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Fabrication and Characterization of Jute-covered Core-spun Yarn Produced on Flyer-spinning Frame

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Article

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ABSTRACT

Recently, the consumption of core-spun yarn is increasing owing to its growing application in functional textiles. In a core-spun yarn, filaments as a core material are being used to provide functional properties, while natural fibers as a cover material are being used to provide surface physical properties and a natural outlook. In this study, jute-covered core-spun yarns containing polyester filaments with different linear densities were made in a modified jute flyer-spinning frame with the distinguishably positioned filament feed. The physico-mechanical properties of the manufactured core-spun yarns were examined, and the results were analyzed with the SPSS software. Compared with the 100% jute yarn, the jute-covered core-spun yarns have significantly higher tenacity (233.13% to 315.5%) and breaking elongation (257.9% to 367%), and lower unevenness (U_m%), imperfection values, and degree of hairiness. Such good-quality core-spun yarn can be used in functional, value-added, and different diversified jute products.

KEYWORDS

long staple spinning, jute yarn, functional jute products, compound yarn

INTRODUCTION

Jute is a lignocellulosic bast fiber with many inherent advantages, like luster, long-staple length, high tensile strength, moderate heat, and fire resistance. It is an inexpensive natural fiber principally used as a packaging material and raw material for a wide range of nontraditional and value-added non-textile products [1]. At present, a wide variety of synthetic fibers are available that offer superior strength, durability, and functional properties. Jute fiber has been confronting extreme competition from these synthetic fibers since their advent in the world textile market [2]. To survive in the competitive market, it is essential to manufacture diversified and functional jute products alongside traditional products. Jute can be combined with these synthetic fibers to take advantage of their functional properties. Such a combination can be achieved by producing composite or hybrid type yarn like core-spun yarn. This yarn will be a potential raw material for the production of diversified and functional jute products.

The prime focus of using core-spun yarn in textiles is to exploit the various properties of the continuous filament (elastomeric, crimped, or stiff filament) and staple cut of artificial fiber or natural fiber. Core-spun yarns containing filament (such as nylon, polyester, etc.) as a core material provide higher strength and functional properties, while a wide range of natural fibers (such as cotton, flax, silk, wool, etc.) as a sheath material provide the natural fiber yarn appearance and surface physical properties [3,4]. Figure 1 shows the view of a typical core-spun hybrid yarn where staple fibers surround a continuous filament in the core as a cover or sheath.

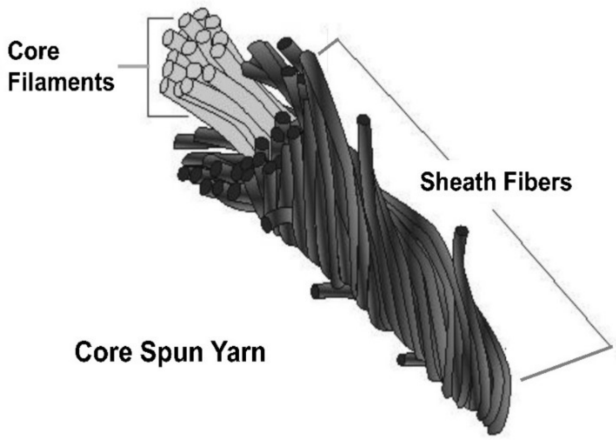

Figure 1. Typical view of core-spun yarn (adapted from [5])

The production process and different properties of core-spun yarn containing polyester filament were studied on a modified ring frame [6-8], rotor frame [9], ring and air-jet spinning frame [10,11], ring, tandem, and friction spinning frame [12], and Dref-III friction spinning frame [13]. Many researchers evaluate these processes in terms of different physico-mechanical properties, structures, and linear density ranges. The impact of the core-sheath ratio on the yarn breaking strength values was studied and it was found that the breaking strength value of core-spun yarn increased with increasing the sheath ratio in the yarn [14]. It was shown that the core feeding emplacement and control highly affect the structure and properties of the core-spun yarn [15]. The effect of the core filament feed-in angle on the covering was investigated, and it revealed that the feed-in angle increasing from 0° to 120° provides a superior cover factor to the core-spun yarn [16]. The impact of filament fineness on irregularity (CV_m%) properties of the core-spun yarn was investigated and found statistically significant [17]. Filament pre-tension in core-spun yarn production was also studied and it was found that it has an exceptionally high impact on the sheath slipping resistance [3].

As a cover material in core-spun yarns, many researchers have studied most natural textile fibers, but the use of jute is not observed yet. In addition, there has been found no research on the jute core-spun yarn production system and its properties, which would be of great interest. From that interest, the present study conducted an empirical approach to produce a jute-covered polyester core-spun yarn on a modified flyer-spinning frame. The study also characterized the physical and mechanical properties of four jute-covered polyester core-spun yarns with the same linear density where all process parameters were kept constant. The authors believe this study will fulfill the research gap on the jute core-spun yarn production system and create a scope for the jute to be used as a viable raw material for the production of diversified and functional jute products.

EXPERIMENTAL

Materials

For this study, jute fibers (Bangla Tossa B Grade) were used as the sheath material, and drawn multi-filament polyester yarn with four distinct linear densities was employed as the core material. The properties of sheath and core materials are shown in Table 1 and 2, respectively.

Table 1. Characteristics of raw jute fibers

Material	Linear Density (dtex)	Tenacity (cN/dtex)	Elongation (%)
Single Jute	22*	0.0343**	1.65

*Average fiber linear density; **Test length 1.0 cm

Table 2. Characteristics of polyester multi-filaments

Specification of multi-filaments	Tenacity (cN/dtex)	Elongation (%)
56 dtex/36 filaments	3.50	21.69
83 dtex/36 filaments	3.75	22.90
110 dtex/48 filaments	4.00	24.20
167 dtex/48 filaments	4.56	34.57

Methods

Core material feeding mechanism

This study conducted preliminary trials to find out the core filament feed positioning of a traditional jute flyer-spinning frame. At first, the filament was fed from an overhung package to the drafted strand of the jute fibers at the nip of the drawing rollers through a disc tensioning device and a V-grooved guide roller [15]. The filament feed positioning in drawing rollers nip was controlled at three different positions of the drafted strand - left, center, and right [18]. However, in all trials, it was found that core filaments at the spinning triangle area were wrapped and twisted at the outer surface of the drafted strand instead of going to the core surface. Hence, further, attempts were carried out to find out

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suitable filament feed positioning to produce the desired yarn. Therefore, a V-groove was introduced by slotting on the top end of the apron plate to guide the filament position at the center of the sliver ribbon (which was just emerging from the nip of the retaining rollers and forwarding to drawing rollers, as shown in Figure 2). Here, the filament was fed to the sliver ribbon through the disc tensioner and the V-slot of the apron plate. Then it passed down between the top apron plate (fixed) and bottom apron (movable) along with the sliver ribbon to the drawing rollers nip and covered, twisted at the spinning triangle area. Thus, core-spun yarn was formed where core filaments were positioned centrally and covered by jute. Then the desired core-spun yarn was wound on a suitable bobbin with the help of a Baxter-type flyer.

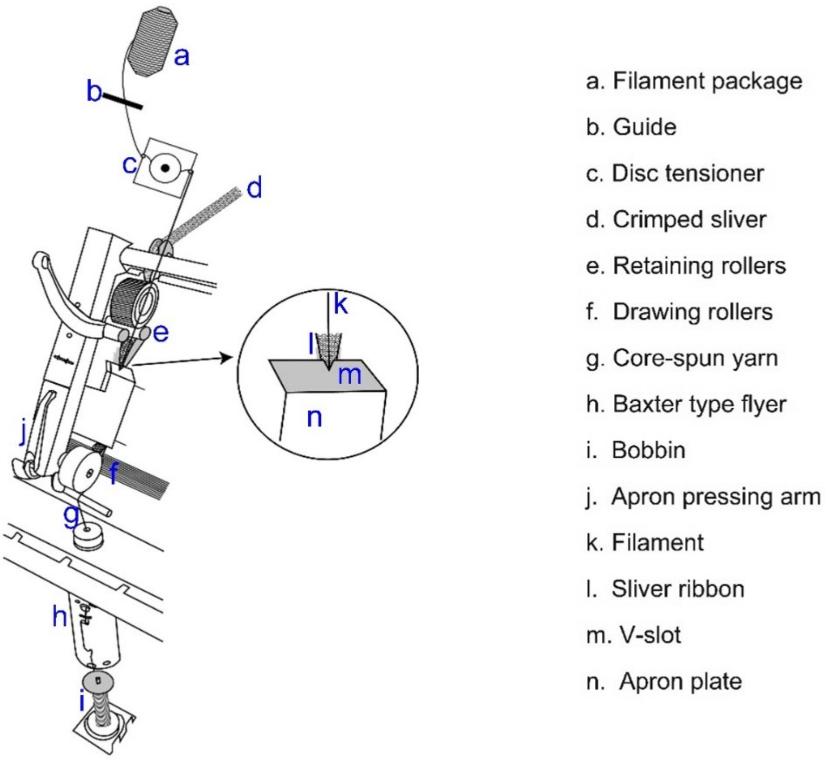

Figure 2. Illustrations of jute-covered core-spun yarn production on jute flyer-spinning frame

Sliver preparation, spinning process, and conditions

In this study, jute fiber was first piled with a 20% emulsion for 48 hours and processed through a jute breaker, finisher card, and three drawing machines consecutively. Then the third drawn jute sliver with a linear density of 4 gm/yd (43600 dtex) was drafted on the modified jute flyer-spinning machine to produce the yarn samples. To examine the effect of linear density of the core filament on core-spun jute yarns' properties, five different yarn samples of 11 lbs/spyndle (3789.5 dtex) were manufactured, where one sample was a 100% jute yarn. Parameters such as spinning draft and filament pre-tension were altered accordingly to produce the same yarn linear density with different filaments linear density. Flyer speed was 3500 RPM and the twist factor (K) was kept at 12, and other process parameters were kept the same throughout all the yarn production.

A digital tachometer (Lutron, DT-2234B) was used to measure the speed of the flyer frame's retaining roller and drawing roller, and a digital tension meter (SCHMIDT ZEF-100, tension range 0.5-100 cN) was used to measure the polyester filament pre-tension. An ordinary twist tester was used to determine the number of twists per inch in the yarn according to ASTM D1422.

Determination of fiber ratio in core-spun yarns

The percentage of polyester and jute fiber in the final yarn was calculated from the resulting yarn linear density (N_R=3789.5 dtex). Table 3 demonstrates the details of the calculation for fiber ratios.

Table 3. Sheath and core fiber ratio in core-spun yarn

Linear density of core filament N_1 (dtex)	Linear density of resultant yarn $^*N_R$ (dtex)	Linear density of jute strand after the draft N_2 (dtex)	Core filament % (N_1/ N_R) × 100	Sheath jute % (N_2/N_R) × 100
56	3789.5	3733.5	1.48	98.52
83		3706.5	2.19	97.81
110		3679.5	2.90	97.10
167		3622.5	4.41	95.59

($^*N_R = N_1 + N_2$)

Measurements of physical and mechanical properties of the yarn

In the testing laboratory, all yarn samples were conditioned for 24 hours under standard atmospheric conditions of 20 ± 2 °C and 65 ± 2% R.H., and then the following testing was conducted [19].

Morphology test: A projection microscope (Projectina-DMM 2000) was used to observe all yarn samples' longitudinal and cross-sectional views, and photos were taken and analyzed.

Breaking strength and elongation test: The tenacity and elongation of the yarn samples were assessed on a Titan Universal Strength Tester (James Heal) under EN ISO 2062:2009 (250 mm, 250 mm/min) [20]. The average value was calculated by taking twenty readings per sample.

Unevenness and imperfection test: A yarn evenness tester (Premier tester-7000) was used to measure yarn irregularity (yarn unevenness, Um%), imperfections, and hairiness. The mean value was calculated using ten readings per sample, where the testing speed was kept at 50 m/min, as per ISO 16549:2021 [21]. The imperfection index (IPI values) was determined by adding the total number of thick places, thin places, and neps at the sensitivity levels +50%, -50%, and +280%, respectively.

RESULTS AND DISCUSSION

Yarn morphology

Figure 3(a) shows the cross-sectional view of a 100% jute yarn and Figure 3(b) shows the cross-sectional view of the preliminary trial yarn. In preliminary trial yarn, as shown in Figure 3(b), polyester filaments are wrapped at the outer surface of the jute yarn. This may be due to the unstable state of filaments which disturb the drafted jute strand in the drawing rollers' nip.

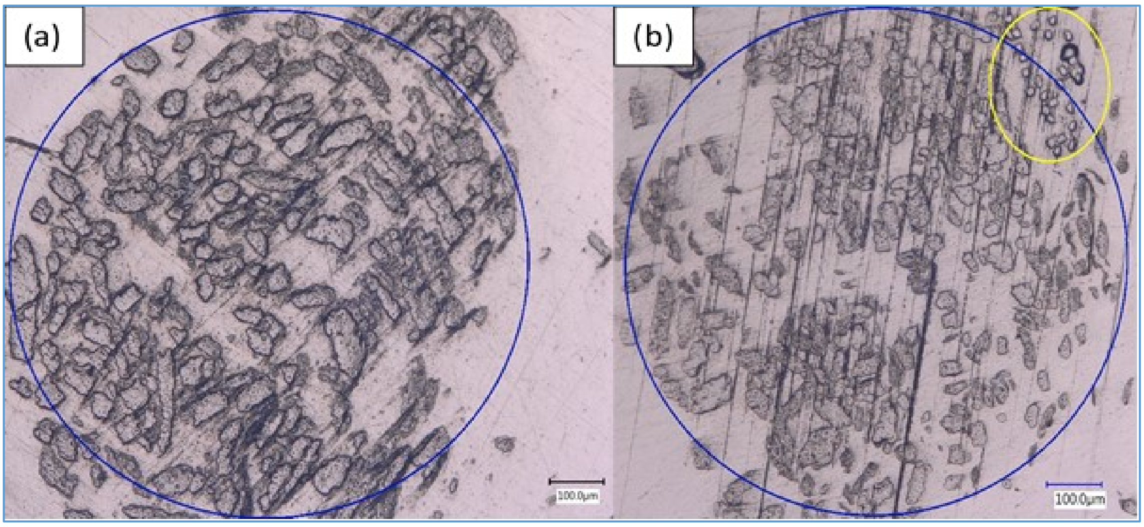

Figure 3. Cross-sectional view of (a) 100% jute yarn and (b) preliminary trial yarn (Small circle indicating the filaments, which are wrapped at the outer surface of the jute yarn)

Figure 4 depicts the cross-sectional view of the desired core-spun yarn where core filaments were positioned almost centrally and 100% covered by jute. This is because when filament and jute fibers are mixed to form a core-spun yarn, the filament is fixed in a steady state and firmly passed down between the top apron plate and bottom apron along with the drafted strand to the drawing roller's nip. The projecting images of the core-spun yarn's outer surface are shown in Figure 9 and discussed later.

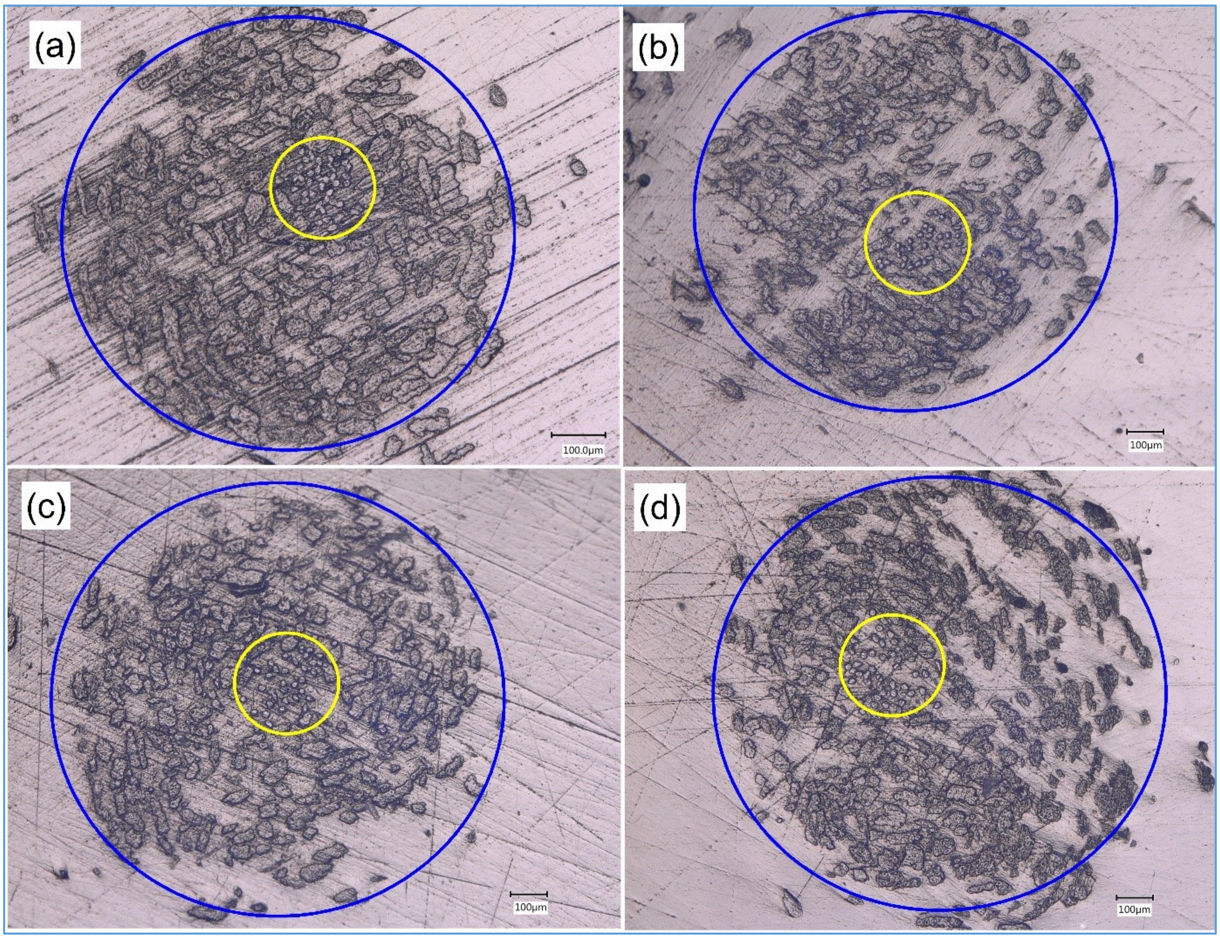

Figure 4. Cross-sectional view of jute-covered core-spun yarn with respect to the filament linear density of (a) 56 dtex, (b) 83 dtex, (c) 110 dtex, and (d) 167 dtex (Small circle indicating the filaments)

Physico-mechanical properties of yarn

The physico-mechanical properties of the core-spun yarn are summarized and given in Table 4. It should be noted that the linear density of core filament 0 dtex indicates 100% jute yarn. The SPSS software was used to evaluate the test results using one-way ANOVA, which was summarized in Table 5. The post hoc LSD method was also performed to determine whether there was any statistically significant effect of different filament linear density on core-spun yarn properties. Table 6 summarizes the findings of the multiple comparison test (LSD), which are discussed below in detail.

Table 4. Properties of jute-covered core-spun yarns

Yarn properties	Linear density of core filament (dtex)				
	0	56	83	110	167
Unevenness, Um%	26.67 (1.23)	23.24 (1.29)	22.15 (1.82)	21.54 (1.61)	22.65 (1.64)
Thin (-50%)/km	2160 (530.66)	512 (86.00)	464 (142.61)	472 (187.43)	480 (162.21)
Thick (+50%)/km	1672 (179.68)	1344 (142.61)	1232 (90.04)	1528 (300.99)	1328 (273.77)
Neps (+280%)/km	48 (49.17)	96 (78.20)	80 (26.67)	96 (68.51)	176 (115.01)
Hairiness	9.05 (0.67)	7.43 (0.40)	7.59 (0.29)	7.14 (0.22)	7.23 (0.46)
Tenacity (cN/tex)	3.29 (0.95)	10.96 (1.78)	12.66 (2.44)	11.78 (1.42)	13.67 (3.56)
Elongation %	1.21 (0.20)	4.33 (0.78)	4.16 (0.81)	4.50 (1.38)	5.65 (1.49)

(Values in parentheses are standard deviations)

Table 5. Summary of statistical analysis results

ANOVA	Yarn properties	F value	Significance
Between groups	Tenacity	34.775	0.000*
	Elongation	25.114	0.000*
	Unevenness	17.277	0.000*
	Imperfection	40.512	0.000*
	Hairiness	31.973	0.000*

*Significant

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Table 6. Summary of Post Hoc (LSD) test results

(I) Core filament linear density	(J) Core filament linear density	Yarn tenacity (Sig. level)	Yarn elongation (Sig. level)	Yarn unevenness (Sig. level)	Yarn imperfection (Sig. level)	Yarn hairiness (Sig. level)
0	56	0.000*	0.000*	0.000*	0.000*	0.000*
	83	0.000*	0.000*	0.000*	0.000*	0.000*
	110	0.000*	0.000*	0.000*	0.000*	0.000*
	167	0.000*	0.000*	0.000*	0.000*	0.000*
56	0	0.000*	0.000*	0.000*	0.000*	0.000*
	83	0.093	0.718	0.121	0.367	0.424
	110	0.413	0.707	0.017*	0.460	0.138
	167	0.009*	0.007*	0.399	0.869	0.317
83	0	0.000*	0.000*	0.000*	0.000*	0.000*
	56	0.093	0.718	0.121	0.367	0.424
	110	0.380	0.462	0.372	0.105	0.025*
	167	0.312	0.002*	0.471	0.288	0.076
110	0	0.000*	0.000*	0.000*	0.000*	0.000*
	56	0.413	0.707	0.017*	0.460	0.138
	83	0.380	0.462	0.372	0.105	0.025*
	167	0.063	0.017*	0.110	0.565	0.619
167	0	0.000*	0.000*	0.000*	0.000*	0.000*
	56	0.009*	0.007*	0.399	0.869	0.317
	83	0.312	0.002*	0.471	0.288	0.076
	110	0.063	0.017*	0.110	0.565	0.619

*At the 0.05 level, the mean difference is significant

Yarn tenacity

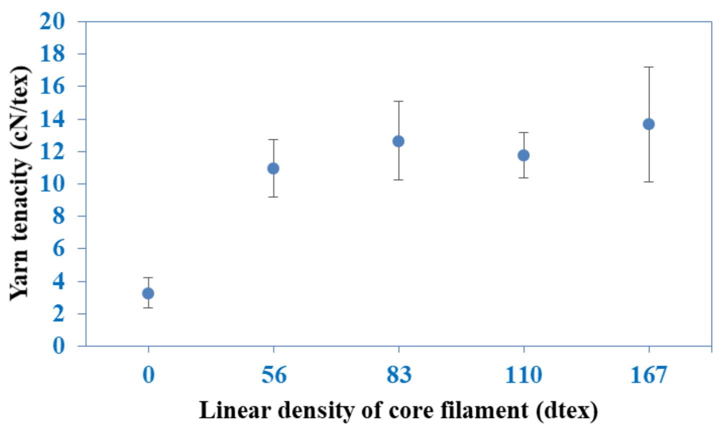

Figure 5. Effect of linear density of core filament on core-spun yarn tenacity

As shown in Figure 5, compared with the 100% jute yarn sample (i.e., 0 dtex), increasing the linear density of core filament from 56 dtex to 167 dtex increased the yarn tenacity from 233.13% to 315.5%. It's because the amount of stronger multi-filament in the core of the yarn has increased. From ANOVA analysis, it is found that at a 5% confidence level, the linear density of the core filament has a major impact on yarn tenacity. As shown in Table 6, multiple-range test results reveal that each jute core-spun yarn containing core filament is significantly different from the 100% jute yarn. It is also shown that core-spun yarn with the core filament of 167 dtex is significantly different from the core filament 56 dtex and the 100% jute yarn but possesses a higher standard deviation than any others (the error bars in Figure 5 represent the standard deviations of yarn tenacity). This may be due to a decrease in the number of cover fibers in the final yarn with the core filament of 167 dtex. The cross-sectional view also supports this statement, as shown in Figure 4.

Yarn elongation

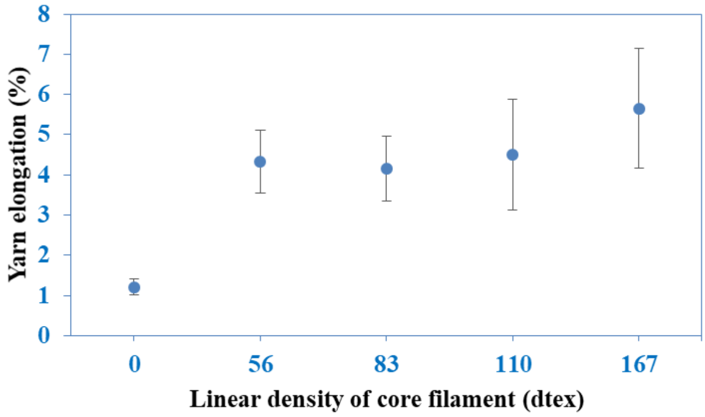

Figure 6. Effect of linear density of core filament on the core-spun yarn elongation

Figure 6 shows the effect of filament linear density on the core-spun yarn breaking elongation. The error bars represent the standard deviations of the yarn breaking elongation. As shown in Figure 6, in comparison with the 100% jute yarn, introducing the core filament from 56 dtex to 167 dtex increased the yarn breaking elongation from 257.9% to 367%. The greater contribution of the core filament is responsible for the increased breaking elongation, whereas the sheath jute fiber has a small contribution due to its low extensibility [1]. According to the ANOVA analysis, at α = 0.05 confidence level, the effect of linear density of the core filament on core-spun yarn breaking elongation is significant. The results of the LSD test given in Table 6 reveal that the core-spun yarn with 167 dtex core filament is significantly different than the 100% jute yarn and any other core-spun yarn. This result is attributed to the higher elongation percentage of the 167 dtex polyester multi-filament than any other polyester multi-filament core.

Yarn unevenness

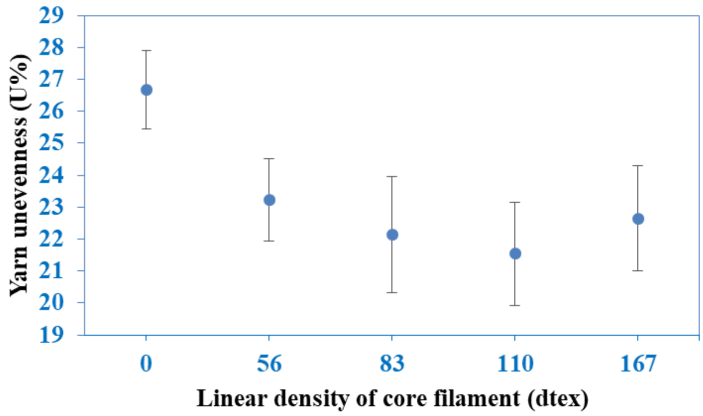

Figure 7. Effect of linear density of core filament on core-spun yarn unevenness

Figure 7 shows the yarn unevenness (U_m%) value of jute-covered core-spun yarns for different filament linear density. At a 5% confidence level, the effect of core linear density on core-spun yarn unevenness is significant. As shown in Figure 7, it seems that the highest yarn unevenness is found in the samples of the 100% jute yarn. It is attributed that jute sliver possesses a higher length CV%, resulting in an uneven length distribution in jute yarn [22]. On the other side, introducing polyester multi-filament (i.e., 56 dtex to 167 dtex) as a core shows improved uniformity of the yarns. This is ascribed to the increase in the number of straight filaments in the core, which then increased the evenness properties of the resultant yarn. According to the LSD test result, shown in Table 6, the sample containing a filament core of 56 dtex linear density is significantly different from 110 dtex filament linear density. It possesses a lower standard deviation than the others.

Yarn imperfection

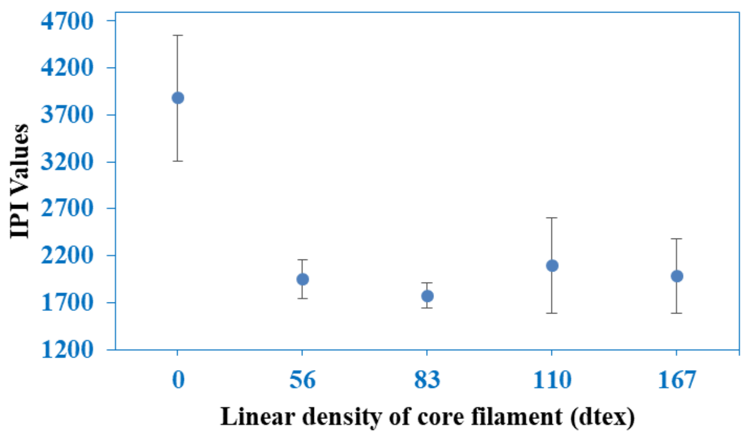

Figure 8. Effect of linear density of core filament on core-spun yarn imperfection

Figure 8 shows the yarn imperfection (IPI Values) of jute-covered filament core-spun yarns for different filament linear density. It is found that at a 5% confidence level, the effect of filament linear density on core-spun yarn imperfection is significant. As shown in Figure 8, it appears that the highest yarn imperfection is found in the samples of the 100% jute yarn. According to the LSD test results, shown in Table 6, the 100% jute yarn is only significantly different from the core-spun samples. With the uneven fiber length distribution and the larger amount of short fibers, the 100% jute yarn exhibits a higher imperfection value than 100% cotton or 100% wool yarn [1]. There is no significant difference in IPI values among the core-spun yarn samples with 56 dtex, 83 dtex, 110 dtex, and 167 dtex filament linear density.

Yarn hairiness

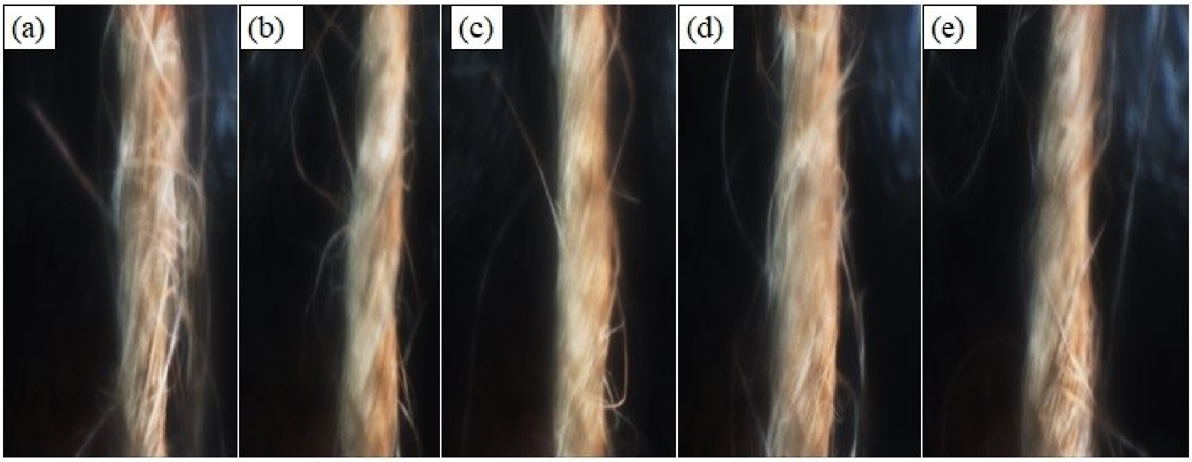

Figure 9. Projectina image shows the outer surface of (a) 100% jute yarn and core-spun yarns concerning the filament linear density of (b) 56 dtex, (c) 83 dtex, (d) 110 dtex, and (e) 167 dtex

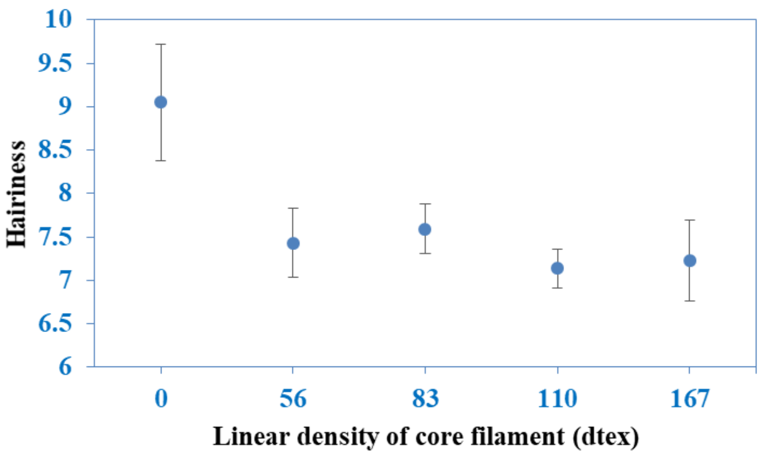

Figure 10. Effect of linear density of core filament on core-spun yarn hairiness

Figure 9 shows the hairy appearance of the jute-covered core-spun yarns and Figure 10 shows the yarn hairiness value of jute-covered core-spun yarns for different filament linear density. It is found that at a 5% confidence level, the effect of filament linear density on core-spun yarn hairiness is significant. As shown in Figure 10, it seems that the highest and lowest yarn hairiness is found for the samples of the 100% jute yarn and the core-spun yarn with 110 dtex filament linear density, respectively. The highest number of protruding ends (hairiness) on the 100% jute yarn surface was due to a higher number of short fibers, leading to increased yarn hairiness [23]. In the case of sample yarns containing polyester multi-filament, sheath jute fibers were trapped with the longer core filament, so they had less tendency to move outward, which resulted in low hairiness. According to the LSD test result, shown in Table 6, the sample with the core filament of 110 dtex is significantly different than the one with the core filament of 83 dtex and the 100% jute yarn and possesses a lower standard deviation than any other.

Correlation of yarn structure with mechanical properties

Figure 11 shows the representative stress-strain curves of the jute-covered core-spun yarn for the filament linear density of 167 dtex. Similar patterns were also found for the jute-covered core-spun yarn with the filament linear density of 56 dtex, 83 dtex, and 110 dtex (not shown here). The shapes of the stress-strain curve of the jute-covered core-spun yarns were almost linear and similar to that of the 100% jute yarn. However, the slope and the endpoint are higher for the jute-covered core-spun yarns indicating that those yarns attained higher strength and elongation than the 100% jute yarn. The reason behind the remarkable mechanical properties of jute-covered core-spun yarns was discussed already.

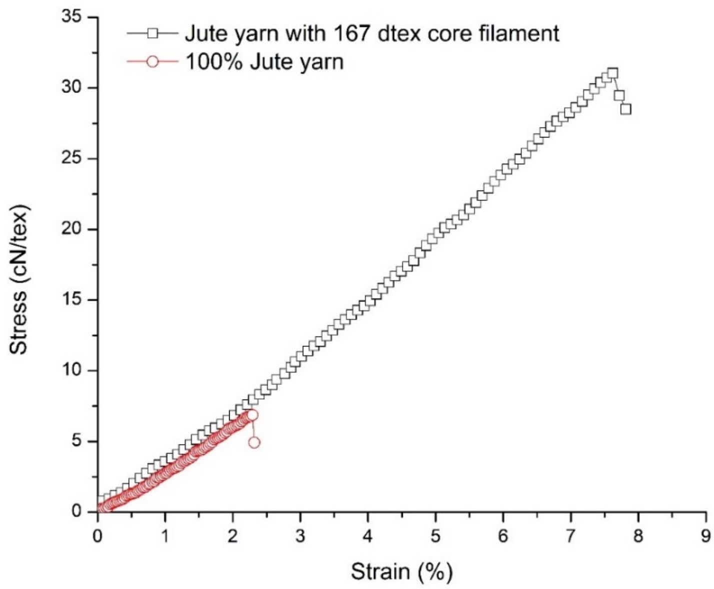

Figure 11. Representative stress-strain curves of jute-covered core-spun yarn to the filament linear density of 167 dtex

CONCLUSION

In this study, jute-covered polyester core-spun yarns were manufactured successfully on a jute flyer-spinning frame with low-end breakage in four core-sheath ratios (1.48/98.52%, 2.19/97.81%, 2.90/97.10%, 4.41/95.59%). A distinguished V-slot was introduced for this experiment to facilitate the filament in the center position of the core-spun yarn.

In comparison with the 100% jute yarn, manufactured jute-covered core-spun yarns showed higher tenacity and breaking elongation, as well as lower unevenness (U_m%), imperfection values, and degree of hairiness. Looking at the ANOVA analysis, all the results for the properties of jute-covered core-spun yarns were also found statistically significant.

According to the overall findings of this study, it can be concluded that jute-covered core-spun yarns can be used in diverse applications, such as floor coverings, quilts, and heavy load-bearing applications like bulk packaging bags. They can also be used in functional applications like hop strings, windshields, field nets, soil-saver, etc. Hence, the variety and utility of jute will grow, increasing its competitiveness in the textile industry.

Based on this study, further research may be carried out to manufacture jute-covered core-spun yarns using a variety of high-performance fibers as core material, such as PES HT, PP, Technora, Dyneema, etc. This would therefore open up the possibility of using natural jute fiber in the development of growing functional textiles.

Author Contributions

Conceptualization– Uddin MB; methodology – Uddin MB, Begum HA; formal analysis – Uddin MB, Nath AD; investigation – Uddin MB, Nath AD, Sowrov K; writing-original draft preparation – Uddin MB, Nath AD; writing-review and editing – Uddin MB, Nath AD, Begum HA; supervision –Sowrov K, Begum HA. All authors have read and agreed to the published version of the manuscript.

Declaration of interest

The authors report there are no competing interests to declare.

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