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ORIGINAL ARTICLE

Valorization of pineapple leaves: Effective conversion of agro waste to textile materials

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Abstract

The demand for sustainable and environmentally friendly practices by reducing the usage of virgin materials and minimizing the environmental impact associated with textile production has increased. However, due to the subjectivity of reuse and recycling for waste management, developing textiles with sustainable and quality yarn characteristics remains a challenge. The main goal of this experiment is to produce a new sustainable blended open end (OE)-rotor yarn by using pineapple leaf fiber (PALF) and recycled waste fiber (RWF). OE-rotor yarns are made in various proportions from RWFs generated from clothing wastes and bleached PALF at 20%, 50%, and 80%, respectively. To provide a more accurate evaluation, the properties of 100% PALF OE-rotor yarns versus PALF-RWF blended OE-rotor yarns are compared. The evaluation of various physical properties led to the discovery that rotor yarns with up to 80% RWF-PALF blended yarns had an acceptable number of physical attributes. The findings were encouraging given that the created yarns from RWF with PALF blended are less expensive than the yarns produced from standard raw materials. It also has a dual-benefit for the manufacturers that it allows them to make money from the waste while also addressing zero waste management and disposal challenges.

KEYWORDS

agro-waste, imperfection index, pineapple leaf fiber, recycled fiber waste, rotor yarn

1 | INTRODUCTION

Environmental safety and garbage reprocessing have turned into a vital issue for the future. Wearing clothing for extended periods of time and making efficient use of waste might greatly reduce demand for completed goods and fibers. In addition to having an effect on the environment, the cost of labor, energy, and raw materials is increasing year after year. Therefore, time must be spent on raw material exploration. One way to accommodate the demand and supply rules of raw materials is to recover fiber from waste. An important hazard to environmental contamination is textile waste. Pre- and post-consumer trash together make up this garbage. Pre-consumer waste is produced throughout the manufacturing process, while post-consumer waste is the wasted material from textiles after they have served their purpose. Apparel waste management is a crucial issue that needs to be taken into account since today's clothing is designed to be used for a short time before being discarded.[1–3]

80–85% of discarded clothing is disposed of in landfills each year, with just 15–20% of it being recycled. This has a negative effect on the environment and causes enormous losses in raw materials and energy.[4,5] According to Rani and Jamal,[6] the demand for effective waste management is brought on by escalating expenses, dwindling land acquirement opportunities, and diminution of natural properties.

However, textile sector is one of the most littering industries. Waste from textiles will be produced during both their production and consumption. Numerous steps have been taken to lessen its harmful effects on the environment. One of them is the manufacture of textiles using a reduce, reuse, and recycle strategy.[7,8] Reusing textiles benefits the economy and ecology, takes down the demand for chemicals, frees up land, consumes less energy, and boosts manufacturing. Payne and Leonas[9] claimed that to support the idea of the circular economy, hard waste has to be recycled and used again.

With the development of technology, as the living standard is rising, people are more conscious about the greener environment. So the researchers are more likely to focus on natural fiber rather than synthetic fiber.[10] Fabrics from pineapple fiber are soft hand feel, easily dye able, exceptional color retention, highly sweat-absorbent, breathable and have high microbial resistance when compared to other natural fibers.[11] By considering all those exclusive properties, pineapple fiber is considered as an excellent raw material to blend with other natural fibers.[12,13] Now-a-days, it is routine practice to intermingle two or more fibers to fabricate textiles with the desired properties and applications.[14,15]

The literature that is now accessible is primarily focused on the exploitation of soft spinning waste with spinning parameters, but there is currently no research on the use of hard waste with jute and PALF. For this experiment, four major categories have been used to classify the experiment's goals. The qualities of the extracted fibers were evaluated in the first step, which involved turning hard wastes like yarn and fabric cut wastes into fibrous form. Processed and extracted fiber characteristics from pineapple leaf were examined in the second section. The third phase involved comparing the qualities of yarn made from 100% pineapple leaf fiber (PALF), recycled waste fiber (RWF), and PALF-RWF blends with various ratios of waste. The final section examined the prices of several blended yarn variants made from recycle waste. The primary target of our study is to recycle and reuse textile and agro-waste so as to lessen adverse ecological effects. Taking into account the current energy crisis, the environmental load associated with the disposal of textile waste, and the economy of manufacturing, such a strategy is sustainable and environmentally benign.[16–18]

The ready-made clothing (RMG) industry consistently produces enormous amounts of waste. There are much too many "Jhuta," or waste from the clothing business, for them to be mere trash. The leftover cloth from garment manufacturing industries in Bangladesh is referred to as "Jhuta." These "Jhuta" consists of yarn and fabric clipped (hard waste) material required mechanically recycling route to extract clean fiber before being used as blend for making yarn. These "Jhuta" are used to make RWF.[19–21]

Research works dedicated to utilization of PALF for making paper, composites, nano cellulose extraction, textile application and other value added products can be found in scientific sources.[22–27] However, there is a lack of investigation in the field of sustainable exploitation of PALF along with apparel waste discarded from garments industry for developing high quality blended yarn.

In this experiment, an effort was given to develop a cost-effective nonpolluting technology to produce better quality PALF-RWF blended yarn to reduce both domestic and foreign demand and identify their appropriate spinning system using existing open-end spinning frame. Therefore, the goal of this research is to determine whether RWF and the agro-waste PALF can be used to create a sustainable yarn that would enable us to achieve zero waste management and it also converts the trash into money as well as encourages the agriculture based economy.

2 | EXPERIMENTAL PART

2.1 | Process of PALF

The PALFs used in this experiment were gathered from a farmer's field in Modhupur, Tangail District, Bangladesh. The strands were decorated, then water retted for 7 days to remove the fleshy portions.[13] For this experiment, 2-year-old leaves from the Ananas *comosus* species (common name is Queen variety) were selected from the lowest part of the plant. Throughout the process, the ratio of material to liquor was kept constant with a 1:15 at room temperature. The quality of fibers and pH of the retting water were measured daily to keep track of the retting procedure. Fibers were picked up from the retting tank after the muscular component was removed, rinsed carefully with clean water and allowed to dry open-air.

The decorticated PALF holds some sticky substance, consequently, the fibers were discovered to be clumped together which could cause issues when spinning yarn.

Retted fiber was degummed using a 1:15 material to liquor ratio and 1% (w/v) caustic soda solution at 80°C for 1 h. After being degummed, the fibers had three rinses: one with water, one with 1% CH_3COOH, and one more with water before being air dried. To preserve a pH of 10 to 11, the degummed PLAF fibers were bleached in a sealed vessel with 30% (w/v) alkaline H_2O_2 at 80°C for 1 h. Fresh water was used to rinse the bleached fibers, after which they were neutralized with 1% CH_3COOH, rinsed once more, and allowed to air dry.

In the apparel business, fabric waste is offered for sale at a discount. The major goal of our effort is to add value to this trash by turning recovered fibers into a brand-new, economically priced yarn. Leftover fabric clipped was collected from the garments industry and turned into RWF to evaluate the impact of waste on yarn quality. An analysis of the statistical data for PALF and RWF attributes is shown in Tables 1 and 2.

2.2 | 100% PALF yarn preparation

In this study, 59 tex ($10^s/1$ Ne) OE-rotor yarns were produced from 100% pineapple leaf fiber (PLF) and RWF and PALF-RWF blends with ratio of 80:20, 50:50, and 20:80 respectively where Table 3 depicts the sampling strategy. For the preparation of 100% PALF yarn, 10 kg of bleached PALF streaks were first processed through a jute goods spreader machine, which helps the emulsion penetrate into the fiber matrix to preserve almost 30% moisture on the weight of fiber and 2% oil, and then stacked in layers in a bin for piling for 48 h. The whole fiber is loosened and softened during piling, making it flexible for mechanical processing.[13] To create continuous fiber fleece, the conditioned PALF streaks were first chopped into 10 cm lengths and fed over an opening machine using carding action. After that, it was processed by a circular dressing device to produce an even sliver. This uniform sliver was then transformed into 0.128 hanks of sliver using three-stage drawing machines. After that, a rotor-spinning frame was used to produce a linear density of 59 tex using the output finisher draw sliver.

2.3 | Preparation of PALF and RWF blended yarn

PALF and RWF were blended at the integrated blow room-carding stage in the following proportions: 80:20, 50:50, and 20:80, respectively. After carding, the fiber bundles are drawn in three stages for parallelization and leveling to create an endless tape of fiber fleece with the correct weight/unit length. These fiber bundles are then twisted into a rotor spinning frame to create yarn. To enhance the blend's homogeneity, three draw frame passages were used. The blending ratio is expressed as a % of weight, while the initials PLF and RWF stand for PALF and RWFs. Following this, 100% PLF & RWF and PLF-RWF blends were processed to create OE yarn samples with a linear density of 59 tex to apply a twist

TABLE 1 Physio-mechanical properties of bleached pineapple leaf fiber (PALF).

Parameters	Bleached PALF
Length (mm)	28
Diameter (mm)	52
Fineness (tex)	3.4
Tensile strength at break (cN/tex)	23
Elongation at break (%)	3.95
Flexural rigidity (cN mm^2)	3.65
Moisture regain (%)	10.7

TABLE 2 HVI values of recycled waste fiber.

Parameters	Average value
Spinning Consistency Index (SCI)	138
Staple length (mm)	28.9
Strength (g/tex)	30.1
Elongation (%)	4.78
Microgram/inch (Mic. value)	5.0
Fiber fineness (tex)	0.175
Short fiber content by number (%)	29.1
Short fiber content by weight (%)	7.8

TABLE 3 Sampling plan.

	Materials (%)		
Sample ID	PLF	RWF	Lot size (kg)
S_1	100	-	10
S_2	-	100	10
S_3	80	20	10
S_4	50	50	10
S_5	20	80	10

Abbreviations: PLF, pineapple leaf fiber; RWF, recycled waste fiber.

and TM (Twist Multiplier) of 610 turns/m and 4900 to the fiber bundle, while the rotor and opening roller speed were maintained at 18,500 and 4500 rpm, respectively. Figure 1 indicates the stepwise representation of 100% PALF, 100% RWF and blended yarn preparation. The spinning features are shown in Table 4. The relative humidity (RH) and temperature were maintained at 80 ± 5% and 30 ± 2°C respectively in the spinning mill shed.[28,29]

2.4 | PLF and RWF testing

A Dokuval photomicroscope (JEOL) was used to determine the diameter and length of PALF. The tensile properties of the fiber was assessed with Instron tensile tester (UK 5567),[30] preserving test length 20 mm and speed 280 m/min separately. The ring-loop approach was used to assess the flexural stiffness of fibers.[31] Under typical situations of 65% RH at 27°C, moisture regain of bleached fibers were assessed using the oven dry method in accordance with ASTM D2654. HVI 1000 was used for measuring the RWF properties.

2.5 | Yarn testing

The fineness (expressed as tex) of produced yarns were measured using the industry-recognized BIS technique IS 685:1962. Twist was measured through untwisting process with a mechanical shirley twist tester ensuring the BIS method IS: 832 (part 1), 2011. Lea Strength Tester was used to conduct the count strength product (CSP) testing in accordance with ASTM 3822. Testing for yarn hairiness, irregularity, and flaws was done using Uster Tester 3 at a testing rate of 220 m/min while maintaining a testing duration of 4 min.[29] Uster Tensorapid was used to perform the tensile properties (tenacity cN/tex and elongation %). For an effective evaluation of each yarn sample, five cones were selected, and five measurements were made on each cone. The tests were carried out in the same atmospheric situations (65 ± 5% RH and 27 ± 2°C) and conditioned samples minimum, 24 h before the tests.

3 | RESULT ANALYSIS

3.1 | Physical properties of PALF and RWF

It may be inferred from Tables 1 and 2 that the length of PLF is almost same as RWF. The PALF were sliced into 10 cm length before being fed into integrated blow room-carding to minimize length differences. The bleaching procedure may have boosted the fiber's strength, tensile modulus, elongation and absorbency due to the partial elimination of pectin and hemicellulose.[25,32] According to Table 2, the RWF has a better staple length, a high breaking strength, acceptable finesse, and a good

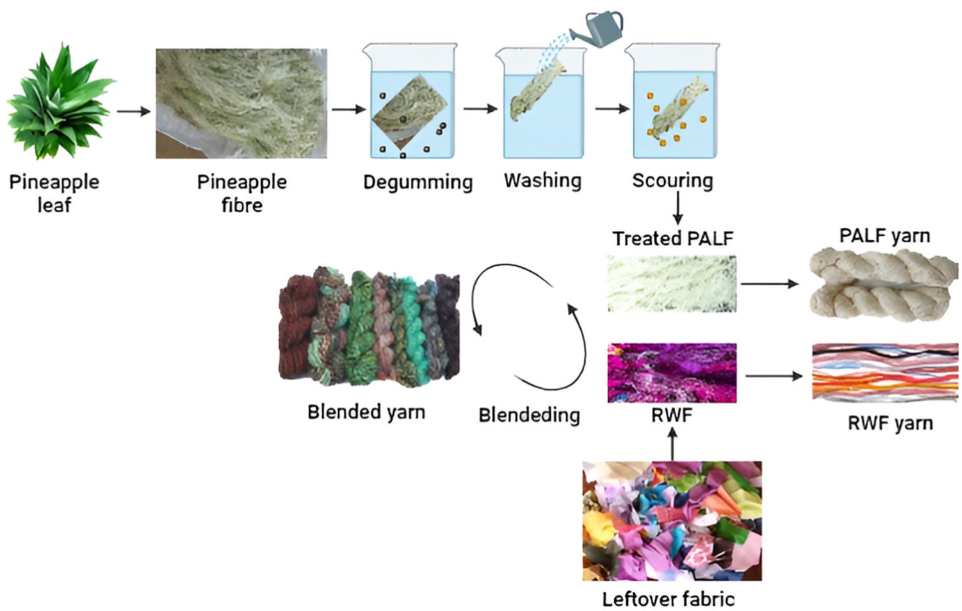

FIGURE 1 Stepwise representation of 100% pineapple leaf fiber (PALF), 100% recycled waste fiber (RWF) and blended yarn preparation.

TABLE 4 Spinning parameters.

Parameters	Description	Parameters	Description	Parameters	Description
Carding specifications		*Drawing frame specifications*		*Rotor specifications*	
Licker-in speed	500 rpm	1st and 2nd draw frame (breaker) delivery	400 m/min	3rd draw frame sliver hank	0.128
Cylinder speed	350 rpm	3rd draw frame (finisher) delivery	350 m/min	Rotor speed	18,500 rpm
Flat bar speed	0.20 m/min	Breaker sliver weight	55.50 grain/yd	Opening roller speed	4500 rpm
Doffer speed	30 rpm	Finisher sliver weight	55 grain/yd	Twist	610 turns/m
Card sliver	60 grain/yd	Breaker draft and doubling	6.5 and 6	Yarn package weight	3.75 lb
		Finisher draft and doubling	7 and 7		

TABLE 5 Average test results for different yarn samples.

Parameters	S_1	S_2	S_3	S_4	S_5
Nominal count (tex)	59				
Actual count (tex)	60.50	60.0	59.85	59.50	60.42
Nominal twist (T/m)	610				
Actual twist (T/m)	614	613	612	611	612
U%	25.44	11.47	13.39	11.80	11.59
CVm%	19.40	14.35	19.01	15.14	14.39
Thin places/km (−50%)	228.12	115.51	226.89	119.43	115.74
Thick places/km (+50%)	210.70	140.25	165.61	142.02	140.44
Neps/km (+280%)	160.50	139.10	151.50	142.00	139.20
Hairiness index	5.80	5.50	4.81	5.71	6.05

Abbreviations: CVm, co-efficient of variation of mass; U, unevenness.

micronaire value. This allows it to be easily blended with PALF in an OE-rotor spinning machine.

3.2 | Use of waste fiber and its influence on yarn properties

According to Tables 1 and 2, the fineness of PALF and RWF differs significantly. RWF is around 20 times as fine as PLF in terms of fineness. To increase spinnability and increase the number of fibers per yarn x-section, finer RWF can be blended with PLF. Once more, it is evident from Tables 1 and 2 that the notable differences in tenacity at break between PLF and RWF are due to the tensile characteristics of the yarn. Table 5 shows that CVm% (Mass variance) of yarn parameter is continuing to fall as the fraction of RWF component rises in blends. Possibly as a result of the increased fineness of the RWF, which provides more fiber per unit of the x-section of the yarn. The diameter of the yarn improves as the RWF component rises in the blend. It might be due to cotton fiber has a higher specific volume than PALF.

3.3 | Yarn irregularities

In accordance with Table 5, the recycled waste samples (S_2–S_5) had less irregularity (U%) and mass variance (CVm%) than the 100% PLF sample (S_1), which is attributable to more uniform and less floating fiber (FF)%. Since recycled wastes have longer fiber than those taken from PLF, that increases the probabilities of irregularities owing to movement of fibers in processing. The U% for samples S2, S3, S4, and S5 decreased by 54.91%, 47.37%, 53.62%, and 54.44% respectively compared to sample S1. Similarly, the CVm% for samples S2, S3, S4, and S5 decreased by 26.03%, 2.01%, 21.96%, and 25.82% respectively compared to sample S1.

3.4 | Imperfections of the yarn

The two most essential properties such as imperfections and hairiness were assessed and recorded in Table 5. The table presented that the number of thick and thin places as well as neps of the yarn were also decreased as the RWF% of the blend increased. The better fineness of RWF may be the cause of the decreased imperfection since it offers more fibers per unit of yarn cross-section.[27] However, when PLF percentage of the blend increased, the yarn's hairiness decreased because the longer PLF produced smoother yarns with little fiber migration and less protruding ends. Although it has been seen variances in the properties of blended yarns, the quality of the yarn won't be severely affected by inaccurately indexed data.

The thin places per kilometer (−50%) decreased by 49.36%, 0.54%, 47.65%, and 49.26% for samples S2, S3, S4, and S5 respectively, compared to sample S1. Similarly, the thick places per kilometer (+50%) decreased by 33.44%, 21.40%, 32.59%, and 33.35% for samples S2, S3, S4, and S5 respectively, compared to sample S1. The neps per kilometer (+280%) decreased by 13.33%, 5.61%, 11.53%, and 13.27% for samples S2, S3, S4, and S5 respectively, compared to sample S1. Additionally, the hairiness index decreased by 5.17%, 17.07%, and 1.55% for samples S2, S3, and S4 respectively compared to sample S1 while it increased by 4.31% for sample S5 compared to sample S1.

3.5 | Tensile properties

The CSP of the yarn as well as other tensile characteristics such as tenacity, elongation and breaking work are essential parameters of the yarn. The tensile strength of various yarns can be determined using the breaking force in cN/tex. Figure 2 shows the mean tenacity as well as elongation percentages for each yarn in the following numerical direction: S_5 20: 80 > S_4 50: 50 > S_3 80: 20 > S_2 0:100 > and S_1 100:0 The greater tenacity & elongation% of PLF-RWF blend yarns is caused by RWFs having higher tenacity and elongation than PLF (S_1). Another explanation is that improved RWF fineness adds a greater number of fibers per unit of yarn cross-section.

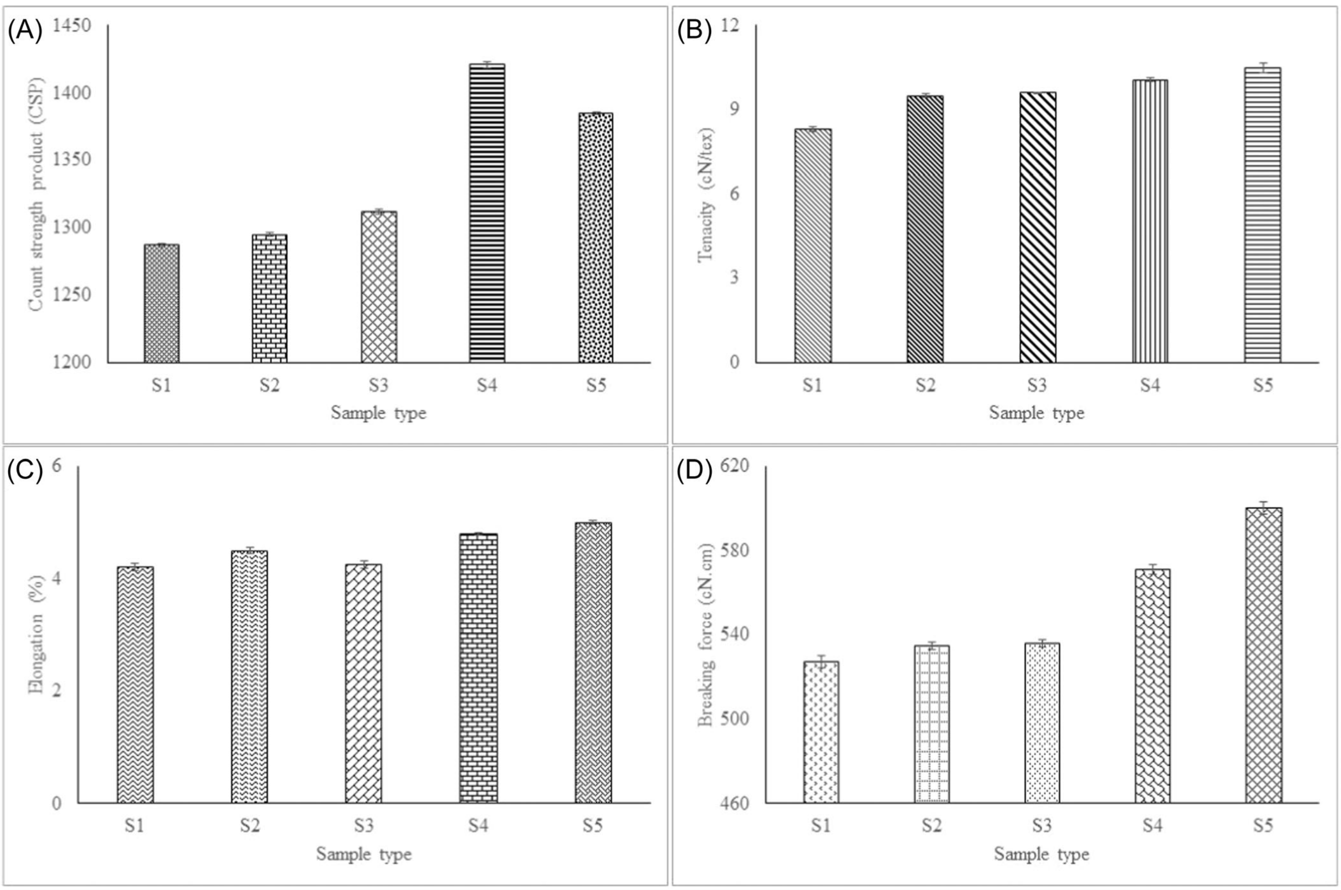

FIGURE 2 Effect of blending ratio on tensile properties: (A) count strength product (CSP), (B) tenacity, (C) elongation and (D) breaking force.

TABLE 6 A cost of comparative statement between recycled waste yarn and the normal raw fiber yarn (price in $US).

Yarn type	Yarn price, ($US)/kg	Reference(s)
PALF	1.07	[13, 27]
Jute	0.85	[13, 27]
Cotton	1.60	[1, 13, 27]
100% cotton yarn waste	0.88	[1]
Different recycle waste with cotton yarn waste	0.79	[1]
Different recycle waste with agro-waste (PALF)	0.67	This article

Abbreviation: PALF, pineapple leaf fiber.

As can be shown, the waste yarn samples (S_2–S_5) have higher CSP and breaking work values than the PLF (S_1) sample because the fibers in the waste yarn samples are longer and have lower FF%. Short fibers in a yarn make it more likely to slip during tensile testing, which lowers the yarn's strength and breaks elongation percentage.[1] This scenario exhibited similarities to yarn irregularity, thin place outcomes, and the possibility that yarn breakages would rise at the weakest locations.

In comparison to sample S1, the CSP increased by 0.62%, 1.92%, 10.41%, and 7.61% respectively for samples S2, S3, S4, and S5. In the same way, the tenacity of samples S2, S3, S4, and S5 was increased by 14.34%, 15.66%, 21.33%, and 26.51%, respectively, when compared to sample S1. From sample S1, samples S2, S3, S4, and S5 showed an increase in elongation of 7.12%, 1.19%, 14.29%, and 19.05%, respectively. In a similar fashion, the breaking force of samples S2, S3, S4, and S5 increased by 1.52%, 1.71%, 8.35%, and 13.85%, respectively, compared with sample S1.

3.6 | Cost analysis

Several factors, including raw materials, energy, labor, and capital, go into the price of yarn. Table 6 shows the specifics of the calculated production costs of PALF blended RWF yarn and other recycle waste yarn and compares them to 100% normal cotton, Jute and PALF yarn. Spinning just recycled materials offers different benefits including increasing the value of waste yarn and reviving available fibers by using them again in the production process. Yarn made entirely of recycled fibers has a pricing advantage over the regular price of raw materials. Raw material expenses make up roughly 60–70% of the overall cost of production.[33] Table 6's pricing breakdown for all blended yarn waste samples makes it clear that recycled waste-based yarns with PALF are more affordable than other yarn waste samples. The price of vargin cotton, jute and PALF fiber yarn is 1.60$/kg, 0.85$/kg and 1.07$/kg, respectively. The price of a sample of all waste yarn is around half that of a sample of regular yarn, saving both money and benefits. It is advantageous for every industry who is involved in the recycling of cloth and fabric waste.

4 | CONCLUSION

This study aims to investigate the production of cheap yarn for fabric using recycled waste sources. The impacts of recycling textile waste and their effects on fiber and yarn were evaluated in this investigation. This study has shown that recycled cotton waste blended with PALF to create a sustainable yarn is more cost-effective and eco-friendly with little difference in physical qualities of the produced yarns. The analysis of sample costs revealed that the cost of producing yarn derived from recycled waste is more cost-effective than yarn created from 100% virgin and normal fiber. A higher percentage of recycled waste reduced yarn irregularity (U% and CVm%) and increased tensile properties (tenacity, strength product, and breaking force). It was found that 100% PALF yarn had the highest irregularity and that 20% PALF-80% RWF blended yarns had the highest tenacity. It was also found that 100% waste can be used to create yarn, resulting in a low-cost product. These yarns are able to be suitably used to create a variety of fabrics, including denim, pina, fancy bag, and chino fabric for towels and pants with handloom and power loom.

AUTHOR CONTRIBUTIONS

Mohammad Abdul Jalil and Md. Reazuddin Repon have contributed to conceptualization, methodology, data collection, data analysis and original draft preparation. Syed Zubair Hussain contributed to the original draft preparation. Sigita Jurkonienė, Aminoddin Haji and Sharof Shukhratov have contributed to editing and reviewing. Md. Reazuddin Repon has supervised all stages of preparing the manuscript. All authors have read and agreed to the published final version of this scientific article.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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