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PROCESSING AND STRENGTH CHARACTERISATION OF BANANA FIBRE CORDAGE

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ABSTRACT

Purpose: The purpose of this study is to investigate the mechanical properties of banana fibres, explicitly focusing on silkiness, length, and morphological strength. The study aims to assess the limitations of fibre bundles and the impact of twist on the final product.
Design/Methodology/Approach: The study employed experimental and analytical methods to investigate the properties and characteristics of banana fibres. SEM examination was used to analyse the mechanical properties of banana fibres. The fibres are examined for silkiness, length, and morphological strength. The universal strength test machine, following the ASTM D3822 standard, is used to evaluate the limitations of fibre bundles and the influence of twist on the final product.
Research Limitation: While this study provides valuable insights into the mechanical properties of banana fibres, it is essential to note that it is limited to evaluating specific aspects such as silkiness, length, and morphological strength. Further research is needed to explore other aspects of banana fibre, such as its dyeability or resistance to environmental factors, to understand its potential fully.
Findings: The study finds that 50 bundled banana fibre cords, with a twist rate of 7.5 tpi, exhibit a strength of 161.61 N/Mm^2, indicating their potential for commercial cord production. The fibre's absorption property is influenced by its scattered crystalline X-Ray Diffractometer (XRD) pattern of 22.82θ and 35.58θ, and FTIR analysis reveals characteristic cellulose and lignin bonds at 3586cm-1. SEM images confirm the fibre and cord's high absorption propensity and strength, further supporting their commercial viability.
Practical Implication: The study contributes to understanding banana fibre yarn and its mechanical properties. The findings can inform the development of commercial cord production using banana fibres, potentially promoting sustainable and eco-friendly textile practices.
Social Implication: This could have positive social implications by reducing reliance on traditional textile materials and supporting the use of natural and renewable resources.
Originality/Value: This research adds value by providing insights into the mechanical properties of banana fibres and their suitability for commercial cord production. The study highlights the effects of twist, tensile strength, and water absorption, providing valuable information for researchers and practitioners in textile engineering.

Keywords: *Banana silk. fibre bundles. mechanical properties. twist. water absorption*

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INTRODUCTION

The introduction of synthetic fibres has brought about varying technological uses of textile materials such as yarns, threads, or cordages, which are used in their raw state or transformed into products for packaging, construction, and even fabric (Maity et al., 2023). They are not environmentally friendly and have led to massive non-biodegradable material being disposed of in the environment, affecting living organisms after it has outlived its usefulness (Al-Bahadly, 2013). It has been an international concern of research for sustainable environmental practices. A steadily growing interest in the application of natural fibres with environmental friendliness; biodegradable, significant strength, and absorbent has propagated into the drive of environmental sustainability; a now preferred way to go widely accessible, non-toxic, non-abrasive, renewable, and inexpensive as well as having a low density. (Khan et al. 2022).

Natural fibres exhibit characteristic differences that make them suitable alternatives for reinforcement. However, inconsistencies in fibre diameter, length, colour, and fineness can be addressed through blending, typically based on weight ratio and fibre length. Hassan et al. (2020) emphasised that optimising the blending conditions can enhance the load-bearing capacities of fibres and cordages.

Cordage, encompassing rope, twine, and thread (Prinselaar, 2016), is formed when three or more strands are twisted, braided, or arranged in parallel with a diameter exceeding 4mm according to ISO 1968:2004(en). The composition and construction of a cord or yarn determine its quality and strength. Depending on their size, cords find extensive applications in fabrics, construction ropes, and industrial pulleys. A larger diameter with a tightly compacted twist yields a stronger cord, ensuring better performance for its intended purpose.

Traditionally, harvested banana fibres have been used to produce cordages in animal husbandry. Techniques such as retting, removal of rotten pulpy sections through knife-edge pressure, or mechanical extraction from newly harvested plants, followed by rinsing, drying, and combing, have been employed for fibre extraction. To assess the economic feasibility, evaluating the fibre's strength attributes and potential as an alternative cord for diverse sectors is crucial.

The strength of a material depends on factors such as composition, environmental conditions, and the experimental apparatus used. Synthetic fibres generally exhibit superior strength, elasticity, and flexibility qualities compared to natural fibres (Ahmad & Zhou, 2022). In contrast, natural fibres tend to be more brittle, have lower elongation properties, and possess higher absorption characteristics. The strength of fibres is further influenced by factors such as the number of fibres in a bundle, degree of twist, and fineness (Wu et al., 2021). As per Ezeamaku et al. (2022), banana fibres exhibit poor resistance to acids and alkalis but demonstrate relatively good temperature resistance, similar to most cellulosic fibres. The potential of utilising banana fibre in cordage production can be explored through the feasibility and market potential of natural fibre-reinforced polymer composites in industrial applications (Abhay & Singh, 2014). Additionally, the properties, applications, and alternatives of banana fibre can be studied in natural fibres and their characteristics in composite materials (Amaral-Labat & Alves-Filho, 2015).

Yarn size is a critical factor in determining its suitability for various applications. The strength required to sustain a given load increases as yarn size increases. Large yarn sizes are typically used

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in cordages, comprising multiple plied yarns with high tensile strength, making them ideal for applications such as pulleys (Mishra et al., 2018).

Nylon and polyester are widely used in the marine industry as anchoring lines due to their superior mechanical properties, high strength, resistance to acidic atmospheres, and low moisture absorption (François et al., 2010). Polyester is also highly resistant to ultraviolet radiation, making it suitable for outdoor applications (Gupta et al., 2019). Additionally, nylon exhibits excellent elongation at break, making it highly suitable for high-stress applications such as ropes and cords (Liu et al., 2020).

On the other hand, natural fibres, such as banana fibres, possess unique mechanical properties such as flexibility, shock absorption, and a longer lifespan than synthetic fibres (Nambiar et al., 2021). However, natural fibres have relatively low abrasion resistance and can be damaged by prolonged exposure to humidity, sunlight, and ultraviolet radiation, making them less suitable for use in marine applications (Mishra et al., 2018). In contrast, natural fibres have been widely used in the agricultural industry due to their biodegradability and low environmental impact (Patil et al., 2020). Banana fibres, in particular, have gained attention due to their high strength and stiffness properties, making them a potential candidate for use in composite materials (Ogunsanwo et al., 2018). Large commercial quantities of banana fibres are available in Ghana and the West African coast, providing opportunities for exploring their potential for commercial use (Nambiar et al., 2021).

Environmental concerns associated with synthetic fibres and the growing interest in natural fibres for sustainable textile practices have increased enormously. Banana fibres, known for their biodegradability, strength, and absorbent properties, are being explored as a potential alternative. The study specifically focused on using leftover banana trunks for cordage production in an eco-friendly manner. The comparison of strengths, compositions, and sizes of natural fibres to synthetic fibres acknowledged that synthetic fibres excel in certain aspects. In contrast, natural fibres like banana fibres possess unique characteristics suitable for specific applications. The availability of abundant banana fibres in Ghana and the West African coast also presented commercial opportunities. Ultimately, the research highlighted the potential of banana fibres in the textile industry as a sustainable and environmentally friendly option. This research proposes the utilisation of left-over banana trunks as a natural fibre source in the textile process of cordages for industrial use, aiming to reduce the use of chemicals and harmful agents while optimising fibre production processes in an ecologically friendly manner.

RESEARCH METHODOLOGY

This study employed experimental and analytical methods to investigate the properties and characteristics of banana fibres. The fibres were retrieved, processed, and prepared for analysis by mechanical extraction, washing, drying, and combing. Scanning Electron Microscopy (SEM) was used to examine fibre morphology, absorption rate was determined using an electronic scale, X-Ray Diffractometer (XRD) analysis was conducted to identify the crystalline region, and tensile strength testing followed standard protocols. Additionally, the fibre diameter was measured using a micrometre screw gauge. These comprehensive steps aimed to gain insights into the properties and characteristics of the investigated banana fibres.

Fibre Processing

Plate 1 shows banana fibres retrieved from a plant harvested by Kwame Nkrumah University of Science and Technology (KNUST) farms. This was done to substantiate the need to prevent landfills on the farms; hence, the retrieved stems were at various levels of degradation. A mechanical fibre extraction method was used to extract the golden fibres finely. These were washed, dried, and combed to a length of 24-32 inches.

Plate 1: Banana/ plantain plant fibre processing

i. Scanning Electron Microscopy (SEM) was used to examine the morphology with the ZIESS EVO MA15 SEM machine of the Faculty of Mechanical Engineering of the University of Mines Tarkwa. SEM imaging is based on the fibre type, magnification, working distance, and the degree of electrons released for charging on the sample for analysis.
ii. A Sartorius electronic scale was used to determine the absorption rate of the fibres about ASTM D570. The done dry fibre was tested by subtracting the dry weight from the wet weight to get the rate of absorption.
iii. An Empyrean Series 2 X-Ray Diffractometer (XRD) machine was used to determine the fibre's crystalline region to ascertain its absorption rate. The fibres were converted into powder using a mortar and pestle and placed in a radiating X-ray at an angle of 20Ө to determine the material's crystallinity.

iv. Tensile strength was determined according to ASTM D3822, the standard for the test standard, on the Tinius Olsen H50KT Universal strength testing machine of Ghana Standard Authority, with a tensile speed of 5 mm/min, a temperature of 24°C, and humidity of 75%. All tests were conducted with a gauge length of 50mm, as required by ASTM D3822, which says that test specimens must have a gauge length of 10 mm [0.4 in.] or more.

Sample Preparatory Process

The material for measuring the diameter of fibres was a micrometre screw gauge to a length that was unique from the typical gauge length of 50mm, allowing for adequate jaw holding with the assistance of the leather strap, as shown in Figure 1. Five (5) statistical point tests were performed

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on each single and bundle fibres (10, 20, 30, 40, and 50) twisted to the limits of 2.5, 3.75, 5, 6.25, and 7.5 TPI for each fibre bundle type. Cotton, sisal, polyester fibres, and yarns were twisted to 7.5 TPI for comparison and analysis. Fibre-fibre composites were twisted to establish their strength after reinforcement. Thus, the tensile strength was measured as:

$$TS = \frac{force}{area}. \quad 1$$

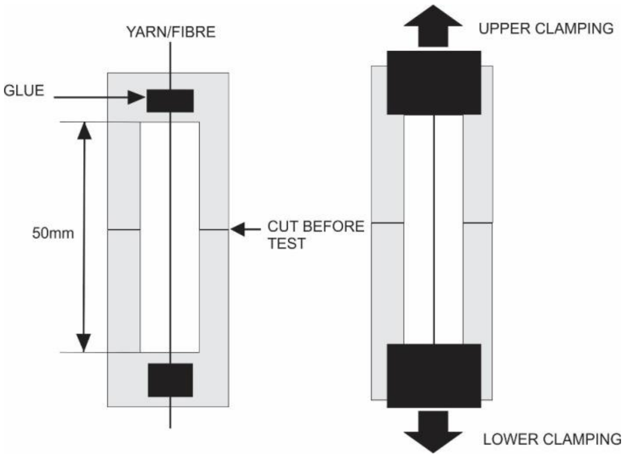
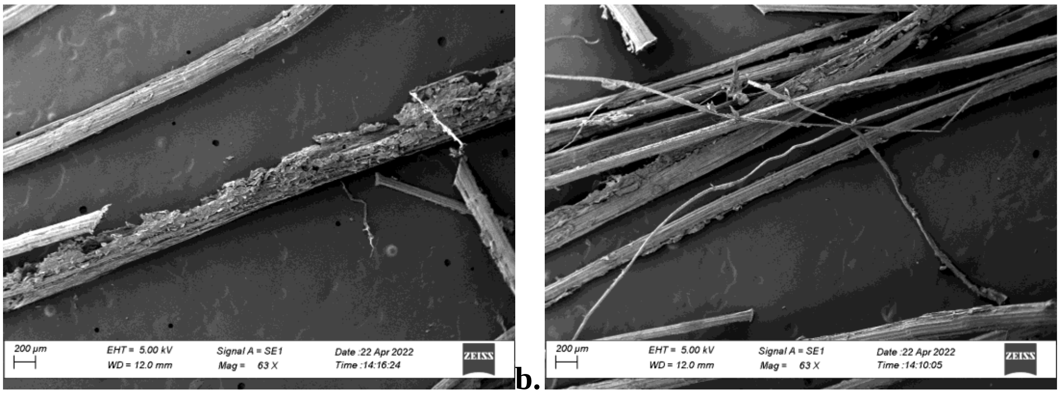


Figure 1: Tensile strength sampling test kit

RESULTS AND DISCUSSION

The extracted fibres were examined using SEM image scanning. Figures 2(a) and (b), magnifying 63x, show a fibre with smooth and fractured surfaces. Figures 2 (c) and (d) reveal the degree of the fractured surface at the same working distance but with magnifications of 393x and 1.11kx. However, the fibre looks bubbled, depicting a destroyed surface, which could be due to the mechanical extraction process.



a **b.**

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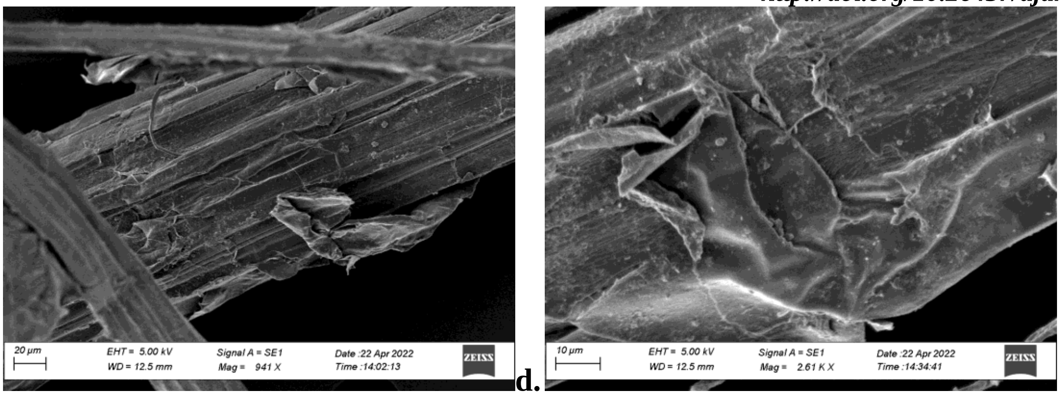
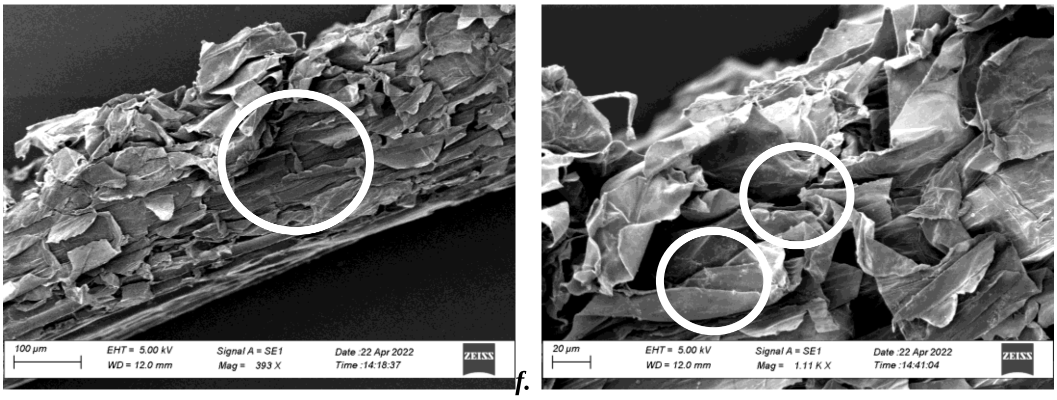


c **d.**

Figure 2 (a, b, c, and d, Magnification SEM on banana fibres

The circled area reveals a series of sheets of layers that form the fibre surface caused by the decorticator's scraping blade, as in Figure 3 e. Further, Figure 3 f shows pores through which water molecules could hide or be absorbed into the fibre.



e. ***f.***

Figures 3e and f: SEM image of scraped damaged of banana fibre

Fibre Strength

Bigger bundled fibres show low-stress values, while smaller ones have high. This explains the fineness of a yarn with reference diameter ratio to fibre length. The efficiency of a rope or cord is made possible by the uniformity of strand strength, diameter and possible elasticity or elongation at break. Single strands of untwisted banana fibres ranged in diameter from 0.09 to 0.11mm, indicating a considerable variance in fibre diameter across all samples and a wide range of stress values of 175.71 to 423.934 N/mm^2. These strands are bundled together to make a robust twisted yarn spun into a cord or rope. A twisted yarn is plied and then further quadrupled to form a strong self-bonded cord, thus shown in figure 4.

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Figure 4: Twisted yarn and cord measurement

The study demonstrated a relationship between fibre diameter and stress in bundled banana fibres. When the same fibre types were bundled in different quantities (10, 20, 30, 40, and 50), it was observed that as the fibre diameter increased, the stress level decreased, and vice versa. For instance, a 10-bundled fibre with an average diameter of 0.29mm exhibited a stress value of 653.54 N/mm², while a 20-bundled fibre with an average diameter of 0.39mm had a stress value of 392.7 N/mm². However, variations in fibre structure could lead to discrepancies that were not directly related to the diameter-stress relationship. Notably, the average density of 30 bundled fibres with an average diameter of 0.592mm measured 185.62 N/mm², which fell outside the expected range of 274.62 to 399.92 N/mm². These findings highlight the impact of fibre diameter and structure on the stress levels in bundled banana fibres. The finding corroborates Khan et al. (2024), which argued that the design approach during textile manufacturing will lead to more environmental and economic gains with high performance.

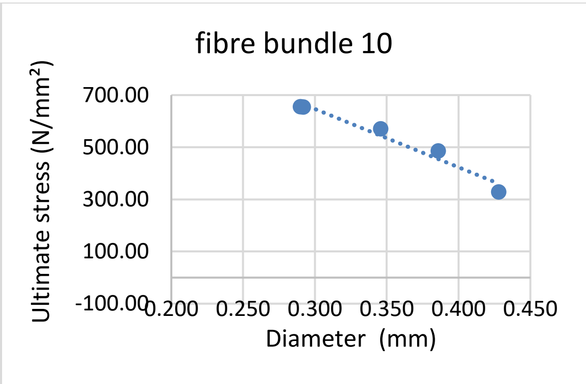

Figure 5: 10 bundles of banana

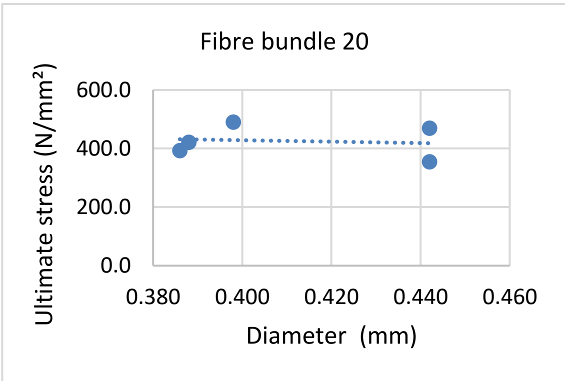

Figure 6: 20 bundles of banana

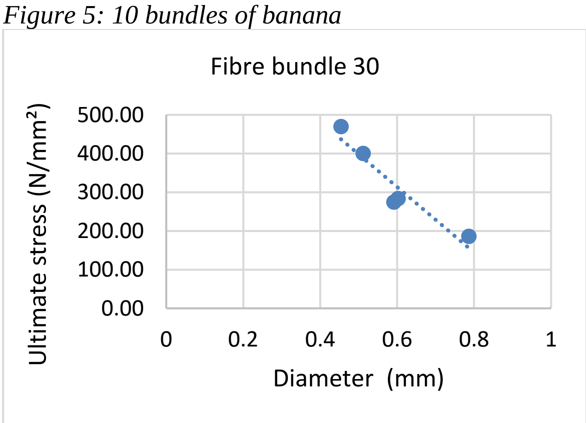

Figure 7: 30 bundles of banana fibres

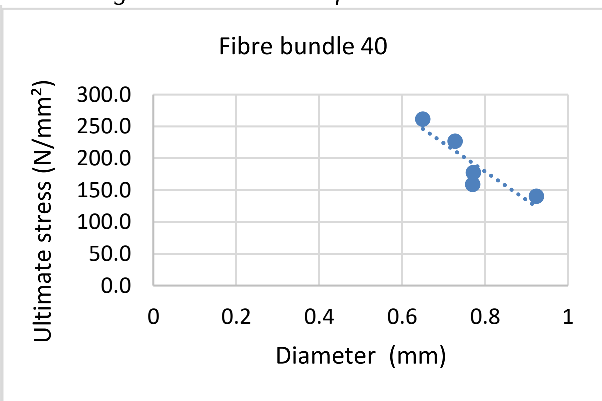

Figure 8: 40 bundles of banana fibres

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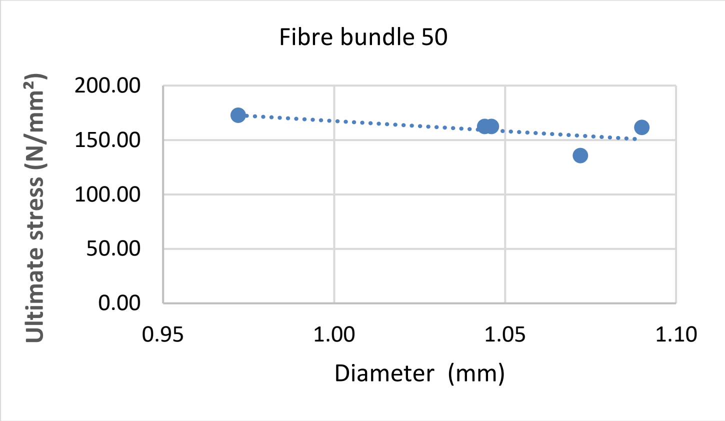

Figure 9: 50 bundles of banana fibres

Figure 10 clearly describes strength variation in the respective fibre bundle sizes. The graph shows an analysis of the differences in the various cords twisted but for 40 and 50 bundles, with less significant values.

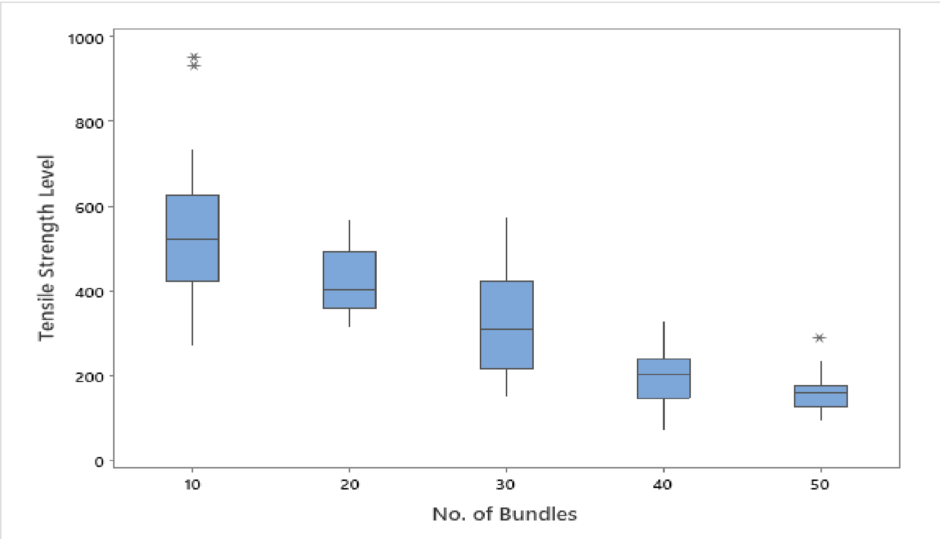

Figure 10: Boxplot for Tensile Strength Level among Bundle Components of Banana Fibre

The analysis of Figures 5 to 9 results reveals the tensile strength levels for different bundle configurations. In Figure 5, the 10-bundle configuration has a median tensile strength of 520.90 N/mm², with a range of 421.70 N/mm² to 625.50 N/mm² and outliers ranging from 269.70 N/mm² to 952.20 N/mm². Figure 6 shows the 20-bundle configuration with a median tensile strength of 402.70 N/mm², ranging from 375.90 N/mm² to 492.40 N/mm² and outliers from 313.70 N/mm² to 567.30 N/mm². Figure 7 displays the 30-bundle configuration with a median stress level of 309.80 N/mm², ranging from 214.80 N/mm² to 422.10 N/mm² and outliers from 149.00 N/mm² to 573.10 N/mm². Figure 8 reveals the 40-bundle configuration with a median tensile strength of 203.00 N/mm², ranging from 148.00 N/mm² to 327.40 N/mm² and outliers from 72.50 N/mm² to 327.40 N/mm². Lastly, Figure 9 shows the 50-bundle configuration with a median tensile strength of

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158.40 N/mm², ranging from 126.93 N/mm² to 290.02 N/mm² and outliers from 45.79 N/mm² to 952.20 N/mm². These findings support Pisupati et al. (2021), who suggested that the number of bundles influences the tensile strength properties of the fibres, with a higher number of bundles leading to reduced tensile strength levels and increased variability in the results.

Table 1: Model Summary for Tensile Strength Level among Bundle Components for Banana Fibre

S	R-sq	R-sq(adj)	R-sq(pred)	F-Value	P-Value
109.224	63.60%	62.39%	60.51%	52.42	0.00

The model has a p-value that is less than the significance level of 0.05. These results indicate that the model is statistically significant. It was found that the R-square was equal to 0.636. This statistic tells us that the model explains 63.6% of the variability in the dependent variables.

i. Content of cellulose: The high cellulose content in banana fibres strengthens the fibre.
ii. High Aspect Ratio: The long, thin fibres have a high aspect ratio, which helps explain their high tensile strength.
iii. Fibre alignment: The fibres are oriented in the same direction and well aligned, increasing tensile strength.
iv. Moisture content: Moisture can also impact the tensile strength of banana fibres. The proper moisture content must be maintained to maximise the tensile strength.

The remaining 36.4% may be affected by;

i. Surface alteration: it could be due to the pre-treatment process of the mechanical extraction process, which was shown in the SEM image of Figure 3 may reduce the tensile strength of banana fibres because of the degree of deformation
ii. The maturity state of the fibre before extracting the fibres.

However, S indicates that the standard deviation between the data points and the fitted values is approximately 109.224 units

Table 2: Descriptive Statistics for Tensile Strength Level Among Bundle Components for Banana Fibre

No. of Bundles	**10**	**20**	**30**	**40**	**50**
Mean	538.50	425.60	322.60	193.00	160.65
SE Mean	34.80	16.40	26.00	12.30	9.16
St. Dev.	173.90	81.90	129.80	61.30	45.79
Coef. Var.	32.29	19.25	40.23	31.78	28.50
Minimum	269.70	313.70	149.00	72.50	95.64
Q1	421.70	357.90	214.80	148.00	126.93
Median	520.90	402.70	309.80	203.00	158.40
Q3	625.50	492.40	422.10	241.10	177.56
Maximum	952.20	567.30	573.10	327.40	290.02
IQR	203.80	134.50	207.30	93.10	50.63
Skewness	0.74	0.18	0.50	0.04	1.04

95% CI (Pooled St. Dev. = 109.224)	(495.2, 581.7)	(382.3, 468.8)	(279.4, 365.9)	(149.8, 236.3)	(117.40, 203.90)
Grouping (Turkey Pairwise Comparisons)	A				
		B			
			C		
				D	D

***NOTE**: Means that do not share a (same) letter are significantly different; Grouping Information Using the Turkey Method and 95% Confidence*

From Table 2, No. of Bundles (10) has the highest mean of 538.50 with a standard deviation of 173.90, followed by the No. of Bundles (20), which has a mean of 425.60 with a standard deviation of 81.90. This is also followed by the No. of Bundles (30) with a mean of 322.60 and a standard deviation of 129.80. The No. of Bundles (40) is next, with a mean of 193.00 and a standard deviation of 61.30. The No. of Bundles (50) has the lowest mean of 160.65 with a standard deviation 45.79. However, all the No. of Bundles are positively skewed.

Figure 11 shows the confidence interval where the population parameter is likely to reside. Therefore, a 95% confidence interval of the mean (495.2 N/mm^2, 581.7 N/mm^2) for the number of bundles (10) suggests that the population mean is between 495.2 N/mm^2 and 581.7 N/mm^2.Also, we can be 95% confident that the population mean (382.3, 468.8) for the number of bundles (20) is between 382.3 and 468.8. Similarly, a 95% confidence interval of the mean (279.4, 365.9) for the number of bundles (30) suggests that the population mean is between 279.4 and 365.9. The 95% confidence interval of the mean (149.8, 236.3) for the number of bundles (40) suggests that the population mean is between 149.8 and 236.3. Lastly, we can be 95% confident that the population mean (117.40, 203.90) for the number of bundles (50) is between 117.40 and 203.90 as depicted in figure 12.

These results indicate that Group A contains 10 bundles, group B contains 20 bundles, Group C contains 30 bundles, and Group D contains 40 and 50 bundles. Differences between means that share a letter are not statistically significant. Specifically, the difference between 40 and 50 bundles is not statistically significant, whereas between 10, 20 and 30 bundles are statistically significant.

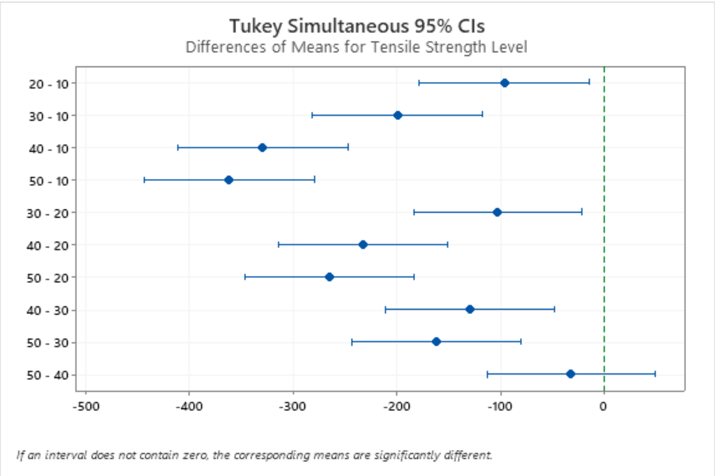

Figure 11: Confidence Intervals for Tensile Strength Level among Bundle Components

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The confidence intervals show all Pairwise differences between factor level means while controlling the error rate. It was revealed that all of these confidence intervals contain actual differences. Specifically, the confidence intervals for the difference between the means of 50 and 40 include zero, which indicates that the differences are not statistically significant. Moreover, the confidence intervals for the remaining pairs of means do not contain zero, which suggests that the differences are statistically significant.

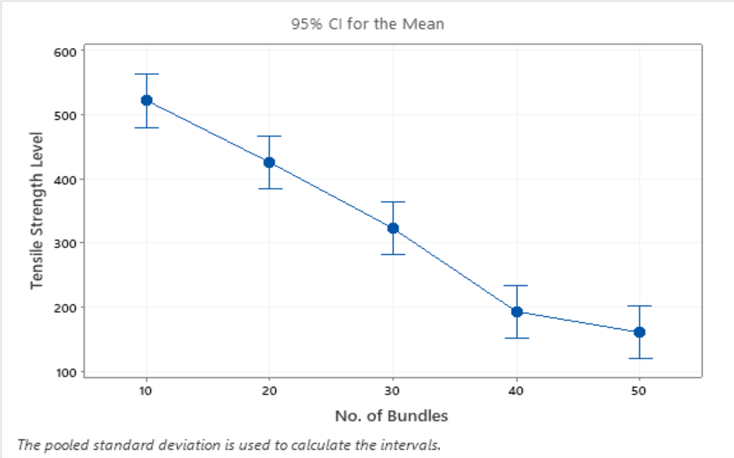

Figure 12: Confidence Intervals Plot for Tensile Strength Level among Bundle Components

In determining whether any differences are statistically significant, this plot reveals that 10 fibre bundles had the highest mean, whereas 50 fibre bundles recorded the lowest.

Impact of a Twist on Stress of Banana Fibres

The most significant aspect of yarn twisting is fibre arrangement, which significantly impacts evenness and strength since it defines the homogeneity of the yarn. The degree of twist and fibre orientation influences the strength of yarn (Ishtiaque & Kumar, 2020). Tensile strength improves with a twist in staple fibre yarns until it reaches a point known as the ‘optimum twist.’ Beyond this point, the yarn’s strength begins to degrade. Filament yarns, on the other hand, are more robust when untwisted, and as the twist increases, their strength decreases (Zuo et al., 2022) In this case, the banana fibre was exposed to a varied degree of twist effect (2.5, 3.75, 5, 6.25, and 7.5 TPI). The graph below depicts twists' influence on fibre bundles' tension. A twist of 2.5 TPI was deemed nearly trivial, while a creep twist of 7.5 TPI was called creep.

Table 3: Stress against twist of banana fibre bundles

2.5 TPI		**3.75 TPI**		**5 TPI**		**6.25 TPI**		**7.5 TPI**	
Fibre Bundles	Ultimate Stress (N/mm²)	Fibre Bundles	Ultimate Stress (N/mm²)	Fibre Bundles	Ultimate Stress (N/mm²)	Fibre Bundles	Ultimate Stress (N/mm²)	Fibre Bundles	Ultimate Stress (N/mm²)
10	653.54	10	654.36	10	490.49	10	485.72	10	328.01
20	654.36	20	421.24	20	490.49	20	469.09	20	354.34
30	469.55	30	399.92	30	185.62	30	274.62	30	283.48
40	177.79	40	261.70	40	226.83	40	158.88	40	140.25
50	160.43	50	162.58	50	172.76	50	135.72	50	161.61

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To make a cord, more strength and less elongation are required as a shock-resistant feature (Khammatova et al., 2021; Elmogahzy, 2006). A 0.5 variation in value change in a twist may not affect the strength of the fibres. Based on the banana fibre test results, high strength is guaranteed for bundled fibres.

It can be hypothesised that there is no significant difference in tensile strength level among different twist lengths, as shown in Figure 13.

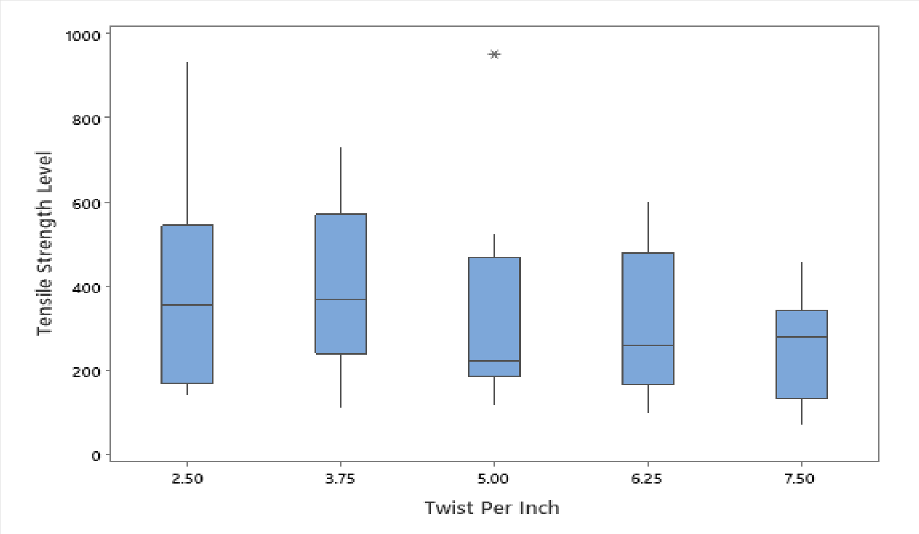

Figure 13: Box plot for Tensile Strength Level among Different Twist Lengths for Banana Fibre Composition Only

This box plot of the tensile strength level for 2.50 TPI shows that the median tensile strength level is 356.80. Most subjects have a tensile strength level that is between 168.40 N/mm^2 and 543.40, but some subjects have tensile strength levels that are as low as 239.80N/mm^2 and as high as 932.40N/mm^2 with a standard deviation of 206.50 N/mm^2. The 3.75 TPI shows that the median tensile strength level is 367.80 N/mm^2. Most subjects have a tensile strength level that is between 240.80 N/mm^2 and 570.20 N/mm^2, but some subjects have tensile strength levels that are as low as 109.50 N/mm^2 and as high as 731.60 N/mm^2 with a standard deviation of 187.30. Also, the 5.00 TPI shows that the median tensile strength level is 223.60 N/mm^2. Most subjects have a tensile strength level that is between 186.40 N/mm^2 and 467.20 N/mm^2, but some subjects have tensile strength levels that are as low as 117.20 N/mm^2 and as high as 952.20 N/mm^2 with a standard deviation of 193.80 N/mm^2 and one extreme value.

The 6.25 TPI also shows that the median tensile strength level is 259.00. Most subjects have a tensile strength level that is between 165.60 N/mm^2 and 478.40 N/mm^2, but some subjects have tensile strength levels that are as low as 239.80 N/mm^2 and as high as 932.40 N/mm^2 with a standard deviation of 158.40 N/mm^2. Similarly, 7.50 TPI shows that the median tensile strength level is 278.20. Most subjects have a tensile strength level that is between 133.10 N/mm^2 and 342.80 N/mm^2, but some subjects have tensile strength levels that are as low as 72.50 N/mm^2 and as high as 456.80 N/mm^2 with a standard deviation of 112.00 N/mm^2.

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Table 4: Model Summary for Tensile Strength Level Among Different Twist Lengths for Banana Fibre

S	R-sq	R-sq(adj)	R-sq(pred)	F-Value	P-Value
174.876	6.70%	3.59%	0.00%	2.15	0.078

The model's p-value is less (more) than the significance level of 0.05, which indicates that the model is statistically significant. We found that the R-square was equal to 0.067. This statistic tells us that the model explains 6.70% of the variability in the dependent variables, possibly because of not-so-less marginal differences between the intervals of the turns per inch chosen for the twisting of the fibre bundles.

The remaining 93.3% could be,

i. Processing circumstances: The circumstances surrounding the fibre's processing, such as temperature, humidity, and tension during spinning, can affect its tensile strength and twist.
ii. Fibre geometry: A fibre's cross-sectional form and surface area, for example, can affect its tensile strength and twist.
iii. Structure of the yarn: The yarn's ply, twist orientation, and yarn architecture can all affect its tensile strength and twist.

However, S indicates that the standard deviation between the data points and the fitted values is approximately 174.876 units.

Table 5: Descriptive Statistics for Tensile Strength Level among Different Twist Lengths for Banana Fibre

Twist per inch	2.50	3.75	5.00	6.25	7.50
Mean	370.80	380.00	329.30	306.80	253.50
SE Mean	41.30	37.50	38.80	31.70	22.40
St. Dev.	206.50	187.30	193.80	158.40	112.00
Coef. Var.	55.68	49.30	58.85	51.64	44.17
Minimum	139.80	109.50	117.20	99.00	72.50
Q1	168.40	240.80	186.40	165.60	133.10
Median	356.80	367.80	223.60	259.00	278.20
Q3	543.40	570.20	467.20	478.40	342.80
Maximum	932.40	731.60	952.20	601.20	456.80
IQR	375.00	329.40	280.80	312.80	209.70
Skewness	0.79	0.43	1.45	0.34	-0.13
95% CI (Pooled St. Dev. = 174.876)	(301.6, 440.1)	(310.7, 449.2)	(260.0, 398.5)	(237.6, 376.1)	(184.2, 322.7)
Grouping (Tukey Pairwise Comparisons)	A	A	A	A	A

NOTE: *Means that do not share a letter are significantly different; Grouping Information Using the Tukey Method and 95% Confidence*

From the table above, 3.75 TPI has the highest mean of 380.00 with a standard deviation of 187.30, followed by 2.50 TPI with a mean of 370.80 with a standard deviation of 206.50. 5.00 TPI follows

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this with a mean of 329.30 and a standard deviation 193.80. 6.25 TPI is next, with a mean of 306.80 and a standard deviation 158.40. 7.50 has the lowest mean of 253.50, with a standard deviation 112.00. However, all the TPI are positively skewed, except 7.50 TPI with a skewness value of -0.13.

Figure 14 disclosed a 95% confidence interval of the mean (301.6, 440.1) for 2.50 TPI , suggests that the population mean is between 301.6 and 440.1. Also, we can be 95% confident that the population mean (310.7, 449.2) for 3.75 TPI is between 310.7 and 449.2. Similarly, a 95% confidence interval of the mean (260.0, 398.5) for 5.00 TPI suggests that the population mean is between 260.0 and 398.5. The 95% confidence interval of the mean (237.6, 376.1) for 6.25 TPI indicates that the population mean is between 237.6 and 376.1. Moreover, we can be 95% confident that the population mean(184.2, 322.7) for 7.50 TPI) is between 184.2 and 322.7.

These results indicate that group A contains all the twist per inch. Differences between means that share a letter are not statistically significant. Specifically, the difference between all the tensile TPI was not statistically significant.

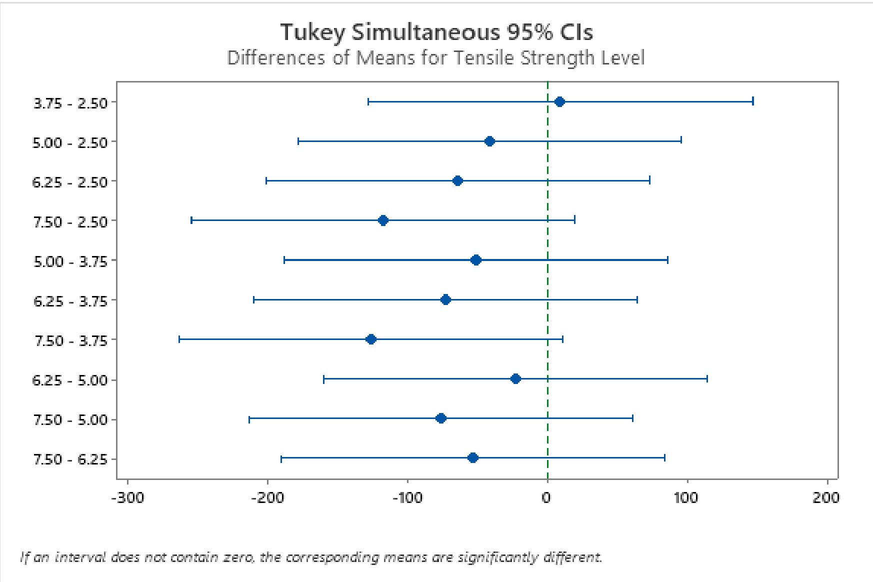

Figure 14: Confidence Intervals for Tensile Strength Level among Different Twist Lengths for Banana Fibre

The figure indicates that the confidence intervals for the pairs of means included zero, which means the differences are not statistically significant. Moreover, the 95% simultaneous confidence level indicates that all these confidence intervals contain actual differences.

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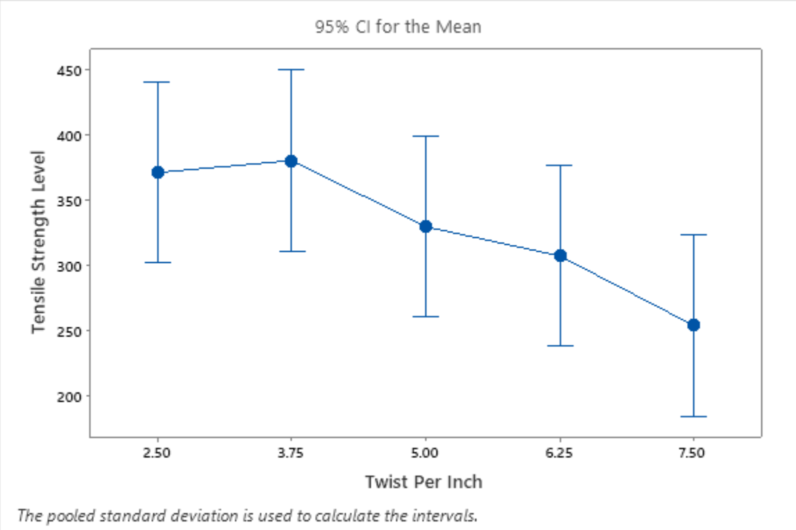

Figure 15: Confidence Intervals Plot for Tensile Strength Level among Different Twist Lengths for Banana Fibre Composition Only

This plot reveals that 3.75 TPI had the highest mean, whereas 7.50 TPI recorded the lowest, indicating whether any differences are statistically significant.

Invariably, the twist affects the strength of the yarn produced. A possible change could occur if the length of the sample is increased from its basic 50mm for the test sample, as confirmed by Bharathi et al. (2021) in yarn characterisation

Percentage of Elongation

Thus, a lower twisted yarn allows for elongation since most fibres can easily slide each other after a strain is applied. The degree of elongation is only required for the function for which it will be used. The elongation percentage is a metric for assessing the flexibility or elasticity of a material. (Ahmad *et al.*, 2017). Elongation percentage is a maximum force called the breaking elongation. A higher percentage implies a malleable material, whereas a lower percentage indicates a brittle material. (Corrosionpedia 2018,). The percentage elongation is computed by comparing the material's ultimate length to its beginning length.

An examination of the 50-bundled fibre and the 10-bundled fibres revealed that a certain amount of twist may be required for a creep yarn before the twist is obstructed for further elongation. As a result, 30, 40, and perhaps 20 bundles could not be extended further since their values peaked, as shown in Figure 16, per the gauge length utilised.

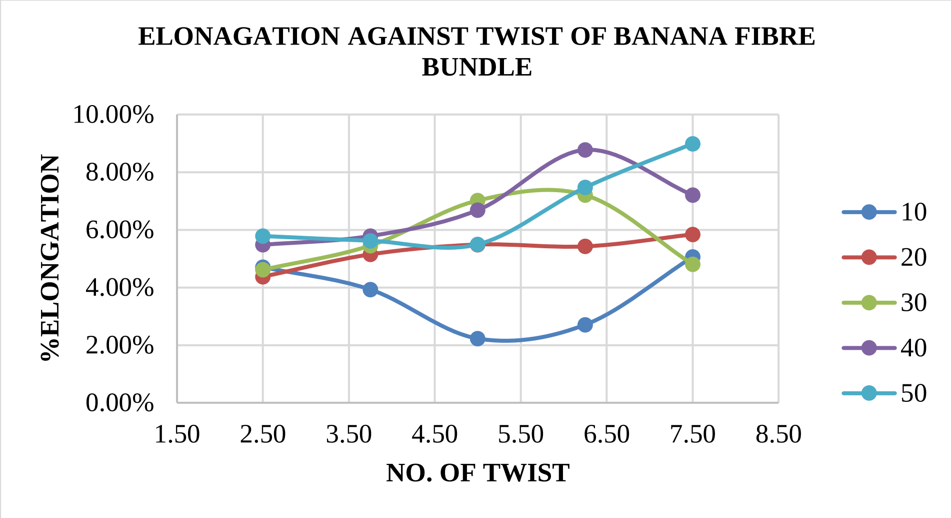

Figure 16: Impact of twist against elongation on banana fibres

Fibre Absorption

Fibre composition is the primary determinant of the ability of a fibre to burn or absorb water. Thus, per the state of natural fibres, they tend to absorb more water than synthetic fibres, hydrophobic and hydrophilic, which are primarily linked to their crystalline areas. Thus, the crystalline areas will absorb no or less water. The amount of crystallinity found in cellulosic fibre may not be defined as perfect crystals due to the dominance of cellulose.

As demonstrated by the Fourier Transform Infrared Spectrometry (FTIR) analysis of banana fibre in Figure 17, where the prominent peak seen at a wavenumber of 3586 cm^{-1} corresponds to the OH stretching vibration of cellulosic fibre, the hydrophilic properties of fibre can be attributed to its inherent bonding and compositional attributes, which supports the findings of Thandavamoorthy et al. (2023).

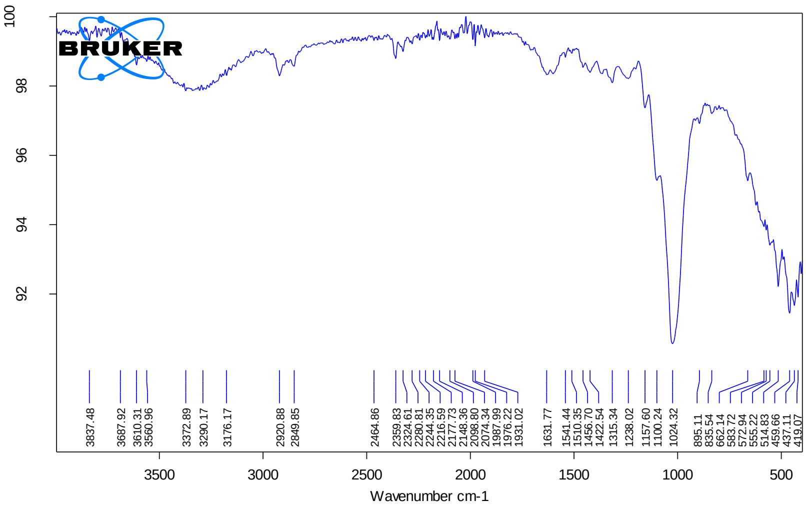

Figure 17: FTIR for Banana Fibre Samples

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XRD observation of the banana fibre revealed a wide area of amorphous regions with scattered crystalline areas. The finding aligns with the study of Vardhini et al. (2019), which indicated that this might be attributed to the degradation of the cellulose of the banana fibre. This indicates that banana fibre has a high ability to absorb more water. The peak point of the XRD graph in the banana fibre reveals a few peaks at 22.82θ and 35.58θ, which may be due to hemicellulose, a minute component of the fibre, as shown in Figure 18. Also, these essentially amorphous regions make it possible to possess more oxygen, which may aid rapid burning when subjected to fire. Removing the amorphous hemicellulose and lignin content by alkali treatment should have improved the crystallinity (Vardhini et al., 2019).

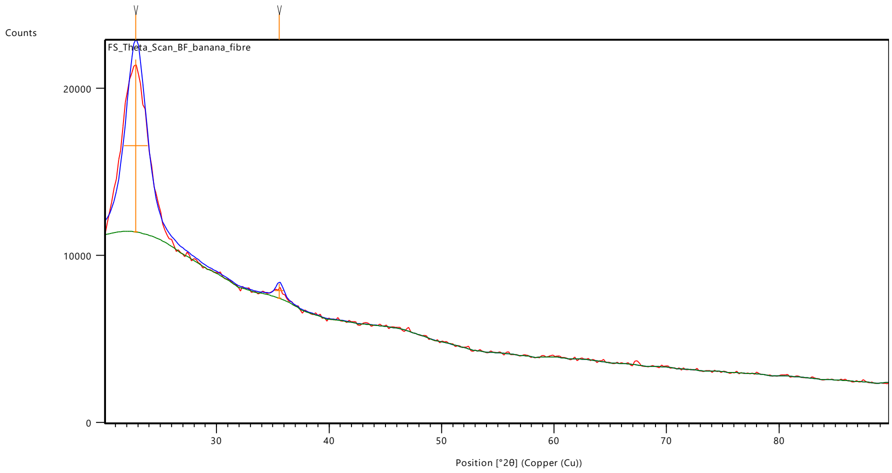

Figure 18: XRD of banana fibre

The condition and characterisation result are the primary influences on the fibre or cordage's water or moisture absorption. However, the processing of the cordage and the degree of fibre twist affect the extent to which water can be absorbed. For the sake of the test and having bulky yarn, 50 bundles of yarn were used.

Table 6: Water absorption of banana cordages

	Dry weight	**Weight (g) for 10 min**	**Weight (g) for 30 min**	**Weight (g) for 60 min**	**Weight (g) for 24 hours**
Sample 1	0.04	0.156	0.327	0.338	0.342
Sample 2	0.05	0.149	0.336	0.341	0.346
Sample 3	0.04	0.151	0.33	0.336	0.351
Sample 4	0.052	0.148	0.288	0.329	0.338
Sample 5	0.04	0.152	0.328	0.339	0.344
Average	**0.044**	**0.151**	**0.322**	**0.337**	**0.344**

The Economic Effect of Banana Fibre for Cordage

Though the characteristics of natural fibre properties are uniformly distributed, there is a degree of conformity of fineness as the bundle of fibres are twisted and overlapped by strong and weaker

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spots of fibres to establish an increase in the strength of fibre bundles. The properties and strengths of each fibre type in the composites complement one another. The evenness of fibre properties enhances the strength espoused by the weakest link theory. (Mansouri, 2007). Hence, the strength quality of a raw fibre bundle may need a considerable number of fibres to establish its relevance for a particular work. The thicker the fibre diameter, the larger the bundles will be, and when the diameter is small, the bundle will be finer and smaller, but this does not establish that thicker fibres are more robust.

The following are the advantages and economic effects of commercialising banana cordages for industrial application.

1. Banana fibre can be cost-effective for cord production due to its renewable and widely available nature. Banana fibre may offer a more affordable and sustainable option than other materials, reducing production costs and increasing profitability.
2. Establishing processing facilities for banana fibre can create job opportunities, particularly in rural areas where bananas are cultivated. This can contribute to local economic development, poverty reduction, and improved livelihoods for banana farming and fibre extraction communities.
3. Processing banana fibre into cords adds value to the raw material. By transforming banana fibre into a usable product, it becomes more marketable and can be utilised in various industries such as textiles, automotive, and construction. Value addition can lead to higher selling prices and increased profit margins.
4. Utilizing banana fibre for cord production provides an additional income source for farmers and communities engaged in banana cultivation. It reduces their reliance solely on banana fruit sales and offers an opportunity to utilise the entire plant, minimising waste and enhancing economic resilience.

Since banana cords for industrial applications are innovative products, some drawbacks may exist, which must be considered for proper marketing.

1. The demand and acceptance for banana fibre cords may vary depending on market preferences, industry regulations, and customer awareness. Market research and analysis are necessary to assess the potential demand for banana fibre cords and ensure a viable market for the product.
2. Processing banana fibre into cords may require specialised equipment, technologies, and expertise. Initial setup costs for processing facilities and the need for trained personnel may pose challenges, particularly for small-scale producers or under-resourced regions.
3. Ensuring consistent quality of banana fibre cords can be a challenge. Variations in fibre quality, processing techniques, and environmental factors may impact the strength and performance of the final product. Quality control measures and standardisation processes are necessary to maintain consistent product quality.
4. Banana fibre cords may compete with other cord materials, such as synthetic or traditional natural fibres. Competing with established materials regarding performance, cost, and customer acceptance can hinder market penetration.

Conduct a thorough feasibility study, market analysis, and cost-benefit analysis to understand the advantages and disadvantages of utilising banana fibre for cord production in a particular context.

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Factors such as local market dynamics, available resources, infrastructure, and industry collaborations significantly determine such ventures' feasibility and economic viability.

CONCLUSION

The era of sustainability and resource management poses challenges in the application of materials that are not widely available, as their production can be expensive and may not achieve the desired properties necessary for evaluating their performance. Sustainable textiles are vital in addressing these challenges, but their importance brings economic obstacles. Specifically, when it comes to producing natural fibre cords, the cost increases due to the requirement of a large mass of fibres to achieve the desired strength.

To overcome this limitation, exploring alternative approaches, such as utilising banana fibres in fibre/fibre composites, is crucial. While banana fibres are abundantly available, combining them with other fibre properties can enhance their attainable strength for broader applications. This augmentation of weaker fibre types allows them to perform effectively in their desired applications. In cordages, strength is of the utmost importance, and the morphological elements directly influence the fibre’s strength, including its ability to withstand loading and pulling under different atmospheric conditions.

Engineering different types of fibres, yarns, and fabrics to meet the specific requirements of each application is necessary to achieve diverse levels of technical performance in various products. By considering these factors and exploring composite approaches, we can enhance the performance and expand the application potential of sustainable materials like banana fibres.

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