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A comprehensive study on Physico-Mechanical characteristics of Okra fibre (*Abelmoschus esculentus*) for textile applications

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Abstract

Objectives: The objectives of this research is to investigate the physico-mechanical characteristics of okra bast fibres (OBF) as well as to go through all the process to make this okra fibre as one of the commercial cellulosic fibres which can be used in different textile applications such as reinforcements in polymer matrix composites, carpets, materials used for absorbing oils and liquids, packaging industries, basic textiles products, coarse decorative textile products, Geo-textiles etc. all over the world. **Methodology:** In this work, OBFs are characterized by using Fourier transform infrared spectroscopy (FTIR), Breaking strength and breaking extension test, linear density analysis, Microscopic view and Scanning electron microscopy (SEM) analysis, and the crystallinity is measured by X-Ray Diffraction (XRD) data. **Findings:** XRD data indicates that the amorphous region is far greater than the crystalline region in OBFs, SEM analysis displays the technical fibres are overlapped and cemented by non-cellulosic compounds. These test results show a great similarity to other bast fibres properties mainly physical, mechanical, microstructural (cross-sectional and longitudinal view) properties.

Keywords: Okra bast fibre (OBF); SEM; FTIR; XRD; Breaking strength and breaking extension; Linear density

1 Introduction

Natural fibres contribute a lot of distinct advantages over other traditional manmade fibres and fillers with its limitless application areas[1]. The necessity of finding ecologically friendly alternatives to traditional synthetic fibres for instance glass fibres to be used as reinforcement in polymer matrix composites and other textile applications

have attracted a rising interest in natural cellulosic fibres recently[2]. The thermal stability of such composites along with less common natural fibre composites and other textile applications will also need to be investigated for specific works on the practical use[3]. In this regard, this work provides a comprehensive overview of a very less common but promising natural cellulosic fibre known as Okra (*Abelmoschus esculentus*) bast fibre. An economically significant vegetable crop okra belonging to the Malvaceae family is grown in tropical and subtropical regions of the world[4] and okra technical fibres are extracted from the skin or bast surrounding the stem of their respective plant[5]. So, it is said that the okra plant consists of core and bast fibre[6]. Generally, Okra has been used as a nutritive vegetable and pharmaceutical material for humans as well as feedstuffs for livestock for a long time[7–9] and the okra plants are agricultural waste products after collecting vegetables. As there is very limited use of okra as a textile fibre, Bangladesh might have a great prospect in cultivating, extraction and go through all the process to make this OBF as one of the commercial cellulosic fibres in this favour and it could be applied as a textile fibre and also as a reinforcement material for polymeric composites as a substitute for other man-made fibre[10]. In this case, it is required to understand their microstructure and mechanical properties for their use as textile fibres and as potential reinforcement in polymer composites[11–14]. Owing to growing environmental awareness, composites manufactured from lingo-cellulosic fibres as reinforcing material are discovering gradually[15–18]. The maximum length of the extracted fibres is more than 60cm[19]. The literature on elevated implementations of okra fibres barely exists. Those studies mainly emphasized on the use of this fibre as a reinforcement in composites ignoring the potential uses in producing basic textile products.

In this work, it has been focused on finding out the morphological structure (longitudinal profile, cross-sectional view) by SEM analysis, chemical bonds and functional groups in the fibre by FTIR, breaking the tension and tensile properties by Single Fibre Strength and elongation tester and cellulosic structure of okra fibre by XRD test. The test results were analyzed by different procedures. This crucially relevant sounder study which can yield some effective insights not only in the fruitfulness of fibre extraction but also in preparation for using the okra fibres as a raw material of higher-profile applications such as producing cloth for wrapping bales of raw cotton, to manufacture coarse cloth and sacks, and producing carpets, area rugs, ropes, twine, hessian cloth etc. along with the application as reinforcements in the polymer matrix composites.

2 Materials and Methods

2.1 Materials

In this work, okra bast fibre (OBF) is used which was collected from Tangail district of Bangladesh. The fibres were extracted by retting and manual extraction method[20]. At first, about 2 months old fresh okra plants having around 2 to 2.2m height were collected and the central part of the stems was removed. Then the stems were kept underwater to allow microbial degradation and the stems degraded sufficiently within around 18-22 days to allow fibre extraction[21]. Fibres were taken off from single okra plants. This was a time-consuming process but delivered a good quality of fibres. The fibre was removed from the water as soon as possible when the regular inspection of the stems showed that the bark could be eliminated simply from the rest of the stem. The fibres were isolated from the degraded stems by washing several times with clean water and then dried in the open air in the form of rope and the moisture-proof container is used to keep these sample fibres afterwards. OBFs show a multilateral shape and thickness of fibre varies along the length.

2.2 Methods

SEM was executed to investigate fibre's microstructure and morphology. Morphology of single okra fibre was done using JEOL JSM-7100F Scanning Electron Microscope with Field-Emission source[22]. The SEM analysis was done in a longitudinal direction, on cross-section (normal), on cross-section (after fracture). The SEM images were magnified 200%, 400%, 600%, 800% and 1000%. Among those images, 200% and 600% magnified images were clear enough to observe. No coating or special treatment was done on OBF for the analysis. The surface structure of the textile fibre is very important because it determines the cohesiveness, adhesiveness, dye penetration etc. X-Ray Diffraction test is done to find out the orientation of the polymeric chain such as crystalline, microcrystalline or amorphous present in the okra fibre. This X-ray diffraction measurement was performed using an X-ray diffractometer. A copper K-α X-ray source with 40kV voltage and 40mA power was used to record the diffraction patterns. The intensity as a function of the scattering angle is evaluated by the MS Excel spreadsheet tool after getting the diffraction patterns. The wavelength of the electron beam was Lambda, $\wedge = 1.54063$. The filter used here was a Solid-state detector. FTIR is used to analyze the chemical bonds and functional groups of the components of OBF. In this work, FTIR was done on raw OBF without any modification of fibre. The chemical bonds and functional groups of the fibre components determine the chemical reactions of the textile fibre in subsequent processes and during end uses. One of the most important characteristics of textile fibre is the strength of the fibre. So, the tensile strength of okra fibre was determined by ASTM D1578-93

method [23]. The sample was in bundle form and three sets of fibers in bundle form were tested. The cross-sectional shape of OBF was observed by using a projection microscope. The determination of linear density of okra fibre was done using gravimetric analysis. For this analysis, first of all, the single okra fibres were separated from the mesh structure manually (hand splitting). Then the individual single fibre's length was measured manually by a scale and weighed individually. This procedure was done for 18 samples (single fibre). After that the linear density of the individual fibre was determined and at the end, the mean value and coefficient of variation of linear density were also calculated.

3 Results and Discussion

3.1 Analysis of tensile strength

Table 1. Tensile strength of okra fibre

Specimen No.	Tensile strength (N/m2)	Extension (%)
1	4.46	2.57
2	5.18	2.22
3	5.31	1.77
4	5.76	2.55
5	5.44	1.83
Mean	5.23	2.19

The tensile strength of OBF is lower at the cut portions [24] and the top compared to the middle because the middle portion contains the higher cellulose content. The breaking strength of the OBF was lower at the cut portion and top. Whereas the center portion showed a better breaking strength the reason for this may be due to the high content of cellulose. Another important issue is that the top and cutting portions fibres were immature and over mature respectively whereas middle portions were matured. With span length, the tensile strength and strain to failure for all portions lessened. This is due to the lesser test span length being considerably influenced by fibre properties and machine parameters [25]. Tenacity is the term normally used for expressing fibre strength which consists of breaking force and linear density of fibre. 5 tests have been done for strength measurement of okra fibres samples (Table 1) taken from the middle portion.

3.2 Analysis of breaking strength and breaking extension

From the Figure 1, it shows that the fibre is very much rigid because there is low elongation through applied force is high. This low extension rate due to for the presence of lignin on the surface of fibres which is a cemented material and the amount of lignin affects the breaking strength and elongation of single fibres considerably. Breaking strength and elongation of single fibres reduce with the increasing of the amount of lignin [26].
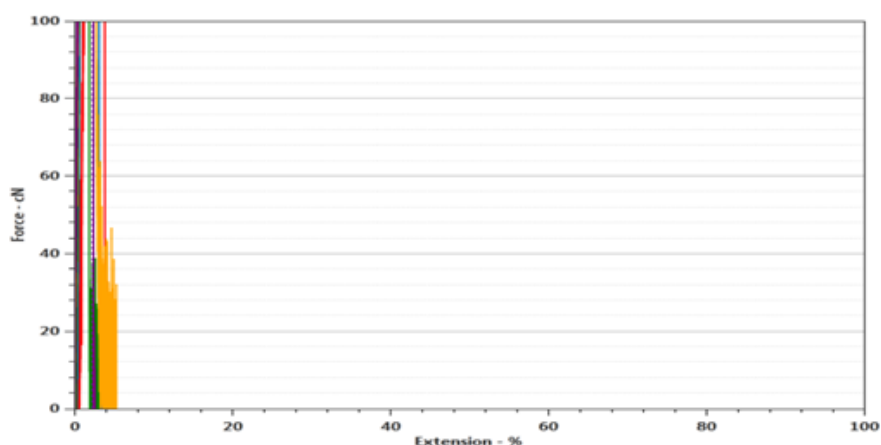

Fig 1. The force-elongation curve of okra fibre

3.3 Analysis of linear density

The linear density of okra fibre was calculated by gravimetric analysis. At first, the single fibres from the meshy structure were separated by hand splitting. So, the thickness of the single fibres was not much even or uniform. Then the length and weight of 18 samples fibres were evaluated.

Table 2. Linear density of okra fibre

Sample No.	Length(mm)	Weight(mg)	Tex (individual fibre)
1	85	0.40	4.71
2	81	0.37	4.57
3	92	0.37	4.02
4	84	0.36	4.64
5	115	0.41	3.57
6	108	0.49	4.54
7	117	0.52	4.44
8	112	0.44	3.93
9	98	0.45	4.59
10	80	0.45	5.63
11	107	0.39	3.64
12	75	0.34	4.53
13	90	0.39	4.33
14	68	0.32	4.71
15	92	0.54	5.87
16	79	0.33	4.17
17	93	0.33	3.55
18	122	0.56	4.59
Mean value of linear density (Tex)			4.446
Coefficient of variation (CV %)			13.84%.

From the Table 2, it shows the higher CV% of linear density of okra fibre and it maybe happened to the uneven hand splitting of single okra fibre from their meshy structure. This separation process is very hard and complicated as these single fibres orientated in a very complex mesh structure which is very difficult to break without damaging the fibres.

Fig 2. Meshy structure of Okra fibre

Fig 3. Single Okra fibre

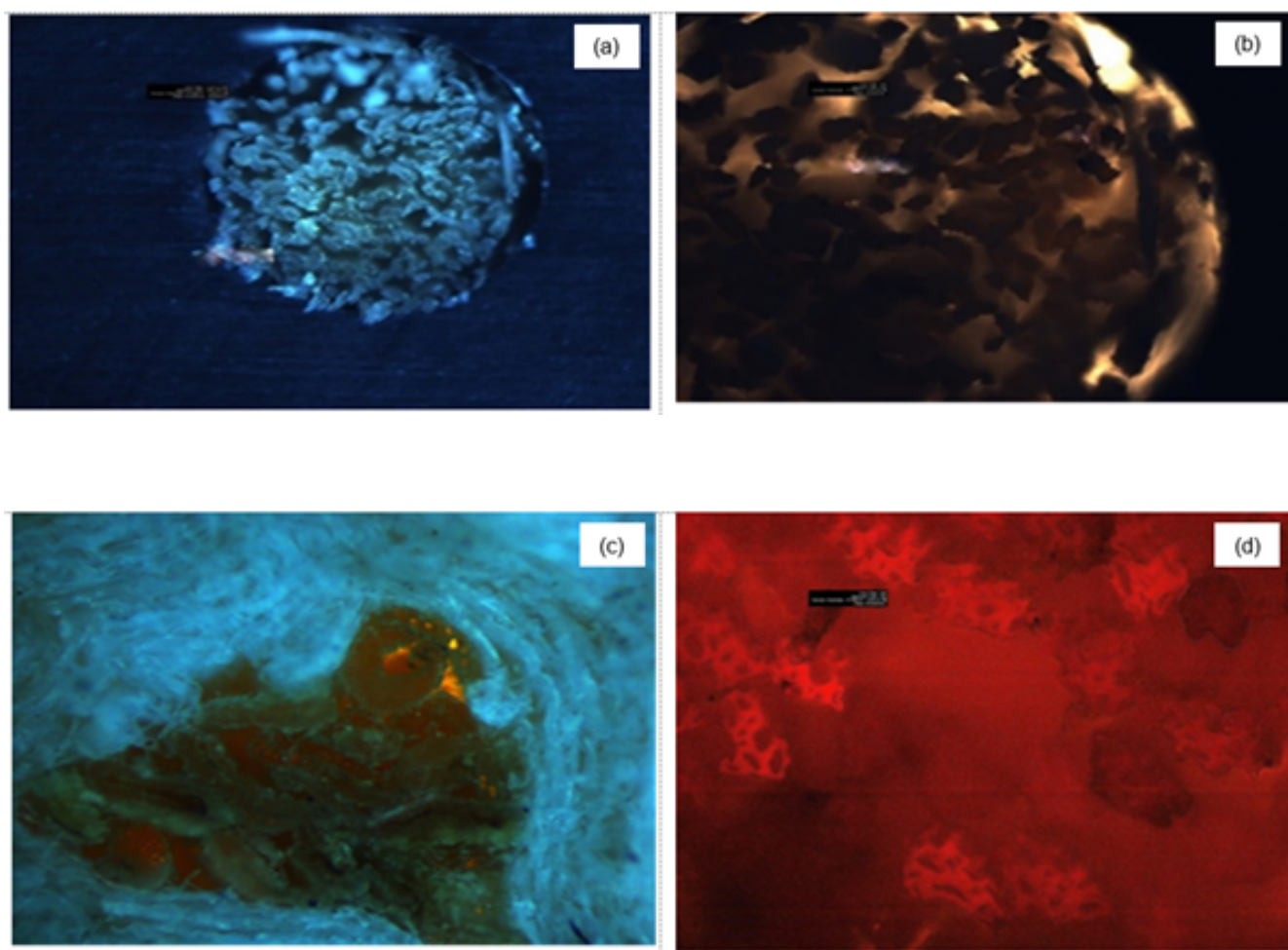## 3.4 Microscopic view of okra fibre

Fig 4. (a) 50 times magnified view (b) 100 times magnified view (c) 100 times magnified view through the cork (d) 400 times magnified view

From Figure 4, it shows that the cross-sectional shape of the okra fibre is observed by using a projection microscope. The cross-section of the okra fibre tends to flat to polygonal shape and the fibre thickness varies a lot. Usually, an okra fibre's structure contains several elementary fibres overlapped along the fibre length and glued firmly together by non-cellulosic compounds and pectin that contribute strongly to the bundle as a whole. These elementary fibres are referred to as ultimate fibres or cells. However, the strength of the elementary cell is considerably higher than that of the bundle structure. The term "Middle lamella" is considered for the region at the interface of two cells. Technical fibres or single fibres are the common terminologies used for the bundles of elementary fibres [27].
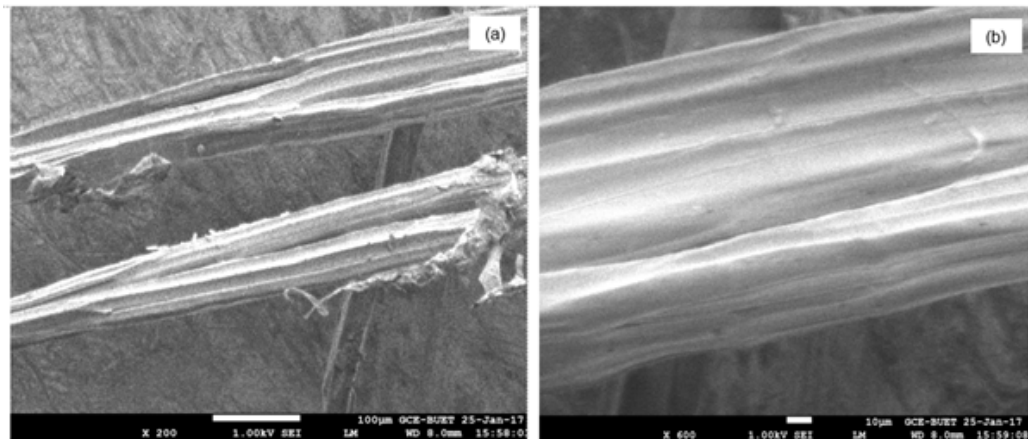
3.5 SEM analysis

Fig 5. (a), (b) SEM images of Okra fibre, 200 and 600 times respectively (longitudinal view)

From Figure 5, it is observed that the overlapping of the cells appears in a longitudinal view of the fibres. Moreover, it shows the presence of some contaminations on the surface of the okra fibre and also the fibres are covered in non-cellulosic compounds.
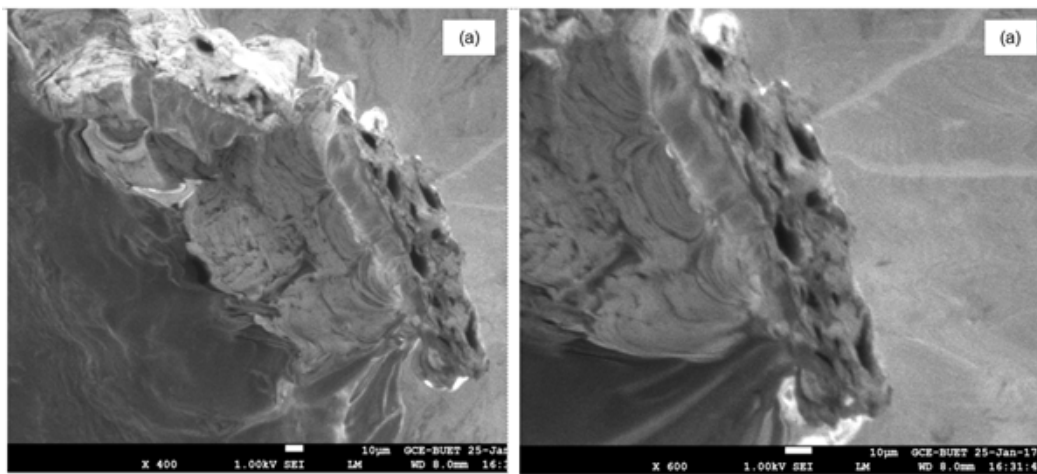

Fig 6. (a), (b) SEM images of okra fibre (cross-section)

From Figure 6, the cross-section of okra fibre indications a polygonal shape. This shape differs particularly from irregular profile to reasonably circular. Besides each ultimate cell is unevenly polygonal in shape having a central hole or lumen. This significant difference between the diameter values of the single fibre and lumen and their rough shape intensely affect mechanical and dimensional properties of OBFs [28].

From Figure 7, it represents that the fracture occurs almost evenly. With the absence of substantial fibril splitting OBFs displayed a brittle behaviour. In the outer portion of the bundle, some fibre pull-out is detected whilst at the centre pull-out is
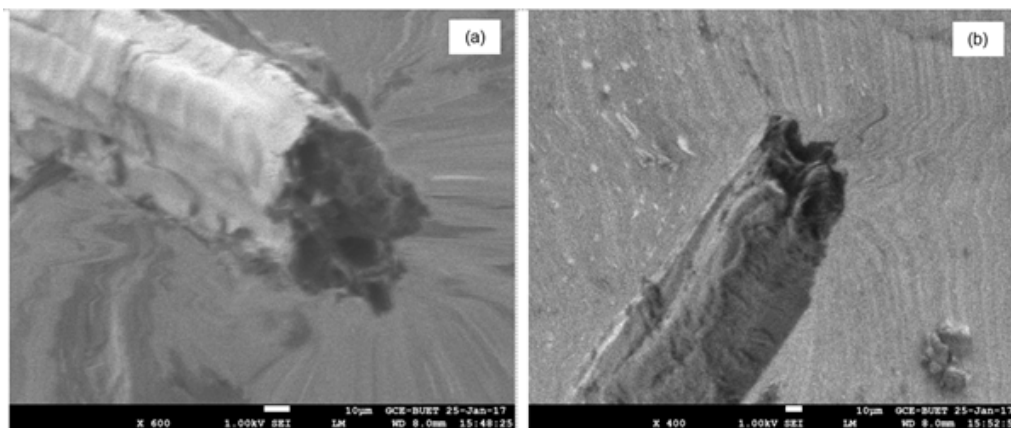
Fig 7. (a), (b) SEM images of fractured okra fibre (cross-section)

not visible that much which directs the presence of adequate binding material (commonly lignin). Additionally, all fibre cells have not fractured at the equal stress level probably due to cell wall defects existing along the fibre length which can generate stress intensities leading to ultimate failure[27]. The SEM images of okra fibres are very much similar to the SEM images of other bast fibres. The ultimate fibres are a cellulosic wall with lignin and pectin are also seen in Jute fibre[28]. Both okra fibre and jute fibres are cemented with a lot of ultimate fibres.

3.6 XRD analysis

An X-ray diffractometer with reflection mode was utilized for XRD measurements.
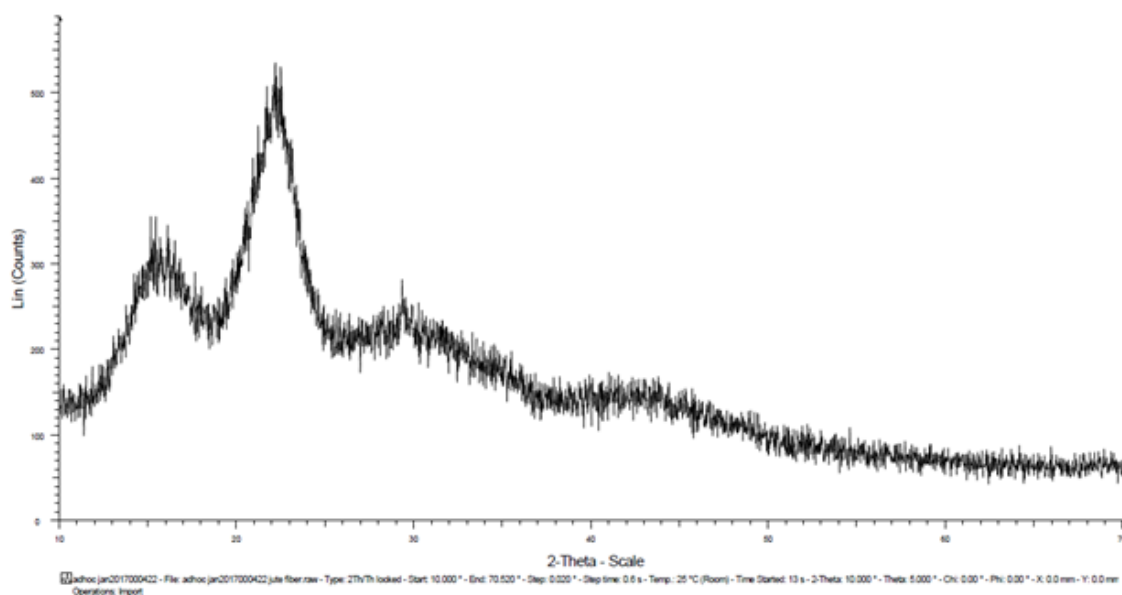

Fig 8. X-raypattern of okra fibre

This pattern (Figure 8) shows the peaks of the diffraction recorded and by using a pattern with the standard the crystalline or amorphous regions are evaluated. Comparison between the actual pattern (Figure 8) and the patter with standard (Figure 9), it shows that the peaks resemble with cellulose I alpha. The formula of the compound evaluated from the pattern resembles
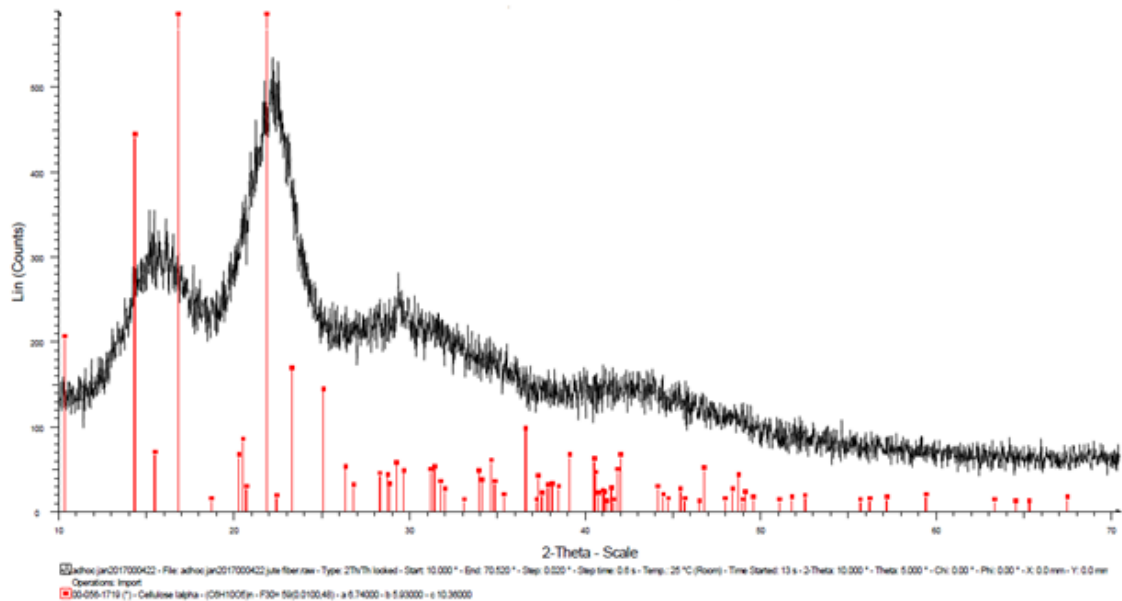
Fig 9. Pattern with the standard of okra fibre

$(C_6H_{10}O_5)_n$. The pattern resembles mostly α-cellulose. On the other hand, the amorphous polymer shows weak medium peaks like structure. By comparison with the basic patterns, it is noticed that examined sample of okra fibre pattern matches with the amorphous pattern. So, the okra fibre XRD pattern shows amorphous regions all over the pattern. As a result, okra fibre is amorphous polymers. As it is known that cellulosic compounds show amorphous characteristics in XRD pattern and the examined sample is a cellulosic compound. So, according to the tests and evaluations, okra fibre is an amorphous polymer. The amorphous region is far greater than the crystalline region in okra fibre.

From the basic crystal structure of okra fibre from the XRD pattern, it observed that there are seven basic patterns of the crystal. These are Triclinic, Monoclinic, Orthorhombic, Tetragonal, Hexagonal, Rhombohedral and Cubic. These seven crystal structure formations maintain some condition in the XRD pattern. These conditions are mainly associated with the miller indices parameters (hkl). From the parameters the value of a, b, c and the angles (α, β, γ) between them are evaluated. Relations between the value and angles of a, b, c are responsible for the conditions which determine the crystal structure. The conditions are given below:

Table 3. Conditions of crystal structure

| Structure	Conditions
Triclinic	No restrictions
Monoclinic	$\alpha=\gamma=90^0$
Orthorhombic	$\alpha=\beta=\gamma=90^0$
Tetragonal	$\alpha=\beta=\gamma=90^0$, a=b
Hexagonal	$\alpha=\beta=90^0$, $\gamma=120^0$, a=b
Rhombohedral	$\alpha=\beta=\gamma<120^0$, a=b=c
Cubic	$\alpha=\beta=\gamma=90^0$, a=b=c

Table 4. Evaluatedvalue of okra fibre

Parameters	Value
a	6.7400^0
b	5.9300^0
c	10.3600^0
α	117.00^0
β	113.00^0
γ	81.00^0

From the evaluated data (Tables 3 and 4), it shows that the value and angles of the parameters maintain no conditions or restrictions. The crystal structure of okra fibre is Triclinic. The molecular weight and the volume are also evaluated from the XRD pattern. From the analysis, the molecular weight is 162.14 and the volume (CD) is 339.50. So, the total evaluation from the XRD pattern is okra fibre is a cellulosic compound whose formula is $(C_6H_{10}O_5)_n$, okra fibre is an amorphous polymer and the crystal structure of okra fibre is triclinic.

3.7 FTIR analysis

The chemical structure of the components of okra fibre from FTIR analysis, it is noticed that the main absorbance peaks of interest have been identified here. FTIR spectrum of the okra shows absorption bands of a chemical group's characteristic of lignocellulosic fibre compound. These are cellulose, hemicellulose and lignin. These components are primarily made of alkenes, aromatic groups and several functional groups containing oxygen (ester, ketone and alcohol).
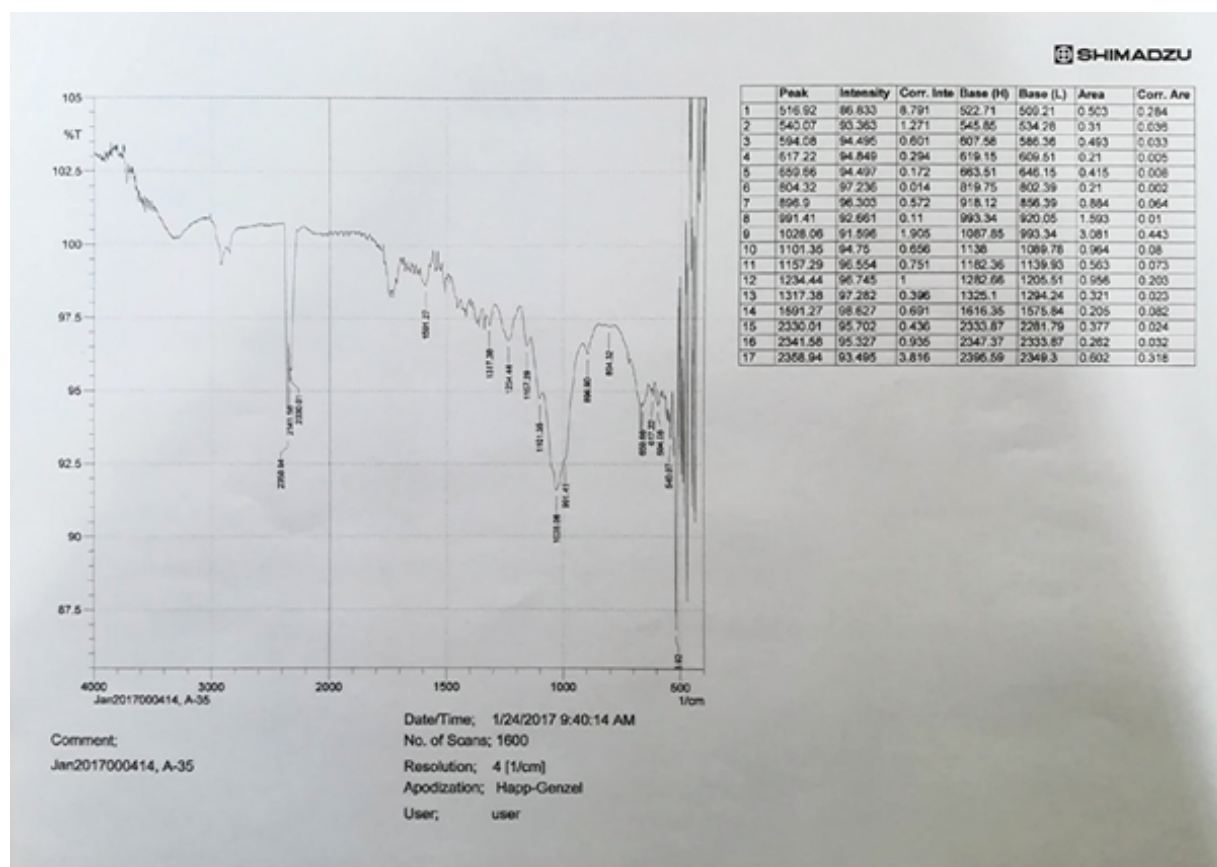
Fig 10. FTIR spectrum of okra fibre

From Figure 10, It shows that the peaks at 2800-2900 cm^{-1} are the distinctive band for C-H stretching vibration from CH and CH$_2$ in cellulose and hemicellulose components whilst the absorbance at 2330.01 cm^{-1}, 2341.58 cm^{-1}, 2358.94 cm^{-1} goes to the carbonyl C=O stretching vibration of carboxylic acid linkage in lignin or ester group in hemicellulose. These carboxylic groups may also be existing in the fibre as traces of fatty acids in oils. The slight shoulder at 1600-1700 cm^{-1} maybe for the existence of H$_2$O in the fibres. A tiny peak at 1591.38 cm^{-1} is for the C=O stretching of the aromatic ring of the lignin. The absorbance peaks at 1101.35 cm^{-1} and 1234.44 cm^{1} attributes to C-O stretching vibration of the acetyl group in lignin and hemicellulose respectively. The peaks at 804.32 cm^{-1} and 991.41 cm^{-1} are attributed to the presence of the C=C symmetric bending of cellulose. The peak observed at 1317.38 cm^{-1} in the spectrum indicates the bending vibration of C-H and C-O of the aromatic ring in polysaccharides. The absorbance peak at 1157.29 cm^{-1} is for the anti-symmetrical deformation of C-O-C band. The significant absorption peak at 1028.06 cm^{-1} is ascribed to the CO and O-H stretching vibration for polysaccharide in cellulose. The peak observed at 896.90 cm^{-1} is ascribed to the existence of β-glycosidic linkages between the mono-saccharides. Besides, the absorbance at 594.08 cm^{-1} corresponds to the C-OH bending. The peaks at 516 cm^{-1} and 540.7 cm-1 are attributed to the presence of the C-I stretching halo compound and peaks at 617.22 cm-1 and 659.65 cm-1 are ascribed to the presence of the C-Br stretching halo compound.

4 Conclusion

All the investigations were done for the characterization of okra fibre using projection microscopy, SEM, XRD, FTIR, tensile strength and linear density analysis. By studying the Physico-Mechanical Characteristics, it is comprehended that okra fibre contains the capability to be used as potential textile fibres and can be spun into yarn and can be converted into cloth mainly coarse cloth, carpets, area rugs, sacks, insulation, animal bedding, decorative hessian cloth etc. together with applications as reinforcements in polymer matrix composites and as cellulosic raw materials in cellulose-based industries owing to containing high cellulose quantity. Okra fibre might have a great chance to be used as commercial bast fibre and might be an alternative to other bast fibres such as kenaf, sisal, jute etc. to meet the growing demand of biodegradable natural fibres.

Conflict of Interest

Authors have declared that they have no conflict of interest regarding publishing the article.

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