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Research article

A novel approach for pineapple leaf fiber processing as an ultimate fiber using existing machines

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ABSTRACT

This research aims to study the spinnability of pristine PALF and PALF blended cotton using the existing spinning machines. Apron draft ring spinning frame and flyer jute spinning frame were used to produce 100% PALF yarn and the yarns count were found 121 tex and 138 tex separately. Besides, 90:10 and 80:20 cotton-PALF blended 30 tex yarn spun in a cotton spinning system with different twist factors. With both yarns, two samples; 1/1 plain and 3/1 twill fabrics, were fabricated through equal density. For plain and twill fabric, PALF yarn of 121 tex and 138 tex were used in the warp way, respectively and PALF blended cotton yarn of 60 tex was used in the weft way. Through the study, physio-mechanical properties of the samples were explored and FTIR & XRD patterns were analyzed to perform the task for diversified use as an ultimate fiber in industrial and domestic purposes.

1. Introduction

Plant fibers from numerous sources are being used for various applications for a very long period. But the natural fiber processing industry has started to lose its market share in the mid-20th century due to the commercialization of synthetic fiber. The vast uses of these synthetic fibers are currently imposing a significant adverse effect on the environment. Along that way, recently, the uses of natural-based fibers have become an inseparable part of the textile industry due to its biodegradability and non-carcinogenic properties. In this context, 2009 was announced as the "International Year of Natural Fiber (IYNF)", to promote natural fibers and materials among manufacturers, nature activists and business people (Jawaid et al., 2011). The wide range of natural fiber production available and adopted can reduce deforestation and dreadful impact on agriculture. Besides, natural ecological balance can be restored with diversified uses of natural raw materials. Again, the wastage from agriculture and forest (usually 30–40%), can be converted into value-added items upon application of different processing (Kenny, 2001).

Researchers are currently looking for a newer source of raw materials and processes comparable with synthetic fibers concerning physio-mechanical properties. Additional parameters like price, environmental effects, health hazards, degree of flexibility, plant lifetime, collection process, and availability (Tserki et al., 2005) are also thoroughly studied in selecting new raw materials.

Only 10% of the required fabrics are made from native knitters and weavers for ready-made clothing in Bangladesh. In order to subdue this intense competitiveness, it is essential to manufacture different types of novel fabrics that can replace fabrics from overseas (Jalil et al., 2009). As a result, pineapple leaf fibers (PALF) and their blended fabrics can be used in the manufacture of furnishings and ornamental fabrics, which can further expand their use in different clothing and textile sectors (Jalil et al., 2015a; Hazarika et al., 2018).

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From the Bangladesh context, pineapple is more popular in Bangladesh as both fresh consumption and juice. As far as production is concerned, the division of Dhaka approaches the upper most planted area and production. As well, the production capacity of pineapple of the Sylhet and Chittagong division comes out with a plentiful amount (BBS, 2018). The Tangail region is the acme of pineapple cultivation which covers 49% of total pineapple planted land and 59% of nationwide mass production (Farid Hossain, 2017; Karim et al., 2021).

Researchers are currently focusing on the improvement of competent yarn forming processes and controlling parameters of related machines for the expansion of textile products diversity. Therefore, improving the parameter of fibers and yarn products, spinning and weaving productivity and marginal investment in the capital may inspire entrepreneurs if the development message of this technology could touch people all over the world (Jalil et al., 2011).

Natural fibers have been used for textile materials since before ancient civilizations. The first indication of fiber used is likely the discovery of flax and wool fabrics at excavation sites of the Swiss lake dwellers (7th and 6th centuries'). Previous research has confirmed that ancient civilizations used elementary types of textiles namely cotton, jute, flax, wool, silk and hemp. Those fibers have historically been enough to clothe humans (Britannica, 2020). Because of particular drawbacks in natural fibers, manufactured fibers have been developed. But the reinvention of conventional or elementary textile fibers and newly pioneering fibers with the modest purpose of providing the requisite characteristics for human clothing can bring a revolutionary change in textile science and technology. Ground-breaking fibers that have been applied in high-performance apparels in advanced materials are called ultimate fiber. The manufacturers are looking for new techniques for developing fibers to meet the different levels of operations. The world looks at how conventional fibers and materials are reused and recycled as an ultimate fiber.

Being an agricultural waste, yarns produced by PALF are coarser and are not suitable for any apparel garments, but coarser yarns can be used as an ultimate fiber to produce both traditional and technical textile products. Disposable fashionable and decorative carrying bags with various color outcomes for ladies purse, shopping sacks, traveling luggage bags, school bags, table cloth, cushions fabric, handmade rugs, curtains, fashionable carpets and mops etc. can be made of PALF. The Barong Tagalong, wedding robes and other Philippine formal dresses are the main end uses of pineapple fiber (Uddin Nasir et al., 2017).

Therefore, the primary goal of this study is to improve a non-polluting and cost-effective technology for altering PALF as an ultimate fiber and identify its spinning and weaving suitability using the existing cotton and jute processing machines for producing dignified quality yarn and fabric to trim down the domestic and international demand.

2. Experimental

2.1. Materials

Pineapple leaf was collected from the local market of Modhupur, Tangail, Bangladesh and fibers were obtained by retting the leaves in freshwater for seven days (Hazarika et al., 2017; Jalil et al., 2019). The PALF was extricated from the *Ananas comosus (Popularly known as Queen Variety)* plant leaf which belongs to the family Bromeliaceae. Medium staple cotton CIS-Uzbek fibers were used for this experiment and this fiber was collected from the Rahmat Spinning Mills Ltd., Dhaka, Bangladesh.

Produced PALF and cotton blended PALF yarns were used for fabrication of two samples of plain 1/1 (40 yards) and twill 3/1 (35 yards) structure fabric using the power loom by the local weavers of Khalihati, Tangail, Bangladesh. The plain and the twill weave fabrics are indicated by "X" and "Y". Both samples were produced using 100% PALF yarn (138 & 121 tex) as warp and cotton blended PALF ply yarn (60 tex) as weft where the areal density of the developed fabrics are 246 and 224 g/m^2, respectively. The loom statuses for producing the samples are: reed count 20, heald eye 680 and heald frame 4.

2.2. Methods

2.2.1. PALF extraction

A blunt kitchen knife is used to manually scrape the hydrophobic waxy layer on the leaf. Patience and care were required to avoid damaging the fibers. The scrapped leaves were being tied and immersed in a retting tank. Urea was added to the tank for quick retting at 27 ± 2 °C. At the end of retting leaves were taken out and washed manually with fresh water and dried. The coarser bundles were next gently combed with fine pins in the wet condition to separate them into their fine fiber components. The process sequence of manual PALF extraction is given beneath Figure 1.

2.2.2. Chemical degumming of PALF

Pineapple fibers were chemically degummed before being exposed to an alkali solution at several time and temperatures in the absence of air. Figure 2 shows the procedure for chemical degumming pineapple leaf fibers. With the degumming process, hemicellulose, which is mostly made of mixed polysaccharides, is broken down into simple sugars that are soluble; saponifiable gums and waxes are converted to soluble soaps, and unsaponifiable oils are emulsified by these soaps and wetting agents.

2.2.3. Pineapple leaf fiber properties

The physical properties of PALF like bundle strength, fineness, tenacity at break and elongation at break were tested in the Bangladesh Jute Research Institute (BJRI) testing laboratory and obtained results are tabulated in Table 1. Table 2 indicates the surface appearance characteristics of PALF fiber.

2.2.4. Cotton fiber properties

Medium staple cotton CIS-Uzbek was used for this experiment and this fiber was collected from the Rahmat Spinning Mills Ltd., Dhaka, Bangladesh. USTER HVI1000 test results of cotton fiber properties are listed in Table 3.

2.2.5. The production process of 100% PALF yarn

For yarn preparation, a batch of 25 kg PALF samples were processed in BJRI, Mechanical Processing Division, Dhaka, Bangladesh. To process the PALF, the fiber was softened in a jute softener machine (Brand name: Douglas Fraser & Sons) using 25% emulsion on the weight of the fibers. For softening the fibers, 79% water, 1.5% emulsifier (Nonidet P-40) and 19.5% jute batching oil were used. For conditioning, the softened PALF was stored for 48 h in a closed vessel (Jalil et al., 2015b). As a result, the emulsion penetrated into the fiber matrix and became lubricated, making further mechanical processing much easier. Then these conditioned fibers were processed in a conventional jute spinning system i.e. through a breaker card, then a finisher card and finally processed in 1st, 2nd and 3rd draw frame machines.

The delivery sliver from the 3rd drawing-frame was spun through the modified apron draft ring-spinning frame and jute flyer-spinning frame to produce yarns of 121 tex and 138 tex separately, having twist factors ranging from 6-12.

The apron draft ring-spinning frame was used here to evaluate its performance with various parameters such as draft, twist, spindle speed and traveller weight etc. In the apron draft ring-spinning frame for 121 tex yarn: draft- 20, spindle speed -7500 rpm, traveller weight-35 mg and twist -375 TPM were used for producing the yarn. On the other hand, in the flyer-spinning frame for the 138 tex yarn: draft -16, spindle speed -4200 rpm, and twist-354 TPM were used to produce the yarn.

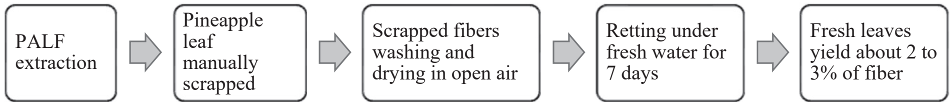

Figure 1. Process flow of manual PALF extraction.

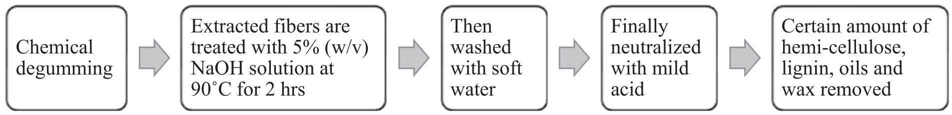

Figure 2. Chemical degumming of PALF.

Table 1. Different physio–mechanical properties of PALF (Jose et al., 2019).

Fiber Type	Fineness (tex)	Bundle strength (Pressly index, kg/mg)	Tenacity at break (gf/tex)	Elongation at break (%)
Retted fiber	4.1 (23)	4.89 (19.04)	31.32 (31)	4.5
Degummed fiber	3.5 (31)	4.21 (23.01)	25.29 (27)	6.1

(Values in parenthesis denote CV %).

Table 2. Surface appearance characteristics of PALF fiber (Hazarika et al., 2017; Jalil et al., 2015b; Jose et al., 2019).

Parameters	Retted fiber	Degummed fiber
Color Strength (K/S)	2.51	2.99
Whiteness Index	58	55
Yellowness Index	50.	46
Brightness Index	35	30
Moisture regains (%)	7.6	9.8
Water absorbency (s)	21	10

Table 3. HVI test results of cotton (CIS-Uzbek) fiber properties.

Fiber properties	Mean value
SCI (Spinning Consistency Index)	142
Staple length	29.9 mm
Strength	32.7 g/tex
Elongation%	4.8
Micronaire value(μg/ inch)	4.7
Fineness (tex)	0.185
SFI (Short Fiber Index)	5
CG (Color Grade)	Strict Middling

2.2.6. PALF yarn characterization

2.2.6.1. Tensile properties of PALF yarn. Different yarn properties were determined using Titan Strength Tester that uses the constant rate of extension (CRE) principle for testing. ASTM D2256 and ASTM D1907 standard test methods were used to measure tensile properties and count (fineness) of yarn, respectively. In addition, a Shirley twist tester was employed for measuring the inserted twist in the yarn. Using the Eq. (1), the quality ratio can be determined. Table 4 shows the results of the sliver unevenness, while Table 5 confirm the physical parameters of PALF yarn.

$$\text{Quality ratio } (\%) = \frac{\text{Tensile Strength in lb}}{\text{Count of yarn } \left(\frac{\text{lb}}{\text{spyndle}}\right)} \text{x } 100 \quad (1)$$

2.2.6.2. Measurement of surface appearance properties. A spectrometer (reflectance: 5100) was used to calculate the whiteness, yellowness and brightness index of the PALF. The color strength (K/S) was also measured separately using the spectrometer at a visible range of 420 nm wavelength (λ_{max}). Then the K/S was evaluated using Eq. (2).

$$K/S = [\{(1\text{-}R)^2/2R\} \quad (2)$$

here R, K and S represent the reflectance, absorbance and scattering respectively.

The moisture regains of retted and degummed fibers were evaluated followed by ASTM-D2654-76 at testing atmosphere. The fiber's water absorbency was determined by dropping a drop of water on its surface and estimating the time it took for the fiber to absorb the water fully (Jose et al., 2019).

2.2.6.3. Determination of compositional properties. The FTIR spectra of raw and chemical degummed PALF were measured in the wavelength range 4000-500 cm^{-1} using an IR Tracer-100, Shimadzu (Japan) in ambient condition. Figure 3 indicates the FTIR spectra of raw PALF and degummed PALF samples. The IR peak positions of raw PALF and chemically degummed PALF are shown in Table 6.

The X-ray diffractograms of raw PALF and degummed PALF samples were recorded using X-ray diffraction (Empyrean, PANalytical-Netherlands) with Cu-Kα radiation (λ = 1.54057A) and the voltage and current of the generator were 42 kV and 37 mA respectively. Angular scanning was conducted from 10° to 40° with 2°/min. There was no background correction made. Figure 4 illustrates the XRD patterns of raw PALF and degummed PALF.

Table 4. Sliver unevenness (Um% and CV %) test results.

Parameters	PALF 3rd draw-frame sliver	Cotton 2nd draw- frame sliver	Cotton (from 2nd draw sliver) +PALF (from 3rd draw sliver) blended finisher draw-frame sliver
Um%	4.41	4.39	4.20
CVm%	5.09	5.23	4.61

Table 5. Physical properties of PALF yarn.

Fiber	Methods	Nominal count in tex	Actual count in tex	Twist tpm	Tensile strength in kg			Quality ratio %
					Mean	CV%	Extension at break (%)	
PALF	Apron draft ring- spinning frame	121	124	375	1.45	7.59	3.10	88.89
PALF	Flyer jute spinning frame	138	141	354	1.55	8.16	3.69	83.17

2.2.7. The production process of cotton-PALF blended yarn

The following are three sets of experimental strategies to perform the spinning trials in the present research work.

2.2.7.1. Selection of twist multiplier. A complete factorial plan of the experiment was used in this work which includes three factors: the form of the blend, the ratio of blend and the twist multiplier. Table 7 gives the respective levels of each factor. The blend composition is given as a percentage of weight, while the letters C and PF reflect cotton and PALF fibers. The twist multiplier (TM) refers to the tangent angle between the fiber consigned outer yarn surface and the yarn centre line. The yarn TM is defined as the function of twist and fineness (tex) of the yarn as shown in Eq. (3).

$$\text{Twist multiplier (TM)} = \text{Turns per meter} \times \sqrt{\text{Yarn fineness in tex}} \qquad (3)$$

As per the experiment strategy, the details of the samples are given in Table 7 and Table 8 along with their compositions and twist multiplier.

Cotton fibers were processed through blow-room, carding, 1st and 2nd drawing. This 2nd draw sliver of cotton and 3rd draw sliver of PALF were blended into a cotton finisher-draw frame maintaining 90:10 and 80:20 ratio (cotton: PALF) respectively. This finisher-draw frame blended sliver was used for the production of roving in Toyoda FL16 simplex machine with the spindle speed of 850 rpm and that roving (hank = 0.59 Ktex) was used as feed material in Merjoly ring-frame with three levels of twist multiplier (2758, 3026 and 3629) at the spindle speed of 12500 rpm. The intended 30 tex yarn was eventually achieved by correcting draft.

2.2.7.2. The prime step for cotton and PALF blending. Cotton-PALF; 90:10 and 80:20 blended yarns having a count of 30 tex with TPM of 504, 553 and 663 were prepared in the cotton spinning system. Two blended yarns were spun by blending cotton and PALF at the cotton finisher-draw frame stage. The process sequence of cotton-PALF blended yarn is provided in Figure 5.

2.2.7.3. Can arrangement for blending. The 2nd draw sliver of cotton and 3rd draw sliver of PALF were blended in cotton finisher draw-frame to the ratio of cotton: PALF (90:10 & 80:20). For better and uniform blending of cotton (C) and PALF (PF), both draw slivers can arrangement was done according to Figure 6.

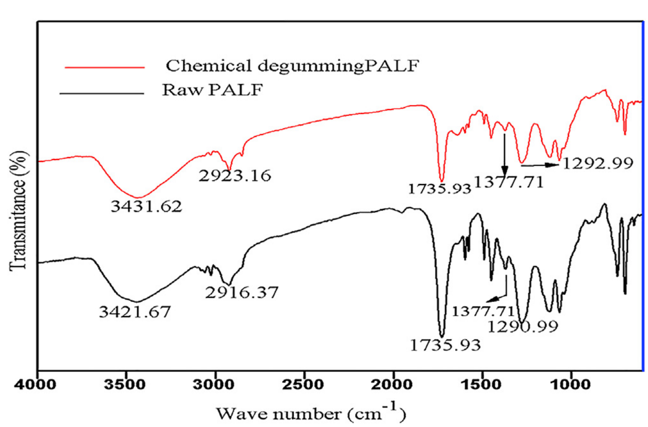

Figure 3. FTIR spectra of raw PALF and degummed PALF samples.

2.2.8. Chemical analysis of the blend

The definite proportions of the blend were evaluated chemically according to method ASTM D276-12 for estimation of the blend. The actual percentages of the blend were estimated chemically by using 60% H_2SO_4 at 20 °C temperature for 5 min where PALF was dissolved and cotton remained insoluble (ASTM D276-12, 2012; Jawaid et al., 2020). All specimens were extracted using a mixture of benzene (2:1) to extract lubricant and any finishing materials which were added during processing. Each sample was tested twice and recorded the mean value in Table 9.

2.2.9. Observation of uniform mixing of the blend

The uniform mixing status of the produced yarns were visually assessed by chemical reactions that changed the blend fibbers' color. Two types of chemicals, such as boiling $ZnCl_2$ and Millon's reagent, were used for this purpose. Both chemicals altered the color of the PALF but not color of the cotton. It is visually observed that PALF is migrated and blended with cotton uniformly (Table 11).

2.2.10. Cotton-PALF blended yarn characterization

Uster tester UT3 was used for the study of CVm%, Um%, hairiness, thick & thin places and neps. For the measurement of tenacity and elongation, Uster Tensojet was used. Different quality parameters of the yarn were tabulated in Table 10 and Figure 7.

2.2.11. Fabric properties evaluation

2.2.11.1. Determination of tensile strength

BS 2576 (strip method) was used to determine the breaking strength and elongation of produced woven fabrics. Both warp and weft five samples were extended in parallel to the warp and weft direction and two samples did not have the same longitudinal threads. During the time of the test, the size and precision of the load cell (0.5–25 kN), the distance of cross-head travel (0.1–2 m) and the rate of cross-head travel (0.1–500 mm/min) must be taken into account (Jinlian, 2008).

2.2.11.2. Abrasion resistance measurement

ASTM D4966 method was used to calculate the resistance to abrasion and weight loss percentage was estimated at 2800 revolutions.

2.2.11.3. Drape co-efficient measurement

IS 8357/1977 method CUSICK Drape meter was used for measuring the drape of the produced fabric. After the deduction of the supporting disk area, the drape was determined as the drape coefficient F, which is the ratio of the draped specimen's predicted area to its undraped region (Equation 4). The drape is a key textile feature of how clothes adhere to the shape of a human silhouette (Kenkare and May-Plumlee, 2005).

$$F = \frac{A_s - A_d}{A_D - A_d} \qquad (4)$$

where, A_D is the specimen area, A_d is the supporting disk area and A_s is the specimen actual projected area.

The light beam casts a shadow of the draped fabric onto a ring of highly even translucent paper placed on a glass screen in the actual test.

Table 6. Peak positions and assignments in FTIR spectra of raw PALF and chemical degummed PALF (Sarah et al., 2018).

Fiber type	Bond/stretching (wave number cm^{-1})				
	-OH stretching of cellulose	C–H stretching of cellulose	C=O stretching of hemi-cellulose	$-CH_2$ stretching of cellulose	C–O stretching of lignin
Raw PALF	3421.67	2916.37	1735.93	1377.71	1290.99
Degummed PALF	3431.62	2923.16	1735.93	1377.71	1292.99

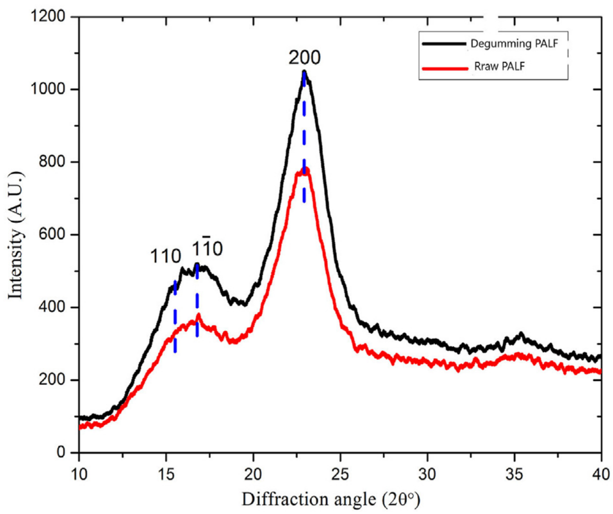

Figure 4. The XRD patterns of raw PALF and degummed PALF.

On the paper ring, the surface drape pattern area is directly proportional to that area's mass. So, the Eq. (5) can be used for computing the drape coefficient (*F*):

$$F = \frac{\text{Mass of shaded area}}{\text{Total mass of preparing}} \times 100\% \quad (5)$$

2.2.11.4. Bending length

The fabric's bending length was measured according to ASTM D1388-2007 by a cantilever test.

2.2.11.5. Flexural rigidity measurement

The flexural rigidity i.e., a fiber's stiffness, is characterized as the pair requiring curvature bending of the fiber to the unit. Curvature is the reciprocal of the curvature radius. This definition eliminates the direct effect of the length of the specimen. In terms of other fiber properties, the flexural rigidity can be measured using the Eq. (6). The comparative tensile strength and flexural rigidity findings of produced fabrics are shown in Table 12.

$$G = WC^3 \text{ x } 10^3 \text{ mg/cm} \quad (6)$$

here, C = Bending length in cm, W = Cloth weight in gm/cm^2.

2.2.12. Atmospheric condition

All physical properties of the fibers, yarns and produced fabrics were evaluated after conditioning at 65 ±2% relative humidity and 27 ± 2 °C temperature for 48 h.

3. Results and discussion

3.1. Physical properties of 100% PALF yarn

From Table 4, the results indicate that the effect of the finisher draw-frame process is highly significant on blended sliver unevenness i. e. the Um% (4.20) of the finisher draw frame sliver is lower than that of the second and third draw sliver. If Um% of sliver is lower, yarn Um% will also lower. So, the finisher draw-frame is essential for processing better quality blended yarn. Any fiber must have certain spinnable attributes such as length, strength, fineness, cohesiveness and elongation to be designated as a textile fiber. These fiber qualities are indispensable for yarn formation and evaluating spinning performance. PALF offers similar spinnable qualities for yarn formation during the spinning process, as shown in Tables 1 and 2. Furthermore, PALF has a very large diameter relative to other textile fibers and due to this larger diameter; PALF produces poor quality ratios (Table 5). The quality ratio (QR) is the yarn property, which indicates the load at break (lb/spyndle). A yarn with higher quality ratio also indicates a higher strength. So, it is said that high tenacity at break causes maximum quality ratio (Jalil et al., 2010, 2011). In this experiment, the yarn QR values for PALF at 121 tex and 138 tex are 88.89% and 83.17%, respectively. This number is relatively low due to the PALF's bigger diameter (less fine). As a result, PALF cannot be spun alone to produce fine yarn of excellent quality. However, because of the bigger diameter and less expensive than jute, PALF could be more useful in the jute industry (Jalil et al., 2019).

In a nutshell, a fiber with better strength cannot spin a yarn of good quality unless its diameter is small. However, the diameter of the PALF is slightly higher than jute; it is possible to manufacture a similar quality of yarn like jute from pineapple leaf fiber. Therefore, pineapple leaf fiber can be used as a potential replacement for cotton, jute and allied fibers. On the other hand, PALF and other natural fibers are facing tough competition with manmade fibers. To overcome this struggle, PALF, jute and cotton must be diversified using the emerging manufacturing system.

3.2. FTIR analysis

The corresponding FTIR data of PALF are presented in Figure 3 and peak positions and assignments in the FTIR spectrum of pineapple leaf fibers are listed in Table 6. A certain amount of hemicelluloses, lignin, oils and wax will be removed from the fiber by the degumming process. The distinct vibrational band at 2916.37 and 2923.16 cm^{-1} was associated with the asymmetric –CH stretching, the peak at 3421.67 and 3431.62

Table 7. Strategy for the experiment.

Parameters	Levels		
	1	2	3
Blend form	C-PF	C-PF	-
Blend %	90:10	80:20	-
Twist multiplier	2758	3026	3629

Table 8. Sample codes with their structure and twist multiplier.

Trial no.	Sample code	Blend form	Twist multiplier
1	C-PF 90-10	90% C/10% PF	2758
2	C-PF 90-10	90% C/10% PF	3026
3	C-PF 90-10	90% C/10% PF	3629
4	C-PF 80-20	80% C/20 PF	2758
5	C-PF 80-20	80% C/20 PF	3026
6	C-PF 80-20	80% C/20 PF	3629

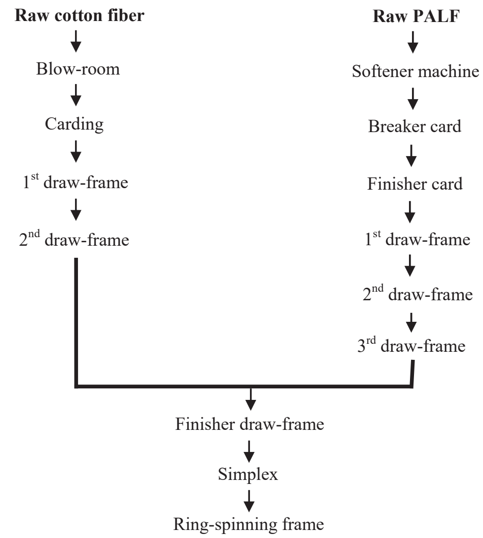

Figure 5. Process sequence of cotton-PALF blended yarn.

cm-[1] were designated as the –OH stretching, respectively. The decreases in the peak specify the removal of hemicelluloses from the raw PALF. The peak at 1735.93 cm-[1] is to allocate a sign of hemi-celluloses. Peaks at 1290.99 cm-[1] and 1292.99 cm-[1] were ascribed to the C–O stretching of lignin in that order. This lignin plays a vital role in the fiber, viz controlling moisture content capacity, defining against biological attacks, and strengthen the stalk against the breeze and high magnitude forces.

3.3. XRD analysis

Figure 4 depicts the XRD patterns of raw PALF and degummed PALF. The pristine PALF sample showed distinctive XRD patterns with the corresponding reflection at $2\theta = 15.50°$ (plane 110), at $2\theta = 16.65°$ (plane $1\bar{1}0$) and at $2\theta = 22.93°$ (plane 200); these peaks are aligned with the distinctive reflections of the cellulose1 crystalline polymorph (Nindiyasari et al., 2016). Upon treating the PALF samples with NaOH, the X-ray patterns of degummed PALF illustrate the same peaks that of typical cellulose materials. However, the chemical treatment alters the stereoregularity of the cellulose matrix by swelling the polymer chain lengths and the interaction of hydrogen bonds (French, 2014; Garvey et al., 2005; He et al., 2008; Hult et al., 2003; Park et al., 2010). From the results, the degummed PALF exhibited the highest crystallinity index 70.31% whereas raw PALF shows crystallinity index of 52.23%. The NaOH treatment on the fiber contributed high crystallinity % in the degummed fiber. The crystallinity index of the degummed fiber augmented due to elimination of amorphous region. All contaminants and unwanted insoluble lignin were transformed into alkali water-soluble molecules by the transition of the crystal structure from cellulose I to cellulose II (Ben, 2012). Cellulose I is the crystal form of native cellulose, whereas cellulose II is the result of cellulose fiber mercerization (Abraham et al., 2011). Other researchers have found the conversion of cellulose I to cellulose II at concentration of 6% NaOH(Le and Navard, 2010). In inference, NaOH solution treatment effectively removes the non-cellulose substances and upsurges the crystallinity % of the fiber.

3.4. Moisture and surface appearance properties

From Table 2, the result shows degumming increasing the moisture regain and absorbency of PALF significantly. The fiber's absorbency increased from 21 s (retted PALF) to 10 s (degummed PALF) due to alkaline treatment, which removes the fat and wax from the surface of the fiber and makes it's more hydrophilic in nature. In the case of natural fibers, absorbency is a crucial characteristic. The absorbency of the fiber determines the fabric's wet processibility as well as its ability to absorb perspiration. Though, the whiteness, brightness and yellowness of the retted fibers were reduced slightly during degumming, but color strength significantly increases to about 19.21% due to the treatment of NaOH.

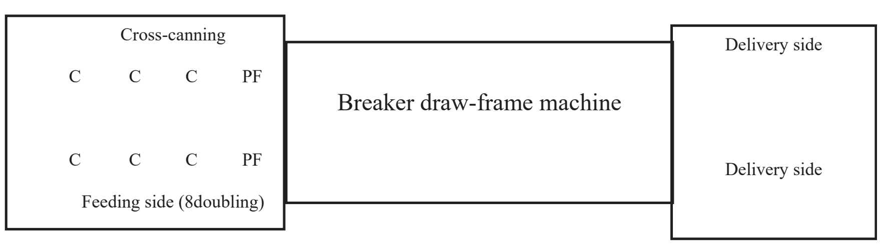

Figure 6. Can arrangement of cotton-PALF blended drawn sliver.

Table 9. Estimation of blending ratio of the blended yarn.

Yarn count in tex	Theoretical blend Blending ratio (%) Cotton: PALF	Sample weight in g	Weight of cotton in g	% of cotton	Actual blend composition Cotton: PALF
30	90: 10	0.350	0.318	90.86	90.86:9.14
30	80: 20	0.438	0.359	81.96	81.96:18.04

Table 10. Relation between blend ratio and physical properties of 30tex cotton-PALF blended yarn processing using a ring frame.

Blending ratio (%) Cotton:PALF	Quality parameters								
	Nominal count tex (Ne)	Actual count tex (Ne)	Um%	CVm%	Thin/km (-50%)	Thick/km (+50%)	Neps/km (+280%)	IPI/km	Hairiness
90:10	30 (20.0)	29 (20.4)	12.8	16.9	29	278	308	615	9.6
80:20	30 (20.0)	31 (19.0)	13.5	18.3	34	297	347	678	8.4

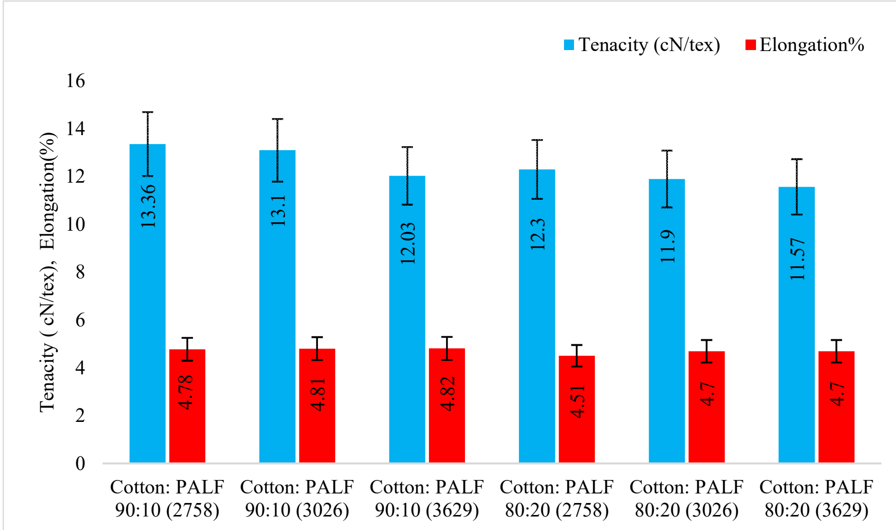

Figure 7. Blended yarn tenacity and elongation percentage at three levels of TM.

3.5. Physical properties of cotton- PALF blended yarn

3.5.1. Tensile properties of cotton- PALF blended yarn

The yarn's tenacity and elongation % are two essential qualities. The breaking force in cN/tex can be used to evaluate the tensile strength of different yarn. In Figure 7, the tenacity and percentage of elongation for each yarn sample relative to its three-twist multiplier (TM) levels are shown. The average tenacity and elongation percentage to every blend yarn was found in the same order from Figure 7: C-PF 90: 10 > C-PF 80: 20, respectively. The higher tenacity and elongation percentage of C-PF blend yarns are due to the more tenacity and elongation of cotton fiber than that of PALF. The reason could also be better cotton fiber fineness provides more fibers per unit x-section of yarn.

3.5.2. Consequence of the twist multiplier on cotton-PALF blended yarn tenacity

The variance in the tenacity of cotton yarns at three points of TM is not fairly noteworthy, as demonstrated in Figure 7. The most likely cause is that the maximum strength of C-PF blend yarn has been achieved at the lowest TM level. Thus, a further rise in TM is not beneficial and will result in production losses (Rieter, 2017b). At the same time, ring spun yarn is however demanded for its the softness, high bulk and low residual torque, and increased productivity linked to low twist levels (Yang et al., 2007).

3.5.3. Yarn imperfections

The main properties of produced yarn like irregularity, imperfections and hairiness were measured using Uster tester and the tested results were tabulated in Table 10. From this Table, it was found that with the increase of cotton% of the blend, yarn unevenness, thick & thin places and neps were also decreased. The reason behind decreased imperfection may be the better fineness of cotton fiber offers a more significant number of fibers per unit x-section of yarn. But with the increase of PALF % of the blend, the hairiness of the yarn decreased as longer pineapple leaf fibers provided smoother yarns, low fiber migration and fewer ends to protrude. However, we have observed variations in the parameters of blended yarns; indexed data of imperfection will not affect the yarn quality notably.

3.5.4. Impact of the cotton-PALF blend ratio of blended yarn

As shown in Tables 1 and 3, there is a prominent difference in fineness between PALF and cotton fiber. The fineness of cotton fiber is seventeen times finer than pineapple leaf fiber. The breaking stress of PALF is greater as compared with cotton fiber. Blending finer cotton fibers with PALF helps to enhance spinnability, resulting in more fibers per yarn x-section regardless of the Hamburger's theory. The break extension of the PALF is just 3.25%, which is comparatively poor compared to cotton fiber. Again, from Table 1 and Table 3, it is clear that the significant difference in tenacity at break between PALF and cotton reflects the tensile properties of the blended yarn. The CVm % of yarn parameter is evident from Table 10 and it continues to decrease with an increase in the proportion of cotton components in the blends. The reason may be the improved fineness of the cotton fiber, which offers more fiber per unit of the x-section of the yarn. As the cotton portion rises in the blend, the diameter of the yarn increases. It can be owing to the higher specific cotton fiber volume compared with pineapple leaf fiber.

3.6. Chemical analysis of the blend

The blending ratios of yarns based on the theoretical blending proportions of cotton-PALF yarns processed on the cotton spinning arrangement examined by the chemical process is shown in Table 9. The findings obtained indicate a high degree of accuracy in the exact compositions estimated by the chemical method.

3.7. Assessment of uniform mixing of the blended yarn

Two chemical methods (boiling $ZnCl_2$ and Millon's reagent) were used to investigate the uniform mixing of the blends of cotton-PALF yarns produced with the cotton ring spinning arrangement. Table 11 shows that cotton fiber is insoluble and remains color unchanged in both reactions where PALF is insoluble but turned into faint brown and yellow respectively.

3.8. Physio-mechanical properties of fabric

From Table 12, the mean tensile strength of sample X is found to be more than sample Y, in both warp and weft ways. This is due to the fact that the X sample has a compact structure compared to the Y sample; therefore, the flexibility of the X sample is minimal. It is obvious that the abrasion resistance of sample X (2.20%) and Y (2.16%) has an insignificant difference. Even after 2800 cycles, the abrasion resistance was found to be significantly high, with a relatively minimal weight loss demonstrating its high durability against being abraded. This may be attributed to the flexibility of movement of yarns with the abrader during the test, due to lose structure of the cloth. Table 12 also reveals that the sample Y drape coefficient is 65.98 % which is 30.32% higher than that of sample X. The compact structure has petite mobility and does not drape like a looser construction. For this reason, the sample Y drape is

Table 11. Assessment of uniform mixing of the blended yarn.

Chemicals	Blending ratio		Reactions		Remarks
			Cotton	PALF	
Boiling $ZnCl_2$ (60^0 F.B.)	Cotton:PALF 90:10	Cotton:PALF 80:20	Insoluble and color unchanged	Insoluble and colored a faint brown	Visually observed that PALF is migrated and blended with cotton uniformly of the produced yarn
Millon's reagent			Insoluble and color unchanged	Insoluble and turned into yellow	

Table 12. Comparative test results of fabric “X” and fabric “Y”.

Fabric type	Design of fabrics		Tensile strength in kg				Abrasion resistance		Drape Co-efficient (%)	Bending length (cm)		Flexural rigidity (mg/cm)	
			Average		CV%								
	EPI	PPI	Warp	Weft	Warp	Weft	Revs.	Wt. loss (%)		Warp	Weft	Warp	Weft
X	30	26	83.75	153.90	2.62	2.30	2800	2.20	50.63	3.25	6.99	3415.10	40800.53
Y	30	26	78.40	145.99	0.52	0.31	2800	2.16	65.98	2.39	5.40	1090.42	14221.32

fine over the sample X. The bending length of the sample X is higher than the sample Y in both warp and weft ways. The Y sample has lower flexural rigidity relative to the X sample from the test results. The crimp that is present in the fabric structure influences the extensibility of the fabric. The greater the number of interlacements per area is caused the greater the crimp. In fact, the longer the floats are made, the fabric will be less stretchable. Taking into consideration all the above properties, it may be concluded that PALF-based fabric is more suitable for making different fashionable and ornamental items.

3.9. Cost factor

As pointed out previously, PALF and PALF blend yarn and fabric can easily be prepared by using the existing conventional jute and cotton processing machine. Therefore, the productions of PALF yarn and fabric do not require any additional machine and also the cost of raw materials is very low, resulting in the expenditure of resources to produce the yarn and fabric are also much less. Considering the price of PALF yarn in the range of US$1.0 to 1.5 per pound and that of 100% jute and cotton yarn in the range of US$.0.5 to 1.0 and US$2.5 to 4.5 per pound respectively. In addition, the price of PALF and cotton blended PALF colored fabric is in the range of US$5 to 10 per meter and 100% jute and cotton cloth in the range of US$0.75 to 1.5 and US$10 to 25 per meter. It may be mentioned that the production of 100% PALF and PALF blended cotton yarn and fabric in traditional production of jute and cotton handling machines will be extremely cost-effective, as these value-added high-performance products can be sold at a much higher price, and the use of cotton fiber can be reduced (Jalil et al., 2015a). Therefore, efforts should be taken in pineapple farming to collect the pineapple leaf and fibers and cost-effective process using modern technologies that can generate adequate revenue for the country's pineapple growers and economic growth, which will also minimize the poverty and build new job opportunities for the local unemployed people. Furthermore, developing small and medium-sized handloom, power loom, and handicrafts businesses where pineapples are grown on a larger scale, might provide new job possibilities and economic hotspots. Because natural fibers are always competing with synthetic fibers, a diverse utilization of PALF in conjunction with Jute may be a better strategy to survive in this situation (Jalil et al., 2019).

4. Conclusion

The conclusion of this work will be the revival of jute, cotton and allied fiber industries of south Asia like Bangladesh, Pakistan, India, China and so on. Consequently, jute, cotton and other allied fibers will get back their glory. There is no problem processing indigenous PALF and cotton-PALF blended yarn with minor modifications in existing traditional cotton and jute spinning and weaving systems. Since PALF is a less scalable fiber with more strength and higher modulus intermingled with better extendable versatile cotton fiber, the perception of the Hamburger theory of blending has become unsound. In fact, the application of finer cotton fiber expands the consistency of the blended yarn. The blended yarn has strong potential for the production of fancy clothing items. It was concluded from the study that the findings would directly impact the jute-PALF industry and could yield better quality yarns and fabrics by implementing the suggested method. This will improve the usage of PALF, which is environmentally friendly and thus bio-degradable. Valuable foreign currency can be saved by supporting the usage of PALF yarn and cloth instead of artificial products and also by uplifting the country's global economic approach. For industrial purposes, PALF can be obtained without any extra charge. Furthermore, residual agro-waste in PALF processing is rich in cellulose, which can be used as relatively inexpensive vermin compost. Subsequently, PALF processing and manufacturing could reach zero-waste management, with the textile industry benefiting the country's economy, thereby turning the “Trash” of the pineapple into “Money”. According to the findings of this study, waste is not a waste, but rather a new dimension to waste material.

Declarations

Author contribution statement

Mohammad Abdul Jalil: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Md. Moniruzzaman, Md. Shohan Parvez, Ayesha Siddika: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Md. Abdul Gafur: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

Md. Reazuddin Repon: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Md. Tanjim Hossain: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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