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Extraction and processing of Indian Okra fibre for Industrial bio-packaging

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An effortless fibre extraction process (7 days water retting with urea) and industrial usage of the crop has been explored. The characterization study carried out on okra fibres confirms them as potent as higher grade jute on account of their similar composition, morphology and properties, which makes them one of the best fibres for heavy duty bio-packaging and industrial textile uses. Spinning trial proves its fitness for bulk processing in commercial scale machines of jute, both in elementarily (pure) and blends. Commercial scale trial of okra:jute blend (25:75) spun threads shows its good spinning performance and endurance (strain 2.9%; tenacity 12.4 cN/tex; modulus 592.3 cN/tex). The strength of the jute: okra cloth and the seam strength are found well within the standard specifications for manufacturing standard bio-packing of 50 kg for food grains. Thus, the use of okra agro residues not only results in cleaner post-harvest practices, but also adds to sustainability of the modern technologies and progressive farmers.

Keywords: Bio-packaging, Fibre extraction, Mechanical property, Okra fibre, Yarn

1 Introduction

Researchers have been looking for the use of various agro residues as major resources to produce conventional (bags, packages) as well as new products, viz. composites, building materials, insulators, geotextiles and paper pulp[1-6]. Usually, these bounty sustainable raw materials are thrown away by the farmers in unorganized manner or burnt out (commonly called 'stubble burning') causing substantial environmental pollution[7-10] as well as loss of potential natural wealth. Appropriate industrial use of agro-residues, being a secondary crop, would give rise to newer economic avenues to the farmers and improve environmental indicators globally. In this direction, some researchers[11] turned their attention towards the use of agro-residue of okra, a poor man's vegetable, produced worldwide.

Botanical name of okra is *Abelmoschuses culentus L*. under the family, Malvaceae, cultivated for green non-fibrous fruits or pods[12], harvested at their youngling stage and eaten as vegetables. The plant is robust, erect and may be grown biannually. Currently, India is the leading okra producing country with nearly 10 million tonnes of production in 2017-18[13]. The bulk of fibres extracted from stems (an agro waste) of okra plants by water retting reported to be very small[14] although having a possibility of reasonable yield (2-4%), which is quite promising for its industrial exploration. So, the fibre extraction needs to be scientifically standardized for getting optimum yield without sacrificing the advantageous properties of the fibres.

Some discrete reports on the characterization and exploitation of okra fibre have demonstrated its potential as a good lignocellulosic material for manufacturing composites[15-19] and pulping raw material[20]. Work on efficacy of acoustic [21] and thermal[22] insulation also indicated that okra fibre may be a better alternative to the commercially available manmade counterparts. But, major hindrance on commercial utilization of the fibre lies in the lack of information on optimum retting parametersfor okra fibre extraction, detail chemical and physical characteristics and subsequent process performance. Textile potential of the fibre in order to create useful industrial items has also not yet been explored.

It may not be out of context that jute industry even in its leading producing countries (Indian subcontinent) has been suffering from varying and short supply of raw material from last several decades [23,24]. The most conventional though promising, jute packaging industry are almost in the verge of their collapse due to high susceptibility to failures of jute crop as the consequence of erratic natural calamity, viz. flood, draught, and tropical cyclones. On the contrary,

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huge growth in agricultural production demands proportional availability of sustainable bio-packaging for its safe storage and transportability. So, it was thought that, fibres of okra may support the jute industry to fill-up the gap of raw jute supply as an additive to the jute products. For this, a detailed investigation is essential to have insight knowledge of chemical composition, structure, physical and mechanical property performance of the fibre. Since decades, a few coarse lignocellulosic fibres, viz. kenaf (*Hibiscus cannabinus*), roselle (*Hibiscus sabdariffa*), Congo jute (*Urenalobata*, *Urenasinuata*), and some others are being used forproducing packaging materials, either elementarily or in blends, at different parts of the world [25, 26].

Considering, the above base survey, the present work endeavours towards exploring the potentiality of Indian variety okra fibres for industrial use. The novelty of the work lies in development of auser friendlyprocess ofextractionof fibres in an effortless and improved way to obtain a higher yield as well as quality fibre. The extraction procedures are kept reasonable in terms of equipment, infrastructure and skilled, thus can be adopted by the rural cultivators without any hesitation. The effect of duration of retting for getting optimum fibre's strength, appearance and yield are major criteria of the study. The extracted fibres are characterized through chemical compositions, structure, and their properties, considering the need of technical applications. Process performance of the okra fibres for producing threads/yarns through commercial scale high-speed machines, both elementarily and in blends with jute, are also assessed. Ultimately, a separate industrial trial has been carried out to manufacture okra fibre and jute fabrics suitable forstandard packaging textiles for food grains.

2 Materials and Methods

2.1 Materials

Okra stem (*Hibiscus esculentus* L.)was collected after harvesting fruits in two cycles, from Assam, a sub-Himalayan zone.The average yield of the fibre/hectare was reported to be 240-250 kg[9]. Tossa daisee jute (*Corchorus olitorius*) of grades TD 2, TD 4, and TD 5 [27], procured from Hooghly and Purnia, India, were used for the detailed study. The TD 2 grade jute fibre was having an average length 113 mm; linear density 2.08 tex; tenacity 23.46 cN/tex; and extension-at-break 1.60%. The subsequent grades (TD 4 and TD 5) are much inferior in their property parameters than TD 2 and were chosen to optimize the property parameters along with cost effectiveness. Chemicals, such as urea was procured from E Merck, India.

2.2 Methods

2.2.1 Extraction of Fibre

Okra fibres from the stems (101-136 cm long) were extracted through water retting process. Retting was carried out by dipping the stems inopen water ditches at ambient condition (temperature 30± 3°C and relative humidity 65±15%), maintaining material-to-liquor ratio at 1:30 in two separate sets. To obtain optimum retting parameters for okra fibre, the partly dried stems were retted in two ways, viz. (i) water retting and (ii) water retting with 6% urea, as is used in case of other stem fibre. Concentration of urea was optimized by treating the fibres with 1-10% of urea on weight of fibre under the similar condition and duration in the laboratory. The doze of 6% urea was found to be optimum in respect of providing best surface colour. The stalks were bundled and immersed in water for several days till the fibre bundles could be easily separated by fingers from stem. The performance of retting was assessed every day. The retted stems were then washed thoroughly with water after detaching the fibre bundles from surface pulps and then dried in air.

2.2.2 Evaluation of Properties of Fibre

All the fibres were conditioned at an environment maintained at 65±2% relative humidity and 27±2 ºC for 48 h, before testing the property parameters[28]. Linear density of fibres was measured by gravimetric method taking 100 fibres each of 50 mm cut-length and weighed them separately to calculate the linear density[29].

The tensile properties of individual fibres, such as breaking tenacity, strain, initial modulus and work of rupture of fibres were evaluated using Instron tensile tester (model 5567). The test length and strain rate were maintained at 20 mm and 20 mm/min respectively. Due to high variability of the natural fibres, an average of 100 tests was taken for each sample[30].

Coefficient of friction between fibre bundles was evaluated by inclined plane method. For this, 3.5 g lightly combed fibre was taken to prepare two fibre pads for each test. Flexural rigidity was measured following the principle of simple supported beam[30]. Ten tests were carried out to evaluate both the properties.

The moisture regain of the fibre samples was determined by oven dry method[31] after conditioning under the standard condition in a desiccator.

2.2.3 Composition Analysis

Analysis of residual gum and α-cellulose content of the fibre samples was carried out using the standard methods[32,30]. The results were obtained taking an average of five tests for each case.

2.2.4 FTIR, SEM, X-ray Analyses

Finely chopped decorticated and treated fibres were examined in FTIR spectrophotometer (ALPHA-Bruker-Germany) using Attenuated Transmittance Resonance (ATR) technique. The FTIR Spectra of 16 scans were collected for wave number ranging from 4000 cm^{-1} to 600 cm^{-1}.

The cross-sectional view of okra fibres was examined using Philips XL-30 scanning electron microscope at 20 kV after preparing the samples with gold-palladium coating with a Sputter Emitech K550 to avoid electrostatic charge and to improve image resolution.

The powder diffractogram was obtained from finely cut fibre samples at room temperature (30°C) using a Philips-1710 X-ray diffractometer. The radial scanning of finely chopped fibres was taken with a step size of 0.1° and a counting time of 10s per step in the 2θ range from 10° to 33° with nickel filtered CuK radiation (1.54 A°) using voltage of 40 kV and a filament current of 30 mA. Crystallinity index was estimated by amorphous substitution method [30].

2.2.5 Preparation of Yarns

The okra and jute (TD 2 grade) fibres were conditioned before spinning them elementarily as well as in their blends. For conditioning, the fibre streaks were softened by flexing and bending continually on a mechanical fibre softening machine for jute, which consists of 16 pairs of heavy weight spirally fluted rollers, where dirt and vegetable matters adhered to the fibre streaks were dropped down. The fibres were then sprayed separately with oil (castor)-in–water emulsion maintaining 2.5% oil and 30% moisture on weight of the fibre and were then processed once again through the softening machine for penetration of applied emulsion into the fibre streaks and stacked in layers in a closed bin for 48 h for uniform spreading of emulsion. During stacking, the oil and water are evenly distributed throughout the entire fibrous mass by wicking process. The moisture regain of fibre streak was maintained at 33-35% before carding. Spun thread (commonly called ‘yarn’ in textile trade) of 100% okra, 100% jute and their blend (75% jute & jute waste with 25% okra)were prepared using standard jute spinning system[29]using single passage of first and second carding machines (Braithwaite, India make) for optimum opening of streak and fibre individualization followed by passing through drawing (having gill pin arrangement) cum attenuating machines (Mackie-Lagan, India make)three times for parallelization of individual fibres in the fibrous bundle and formation of tape like continuous narrow fibre fleece(commonly known as ‘sliver’) of sufficiently reduced weight per unit length. Threads/yarns of about 330tex were prepared using a flyer spinning machine (Mackie, Scotland make) at a spindle speed of 4250 rpm, maintaining a twist level at 165 turns/m.

2.2.6 Evaluation of Spinning Process Performance

Fibre wastes, dropped during carding process, were collected and weighed using electronic balance to determine wastage in percentage of the weight of total fibre fed to the machines. Moisture retention of sliver prior to spinning was evaluated by the method described earlier. Yarn breakage rate during spinning was evaluated by noting the total number of yarn breaks at running spindles for 6.0 h and has been expressed in number of breaks/spindle/h [29].

2.2.7 Trial for Commercial Scale Processing of Okra in Blend with Jute

A commercial trial was carried out to use okra fibre in blend with jute for manufacturing woven cloth (64 × 28 threads/dm, 500 g/m^2). The cloth is used to make industrial bio-packages of outside dimension (94 cm × 57 cm), for packing 50 kg food grains as per standard specification [33]. A standard 95 cm reed width, shuttle weaving machine (cone over-pick with auto shuttle package replenishing mechanism) as utilised in the jute industry, was employed for this. The cloth was woven as per standard [33] structural design having two parallel threads of warp (Double warp or DW), and single weft thread, in a single repeat of 2 up and 1 down twill weave. Threads of 330 tex100 % jute yarn was used in machine direction (warp). Threads of 965 tex jute: okra blend (75:25) was used in cross machine direction (weft). In case of 965 tex weft yarn, a separate fibre mix consisting of 10% TD 4 and 20% TD 5 grade virgin jute, 40% pre-carded root buts, 5% mill floor waste (short fibres less than 2cm) and 25% okra fibre was used. The number of breaks of thread at machine direction and also cross machine direction was counted in 5 h and results were expressed as follows:

$$\text{Thread breakage rate (threads/h/m)} = \frac{\text{(No. of end breaks/h)}}{\text{width of cloth (m)}}$$

Table 1 — Construction parameters of okra stem fibre mixed jute vis-à-vis 100% jute cloth

Parameters	Conventional	Developed
Cloth		
Weight, g/m^2	500	500
Fibre composition of thread		
Machine (warp) direction	100% jute	100% jute
Cross (weft)direction	Mix (50% long jute with 50% jute waste)	Mix (75% jute & jute waste with 25% okra)
Linear density of thread, tex [a]		
Machine (warp) direction	330	330
Cross (weft) direction	950	965
Mesh density of cloth threads/dm	64 × 28	64 × 28
Weaving machine efficiency, %	73.3	72.5
Bio-package		
Dimension of bag, cm	94 × 57	94 × 57
Mass of bio-package at 16% moisture, g	595	598

[a] Weight in gram of 1000 m long fibre/filament

Due to the multiple fibre mix, an extra carding was given at preparatory stage before spinning, to improve blending regularity of the weft yarn. Table 1 demonstrates the construction parameters for engineering the cloth and package based on okra fibre/jute yarn in accordance to the conventional packaging textiles used for the food grain storage.

2.2.8 Evaluation of Properties of Yarn

Threads were tested for mechanical properties using Instron tensile tester according to IS 1670 (1991) method following principle of constant rate of traverse, maintaining the test length and strain rate at 610 mm and 300 mm/min respectively[34]. The tensile parameters were averaged out from 75 observations for each thread samples.

2.2.9 Evaluation of Tensile Strength of Cloth and Seam

The cloth and seam were tested for their tensile strength using Instron tensile tester and following principle of constant rate of traverse. Tensile strength of cloth was determined keeping size of the samples as 200 mm × 100 mm[33]. For seam strength, size of the samples was 350 mm × 100 mm. The samples were prepared by ravelled- strip method to keep effective width at 50 mm[35]. For both the cases, test length was set at 200 mm and strain rate was maintained at such a speed, so that the samples break within 20±3 s.

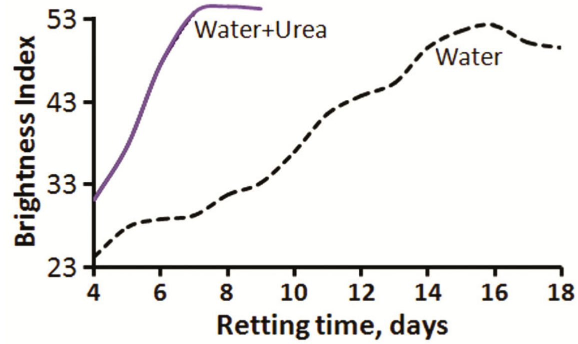

Fig. 1 — Effect of duration of water retting on fibres brightness index

3 Results and Discussion

3.1 Extraction of Fibre

Water retted okra fibres (Fig. 1) show an enhancement in brightness index during water retting, which is further steepened from the 10 days of immersion and declined after 16 days. Increase in brightness index is intended to study the reduction in surface adhered impurities of the bark fibre, which is inherited to a stem as macro level cementing agent binding the fibres together. Thus, the more and more removal of the surface impurities enhances the surface's cleanliness and smoothness of fibres along with their separation. The uniform surface contributed towards an increase in brightness index, may positively correlated to the enhancement of ordered region of cellulosic chains, as is happened in jute fibre[36, 37]. It can be affirmed that the extent of removal of non-cellulosic content has a positive correlation with crystallinity and consequent regular reflection of light (Lustre). Increase in period of retting causes decrease in brightness and breaking tenacity due to disintegration of fibrous entity, as microorganism attacks the cellulose chains. During the retting period, the environmental temperature is kept 27±3°C and humidity 85±5%.

Water retted fibres shows separation of the fibres from 13 days onwards (Table 2). The optimum conventional water retting time for okra stems is 15-16 days, having yield of about 2.24% and tenacity 28.13 cN/tex. The fibre extracted with water retting along with urea at similar treatment conditions shows much better removal of gummy matter and thus, well separated fibre bundles could be extracted on very short period of 7 days. The yield of 2.47% okra fibre is obtained over dried stems/kg having 10.4%

Table 2 — Effect of duration of water retting on tenacity of okra fibre

Observation	Without urea [a]		With urea [b]	
	Duration day	Fibre tenacity, cN/tex	Duration day	Fibre tenacity cN/tex
Partial removal of gummy substance	12	-	3	-
Fibre smoothened, but not easily separable	13	25.67 (39)	5	27.37 (61)
Smooth fibre, easily separable	15-16	28.13 (42)	7	29.67 (39)
Fibre disintegrated on rubbing between fingers	17 – 18	22.13 (89)	9	27.04 (42)

[a]Fibre yield on 16th day was 2.24% over dried stems/kg.
[b]Fibre yield on 7th day was 2.47% over dried stems/kg.
The results are mean of five observations.
Figures in parentheses indicate CV% of corresponding value.

moisture content. The result also confirms a positive correlation between time of retting and yield of fibre over the optimum period of retting.

Urea accelerates the process of retting due to the two phenomena. Firstly, the presence of urea enhances the nitrogenous and organic content acts as supplements for the growth of microorganisms. This helps improved growth of microbes, which removes the gums and coloring matters and also restricts redeposition of coloring matters much effectively[38]. Secondly, it is known that, the carbohydrates released by the process due to the rotting of agro-residues by microbial consortia break down into organic acids, owing to lowering of *p*H of retting water sharply. The presence of urea counteracts the effect, which is sustaining the effectiveness of retting by maintaining the *p*H at neutral region. It has been reported that, urea increases the *p*H of aqueous solutions, thus causing dissociation of weak acids due to the increase ionization of water. Further, urea drastically reduces the activity of hydrogen ions, leaving the activities of the other ions more or less unchanged[39]. This synergistically leads in saving of time by more than 50%. At the same time, urea retting increases yield by 18% with a marginal increase in fibre tenacity (29.67%) due to much shorter retting exposure and higher removal of non-cellulosic impurities[30]. The brightness index (57%) also shows promising results for the fibre extracted on 7th day (Fig. 1).

3.2 Chemical Constituents

According to estimates (Table 3), the basic constituents of extracted retted okra fibre without and with urea water comprises 75.9% and 83.3% holocellulose (celluloses and hemicellulose) respectively, which is higher than in jute fibre. Urea retting results in a notable reduction in non-cellulosic elements (hemicelluloses by 33.61%, lignin by 19.02%, and pectin by 69.01%) for okra fibre, resulting in a considerable increase (30.6%) in net cellulose content. The improvement in constitutional purity in terms of cellulose improves the hygroscopic and mechanical properties further. Retting also demonstrates considerable reduction in ash and wax and fats contents, particularly due to removal of surface adhered impurities and minerals. The easy and privileged loss of non-cellulosic constituents during the water retting also suggests that the okra fibres can be an excellent raw material for obtaining regenerated cellulose. The availability of high cellulose contents in retted fibre also suggests this as a precursor material for producing microcrystalline cellulose and nano-celluloses with lesser chemical consumption.

Table 3 — Chemical constituents of water retted okra and jute fibre

Constituent	Weight % on oven dry basis		
	Okra		Jute [a]
	Without urea	With urea	
α – cellulose	50.91 (0.40)	66.50 (0.83)	58-59
Hemi-cellulose	25.10 (0.89)	16.79 (0.59)	14-25
Lignin	13.81 (0.25)	11.22 (0.73)	12-14
Pectin	6.78 (0.36)	2.1 (0.03)	0.2-0.5
Fat and wax	1.63 (0.01)	1.01 (0.02)	0.4-0.9
Ash	1.11 (0.04)	0.54 (0.05)	0.5-1.2

[a] Data for jute are reported from Mishra and Basu[40].
The figures in parentheses indicate standard deviation of the corresponding value.

3.3 Functional Group Analysis

The loss of non-cellulosic mass during the water retting could be easily visualized by the reduction in height of the peaks (1700- 1200 cm^{-1}) in the FTIR spectra (Fig. 2) of retted fibres. The figure also shows that the entire spectrum of urea retted sample is distinctly different than that of the water retted fibre. The elimination of pectin and hemicellulose elements with greater –OH groups than those of celluloses results in a

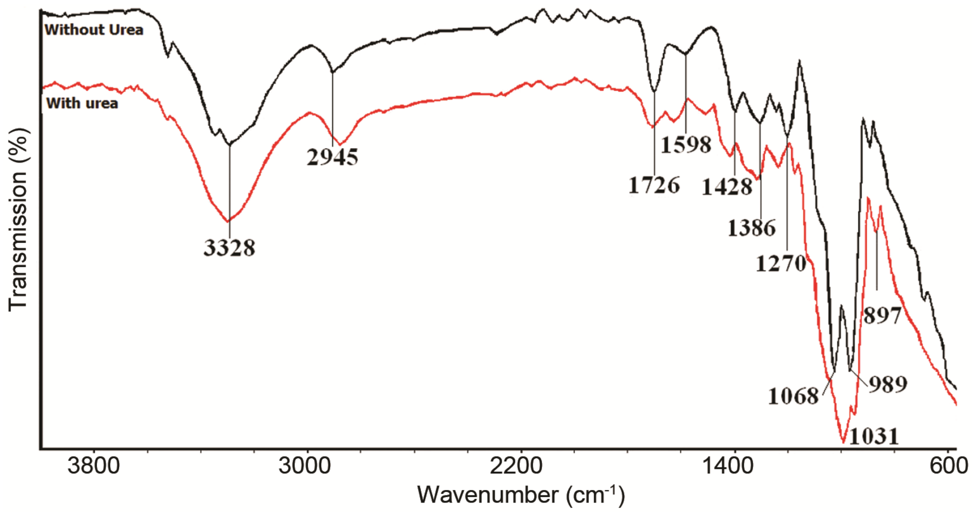

Fig. 2 — FTIR spectra of water retted okra fibre (a) without urea, and (b) with urea

noticeable sharpening of peaks detected in urea retted samples at 3328 cm^{-1} and 1031 cm^{-1}. The peaks at 1726 cm^{-1} (conjugated >C=O stretching of ester and aldehyde of hemicellulose),1598 cm^{-1} and 1428 cm^{-1} (C=C aromatic ring vibrations of lignin) are reduced strongly in urea retted fibre. The small peaks at 1332 cm^{-1} (between 1386 cm^{-1} and 1270 cm^{-1}) for C-H in plane deformation of cellulose rings, at 897 cm^{-1} for stretching for glucose ring structure of cellulose and at 1031 cm^{-1} (C-O groups of hemicelluloses, cellulose and C-H deformation of lignin)intensified considerably[41] in the IR spectrum. These peaks also justified the considerable increment in cellulosic content, owing to the loss of non-cellulosic mass. It may be stated that the cellulosic purity of urea retted samples is much higher than the plain water retted samples.

3.4 X-ray Diffractometry

Figure 3 shows the radial X-ray diffractogram of okra fibres. The figure reveals that the 2θ peak values of urea retted okra fibre, are shifted towards the left on the horizontal axis, demonstrating an enhancement in the inter planner lattice distance (*d*) in comparison to the plain water retted fibre sample. The diffractogram peaks 101, 101 and 200 are also considerably intensified with peak widening for urea retted fibre as compared to the peaks of water retted sample. Crystallinity (ordered region) index of urea retted okra fibre is found to be higher (61%) than that of the plain water retted okra (54%). Shifting of peak towards the lower 2θ indicates an overall increment in porosity, but associated increment in peak height confirms its better crystalline arrangement or orientation in the urea retted fibres.

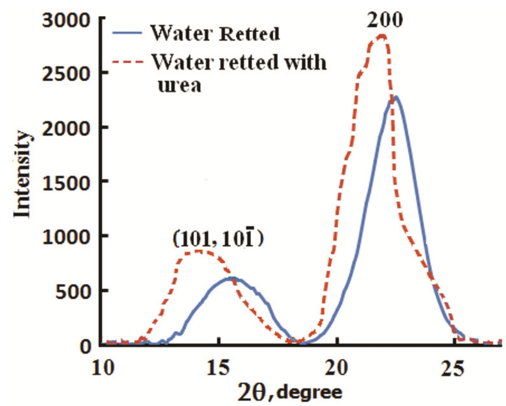

Fig. 3 — X-ray diffractogram of okra stem and retted fibres

3.5 Fibre Morphology

Figure 4 depicts the morphological and cross-sectional scanning election micrographical view of water retted okra fibre with urea. Okra fibres exhibit somewhat fewer interlinking branches with a prominent single strand structure. The morphology shows numerous longitudinal ridges running parallel to the fibre axis with an average smooth surface at macro level. In respect of cross-sectional view, micro construction of okra fibres is found slightly dissimilar to that of other lignocellulosic fibres, which are made up of several elementary ultimate cells arranged in a vascular structure. So, the cross-section appears to have longer and wider ultimate cells which are placed side by side, may be overlapping each other, while being firmly bonded together by lignin and other non-cellulosic compounds[18]. The ultimate cross-section of fibre appears to be nearly spherical with a central lumen. Hollow lumen decreases the heat transfer

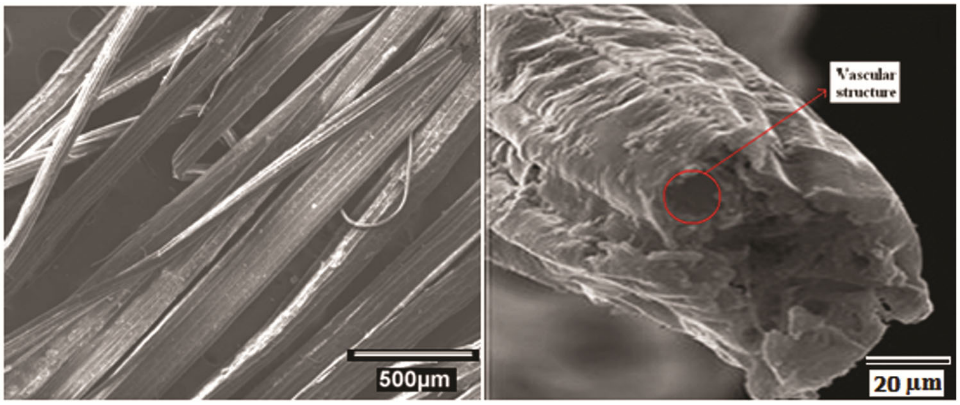

Fig. 4 — Scanning electron micrographs of water retted okra fibre (a) surface and (b) cross-section

across the fibre, suggesting its use as good thermal insulation material for industrial use [22]. Surface serration/ridges indicate its ability to flow water particles through capillary action. On the contrary, in case of structures with fibre mass, the ridges may partly restrict the flow of air through the fibrous mass in assembled structure.

3.6 Physico-mechanical Properties of Fibre

Indian okra fibre as a member of bast fibres is visually looked as a good quality fibre, which is whitish, light cream or yellowish in colour and lustrous, but coarser and stiff by feel. Efficient retting is a major challenge to obtain good quality fibres. The ultimate cell properties along with the physical and mechanical properties of fibre entity which may affect its mechanical process performance are presented in Table 4. The range of diameter (129-395 µm) and length (14-38 mm) of okra fibre are very wide having high linear density 8.77 tex. However, length: breadth ratio is found to be 1096 (more than 1000), indicating its good spinning potentiality [30] for making twisted thread. Okra has similar length distribution, length to diameter ratio, and apparent density as jute, thus is compatible to spin into thread/yarn, either elementarily or in blends.

It is noted from Table 4 that, breaking tenacity of okra fibre is 16% lesser than that of jute. Okra fibres possess lower initial modulus (1183 cN/tex) and much similar extensibility (2.01%) to jute. Good breaking tenacity and extensibility result in high specific work of rupture (3.24 mJ/tex-m) of okra fibre. Okra fibre possesses high flexural rigidity (149.38 mN-mm²), may be due to large diameter and nearly circular cross-section with multi-tubular micro structure and surface ridges along the length (Fig. 4). However, specific flexural rigidity of the okra fibre (0.42 cN-mm^2/tex^2) is much lower as compared to jute (6.64 cN-mm^2/tex^2). Coefficient of friction for okra fibre (0.51 in parallel direction and 0.39 in perpendicular direction) is observed to be much closer to that of jute (0.54 and 0.45 in parallel and perpendicular directions respectively).

Table 4 — Properties of okra and TD 2 grade jute fibres

Parameter	Urea retted okra	Jute [a]
Ultimate cell		
Length, mm	1.2-4.5	0.75 - 6.0
Breadth, µm	8.0– 22.0	5-25
Length breadth ratio	145	-
Wall thickness, µm	3-10	-
Lumen diameter, µm	0.1 – 6.0	-
Apparent density	1.45	1.50
Fibre entity		
Length, cm	26.45 (24)	49 (43)
Diameter, µm	248.54 (19)	60 (32)
Fineness, tex	8.77 (23)	2.95
Length-diameter ratio	1096 (30)	1035 (48)
Bundle tenacity, g/tex	19.18 (12)	22.4 (18)
Max load, cN	5.26 (44)	5.32 (42)
Breaking tenacity, cN/tex	28.13 (41)	33.6 (45)
Elongation, %	2.01 (28)	1.8 (41)
Initial modulus, cN/tex	1183.09	1900 (54)
Specific work of rupture, mJ/tex-m	3.24 (65)	2.7 (57)
Coefficient of friction		
Parallel	0.51	0.54
Perpendicular	0.39	0.45
Flexural rigidity, cN-mm^2	149.38	61.19
Specific flexural rigidity cN-mm^2/tex^2	0.42	6.64
Moisture regain, %	11.2	13.00

[a]Data obtained from Mishra and Basu[40]. Value in paratheses indicate CV% of corres ponding value.

Table 3 illustrates that the okra is a lignocellulosic fibre which is closely allied to jute fibre in terms of its

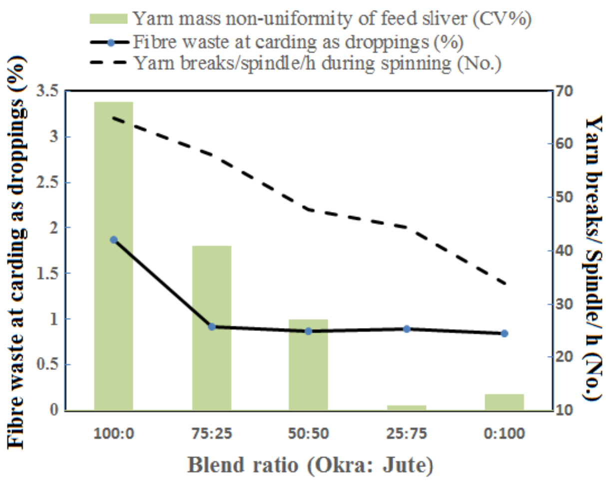

Fig. 5 — Spinning process performance of okra and jute fibres

chemical composition. The fibre shows marginally lower moisture regain of 11.2% as compared to jute (13.0%). The good moisture regain of okra fibre may be due to its high hemicellulosic content with large quantities of hydroxyl groups as revealed in FTIR. Thus, it is evitable by characteristics; okra is a compatible material to jute and may be processed in jute processing machinery to spin yarn/thread.

3.7 Spinning Process Performance

Figure 5 shows the spinning process performance of okra fibre. Table also demonstrates that processing of 100% okra fibre does not show promising performance at the presently available commercial spinning system. Fibre loss as droppings at carding machines (1st and 2nd carding) is found much higher in case of 100% okra fibre, which is acceptable [42]. The droppings are bellowed to 1% in processing with jute blending. The higher fibre loss as droppings could be owing to the higher diameter and less meshiness in the streaks of okra than jute, ultimately applied bit harsher processing of okra fibre in jute carding machine. Due to the high carding force (longitudinal splitting and transverse breaking), some short fibres are produced, necessitating the use of jute as a carrier fibre for the fibres to come out of the machines in continuous uniform sheets (slivers).

Addition of 25% jute in okra fibres leads to abrupt reduction in droppings, which does not change much in further increasing of jute content in the other blend ratio of jute with okra fibre. The moisture content of the slivers is maintained within 34-36% during carding, which helps in easy bending of the fibres around the pins and rollers of the machines due to reduction of flexural rigidity of fibres and ultimately causes better individualization of fibre at the wet condition [29]. At spinning, the moisture content of the feeding slivers is around 23-24%, which certainly has a benefit of good control over inter-fibre slippage during attenuation. The mass variation and non-uniformity are reduced in the blend in jute. Because jute is a finer fibre, it enhances the specific surface area of the fibrous mass, improving inter-fibre frictional resistance and allowing for regulated slipping of fibres during sliver attenuation in drawing and spinning.

Table 5 — Properties of okra: jute blend yarn (330 tex)

Blend ratio Okra: Jute	Tenacity cN/tex	Extension %	Initial modulus cN/tex	Sp. work of rupture mJ/tex.m
100:0	5.0 (74)	1.23 (87)	261.62 (38)	0.20
75:25	5.5 (41)	1.67 (38)	348.23 (29)	0.49
50:50	7.9 (33)	1.66 (35)	395.51 (10)	0.46
25:75	12.4 (14)	2.93 (11)	592.30 (11)	1.28
0:100	11.5 (18)	2.88 (19)	629.01 (16)	1.11

Figure in parentheses indicate the value of coefficient of variation (%) of corresponding parameter.

3.8 Property of Yarn

One of the aims of the study is to explore the processability of okra fibre in commercial scale jute processing machines. Table 5 shows that overall mechanical properties of 100% okra fibre based yarn are much inferior as compared to 100% jute yarn of equivalent linear density. Comparatively high coarseness of okra fibre reduces the number of fibres present in the given yarn cross-section, leading to low inter-fibre cohesiveness. Further, high flexural rigidity hinders compaction of fibre bundle when twisted, thus causing less fibre strength realization, and consequently decreasing the tensile parameters for 100% okra yarn with high variations (CV%).

Mixing of jute fibre improves the yarn performance of blend. The blended yarn property is improved with the increase in percentage of jute in the fibre mix. This may be due to an increase in the number of fibres in yarn cross-section as mentioned earlier by the addition of finer jute fibres. Increase in number of fibres results in increase in number of load sharing entities in the twisted fibre bundles as well as increase in resistance to inter fibre slippage due to increased fibre surface area for frictional resistance during small strain. Table 6 shows that 25% okra and 75% jute in a fibre batch yields much acceptable yarn property performance [42]. The okra: jute (25:75) blend yarn of low extensibility (2.9%), good breaking tenacity (12.4

Table 6 — Property parameters of okra stem fibre mixed jute vis-à-vis 100% jute cloth

Parameters	Conventional (100% Jute)	Developed (75:25 Jute:Okra)
Breaking tenacity of thread cN/tex		
Machine (warp) direction (100% Jute)	9.5 (18.4)	9.3 (17.3)
Cross (weft) direction	6.9 (26.1)[a]	7.3 (24.6)[b]
Weaving machine efficiency, %	73.3	72.5
Breaking strength of packaging cloth, N		
Length wise	1578	1572
Width wise	1895	1910
Seam strength of bag, N	517	523

[a] Commercial yarn for cross direction prepared with blends of jute and its processing waste as convention of a jute mill.
[b]Fibre mix of 30% fresh jute (10% TD 4,20% TD 5 grade), 40% jute waste (pre-carded root buts), 5% mill floor waste (very short fibre) and 25% okra fibre is used based sample.
Figures in parentheses indicate coefficient of variation (%) of corresponding parameter.

cN/tex), high modulus (592.3 cN/tex) and reasonable specific work of rupture (1.28 mJ/tex.m) would have potential use in manufacturing conventional packets/ bags and new types of packaging materials as well. High initial modulus, along with low extensibility of yarn indicates its suitability of use in technical textiles[43] for robust uses, and greener composites also.

3.9 Commercial Trial

Laboratory test demonstrates that okra fibre had a lot of potential for making technical yarn when mixed with jute. To establish the techno-commercial viability, okra fibre is used in large scale trial to manufacture standard packages. The linear densities of threads are chosen as per usual practice in the jute industry for manufacturing 50 kg packages for food grain. Table 6 shows some major properties of commercial yarn and the cloth produced from okra and jute fibre blend yarn in comparison to conventional 100% jute cloth used for packages making.

In conventional bio-packaging based on jute, cloth is woven by interlacement of two perpendicular sets of threads, in shuttle weaving machines. In machine direction (commonly called ‘warp’ in textile trade), 100% jute (TD 4 grade) fine yarns are used with good mechanical properties. On the contrary, yarn used in cross machine direction (called ‘sacking weft’ in jute trade) is traditionally a very coarse having linear density ranges from 890 tex to 1100 tex (ref. 44). The purpose of weft yarns is merely to act as filler for the packaging cloth. Thus, inferior quality of jute and short fibres would conveniently be used to achieve an acceptable level of yarn breaking strength (7-7.5 kN), sufficient for run in weaving looms. Usually, 40-50% waste composed of root buts, and thread waste, ropes, gunny cuttings, mill floor waste are used with 50% long to achieve the economic fibre batch as input raw material. The fibre batch has been found to be adequate to attain requisite mechanical properties of cloth.

In the present work, to replicate the construction and property parameters of the conventional fabric used for making package, the comparable coarse weft yarn (965 tex) has been prepared with a batch mix consisting of jute (fibre and waste) and okra fibre (blend ratio 75:25). The yarn shows good breaking strength (7.2 kN), extension (1.95%) and breaking tenacity (7.3 cN/tex). The study shows that the yarn could be run in the cross machine direction at efficiency of 72.5%. Loss of efficiency of mending of weft yarn (10.7%) is comparable to traditional practice. The strength of the jute-okra cloth and the seam strength of the packages are well within the standard specifications for conventional packages (IS 16186: 2014) for packing of 50 kg food grains. The result shows that the use of okra stem fibre in manufacturing jute based packages would find a ready market of the fibre with much less technological challenges for the industry. Farmers would likewise be benefitted from an additional return on much less invested time and labour. Our estimation shows that the price of okra stem fibre would be US $ 685 per tonne (at factory gate) including cost of manpower, logistics, and a 10% profit margin on investment are all factored into the equation. This is very close to the current market price of the jute fibre mix (US$ 698).

4 Conclusion

The reported work infers that the blended yarn of jute:okra stem fibre may efficiently be used for manufacturing cloth for packaging. This will prevent environmental damage caused by discarding or burning leftover stems after harvesting fruits. Farmers can effectively extract the okra fibre in much short retting period of 7 days. The fibre has essentially identical mechanical properties to jute in terms of tensile strength, flexural rigidity, and frictional resistance, indicating its potential for spinning in commercial jute processing machines. It is possible to spin a yarn with a high modulus (592.3 cN/tex), low extensibility (2.9%), and good specific work of rupture (1.28 mJ/tex.m) from an okra:jute fibre blend (25:75). Commercial trial of the okra:jute fibre (25:75) mix yarn, to produce standard packaging materials for food grains is found successful without requiring much technical changes to a jute processing facility. So, an idea for the industrial use of okra stem fibre, an agricultural leftover, would cover the gap between demand and availability of raw materials to jute and allied fibre industry. On the other hand, it leads to a cleaner post-harvest procedure for okra farming, as well as a rise in farmer earnings.

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