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Influence of blend proportion on mechanical properties of banana/cotton blended knit fabric

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This study is aimed at analysing the effect of blend proportion on the mechanical properties of banana/cotton blended knit fabrics. The banana fibre is extracted and subjected to alkali treatment and silicon softening followed by blending with cotton fibres in different proportions to produce banana/cotton blended yarns. Single jersey weft knitted fabrics are produced using these banana/cotton blended yarns and the fabric properties are analysed and compared with 100% cotton knitted fabric. It is observed that the banana/cotton blended yarns show decreased strength with increase in banana fibre content. In the banana/cotton blended knit fabric, with the increase in banana fibre proportion, the abrasion resistance increases, bursting strength decreases and pilling decreases.

Keywords: Banana fibre, Banana/cotton blended yarn, Knit fabric, Silicon softening

1 Introduction

Banana fibre is one of the natural, ligno-cellulosic, strong, lustrous and fine bast fibres obtained from the pseudo-stem of the banana plant with relatively good mechanical properties. An inherent drawback of the banana fibre is its greater stiffness, less cohesiveness and higher irregularity, owing to the multi-cellular nature of the fibres. The individual cells are cemented with hemicellulose and lignin and thus form a complex fiber[1-2]. In textile processes, it is difficult to spin the fibre with 20-30% of adhered lignin and hence lignin needs to be removed by the process of degumming, otherwise, the low-quality product will be the result[3-5].

To remove lignin and impart pliability, various treatments such as alkali treatment, acetylation, benzoylation, enzyme treatment and softening are carried out. Among all these treatments, mercerization or alkali treatment is a versatile one which removes the non-cellulosic content, specifically lignin[6-8]. By boiling in optimum NaOH solution, lignin can be accessed and removed that allows rearrangement of molecules, which increases crystallinity and crystallite sizes[9,10]. The removal of lignin, hemicellulose and other contents by alkali treatment roughens the surface of the fibre and results in high α-cellulose and low lignin content which are advantageous in textile application[11]. Available literature reveals that alkali treatment removes the binding materials, depending on the treatment time, concentration of alkali used, temperature of treatment, liquor ratio, etc[12-15].

There are different methods to soften the banana fibres. Treatment of banana fibres with 20% acetic acid causes a reduction of diameter but at the same time enhances the properties to a great extent, which will further improve the bending capacity of banana fibres for apparel use. Enzyme application increases tensile energy, extensibility and improves the surface characteristics of the banana fibre[16,17]. Banana fibres are reported to have been spun on the jute spinning machinery and used in making ropes and sacks[18-19].

The banana fibre was extensively used as blending material in textile industries in countries such as the Philippines, Malaysia, Japan and Korea. Being a natural fibre, it easily blends with other fibres such as jute and mesta[20]. Banana /jute blended yarn production was attempted by few authors. Addition of 20% jute with the banana fibres has improved the breaking extension and the tenacity of the blended yarns. Union fabrics produced using cotton yarns as warp and jute/banana blended yarn as weft have good flexibility in warp direction (cotton) and are stiffer or less pliable in the weft direction[21]. Similarly, Mishra[22] made a comparative study of pure cotton and banana fibre blended fabric to promote its use in textile applications.

The sewability analysis of cotton-banana blended fabrics revealed that they have higher/better seam

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pucker but higher bending rigidity than 100% cotton[16-17]. Balan & Vandana[23] analysed the effect of various alkali and softener treatments on the physical, chemical and mechanical properties of the banana and banana: jute fibres blended yarns and fabrics. So far no attempt has been made to develop knitted fabric using banana/cotton blended yarns and hence this research work aims at developing knitted fabric using banana/cotton blended yarns.

2 Materials and Methods

In this research, banana fibre was subjected to alkali treatment and silicon softening. The effect of these treatments on banana fibre properties was analysed. Banana and cotton fibres were blended in different proportions to produce banana/cotton blended yarns and their properties were compared with 100%cotton yarn. Single jersey weft knitted fabric was produced using the banana/cotton blended yarns and the fabric properties were analysed and compared with 100% cotton knitted fabric.

Mechanically extracted raw banana fibre was used for this study. The cultivar of banana plant selected was 'Peyan' which belongs to ABB genome of *Musa species*. The fiber extractable pseudostem was 62.29% and cellulose content was 56.07%. MCU-5 Cotton fibre was selected to blend with the treated banana fibre. The cotton fibre parameters are fineness 3.6 µg/inch, span length (2.5%) 27.9mm and span length (50%) 14.9mm.

During alkali treatment, banana fibres were treated with 8g/L, 10g/L, 12g/L and 16g/L of NaOH, at 70^0C, 80^0C and 90^0C for 60 min, 120 min 180 min and 240 min separately. At the end of the treatment, the fibres were washed with hot and cold water. For softening, the banana fibres were treated with 1.5% silicon softener for 30 min and then washed with hot water followed by cold water. Banana/cotton blended yarns of 30^s Ne count were spun with three different blend compositions (10:90, 20:80, 30:70) and 100% cotton using the TRYTEX mini ring spinning frame. It was not possible to try a higher percentage of banana fibre, because of the limitations of the spinning machines.

The banana/cotton blended yarns were tested for yarn strength and elongation using single yarn strength tester by ASTM D2256-02 method. Lea strength and elongation were also measured using Lea strength tester by ASTM D1578-9 method**.** Yarn TPI was measured as suggested in ASTM D1423-99 direct counting type twist tester. The unevenness of the yarns was measured as suggested in ASTM D1425-96 using capacitance based Premier tester 7000.

Single jersey knitted fabrics were produced from banana/cotton fibre blended yarns and 100% cotton spun yarn using VEETEX SOLAMAN socks knitting machine. The developed fabric was tested for abrasion resistance as per the ASTM D3884-09 standard using Eureka fabric abrasion tester. Pilling resistance was tested as per the ASTM D3512 standard, using the Autopill 2BX pilling tester. The bursting strength was tested as per ASTM D3787 standard using the Auto-Burst 28 bursting strength tester. The dimensional stability was tested as per the AATCC 135/150 standards.

3 Results and Discussion

3.1 Effect of Alkali Treatment on Lignin Decomposition

To optimize the NaOH concentration for degumming, banana fibres were treated with four different concentrations of sodium hydroxide (8g/L, 10g/L, 12g/L, 16g/L) along with 1g/L sodium carbonate, maintaining fibre - to - liquor ratio 1: 20, temperature 90^0C treatment time 120 min, followed by washing and finally drying in an oven. The treated fibres were tested for lignin degradation to estimate the effect of sodium hydroxide concentration.

Alkali treatment removes a certain amount of lignin, wax and oil covering the external surface of the fibre cell wall, depolymerizes cellulose and exposes the short length crystallites. The lignin degradation value steadily increases up to 36% with the increase in NaOH concentration levels up to 12 g/L, and shows a slight increase thereafter. At lower concentrations, the alkali is not efficient to decompose the lignin and other impurities from the fibre and at higher concentrations, lignin macromolecules are degraded more thoroughly.

3.2 Effect of Treatment Time on Lignin Decomposition

To determine the optimum process time for degumming, the banana fibre is treated for different durations, viz 60 min, 120 min, 180 min and 240 min, using the solution containing NaOH 16g/L with, fibre - to - liquor ratio 1: 20, and tempratue 90^0C, followed by washing and drying. Finally, lignin content is analysed to study the effect of treatment time on banana fibre.

Figure 1 (b) shows that the lignin decomposition value increases almost linearly with the increase in treatment time up to 180 min, but minimum changes are observed after 180 min. The extent of banana fibre swelling is increased with time and is fairly found complete within 180 min. The gum loosenes and openes up, thus allowing the auxiliary agents to easily penetrate the fibre. As a result, the auxiliary agents react sufficiently with non-cellulosic materials, and decompose and dissolve them in the treatment solution. All the decomposable materials are removed by 180 min, indicating the maximum time limit for lignin decomposition.

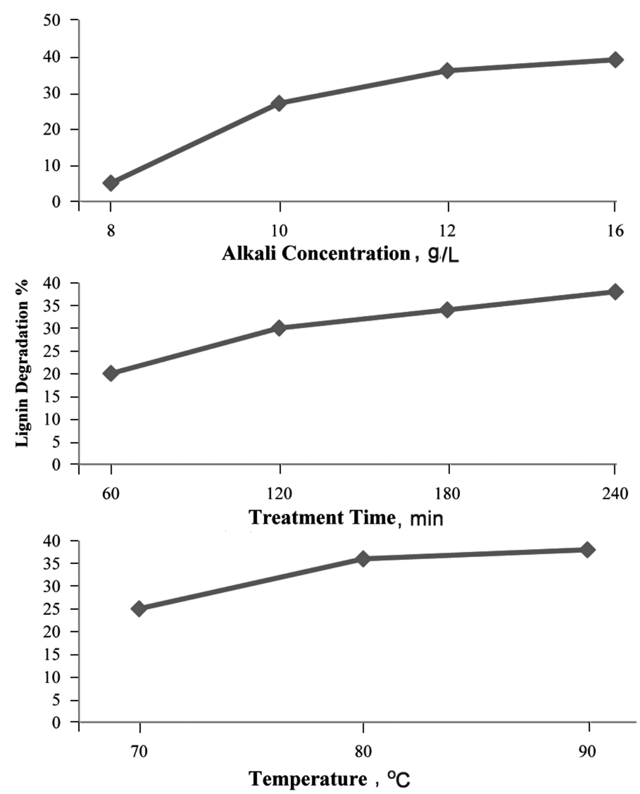

Fig. 1 — Effect of alkali treatment on lignin decomposition (a) alkali concentration, (b) treatment time and (c) temperature

3.3 Effect of Treatment Temperature on Lignin Decomposition

To decide the optimum temperature for degumming, the banana fibres are treated at different temperatures (70^0C, 80^0C and 90^0C.) using the solution containing NaOH 16g/L, sodium carbonate 1g/L, with fibre – to - liquor ratio 1: 20, and treatment time 120 min, followed by washing and finally drying in an oven. Then the lignin content is analysed to study the effect of temperature on lignin decomposition of banana fibre.

Figure 1(c) shows that the lignin decomposition value almost linearly increases with the increase in temperature. A lower temperature is not sufficient to loosen the lignin and also to remove it. The increase in temperature increases the possibility of lignin removal by swelling the fibre and allowing the auxiliary agents to penetrate the fibre. High temperatures accelerate the penetration of alkali and leads to a synchronous stripping of single cells in the radial direction of fibre bundles. There is a possibility of decomposition of cellulose at > 100^0C. So, 90^0C is found sufficient to swell the fibre and remove the unwanted substances from the fibre without affecting the cellulose content.

Hence, alkali concentration of 12g/L, temperature of 90^0C and treatment time of 180 min are optimized for carrying out the alkali treatment of banana fibre. The SEM images of untreated and NaOH treated banana fibres are shown in Fig. 2. The result shows that the average diameter is 20 micrometre.

The SEM micrographs of the morphological analysis of the untreated and NaOH treated fibres [Fig. 2 (b)] reveal that the surfaces of the untreated fibres are bound with a layer of substances, which include lignin, hemicellulose, pectin and other non-cellulosic content. The alkali-treated fibres show a smooth surface with clear ridges due to the removal of these bonding substances.

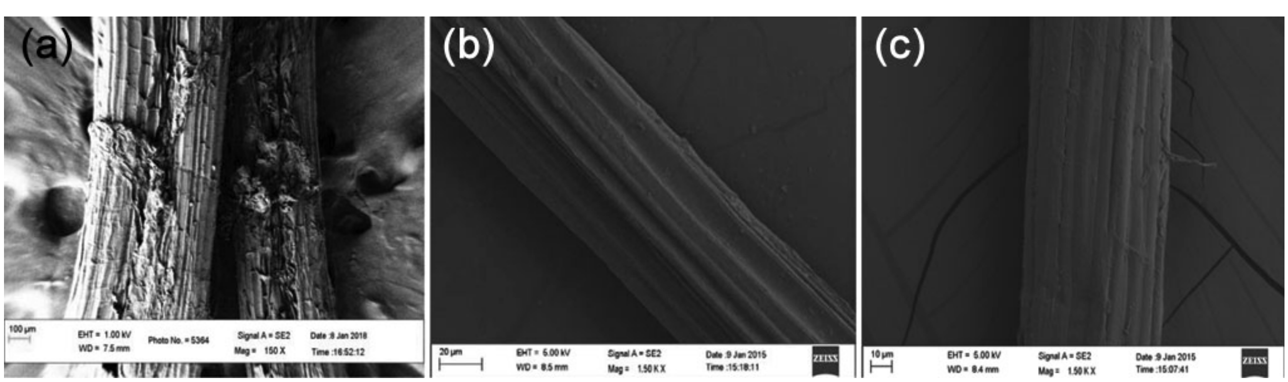

Fig. 2 — SEM images of (a) untreated, (b) NaoH treated, and (c) silicon softener treated banana fibres

3.4 Effect of Silicon Softening on Banana fibre

From the SEM image of silicon softener treated banana fibre [Fig. 2 (c)], it is observed that the average fibre diameter is 10 micrometre. The image shows very clear ridges on the fibre surface, showing micro fibrillation due to the complete removal of bonding substances between the microfibrils.

The untreated, alkali-treated and silicon softener treated fibre samples have been tested for single fibre strength, elongation %, moisture content, cellulose content and lignin content. The experimental results show the changes in the basic mechanical properties of the banana fibres after alkalization and softening processes. The results of the fibre properties are given in Table 1.

Due to the removal of a certain amount of lignin, wax and oils covering the external surface of the fibre cell wall, the diameter of the banana fibre has reduced from 65 µm (raw fibre) to 20 µm (alkali treated). Further, the silicon softening process also results in a reduction of fibre diameter to 10 µm. The moisture content is reduced from 11% to 9%, which may be attributed to the loss in the lignin and hemicellulose contents of the fibre. It is known that the lignin is less hydrophilic than the cellulose content and the hemicelluloses contain more hydroxyl groups than the celluloses. Removal of lignin should have increased the moisture regain to a higher level but the simultaneous removal of hemicelluloses has decreased the moisture regain values. Lignin content has reduced drastically from 18% to 9% and then to 7 % due to alkali treatment and silicon softening respectively. Due to the reduction in lignin content, the cellulose content has improved.

The single fibre strength and elongation % register reduction due to alkali treatment and a slight increase after silicon softening. The decrease in tensile strength may be due to the action of alkali on the non-cellulosic contents and their removal, resulting in reduced fibre content and diameter of the fibre. Since lignin acts as major adhesives between cellulose macromolecules or single cells, removal of these adhesives inevitably leads to a reduction in the breaking strength of banana fibres. The increase in fibre strength and elongation % after softening treatment may be attributed to the flexibility and mobility among the fibrils to reposition themselves in the direction of loading.

Table 1 — Comparison of banana fibre properties

Properties	Untreated	Treated with NaOH	Treated with NaOH & silicon softener
Fiber diameter, µm	65	20	10
Moisture content, %	11	9	9
Elongation, %	2.5	1.8	2.0
Lignin content, %	18	9	7
Cellulose content, %	69	72	75
Single fibre strength g/tex	27	23	25

3.5 Analysis of Waste% in Carding

During the spinning process, analysis of waste % of fibre while processing through carding is recorded for untreated and treated fibres. The licker-in waste of raw banana fibre is found as high as 40%. The raw banana fibres, delivered from the front zone of the carding machine, are stiff and almost in a broken form. The fibres remain in individual state and unable to form a web, and hence results in high waste %. This may also be attributed to the higher diameter (6- 7 times) of the raw fibre when compared to cotton. The alkali and silicon treated fibres register 11% and 7% reduction in waste respectively.

Using the alkali-treated and silicon softened 100% banana fibres, webs can be obtained from the carding machine, which can be used to produce nonwovens. But sliver formation dose not happen, because they are not pliable and there is lack in fibre - to - fibre cohesion. The loosely bound shorter banana fibres are dropped down in licker-in zone during carding action and finaly get removed, Hence, the fibre has to be blended with cotton for further processing in the spinning.

3.6 Mechanical Properties of Banana/Cotton Blended Yarn

Three different banana/cotton blended yarns have been produced with three different blend proportions (B/C-10/90, 20/80, 30/70) along with the 100% cotton yarn of the equivalent count. The strength and evenness of the yarn samples are given in Table 2. It shows that the cotton: banana fibre blend ratios have significant effects on various mechanical properties.

The cotton and banana fibre blend proportion cause greater influence in yarns and fabrics mechanical properties. From Table 2, it is clear that with the increase in banana fibre % in the yarn structure, the single yarn strength, lea strength and CSP of the yarn decrease and its CV% increases. The single yarn strength of the banana fibre blended yarns has decreased compared to 100% cotton yarn (Table 2). The banana fibre has a relatively low breaking strength as compared to cotton. Therefore, increasing

Table 2 — Parameters of banana/ cotton blended yarns

Parameter	100% Cotton	Banana/Cotton 10/90	Banana/Cotton 20/80	Banana/Cotton 30/70
Count, Ne	22.85	22.41	24.62	25.24
Count CV%	3.41	5.04	6.21	7.92
Strength, lbs	80.00	72.63	62.54	54.36
Strength CV %	2.72	4.62	5.63	6.66
CSP	1828	1627.64	1516	1372.04
Yarn TPI	27.88	27.56	27.34	26.91
Yarn Irregularity CV%	7.2	9.9	12.6	22.5
Yarn Um%	8.1	10.08	19.12	23.13
Thin place(-50%)/1000m	128	536	834	1035
Thick place (-50%)/ 1000m	36	1236	1626	2412
Neps (+200%)/ 1000 m	23	725	1215	1827
Hairiness (H)	4.23	5.33	6.21	9.21

the ratio of banana fibre will inevitably lead to a reduction in breaking strength of banana/cotton blended yarns. Reduction in strength may also be attributed to the more surface wrappings of banana fibre in the yarn structure. The fibre migration theory states that coarser fibres move towards the sheath and finer fibres move towards the core of the yarn. Banana fibres are coarser than cotton fibres and based on the migration theory, banana fibres migrate towards the sheath and cotton fibres move towards the core. Banana fibres present on the yarn surface are not twisted due to rigid structure and easily stick out from the yarn surface and hence are not contributing to the yarn strength.

Yarn uniformity decreases as the banana component increases in the yarn. The banana fibres have no natural convolutions and are coarser than cotton, which rendered them more difficult to be blended or carded. Therefore, the increase in ratio of banana fibre increases the weak points of banana/cotton blended yarns, as indicated by an increase in thick and thin places, unevenness and its CV%. When the banana/cotton blended yarns are stretched, the yarns are always easily broken at these week points.

3.7 Mechanical Properties of Banana/Cotton Blended Knit Fabric

Single jersey knitted fabrics are produced using the 100% cotton and banana/cotton blended yarns using the specifications as shown in Table 3. The abrasion resistance, bursting strength, pilling resistance and shrinkage properties of the knitted fabrics are given in Table 4.

3.7.1 Abrasion Resistance

The abrasion resistance is tested for the developed knitted fabrics as per the ASTM D3884-09 standard using Eureka fabric abrasion tester. The samples are subjected to abrasion for 100 cycles. Banana/Cotton samples show better abrasion resistance; the B/C (30/70) samples show maximum abrasion resistance as compared to the other samples (Table 4). A fabric made up of longer fibres gives better abrasion resistance because they are harder to remove from the yarn. Banana fibre, being a longer fibre, takes a longer path inside the yarn compared to cotton fibre and exhibits better abrasion resistance. Also due to low density, bulky structure and lightweight of banana fibres as compared to cotton, the number of fibres per yarn, the thickness and the mass per unit area increase, and this causes an improvement in abrasion characteristics of the fabric[24].

Table 3 — Specifications of the knitted fabric

Property	100% Cotton	10/90 (B/C)	20/80 (B/C)	30/70 (B/C)
CPI	29	29	28	26
WPI	25	24	22	21
GSM	210	203	194	190
Tightness factor	11.30	12.83	9.79	9.67
Loop length	0.4	0.4	0.5	0.5

3.7.2 Bursting Strength

The bursting strength of knitted fabrics is tested as per ASTM D3787 standard using the Auto-burst 28 bursting strength tester. Cotton fabric shows higher bursting strength as compared to banana/cotton fabric (Table 4). Banana/cotton (30/70) sample is found to have low bursting strength as compared to all other samples. Increasing the ratio of banana fibre decreases the breaking strength and elongation of banana/cotton blended yarns, thereby causing a decrease in bursting strength of their fabrics.

Table 4 — Mechanical properties of banana/cotton blended knitted fabrics

Property	100%/ Cotton	Banana/ Cotton 10/90	Banana/ Cotton 20/80	Banana/ Cotton30/70
Abrasion resistance, wt loss%	7.2	6.5	6.3	5.1
Bursting strength, lbs/inch²	100	90	75	70
Pilling test (grade of pilling)	3	3	4	4
Shrinkage, % (+ or -)				
Length	-3.4	-3.2	-3.0	-2.9
Width	- 4.0	- 3.2	- 3.2	– 3.0

Moreover, the banana fibre is coarser and stiffer than cotton; therefore, the blended fabrics with higher banana ratio has a rougher and stiffer handle and breaks easily. Also due to increased unevenness of the yarn, yarn rupture takes place at weak places at lower load, resulting in reduced bursting strength.

3.7.3 Pilling Test

The pilling was tested as per the ASTM D3512 standard, using the Autopill 2BX pilling tester. The banana/cotton (30/70 and 20/80) blended knitted fabric samples showed a pilling grade of 4 (slight pilling) as compared to blended banana/cotton (10/90) and 100%C knitted fabric samples which show a pilling grade of 3 (moderate pilling) (Table 4). This behaviour may be attributed to the longer length, more bulkiness, rougher surface and hydrophilic nature of the banana fibre. The finer the fibre, the more fibre tips are exposed to the yarn surface, which easily entangles to form pilling as compared to courser fibres. Banana fibre being, coarser and longer, the number of fibre tips exposed to the surface is less. In addition to the influence of fibre tips, due to the rougher surface and longer length of fibre in the yarn, the frictional force and cohesion are more, making it difficult for the fibres to slide to the surface of the fabric and thus entangle into a ball. The hydrophilic nature of the fibre also reduces the pilling tendency as the banana fibre content increases in the fabric.

3.7.4 Dimensional Stability

The dimensional stability of the knitted fabrics is tested as per the AATCC 135/150 standards, by giving three cold wash. The fabrics are then dried naturally and tested for length-wise and width-wise shrinkage.

Length-wise Shrinkage

The length-wise shrinkage value after 3 washes is shown in (Table 4). After three washes, the length-wise shrinkage of knitted fabric samples decreases up to -3.4% in 100% cotton fibre. When compared to the banana/cotton blended fibres, cotton is having more shrinkage due to the swelling of fibre. By increasing the proportion of banana fibre, shrinkage reduces due to the better dimensional stability of banana fibre.

Width- wise Shrinkage

The width-wise shrinkage value after 3 washings is shown in Table 4. After three washings, the width-wise direction of knitted fabric is decreased up to -4% in 100% cotton fabric. The banana/cotton blended fabrics have more dimensional stability as compared to 100% cotton fabric in both course and wale directions.

4 Conclusion

The banana fibre is mechanically extracted and subjected to alkaline treatment and silicon softening. During the alkaline treatment, the reduction of lignin% increases with an increase in alkali concentration, treatment temperature and duration. Single fibre strength, elongation % and moisture content of the fibre are reduced after alkali treatment and improved slightly after silicon softening. Compared to cotton yarn, the blended yarns (banana/cotton – 30/70, 20/80 and 10/90) are characterized by lower strength and higher coefficient of variation of strength and elongation. Also, the unevenness of fibre increases with the increase in banana fibre percentage. In the banana/cotton knitted fabric, with the increase in banana fibre component, the abrasion resistance increases, bursting strength decreases and pilling tendency decreases.

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