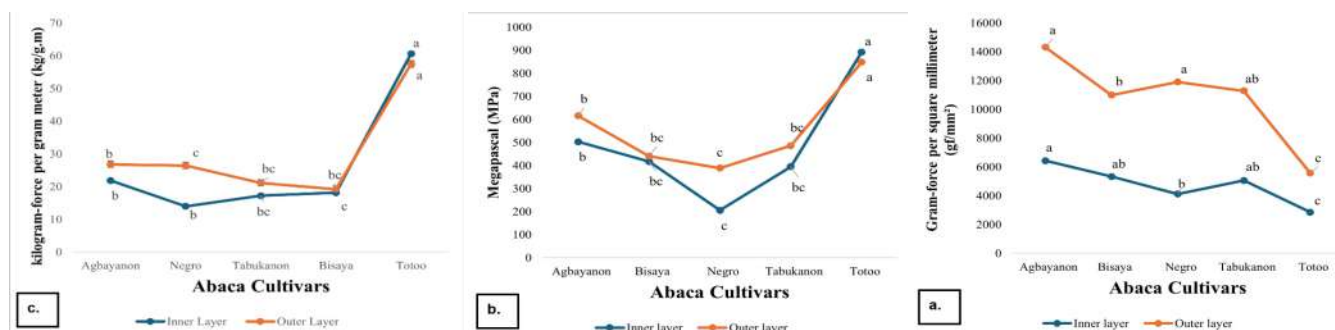
Tensile Strength

The study presented three testing methods for tensile strength, depending on the application and industry: gram force (gf/mm²), megapascal (MPa), and kilogram force per gram meter (kgf/g·m), which were further converted to compare with Philippine National Standards (PNS) (Figure 2a–c). The kilo- and gram forces are usually used in the textile industry, such as fabric and fiber processing, to help determine the durability of fibers and hold them under stress. Meanwhile, megapascal is used for engineering, reinforced fiber applications, and other industrial applications. This data provides relevant information on how fibers withstand high tension and stress commonly used in ropes, constructions, textile, industrial, and marine applications.

The Welch’s ANOVA (Table 1) results indicate that Abaca fiber cultivars differ significantly in terms of tensile strength in gram force, F (4, 20.502) = 72.79, p <.001 in the outer layer. According to results, *Agbayanon* has the highest tensile strength in gram force (M = 7,888, SD = 1,169), followed by *Negro* (M = 7,782, SD = 1,219), *Tabukanon* (M = 6,220, SD = 1,760), and *Bisaya* (M = 5,655, SD = 1,457), while *Totoo* has the lowest tensile strength (M = 2,714, SD = 444), (Figure 2a and Table 2). Furthermore, the results indicate that *Agbayanon* exhibits significantly higher outer layer tensile strength (gf) compared to *Totoo* (MD = -5174, p < .001) and *Bisaya* (MD = -2233, p = .011). Additionally, *Totoo* has significantly greater tensile strength than *Bisaya* (MD = 2941, p < .001), *Tabukanon* (MD = 3505, p < .001), and *Negro* (MD = 5068, p < .001). *Bisaya* also demonstrates significantly higher tensile strength compared to *Negro* (MD = 2128, p = .018). In terms of megapascal, findings revealed that Abaca fiber cultivars differ significantly in terms of the tensile strength, F (4, 45) = 26.7, p < 0.001, in the outer layer as shown in

Table 2. Descriptive statistics for tensile strength of outer and inner layers of Abaca fiber by cultivars

Characteristics	Mean	SD	Median	IQR
Outer Layer				
Tensile Strength (g)				
<i>Agbayanon</i>	7888	1169	7678	1082
<i>Bisaya</i>	5655	1457	5489	1890
<i>Negro</i>	7782	1219	8391	1194
<i>Tabukanon</i>	6220	1760	6084	2373
<i>Totoo</i>	2714	444	2806	596
Tensile Strength (MPa)				
<i>Agbayanon</i>	616	91.3	599	84.4
<i>Bisaya</i>	441	114	429	148
<i>Negro</i>	389	60.9	419	59.7
<i>Tabukanon</i>	486	137	475	185
<i>Totoo</i>	848	139	876	186
Inner Layer				
Tensile Strength (g)				
<i>Agbayanon</i>	6437	1122	6678	1218
<i>Bisaya</i>	5338	1773	5114	1009
<i>Negro</i>	4121	2109	3450	2288
<i>Tabukanon</i>	5064	1150	5268	1768
<i>Totoo</i>	2858	597	2874	725
Tensile Strength (MPa)				
<i>Agbayanon</i>	503	87.6	521	95.1
<i>Bisaya</i>	417	138	399	78.7
<i>Negro</i>	206	105	172	114
<i>Tabukanon</i>	395	89.8	411	138
<i>Totoo</i>	892	186	897	226

**Figure 2.** Line graph of mean tensile strengths of outer and inner Abaca fiber layers by cultivar: (a) Gram force (gf/mm²), (b) Megapascal (MPa or N/mm²) and (c) Kilogram force per Gram Meter (kgf/g.m). Individual points represent the mean tensile strengths for each cultivar with lines connecting values within fiber layers to visualize differences. Lowercase letters above the points indicate statistically significant differences among cultivars based on Welch ANOVA with Games-Howell post hoc test for outer layer and Kruskal-Wallis test with Dunn's post-hoc test for inner layer.

Welch's ANOVA (Figure 2b). In contrast to the results of tensile strength in gram force, *Totoo* exhibits the highest value ($M = 848$, $SD = 139$), followed by *Agbayanon* ($M = 616$, $SD = 91.3$), *Tabukanon* ($M = 486$, $SD = 137$), *Bisaya* ($M = 441$, $SD = 114$), and *Negro* ($M = 389$, $SD = 60.9$) exhibiting lower tensile strength value for the outer layer. Results were converted to kilogram-force to compare the tensile strength of Aklan cultivars with the Philippine National Standards for Abaca, specifically for Abaca fiber grading. Results showed that only the *Totoo* cultivar (57.52 kg/g.m) had excellent fiber quality when measured in kilogram force in the outer layer. *Totoo* exceeded the Philippine National Standards (35 to 55 kg/g.m) for Abaca fiber grading. The other cultivars, *Agbayanon* (26.81 kg/g.m), *Negro* (26.45 kg/g.m), *Tabukanon* (21.15 kg/g.m), and *Bisaya* (19.23 kg/g.m), were all below the PNS range, as shown in Figure 2c.

For the inner layer of gram force, Kruskal-Wallis's test revealed significant differences in tensile strength among cultivars ($H(4) = 24.3$, $p < 0.001$) (Table 1). Data revealed that *Agbayanon* ($z = 3.099$, $p = .001$), *Bisaya* ($z = 3.053$, $p = .011$), and *Tabukanon* ($z = 2.961$, $p = .015$) exhibited significantly higher tensile strength (gram force) compared to *Totoo*. *Agbayanon* also showed significantly higher tensile strength than *Negro* ($z = 3.099$, $p = .001$) (Table 3). Meanwhile, for the megapascals, Kruskal-Wallis's test revealed significant differences in tensile strength among cultivars $H(4) = 35.803$, $p < 0.001$. Similarly, tensile strength for the inner layer reveals that *Totoo* again exhibits the highest value ($M = 892$, $SD = 186$), followed by *Agbayanon* ($M = 503$, $SD = 87.6$), *Bisaya* ($M = 417$, $SD = 138$), *Tabukanon* ($M = 395$, $SD = 89.8$), and *Negro* ($M = 206$, $SD = 105$) exhibiting lower tensile strength as shown in Figure 2b and Table 2. Further tests confirmed that *Totoo* demonstrated

Table 3. Descriptive statistics for tensile strength of outer and inner layers of Abaca fiber by cultivars

Cultivars		Tensile Strength (g)		Tensile Strength (MPa)	
i	j.	MD	p-adj	MD	p-adj
Outer Layer					
<i>Agbayanon</i>	<i>Bisaya</i>	-2233	0.011*	-174.32	0.010**
	<i>Negro</i>	-106	1.000	-226.949	<0.001**
	<i>Tabukanon</i>	-1668	0.141	-130.237	0.089
	<i>Totoo</i>	-5174	<.001**	231.80	<0.001**
<i>Bisaya</i>	<i>Negro</i>	2128	0.018*	-52.629	0.832
	<i>Tabukanon</i>	565	0.933	44.084	0.904
	<i>Totoo</i>	-2941	<.001**	406.12	<0.001**
	<i>Tabukanon</i>	-1563	0.192	96.713	0.319
<i>Negro</i>	<i>Totoo</i>	-5068	<.001**	458.749	<.001**
	<i>Totoo</i>	-3505	<.001**	362.037	<.001**
Cultivars		Tensile Strength (g)		Tensile Strength (MPa)	
i	j.	z	p-adj	z	p-adj
Inner Layer					
<i>Agbayanon</i>	<i>Bisaya</i>	1.549	0.607	1.488	0.684
	<i>Negro</i>	3.099	0.001**	3.636	0.001**
	<i>Tabukanon</i>	1.641	0.504	1.488	0.684
	<i>Totoo</i>	4.602	<0.001**	-2.086	0.185
<i>Bisaya</i>	<i>Negro</i>	1.549	0.607	2.148	0.159
	<i>Tabukanon</i>	0.092	1.000	0.000	1.000
	<i>Totoo</i>	3.053	0.011*	-3.574	0.002**
	<i>Tabukanon</i>	-1.457	0.725	-2.148	0.159
<i>Negro</i>	<i>Totoo</i>	1.503	0.664	-5.722	<0.001*
	<i>Totoo</i>	2.961	0.015*	-3.574	0.002**

Variety i and j denote the two Abaca fiber varieties being compared; MD = Mean Difference; p-adj = Adjusted p-value for multiple comparisons, z = z-score; The Games-Howell test was used for outer layer tensile strength (g) due to unequal variances. Tukey's HSD method was applied for outer layer tensile strength (MPa); The Dunn's test with Bonferroni correction was used for inner layer tensile strength (g), length, and tensile strength (MPa), and outer layer length; *Significant at the 5% level; **Significant at the 1% level.

significantly higher tensile strength compared to *Bisaya* ($z = 3.574$, $p = .002$), *Negro* ($z = 5.722$, $p < .001$), and *Tabukanon* ($z = 3.574$, $p = .002$) (Table 3). Conversely, *Agbayanon* exhibited no significant differences from *Bisaya*, *Tabukanon*, and *Totoo*, except for *Negro*, which showed higher tensile strength in the inner layer ($z = 3.636$, $p = 0.001$). Additionally, the data also revealed that *Totoo* (60.65 kg/g.m) has superiority in kilogram force for the inner layer, surpassing the PNS of fiber abaca grading. In contrast, the remaining cultivars, namely, *Agbayanon* (21.89 kg/g.m), *Negro* (14.02 kg/g.m), *Tabukanon* (17.23 kg/g.m), and *Bisaya* (18.15 kg/g.m), fall below the PNS range as presented in Figure 2c.

Findings revealed that Abaca cultivars vary significantly in fiber strength in terms of gram force (gf/mm²), indicating that *Agbayanon* and *Negro* are much more durable and stronger, exhibiting high tensile strength in gram force and requiring a huge force to break. In contrast, *Totoo* shows the lowest tensile strength and requires a weaker force to break. This is primarily due to the density and fiber sizes, *Negro* (JK grade for both the inner and outer layer) and *Agbayanon* (S3 for the outer layer and S2 for the inner layer) have larger fiber strand sizes compared to *Totoo*, having fine and smaller fiber size (S2 for the outer and EF for inner grade). Although the different fiber grade strands, *Agbayanon* and *Negro* fibers used in the study, are both 0.5 mm in diameter, *Totoo*

has a diameter of 0.2 mm. Gram force is a more direct measurement of force, where fiber strength is based on the weight rather than the cross-sectional area of the fiber. Hence, the higher the value of the gram force, the more force it requires to break, and the lower the value of the gram force, the lower force it needs to break. The results highlighted that the only *Totoo* cultivar surpasses the PNS standards for fiber grading, both for inner and outer layers, in kilogram force, while other cultivars fell short and did not meet the PNS for tensile strength in both layers. Conversion of the fiber according to national standards is important for quality assurance within the country and ensures suitability for commercial or industrial applications required for local or international trade (BAFS, 2016).

Studies showed that the tensile strength of the untreated single Abaca fiber ranges from 417 MPa to 1548 MPa (Sabri, et al. 2022) and the average tensile strength ranges from 717 MPa - 957 MPa (Suhelmidawati, 2016; Cai et al. 2016; Cai et al. 2015; Pothan et al. 2003; Liu et al. 2019). In comparison, the average tensile strength of some cultivars is lower than the average tensile strength ranging from 389 – 848 MPa (outer layer) and 206– 892 MPa (inner layer), with *Totoo* consistently exhibiting the highest tensile strength and *Negro* showing weaker tensile strength values in both layers. The finding suggests that cultivars *Totoo* and *Agbayanon* are ideal for



Figure 3. Fiber grades of Abaca cultivars in Aklan based on the Philippine National Standard (BAFS, 2016): (a–e) Outer layer fibers – (a) *Bisaya* – Grade S3 (0.20–0.50 mm), (b) *Tabukanon* – Grade S3 (0.20–0.50 mm), (c) *Agbayanon* – Grade S3 (0.20–0.50 mm), (d) *Totoo* – Grade S2 (0.20–0.50 mm), (e) *Negro* – Grade JK (1.00–1.50 mm). (f–j) Inner layer fibers – (f) *Bisaya* – Grade S2 (0.20–0.50 mm), (g) *Tabukanon* – Grade S2 (0.20–0.50 mm), (h) *Agbayanon* – Grade S2 (0.20–0.50 mm), (i) *Totoo* – Grade EF (0.10–0.50 mm), (j) *Negro* – Grade JK (1.00–1.50 mm).

industrial applications such as ropes, marine ropes, geotextiles, reinforcement materials, and biodegradable composites (Armecin et al. 2014; Barba et al. 2020; Bledzki et al. 2015). Meanwhile, *Negro* cultivar is still useful for non-load bearing products such as pulp and paper production such papers, cigarette filters, toiletries, lens cleansing, tea bags, and other related products (Armecin et al. 2014). Moreover, Abaca fiber is proven to have excellent mechanical fibers as compared to other fibers and best alternative to synthetic fibers (Paglicawan et al. 2022) and has environmental advantages compared to synthetic fibers (with 8–46% increased tensile strength) and carbon footprint reduction (55–86%) compared to polypropylene fibers (Alcivar-Bastidas et al. 2024).

Influence of Fiber Grades on Tensile Strength

Abaca fibers have different fiber grades classification, and the tensile strength of the fibers varies with fiber grades (fiber size, color and texture) and where the fibers are extracted from. Results showed that the outer layer, *Bisaya*, *Tabukanon*, and *Agbayanon*, produced S3 fibers and S2 inner layer fibers (Figure 3a–c and 3f–h). Data revealed that the highest tensile strength among all cultivars for the S3 fiber grade in terms of gram force and megapascal in the outer layer was observed in *Agbayanon* cultivar ($M = 7888$ gf; 616 MPa), followed by *Tabukanon* ($M = 6220$ gf; 486 MPa) and *Bisaya* ($M = 5655$ gf; 441 MPa). Meanwhile,

the highest tensile strength for the S2 fiber grade in terms of gf ($M = 6437$ gf) for the outer layer was observed in *Agbayanon* cultivar but ranked second in terms of MPa (503 MPa), followed by *Bisaya* ($M = 5338$ gf; 417 MPa) and *Tabukanon* ($M = 5064$ gf; 395 MPa). Meanwhile, *Totoo* also produces an S2 fiber grade (Figure 3d) extracted from the outer layer, the same fiber grade produced by *Bisaya*, *Tabukanon*, and *Agbayanon*, but extracted from the inner layer. However, after conversion of the tensile strength in kilogram force to compare with PNS of fiber grading all S3 and S2 fibers extracted from the *Agbayanon* ($S3 = 26.81$; $S2 = 21.89$), *Tabukanon* ($S3 = 26.45$; $S2 = 17.23$) and *Bisaya* ($S3 = 19.23$; $S2 = 18.15$) are below the PNS range (35 to 55 kg/g.m), except for the S2 fiber grade extracted from *Totoo* cultivar (57.52 kg/g.m) exceeding the PNS. In contrast, the *Totoo* cultivar has the lowest tensile strength values in terms of grams force ($M = 2714$ gf), but the highest in terms of megapascals ($M = 848$ MPa). The S2 fiber grade produced from *Totoo* was extracted from the outer layer due to its color, texture, and fiber strand size, while the inner layer extracted EF-grade fibers (Figure 3i) having the highest tensile strength in terms of megapascal (892 MPa) overall across cultivar, regardless of the fiber grades. Additionally, the EF fiber grade of *Totoo* exceeds the PNS for fiber grading having the highest tensile strength (60.65 kgf/g.m) among all fiber grades and cultivars.

On the other hand, *Negro* produces the same JK fiber grade in both the outer layer (Figure 3e; M = 7782 gf; 389 MPa) and inner layer (Figure 3j; M = 4121 gf; 206 MPa). The outer layer JK fiber grade exhibited the second highest in terms of gram force; however, it is the lowest in terms of MPa due to larger fiber strand size (1.00–1.5 mm) and did not pass the PNS standards in terms of kilogram force per gram meter for fiber grading (outer = 26.45; inner = 14.02). Hence, JK fiber is not suitable for high-grade textiles and is recommended for ropes, mats, and industrial-grade products. Data emphasized that the *Agbayanon* cultivar outperforms most cultivars in terms of gram force and is the second highest in terms of MPa, possessing both coarse and finer fibers, making it ideal for industrial and marine-grade composites. While *Totoo* exhibited high tensile strength in terms of MPa due to its fine fiber strand (0.10 - 0.5 mm), it was lowest in terms of gram force, making it ideal for specialty paper and textiles.

Data showed that fiber tensile strength is significantly affected by the fiber grades (size, diameter, and cross-sectional area) and the source of the fiber extracted (inner and outer layers). Fiber grades extracted from outer layers demonstrated higher tensile strength values than inner-layer fiber grades. Notably, all S3 fiber grades have high gram force values, but low in MPa due to their thick fiber strands, while S2 fiber grades exhibited a balanced tensile strength result between the other fiber grades (EF and JK). EF fiber grade, on the other hand, demonstrated the highest tensile strength values in MPa, but was low in gram force, requiring less force to break the fibers due to its thin size, making it suitable for textile applications. Whereas JK fiber grades extracted from both the outer and inner layers of *Negro* exhibited the same observations as S3, having thick and coarser fibers, which required more force to break due to their larger fiber size, resulting in high tensile values in grams-force but low values in MPa, making them suitable for industrial-grade applications.

Thicker fibers (larger in diameter) exhibited higher tensile strength in grams force, as it measures the force exerted to break the fiber. Hence, thinner fibers require less force to break, while thicker fibers require more. Meanwhile, megapascal measures the unit of stress regardless of its fiber size and consider the cross-sectional area of the fiber. Hence, larger diameter fibers are stronger, and more force is required to break; however, their force per unit area is low due to their larger cross-sectional area (Sabri et al. 2022; Ramnath, 2014). Moreover, the source of fibers (pseudostem layers) also significantly affects the tensile strength properties of the fibers. The S3 fiber grades extracted from the outer layers are stronger than the S2 fibers extracted from the inner layers. Primary fibers are extracted from the outer layer of the leaf sheath; however, it is predominantly darker (brown or reddish-brown) in color, making them less expensive in the market. While inner fibers produce weaker fibers due to being less mature (secondary fibers), which have less resistance and elasticity, and tend to produce more pulp than fibers. Inner layer fibers produce lighter (ivory white) colors, which are softer and finer than those of the outer

layer, making them more expensive in the market (Araya-Gutiérrez, 2023; Montañez and Barrera, 2020). Hence, the source of fibers (layers extracted from) greatly contributes to the difference in color, quality, and value (Richter et al. 2013; Cinco et al. 2025).

Abaca fiber can be classified into ten normal, four residual, and one uncategorized quality grade as prescribed by the Philippine Fiber Industry Development Authority (Barba et al. 2020). In the interest of composite fabrication, the top grades Streaky Two (S2) and Streaky Three (S3) are commonly used as reinforcement due to their high tensile strength, durability, and resistance to saltwater damage (Bledzki et al. 2008; Indrawati et al. 2024; Armecin et al. 2014; Ojeda et al. 2012). The S3 fibers are produced from the external leaf sheath exposed to the sun and produce light red, dark red, purple, or brown fibers, with excellent stripping properties and a soft texture. On the other hand, S2 fibers are found next to the outer leaf sheath, and their fiber color ranges from ivory white to light to dark brown, red, or purple streaks. They are soft and of excellent quality, similar to Abaca (Paglicawan et al. 2021). Fibers are the ultimate product of Abaca; several factors affect fiber quality, such as the method of stripping and the blade used (Cabotage et al. 2021). Other studies also confirm that the number of knife serrations significantly influenced abacá quality (Richter et al. 2013). Additionally, the study confirmed that fiber grade quality depends on the different levels of leaf sheaths, as these produce fibers with varying colors, durability, texture, and tensile strength (Waller and Wilsby 2019). Moreover, outer fiber produces fractions of fiber that are suited to industrial applications. The outermost layer is usually darker in color, while the inner layers possess an ivory color and are also stronger than the outer ones (Göltenboth and Mühlbaue 2010).

CONCLUSION

Among cultivars, *Totoo* cultivar demonstrated lower values in gram force (outer–2,714; inner–2,858) but exhibited excellent quality in terms of megapascal (outer–848; inner–892) and kilogram force (outer–57.52; inner–60.65), exceeding PNS standards. This is due to gram force, which measures the total force required to break fiber, while megapascal (MPa) reflects the force per unit area. Hence, thicker fiber sizes are high in gram force while finer fiber strands are high in MPa relative to their size (smaller cross-sectional area). In contrast, *Negro* showed high tensile strength in gram force (outer = 7782; inner = 4121) but was weakest in megapascal (Outer = 389; Inner = 206) suited for rope, pulp, and paper production. Meanwhile, *Agbayanon* had the highest tensile strength in terms of gram force (outer = 7,888; inner = 6,437) and ranked second megapascal (outer = 616; inner = 503), but under the PNS standard in terms of kilogram force (outer = 26.81; inner = 21.89), suited for fiber production and for industrial applications. *Bisaya* and *Tabukanon* demonstrated consistent mid-to-high tensile values suitable for pulp and paper processing, as well as moderate strength applications.

The study showed that tensile strength is not only dependent on fiber grades but also on the source from which the fibers were extracted. Fibers from the outer layers with a coarse fiber grade (S3 and JK) had high gram force values, but weaker megapascal values due to their thickness and fiber size. On the contrary, fiber grades extracted from the inner layers (S2 and EF) exhibited high megapascal values, but weaker gram force values due to their fine fiber size and smaller cross-sectional area. Moreover, fiber grades from *Totoo* cultivar produced excellent fine-quality fibers suitable for export and the textile industries. Therefore, the *Totoo* cultivar should be considered for fiber production in engineering, composite materials, and industrial applications, such as rope, marine applications, and engineering applications. The results of the study are valuable for the government, farmers, and stakeholders in formulating policy such as cultivar-specific production policy that encourages farmers to plant cultivars that produce high-quality Abaca fibers that fit the Philippine National Standards (PNS), high value and export quality, specifically *Totoo*, which had superior fiber grades with tensile strength.

ACKNOWLEDGEMENT

The researchers would like to acknowledge Aklan State University (ASU) for providing financial support, to the Provincial Environment and Natural Resources Office (PENRO) Aklan, headed by For. Merlene B. Aborka, and Philippine Fiber Industry Development Authority (PhilFIDA) Aklan, headed by Lindelle Villoriente, for their assistance in conducting the study. The researchers also extend their gratitude to all the faculty and staff of Central Luzon State University for their guidance and support.

LITERATURE CITED

- Alcivar-Bastidas S, Petroche DM, Ramirez AD, Martinez-Echevarria MJ. 2024. Characterization and life cycle assessment of alkali-treated Abaca fibers: The effect of reusing sodium hydroxide. *Constr Build Mater* 449:138522.
- Araya-Gutiérrez D, Monge GG, Jiménez-Quesada K, Arias-Aguilar D, Cordero RQ. 2023. Abaca: A general review on its characteristics, productivity, and market in the world. *Rev Fac Nac Agron Medellín* 76(1):10263–10273.
- Armecin RB, Sinon FG, Moreno LO. 2014. Chapter 6 – Abaca fiber: A renewable bio-resource for industrial uses and other applications. In: Rehman K, Jawaid M, Rashid U, editors. *Biomass and Bioenergy*. Cham: Springer.
- [ASTM] ASTM International. 2020. Standard test method for tensile strength and Young's modulus of fibers (ASTM Standard No. C1557). Retrieved from <https://cdn.standards.iteh.ai/samples/105089/fe063cff70f744efa635e1fa6478a98f/ASTM-C1557-20.pdf>
- Barba BJD, Madrid JF, Penaloza JR DP. 2020. A review of Abaca fiber-reinforced polymer composites: Different modes of preparation and their applications. *J Chilean Chem Soc* 65(3):4919–4924.
- Bledzki AK, Franciszczak P, Osman Z, Elbadawi M. 2015. Polypropylene biocomposites reinforced with softwood, Abaca, jute, and kenaf fibers. *Industrial Crops and Products* 70:91–99.
- Bledzki AK, Gassan J. 1999. Composites reinforced with cellulose-based fibres. *Progress in Polymer Science* 24(2):221–274.
- Bledzki AK, Mamun AA, Lucka-Gabor M, Gutowski VS. 2008. The effects of acetylation on properties of flax fibre and its polypropylene composites. *Express Polymer Letters* 2(6):413–422.
- [Bureau of Agriculture and Fisheries Standards]. 2016. Abaca fiber – Grading and Classification – Hand-stripped and Spindle/Machine stripped. Philippine National Standard. Retrieved from: <https://philfida.da.gov.ph/images/Publications/PNS/PNSBAFS1802016AbacaFiberHandstrippedandMachineStripped.pdf>
- Cabotage AG, Lam JCS, Lozada GPW, Pascasio MMS. 2021. Advantages and disadvantages of traditional Abaca, genetically modified Abaca, and cross-hybrid Abaca. [MS Thesis].
- Cai M, Takagi H, Nakagaitio AN, Katoh M, Ueki T, Waterhouse GI, Li Y. 2015. Influence of alkali treatment on internal microstructure and tensile properties of Abaca fibers. *Industrial Crops and Products* 65:27–35.
- Cai M, Takagi H, Nakagaitio AN, Li Y, Waterhouse GI. 2016. Effect of alkali treatment on interfacial bonding in Abaca fiber-reinforced composites. *Composites Part A: Applied Science and Manufacturing* 90:589–597.
- Cinco, C. D., Dominguez, L. M. R., & Villaverde, J. F. (2025). Abaca Blend Fabric Classification Using Yolov8 Architecture. *Engineering Proceedings*, 92(1), 42.
- Dabet A, Homma H, Homma H. 2018. Statistical approach to tensile strength of Abaca single fiber. *Mechanical Engineering Journal* 5(5):18–00078.
- Göltenboth F, Mühlbauer W. 2010. Abacá – Cultivation, extraction and processing. In: Müssig J, editor. *Industrial Applications of Natural Fibres*. Chichester, UK: John Wiley & Sons, Ltd. p. 163–179.
- Indrawati S, Yuwana L, Zainuri M. 2024. The characterization of structures and porosity of Abaca fiber. In: *Journal of Physics*:

- Kurien RA, Selvaraj DP, Sekar M, Koshy CP, Paul C, Palanisamy S, Kumar P. 2023. A comprehensive review on the mechanical, physical, and thermal properties of Abaca fibre for their introduction into structural polymer composites. *Cellulose* 30(14):8643-8664.
- Liu K, Takagi H, Yang Z. 2013. Dependence of tensile properties of Abaca fiber fragments and its unidirectional composites on the fragment height in the fiber stem. *Composites Part A: Applied Science and Manufacturing* 45:14-22.
- Liu Y, Ma Y, Yu J, Zhuang J, Wu S, Tong J. 2019. Development and characterization of alkali-treated Abaca fiber-reinforced friction composites. *Composite Interfaces* 26(1):67-82.
- Ojeda G. 2012. Teñido de fibra de abacá (*Musa textilis*) utilizando colorante extraído de la cochinilla (*Dactylopius coccus* Costa). [Tesis de grado]. Loja, Ecuador: Universidad Técnica Particular de Loja. 65 p.
- Montañez, N., & Barrera, J. (2020). Automated abaca fiber grade classification using convolution neural network (CNN). *Advances in Science, Technology and Engineering Systems Journal*, 5(3), 207-213.
- Paglicawan MA, Emolaga CS, Sudayon JMB, Custodio CL. 2022, July. Influence of Abaca fiber on the performance of Abaca-glass fiber reinforced polymer composites. In: IOP Conference Series: Materials Science and Engineering, Vol. 1250, No. 1, p. 012004. IOP Publishing.
- Paglicawan MA, Emolaga CS, Sudayon JMB, Tria KB. 2021. Mechanical properties of Abaca-glass fiber composites fabricated by vacuum-assisted resin transfer method. *Polymers* 13(16):2719.
- [Philippine Fiber Industry Development Authority]. 2002. ABACA: Improvement of fiber extraction and identification of higher-yielding cultivars. *PhilFIDA Progress Report*.
- [Philippine Fiber Industry Development Authority]. 2016. Abaca sustainability manual. Department of Agriculture, Republic of the Philippines. <https://philfida.da.gov.ph/images/Publications/abacasustainabilitymanual/ASM.pdf>
- [Philippine Statistics Authority]. 2023. Abaca. Major Non-Food and Industrial Crops Quarterly Bulletin, April-June 2023. Retrieved from: <https://psa.gov.ph/major-non-food-industrial-crops/Abaca>.
- Pothan LA, Oommen Z, Thomas S. 2003. Dynamic mechanical analysis of banana fiber reinforced polyester composites. *Composites Science and Technology* 63(2):283-293.
- [Precedence Research] Precedence Research. 2023. Abaca Fiber Market. Press Release. Retrieved from <https://www.precedenceresearch.com/press-release/Abaca-fiber-market>
- R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.
- Ramnath, B. V., Manickavasagam, V. M., Elanchezian, C., Krishna, C. V., Karthik, S., & Saravanan, K. (2014). Determination of mechanical properties of intra-layer abaca-jute-glass fiber reinforced composite. *Materials & Design*, 60, 643-652.
- Richter S, Stromann K, Müssig J. 2013. Abacá (*Musa textilis*) grades and their properties—A study of reproducible fibre characterization and a critical evaluation of existing grading systems. *Industrial Crops and Products* 42:601-612.
- Sabri S, Fuadi Z, Kurniawan R, Rizal S, Homma H, Kosukegawa H, Miki H. 2022. Tensile strength and fracture behavior of single Abaca fiber. *Journal of Natural Fibers* 19(14):8796-8810.
- Seculi F, Espinach FX, Julián F, Delgado-Aguilar M, Mutjé P, Tarrés Q. 2023. Comparative evaluation of the stiffness of Abaca-fiber-reinforced bio-polyethylene and high-density polyethylene composites. *Polymers* 15(5):1096.
- Suhelvidawati E. 2016. Tensile test of Abaca fiber as one of alternative materials for retrofitting of unreinforced masonry (URM) houses. *Jurnal Rekayasa Sipil Politeknik Negeri Andalas* 13(2):139494.
- Tapado BM. 2022. Enhancing Abaca fiber production through a GIS-based application. In: 2022 IEEE 7th International Conference on Information Technology and Digital Applications (ICITDA). IEEE. p. 1-4.
- Waller V, Wilsby A. 2019. Abaca in the Philippines: An overview of a potential important resource for the country, relating the tensile strength of the single fiber to the microfibrillar angle.