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Effect of Blending Methods on the Mechanical Properties of PALF-Cotton Hybrid Yarns Produced via Open-End Spinning

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ABSTRACT

The increasing demand for eco-friendly materials in the textile industry has led to greater attention on the use of natural fibers, such as pineapple leaf fiber (PALF), which is abundant as agricultural waste. However, its coarse structure and limited spinnability pose challenges in yarn manufacturing. This study aims to compare two fiber blending methods, sliver blending using a drawing frame and fiber blending using a blowing machine in the production of PALF-cotton hybrid yarns via an open-end spinning system. Both samples were prepared using a 50:50 PALF-cotton ratio and evaluated for yarn count, tenacity, and elongation. The results showed that the yarns blended through the blowing process demonstrated superior tenacity and more consistent yarn count. Statistical analysis using an independent sample *t*-test confirmed that these differences were significant ($p < 0.05$). Elongation values were also significantly higher in yarns processed using the blowing method. These findings highlight the importance of blending technique in improving fiber distribution, inter fiber cohesion, and overall yarn quality. It can be concluded that the blowing method offers a more effective strategy for producing sustainable PALF-cotton hybrid yarns, suitable for industrial scale applications. This research contributes to the advancement of sustainable textile processing and provides a practical reference for industries seeking to utilize agro waste fibers in yarn production.

Keywords: PALF, Hybrid yarn, Fiber blending method, Open-end spinning

ABSTRAK

Meningkatnya permintaan akan material ramah lingkungan dalam industri tekstil mendorong pemanfaatan serat alam seperti serat daun nanas (PALF), yang melimpah sebagai limbah pertanian. Namun, struktur kasar dan keterbatasan kemampuan pintalnya menjadi tantangan dalam proses produksi benang. Penelitian ini bertujuan untuk membandingkan dua metode pencampuran, pencampuran sliver menggunakan drawing frame dan pencampuran serat menggunakan mesin blowing dalam produksi benang hibrida PALF-kapas melalui sistem open-end spinning. Kedua sampel dibuat dengan rasio 50 : 50 PALF-kapas, kemudian diuji nomor benang, kekuatan tarik, dan mulur. Hasil menunjukkan bahwa benang yang dihasilkan melalui metode blowing memiliki kekuatan tarik yang lebih tinggi dan nomor benang yang lebih konsisten. Analisis statistik dengan *t-test* menunjukkan perbedaan yang signifikan ($p < 0.05$). Nilai mulur juga lebih tinggi secara signifikan pada metode blowing. Temuan ini menegaskan pentingnya teknik pencampuran dalam meningkatkan distribusi serat, kohesi antar serat, dan kualitas benang secara keseluruhan. Dapat disimpulkan bahwa metode blowing merupakan strategi yang lebih efektif untuk memproduksi benang hibrida PALF-kapas yang berkelanjutan dan layak untuk skala industri. Penelitian ini berkontribusi dalam pengembangan proses tekstil ramah lingkungan dan memberikan referensi praktis bagi industri yang ingin memanfaatkan limbah pertanian dalam produksi benang.

Kata kunci: PALF, benang hibrida, metode pencampuran serat, open-end spinning

INTRODUCTION

The growing environmental concern over synthetic fiber pollution and the textile industry's dependency on non-renewable resources has driven global efforts to explore alternative, sustainable materials (Farhana *et al.*, 2022; Nayak *et al.*, 2023). Natural fibers derived from agricultural waste, such as pineapple leaf fiber (PALF) are increasingly being studied as eco-friendly reinforcements in composite materials and textiles (Jain & Sinha, 2022; Sethupathi *et al.*, 2024). PALF, a lignocellulosic fiber extracted from discarded pineapple leaves, offers several advantages including high tenacity, biodegradability, and cost-effectiveness due to its status as a waste byproduct (Abdel *et al.*, 2025; Thapliyal *et al.*, 2023). However, despite its mechanical potential, PALF faces limitations in processability, flexibility, and spinnability when used as a single raw material in conventional yarn manufacturing systems (Rusman *et al.*, 2025; Shahzad & Nasir, 2016).

To address these challenges, fiber blending has emerged as a strategic approach. Blending PALF with more spinnable fibers such as cotton enables improved yarn handling, mechanical stability, and textile compatibility (Liao *et al.*, 2025; Zolkifflee *et al.*, 2024). Previous studies have demonstrated that hybrid yarns composed of natural fiber blends can enhance performance characteristics while maintaining spinning parameters and fiber blending ratio (Zolkifflee *et al.*, 2024). In particular, cotton remains the preferred blending partner due to its softness, strength, and widespread industrial use (Tausif *et al.*, 2018; Wang *et al.*, 2020; Zardari *et al.*, 2025). Nonetheless, the method of blending and the sequence of fiber preparation processes are crucial factors influencing the final yarn quality (Kravaev *et al.*, 2014; Ray, 2018).

Recent research has explored the mechanical and structural properties of hybrid yarns made from natural fibers such as jute, sisal, or wool combined with cotton (Ashadujjaman *et al.*, 2021; Meena *et al.*, 2022; Rajesh, 2017). However, only limited studies have addressed the optimization of blending techniques for PALF-cotton yarns, especially within the context of open-end spinning systems. Furthermore, little attention has been given to the role of blending processes, such as fiber opening using a blowing machine, in comparison to direct sliver blending using drawing frames, both of which could significantly influence fiber distribution, alignment, and yarn integrity (Cao *et al.*, 2025).

This study addresses this gap by investigating the impact of two distinct fiber blending methods direct sliver blending and fiber blending using a blowing machine on the quality of PALF-cotton hybrid yarns produced through open-end rotor spinning. The novelty of this research lies in its systematic evaluation of how different blending approaches affect the yarn's physical (yarn count) and mechanical (tenacity and elongation) properties. Unlike previous study that primarily focused on fiber treatment, reinforcement ratios or composite properties, this study introduces a process level innovation by comparing two blending routes within the spinning process. This comparison has not been previously reported for PALF-cotton hybrid systems, particularly in the context of open-end spinning. Moreover, this research uniquely integrates sustainable material utilization combining industrial cotton and recycled cotton waste with agro based pineapple leaf fiber, establishing a circular production concept that aligns with the principles of green manufacturing.

The central hypothesis of this study is that fiber blending conducted at the back process stage using a blowing machine will result in more uniform fiber distribution and improved fiber cohesion, thereby producing yarns with higher tenacity and better consistency, compared to direct sliver blending. The mechanical differences are also expected to correlate with variations in yarn count, influenced by drafting behavior and fiber integration during spinning.

The purpose of this research is to evaluate and compare the effects of different fiber blending methods, specifically back process blowing blending versus direct blending on the tenacity, elongation, and yarn count of PALF-cotton hybrid yarns produced via open-end spinning, with the ultimate aim of improving process efficiency and product quality in sustainable yarn manufacturing.

METHODOLOGY

The experimental procedure was structured into two distinct stages to evaluate the influence of blending methods on the properties of PALF-cotton hybrid yarns. Two fiber blend samples were developed using PALF and cotton as the base materials. The PALF used in this study was supplied in the form of ready to spin slivers by PT Serat Nanas Indonesia, had undergone mechanical decortication and cleaning as part of the extraction and pretreatment process. The cotton material was sourced from two origins: industrial grade virgin cotton and recycled cotton waste sliver obtained from leftover materials in prior spinning operations. The combination of virgin and recycled cotton was selected to align with circular economy principles and enhance material efficiency in yarn production.

Table 1. Experimental design for hybrid natural fiber yarn production

Sample	Blending machine	PALF : cotton Ratio	Number of drawing passes	Description
A	Drawing frame	50 : 50	2x	Sliver blending was carried out directly on drawing frame.
B	Blowing Machine	50 : 50	2x	Fiber blending process was performed using a blowing machine and subsequently processed through two sequential drawing passages.

In the first experimental stage, Sample A was produced by directly blending PALF and cotton slivers in a 50:50 ratio using a drawing frame without any prior fiber opening treatment. In the second stage, a pre-treatment blending approach was implemented in which the fibers were initially opened and blended using a blowing machine before undergoing the drawing process. This method resulted in Sample B, which was also processed through two drawing passages. Both Sample A and Sample B were then subjected to identical spinning and post spinning treatments to ensure a fair comparison of their physical and mechanical yarn properties. The experimental design, summarized in Table 1.

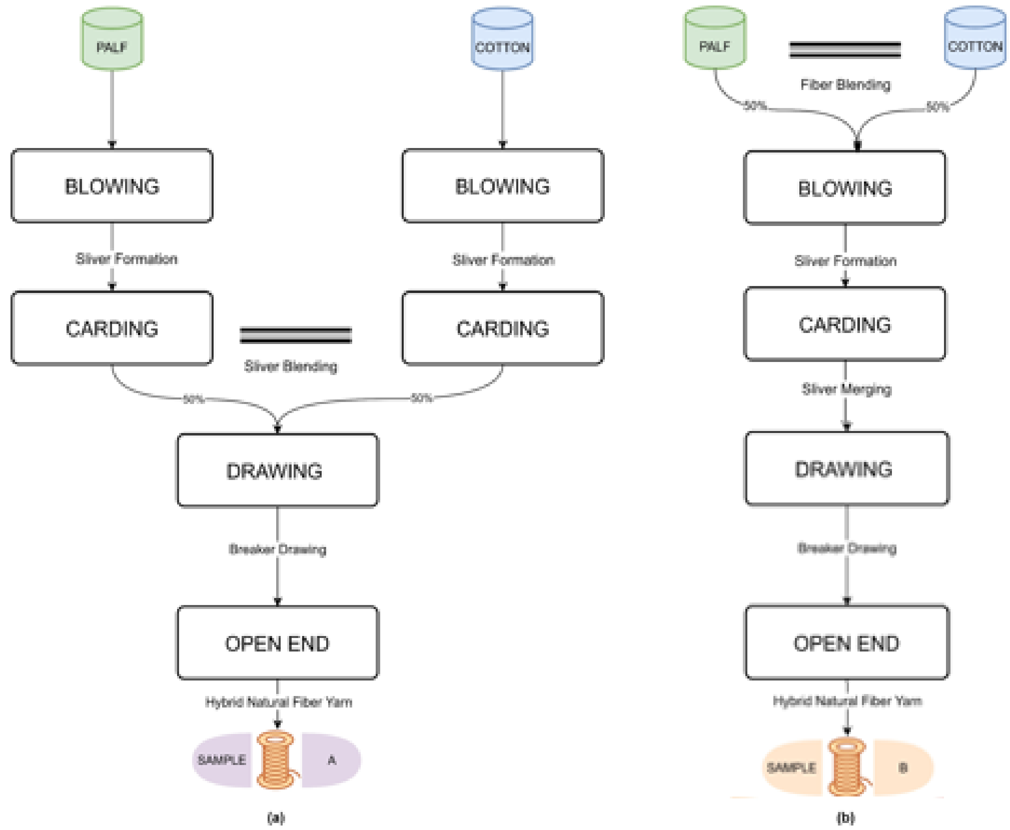

Figure 1. Flow process of the experimental design for hybrid natural fiber yarn production

Following the pre-treatment stage, PALF was blended with cotton fiber at a fixed weight ratio of 50:50, using approximately 20 kilograms of each fiber type. The blending process was carried out using a blowing machine, which played a vital role in ensuring the homogeneous mixing of the two fiber types (Nurazzi *et al.*, 2021). Achieving consistent blending of equal quantities of PALF and cotton was essential for ensuring sliver uniformity, thereby contributing to the reproducibility and reliability of the resulting yarn properties (Hossain *et al.*, 2024).

Following blending, the fiber lap was directly fed into a carding machine. Carding is a critical process for individualizing, cleaning, and aligning fibers prior to spinning. In this study, a single stage carding process was performed in an industrial setting to convert the blended PALF-cotton lap into a uniform sliver. The machine parameters including feed rate, cylinder speed, and wire configuration were optimized to accommodate the distinct fiber characteristics, particularly differences in fineness and staple length, thereby minimizing fiber damage and loss during processing.

Subsequently, the drawing process was conducted to enhance sliver uniformity and improve fiber alignment. The input material was a carded sliver with a linear density of 0.1108 Ne, derived from the 50:50 PALF-cotton blend and processed at a delivery speed of 250 m/min. Drawing was performed using a breaker draw frame with a 6 doubling system, in which six individual slivers were combined and drafted into a single, more uniform sliver suitable for spinning.

The final spinning process was conducted using an open-end rotor spinning machine, which is well suited for processing short or coarser fibers such as PALF and recycled cotton. Open-end spinning was selected due to its high production efficiency and its ability to tolerate greater fiber variability, making it an appropriate method for the PALF-cotton blended sliver used in this study. The drawn sliver, which had previously undergone two stages of breaker drawing, was directly fed into the rotor spinning unit. Within the machine, the fibers were further individualized, transported via an air stream into a high speed rotor, and continuously twisted into yarn without the need for an intermediate roving stage. This spinning method simplifies the overall process and reduces energy consumption compared to conventional ring spinning systems.

Previous studies have demonstrated that the spinning machine setting parameters play a crucial role in determining the final yarn properties (Fahad *et al.*, 2025; Nurazizah *et al.*, 2025; Pradifta *et al.*, 2025; Rusman, *et al.*, 2025; Wijayono *et al.*, 2025). Key machine parameters, particularly rotor speed, were optimized through a series of trial and error experiments to determine the most stable operating conditions. These adjustments ensured smooth yarn formation with minimal breakage and reduced machine downtime during production. The technical parameters used in the open-end spinning process are presented in Table 2.

Table 2. Technical parameters of the open end spinning process

Parameter	Value	Unit	Description
Target yarn count	20	Ne_1	Medium yarn counts, suitable for open-end spinning.
Rotor speed	55,000	Rpm	High speed rotor operation.
Twist Multiplier	5.5	-	Chosen for optimal strength.
Twist per inch	24.60	Twist/inch	The number of twists inserted into a yarn over a linear distance of one inch.
Twist per meter	968.73	Twist/meter	The number of twists inserted into a yarn over a linear distance of one meter.

The spun yarns were automatically wound onto cylindrical bobbins and subsequently conditioned under standard atmospheric conditions (65 ± 2% relative humidity and 21 ± 2 °C) for a minimum of 24 hours prior to testing, in order to stabilize moisture content and ensure consistent test results. After the spinning process, the yarn samples were evaluated to determine their physical and mechanical properties using standardized testing equipment and procedures, in order to assess their quality and suitability for textile applications. The specific testing methods and instruments employed in this study are summarized in Table 3.

Table 3. Testing standards and instruments for evaluating yarn properties

Testing Property	Standard	Instrument Used	Unit
Yarn count	ASTM D1059	Wrap Reel & Analytical Balance	Ne_1
Tenacity	SNI 7650:2010	Instron Strength Tester	cN/Tex
Elongation at Break	SNI 7650:2010	Instron Strength Tester	%

To analyze the experimental results and identify the optimal composition and processing parameters, the collected data were subjected to quantitative statistical analysis. Descriptive statistics including mean, standard deviation, and coefficient of variation (CV%) were calculated to summarize the performance of each yarn sample with respect to yarn count, tenacity, elongation, evenness, and hairiness. These metrics provided a preliminary understanding of data consistency and variability across the different process stages.

To further examine the influence of key process variables, particularly the blending methods on yarn quality, a one-way Analysis of Variance (ANOVA) was conducted. This statistical technique was applied to evaluate whether significant differences existed among the processing groups. A significance level of $p < 0.05$ was adopted to determine the statistical relevance of observed differences, thereby identifying which combinations of blending had the most significant impact on the yarn properties.

RESULTS AND DISCUSSION

This section presents the results of yarn testing and analysis derived from the experimental procedures described in the previous sections. The discussion is organized according to key yarn performance parameters: yarn count, tenacity and elongation. Particular attention is given to how these properties are influenced by the blending of PALF with cotton and the conditions applied during the open-end spinning process.

Yarn Count

Yarn count testing was carried out to determine the fineness of the yarn, which is defined as the ratio of its length to weight. The yarn count unit used in this study was the English Cotton Count (Ne_1), where a higher Ne value corresponds to a finer yarn, and a lower value indicates a coarser yarn. In this experiment, the final yarn production stage was conducted using an open-end spinning machine, with a target yarn count of Ne 20. All yarn samples followed an identical processing sequence, including blowing, carding, drawing, and open-end spinning.

The results of the yarn count measurements for each sample are presented in Table 4, which summarizes the actual yarn counts achieved compared to the target specification. These measurements were calculated using standard conversion methods based on the Ne system, where one Ne represents a yarn length of 840 yards per pound. This unit is widely used in cotton-based textile production and provides a consistent reference for evaluating yarn fineness. To calculate the Ne value, the following formula was applied:

$$Ne1\left(\frac{hank}{lbs}\right) = \frac{100\,(m)\,x\,453{,}6\left(\frac{g}{lbs}\right)}{768\,\left(\frac{m}{hank}\right)\,x\ weight\,(g)} \tag{1}$$

In this formula, 100 represents the standard test length (in meters), 453.6 is the conversion factor from grams to pounds, and 768 corresponds to the number of meters in one hank (equivalent to 840 yards). The variable *weight* refers to the measured mass of yarn (in grams) for the 100 meter sample. This formula provides a standardized method for converting yarn length and weight from metric units into the English Cotton Count (Ne) system.

Table 4. Yarn count results of PALF-cotton blended yarn samples

Sample	Length (m)	Weight (g)	Tex	Ne_1
A	100	3.266	32.66	18.08
B	100	2.920	29.21	20.22

To assess the consistency of the spinning process in achieving the intended yarn fineness, the actual yarn count of each sample was compared against the target specification of Ne 20. The percentage deviation from the target was calculated to evaluate the precision of yarn production across different blending and processing methods. The results are summarized in Table 5.

Table 5. Comparison between actual and target yarn count

Sample	Target Count (Ne_1)	Actual Count (Ne_1)	Deviation (%)
A	20	18.08	-9.6
B	20	20.22	1.1

Among the two samples, Sample B demonstrated the smallest deviation from the target count, with a positive variance of only +1.1%. This suggests that the combination of fiber blending using a blowing machine followed by two drawing passages provided the most stable processing conditions. The improved fiber integration and alignment likely contributed to better drafting performance and more consistent sliver linear density, ultimately resulting in a yarn count closer to the desired specification.

Tenacity and Elongation

Tenacity and elongation are critical indicators of yarn quality. Tenacity refers to the maximum force a yarn can resist before breaking, whereas elongation represents the extent to which the yarn can stretch under tension prior to rupture. These mechanical properties are essential for evaluating yarn performance during downstream processes such as weaving and knitting, and they also influence the comfort, durability, and functional performance of the final textile product. In this study, tenacity tests were conducted using a universal instron machine, following the standardized procedures outlined in SNI 7650:2010. The testing parameters, including gauge length, pulling speed, and the number of test specimens, were set according to the standard to ensure data reliability and comparability. The individual tenacity and elongation curves for the yarn samples are illustrated in Figure 2 and Figure 3, while the average values for Samples A and B are summarized in Table 6. To enable a standardized comparison of yarn strength independent of linear density, tenacity was also calculated. Tenacity is defined as the breaking force per unit of linear density and is typically expressed in centiNewtons per Tex (cN/Tex). It was calculated using the following formula:

$$Tenacity\left(\frac{cN}{Tex}\right) = \frac{Breaking\ Force(cN)}{Yarn\ Linear\ Density(Tex)} \tag{2}$$

Table 6. Average strength and elongation of PALF-cotton blended yarn samples

Sample	Average Break Force (cN)	Yarn Count (Tex)	Average Elongation (%)	Average Tenacity (cN/Tex)
A	297	32.66	5.2	9.09
B	305	29.21	4.8	10.44

The tenacity and elongation values obtained from yarn testing indicate clear differences in mechanical performance between Sample A and Sample B. Sample A exhibited a tenacity of 9.09 cN/Tex and an elongation of 5.2%, whereas Sample B demonstrated a higher tenacity of 10.44 cN/Tex, albeit with slightly lower elongation at 4.8%. These results reflect the influence of the blending method and the processing sequence on yarn structural integrity and fiber cohesion.

In terms of yarn count, Sample A had a coarser count (Ne_1 18.08) compared to Sample B (Ne_1 20.22), meaning Sample A had a higher linear density (i.e., thicker yarn). Typically, coarser yarns are expected to have higher tenacity due to the greater amount of material (mass per unit length). However, in this study, despite being finer, Sample B exhibited greater tenacity, indicating that processing quality (particularly blending uniformity) had a more dominant effect than mere linear density. This highlights the importance of blending efficiency and fiber preparation in achieving mechanical performance.

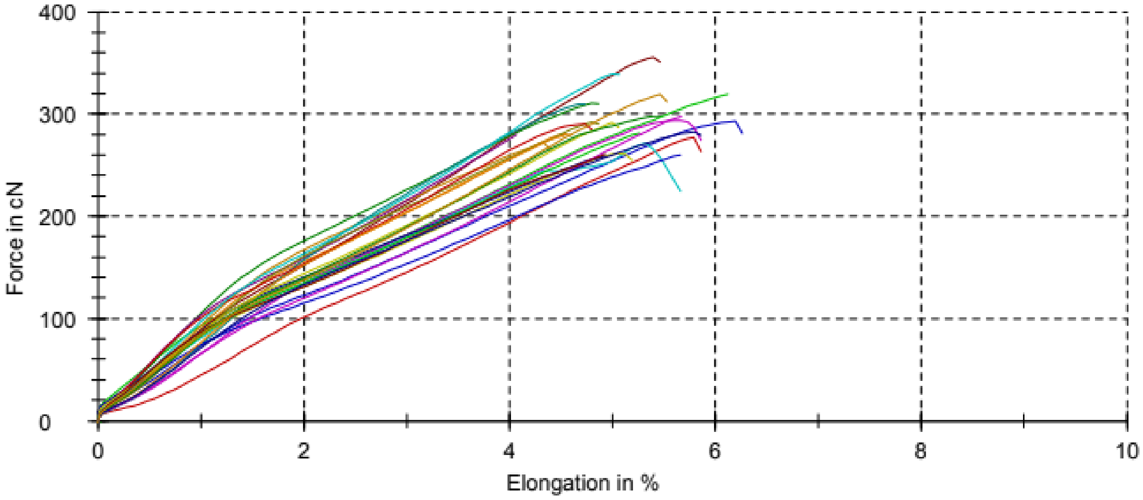

Figure 2. Tenacity and elongation curves of palf-cotton yarn (sampel A)

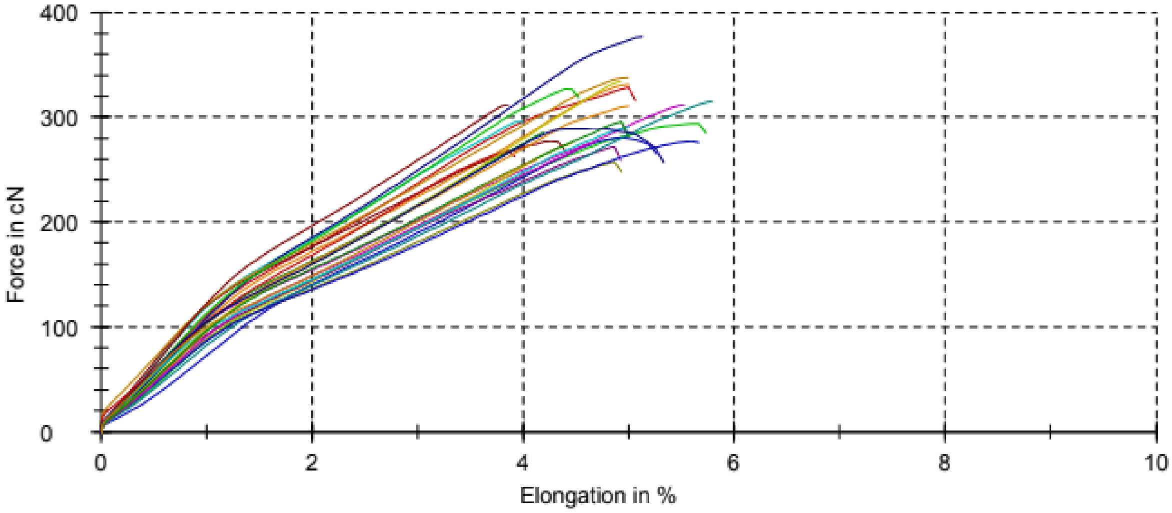

Figure 3. Tenacity and elongation curves of PALF-cotton yarn (sampel B)

Regarding elongation, the slightly higher value observed in Sample A may be due to the lower packing density and less compact structure resulting from suboptimal blending. With more space between fibers, Sample A may have allowed more extensibility under load, though at the expense of strength and uniformity. Sample B, on the other hand, was more compact and well-aligned, which limited elongation but improved tensile resistance. This trade-off is typical in fiber-reinforced structures, as packing density and alignment improve, strength increases while extensibility slightly decreases.

The results suggest that fiber blending using a blowing machine prior to drawing (as applied in Sample B) is more effective for producing PALF-cotton hybrid yarns with better mechanical properties. The process promotes fiber homogenization, minimizes weak spots, and improves fiber orientation during drafting and spinning.

Statistical Analysis

In order to assess the statistical significance of the observed differences in mechanical properties between the two blending methods, an independent two sample t-test was conducted for both tenacity and elongation value. Figure 4 shows the statistical analysis of tenacity and elongation between two blending methods.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Mulur	Equal variances assumed	.271	.605	2.413	48	.020	.37600	.15585	.06265	.68935
	Equal variances not assumed			2.413	47.961	.020	.37600	.15585	.06264	.68936
Kekuatan	Equal variances assumed	2.154	.149	-4.244	48	.000	-1.01200	.23848	-1.49149	-.53251
	Equal variances not assumed			-4.244	45.375	.000	-1.01200	.23848	-1.49221	-.53179

Figure 4. Screenshot of the output display from SPSS analysis

The Levene's Test for equality of variances indicated no significant difference in variance for both elongation ($p = 0.605$) and tenacity ($p = 0.149$), justifying the assumption of equal variances in the t-test analysis. The results revealed a statistically significant difference in elongation between the two samples ($t(48) = 2.413$, $p = 0.020$). The yarn produced via the blowing method exhibited a higher elongation value, with a mean difference of 0.376%, and a 95% confidence interval ranging from 0.062 to 0.689. This suggests that the fiber blending technique enhances the fiber distribution and inter-fiber mobility during spinning, contributing to improved extensibility of the resulting yarn.

For tenacity, the t-test yielded an even more pronounced difference ($t(48) = -4.244$, $p < 0.001$), with Sample B achieving significantly higher strength than Sample A. The mean difference was -1.012 cN, with a 95% confidence interval between -1.491 and -0.533, indicating that the blending process through blowing led to more effective fiber integration and stronger inter-fiber cohesion. These findings support the hypothesis that blending at the fiber stage (using a blowing machine) offers superior mechanical outcomes compared to direct sliver blending, particularly in the context of hybrid PALF-cotton yarn production via open-end spinning.

CONCLUSION

This study confirms that the fiber blending method significantly affects the mechanical properties and consistency of PALF-cotton hybrid yarns produced via open-end spinning. The yarns produced through fiber blending using a blowing machine exhibited higher tenacity and more consistent yarn count compared to those produced through sliver blending in the drawing frame. Statistical analysis using the independent samples *t*-test confirmed that the differences in tenacity ($p < 0.001$) and elongation ($p = 0.020$) were statistically significant. Therefore, blending fibers at the pre-processing stage using a blowing machine is recommended for achieving better yarn performance and processing stability. Future research should explore different fiber blending ratios, other spinning systems, and the environmental and economic implications of using PALF in sustainable textile production.

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