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ORIGINAL ARTICLE

Characterization of a novel natural plant-based fiber from reddish shell bean as a potential reinforcement in bio-composites

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Abstract
The main aim of this study is to identify a new sustainable plant-based fiber extracted from the reddish shell bean plant to investigate its usage in polymer matrix composites. Natural reddish shell bean fiber was extracted from vegetable shells with a biological degradation method. To determine the fiber characteristic properties, physical, chemical, and instrumental tests were performed on reddish shell bean fiber. The surface of the sample was determined with a scanning electron microscope, and it shows that the fiber has a rough surface along its length. In addition, an image processing approach was devised and implemented to determine the average fiber diameter of the reddish shell bean fiber. The elemental composition of fiber was obtained as 50.67 wt.% oxygen, 47.89 wt.% carbon, and 1.52 wt.% calcium with an energy disperse X-ray analysis device. In addition, fiber diameter was predicted as 785.87 µm with the image processing technique. The fiber density was measured as 1080 kg/m^3. The crystallinity index of reddish shell bean fiber was calculated as 57%, and the fiber stables up to 328.23°C. The ultimate tensile strength of reddish shell bean fiber was obtained as 111 MPa. The elongation at break and estimated values of Young's modulus of reddish shell bean fiber are 1.83% and 6.11 GPa, respectively. According to the results, reddish shell bean fiber can be utilized as reinforcement in polymer matrix composites.

Keywords Reddish shell bean fiber · Plant-based fiber · Elemental composition · Thermal behavior · Mechanical properties · Image processing

1 Introduction

The results of high consumption of petroleum-based material, such as growing landfills, health problems, environmental pollution, and greenhouse gas emissions, have led material science researchers to investigate new materials within the concepts of sustainability and circular economy. This exertion to increase the quality of products has improved attention to natural sources as alternatives to fuel-based materials. Based on their abundance, availability, eco-friendliness, sustainability, less skin irritation, and less tool wear, natural fibers have commonly been used in many different areas [1]. Plant-based fibers have been commonly used as reinforcement in composite materials since pre-historic times [2]. Furthermore, plant-based natural fibers are very well known as row materials for many kinds of areas, such as home textiles, polymeric composites, wastewater treatment, and paper production [3, 4].

Plant-based fiber-reinforced composite materials are focused on by researchers due to compelling governing laws and increasing environmental issues. Renewable and sustainable resources have been utilized as substitutes for petroleum products, supplying an eco-friendly alternative for certain productions. Due to their desirable properties, new plant-based fibers have been discovered with advantageous characteristics for composite reinforcement to meet the industry's goals for sustainable development, including aerospace, construction, and military applications, resulting in an increased demand for raw cellulose fibers. Many researchers are focused on cellulosic fiber extracted from plants, such as bark, twigs, foliage, stems, and fruit bundles,

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to provide an approach that is already efficient at producing fibers of a higher grade without sacrificing their mechanical and physicochemical properties. Plant-based fibers are made from cellulose fiber plants like jute, flax, hemp, sisal, kenaf, ramie, coir, banana, bamboo, and pineapple. The amorphous matrix of lignin and hemicellulose, which encase cellulose microfibrils, gives natural cellulosic fibers their characteristic appearance. This structure is also a main factor in the mechanical and physical behaviors of plant-based fibers. They are known as complex compounds consisting of cellulose, hemicellulose, pectin, wax, and lignin. The quality and proportion of these components vary depending on the type of plant used and the kind of plant. The cellulose percentage in the fibers of plants affects the mechanical behavior of fibers. High strength and rigidity correlate with a high cellulose percentage. In an effort to find sustainable and environmentally friendly substitutes for traditional materials, the quest for innovative plant fibers is a field that is continually expanding [5, 6]. Manimaran et al. investigated a novel plant-based fiber obtained from *Typha Angustata* grass. The fiber has a 73.54% amount of cellulose and a density of 1.015 g/cm^3. The tensile strength, Young's modules, crystallinity index, and crystalline size of the fiber were determined as 665 ± 7 MPa, 27.45 ± 3.46 GPa, 65.16%, and 6.40 nm. The activation energy and thermal stability of fiber are 67.99 kJ/mol and 298.48 °C [7]. Lemita et al. characterized a new cellulosic fiber obtained from the stem of the *Strelitzia reginae* plant. Differential scanning calorimetry and thermogravimetric analysis results show that the fiber is stable up to 233°C. Young's module and tensile strength are 9.89 GPa and 271.79 MPa, respectively. The crystallinity index of fiber was calculated as 70%. These results show that *Strelitzia reginae* fibers might serve as a possible reinforcement in composite materials [8]. Singh and Rout extracted and compressively characterized new cellulosic fiber from *Borassus flabellifer L.* leaf. The crystallinity index and crystallinity size of the fiber were determined as 50.34 and 2.72 nm, respectively. Thermogravimetric analysis shows that the fiber is stable up to 316°C [9]. In another study, new cellulosic fiber was extracted from the lavender plant stem. X-ray diffraction analysis shows that the crystallinity index of lavender stem fiber is 65%. Thermogravimetric analysis indicates that the fiber is stable up to 362°C. Tensile strength, elongation at break, and Young's modulus of single fiber were determined as 226.65 MPa, 2.94–4.69%, and 7.68–4.82 GPa [10]. Manimaran et al. aimed to understand the physicochemical properties of *Celosia argentea* fiber. The physicochemical properties of *Celosia argentea* were characterized by X-ray diffraction, thermogravimetric analysis, Fourier transform infrared analysis, and scanning electron microscope. Crystallinity index (52.54%), cellulose content (64.34 wt.%), and density (843 kg/m^3) were determined, and thermogravimetric analysis shows that the maximum thermal degradation temperature is 324°C. These results show that *Celosia argentea* fiber might be a potential reinforcement material for ecological composite applications [11]. Eyupoglu et al. aimed to extract and characterize a substitute fiber for synthetic fibers from the *Sambucus ebulus* L. plant. The chemical composition of fiber was determined as 76 wt.% cellulose, 66 wt.% hemicellulose, and 4.47 wt.% lignin. Fiber thickness was estimated as 759.41 nm with image processing. Crystallinity index and crystalline size were calculated as 72% and 3.9 nm. A single fiber tensile test proved that the fibers have the mean tensile strength, Young's modulus, and elongation at break of fiber 90.6 MPa, 1.46 GPa, and 6.45%. In addition, the fibers are thermally stable up to 456.98°C with thermogravimetric analysis [12]. Wirawan et al. investigated the physicochemical properties of *Hibiscus Tiliaceus* fiber. Cellulose, hemicellulose, and lignin content of *Hibiscus Tiliaceus* fiber were founded as 58.63%, 18%, and 23.35%, respectively. The crystallinity index and tensile strength of fiber were determined as 56.54% and 207.30±83.75 MPa, respectively [13]. In addition to these fibers, researchers obtained new cellulosic fibers from *Tithonia diversifolia, Ficus benjamina L, Abutilon Indicum,* and *Bauhinia Vahlii* [14–17]. Overall, the above-mentioned fibers may be a practical reinforcing material for fiber-reinforced polymer matrix composites.

The main aim and contribution of this study is to obtain an original fiber from the vegetable shell of reddish shell bean as a substitute for synthetic fibers. To the best of the authors' knowledge, there is no other research in literature on a new fiber extracted from the reddish shell bean plant. For this aim, morphological and physico-chemical behaviors of reddish shell bean fiber were investigated with X-ray analysis (EDX), scanning electron microscope (SEM), Fourier transform infrared (FT-IR), X-ray diffraction (XRD), and thermal gravimetric analysis (TGA). In addition, the fiber diameter was predicted with an image process. The mechanical behaviors of fibers were performed with the use of a single fiber strength machine instrument. Furthermore, all results were compared with some other novel plant-based fibers reported in literature.

2 Material and method

2.1 Reddish shell bean fiber

Reddish shell bean vegetables were purchased in October 2022 from Istanbul, Turkey. After the shells and seeds were separated from each other, the shells were submerged in distilled water for 2 weeks at atmospheric conditions. After 2 weeks, the shells became soft, and the fibers were obtained manually. Then, the extracted fibers were rinsed with running water, and the fibers were left in sunlight for 15 days to



Fig. 1 Reddish shell bean plant with its extracted shell fiber

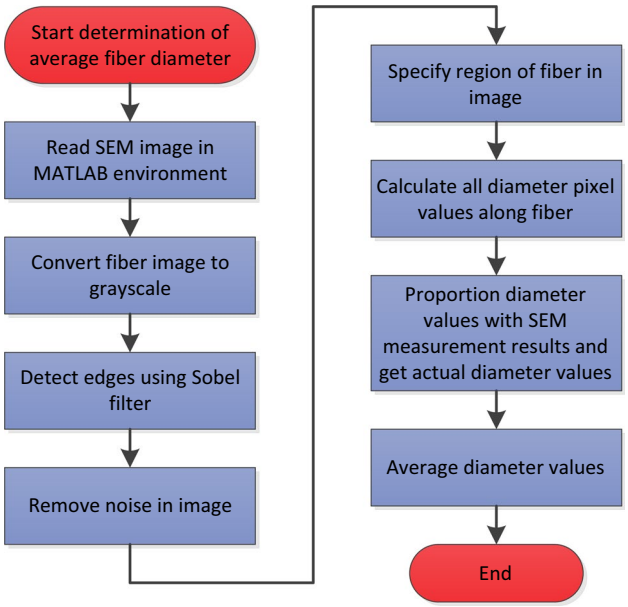


Fig. 2 The flowchart of the presented image processing approach

move away moisture. An average of 10% fiber was obtained from the vegetable shells. The reddish shell bean plant with its extracted shell fiber was given in Fig. 1.

2.2 Determination of average fiber diameter

The fiber diameter of the reddish shell bean fiber was measured with an electron microscope (FEI QUANTA model FEG 250) which produces images of the fibers in longitudinal direction. In this study, the average fiber diameter was designated using a novel image processing approach. Figure 2 depicts the flowchart of the presented approach.

As seen in the Fig. 2, the SEM image of the reddish shell bean fiber is first read in the MATLAB environment and grayscaled. The Sobel filter technique is used to detect edges in the image, and then the noise in the image is eliminated. Following that, the area of the fiber in the image is determined. Along the fiber, all diameter pixel values are computed. Afterwards, the diameter values are proportioned with the reference SEM diameter results to provide the real diameter values. Lastly, the average fiber diameter for the chosen fiber is calculated.

2.3 Fiber surface morphology

Reddish shell bean fiber surface morphology was characterized using a FEI QUANTA model FEG 250 scanning electron microscope. The surface scanning was taken at 5 kV voltage under a huge vacuum with 2000× and 250× magnification. Before the scanning of the fiber surface, samples were coated with cold-palladium (Au-Pl).

2.4 Density of fiber

The density of fibers was determined in terms of physical properties as per Archimedes' Law according to the ASTM D8171-18 standard and calculated with the Equation 1.

$$d = \frac{W_d}{W_d - W_s} \tag{1}$$

In this equation, d, W_d, and W_s represent density (g/cm^3), dry weight, and effective mass of fiber submerged in water, respectively [18].

2.5 Energy-dispersive X-ray analysis

Energy-dispersive X-ray analysis was carried out using a FEI QUANTA model FEG 250 energy-dispersive X-ray spectroscope (Fei Company, Oregon, USA) to obtain the elemental components of reddish shell bean fiber. Before the EDX analysis, the samples were coated with gold-palladium (Au-Pl).

2.6 Thermogravimetric analysis

The thermal stability of reddish shell bean fiber was analyzed with a Hitachi thermal analyzer (STA-7300 Model, Tokyo, Japan). During the test, the samples were placed in an alumina case and warmed up from 30 to 1000°C with 10°C per minute heating rate in high purity nitrogen atmosphere.

The kinetic activation energy (Ea) of reddish shell bean fiber was predicted with Broido's formula [12]:

$$\ln\left[\ln\left[\frac{1}{y}\right]\right] = -\left(\frac{E_a}{R}\right)\left[\left(\frac{1}{T}\right) + K\right] \quad (2)$$

In this equation, R is gas constant (8.32 J/mol K), T is temperature (K), y is normalized weight (wt/wi), wt is weight of the sample at any time t, and wi represents the initial weight of fiber sample.

2.7 Mechanical properties' analysis

Tensile loading and elongation at break of samples were carried out with the Splice-Scanner 2 Portable Strength Tester (Mesdan Lab 25,087) according to the ASTM D3822-07 standard. Before the test, all samples were conditioned for 24 hours at 65±2% relative humidity and 20±2°C temperature. The tests were performed with 20 mm gage length and 50 N load in atmospheric condition. During the test, the cross speed was recorded as 0.1 mm/min. In addition, the microfibril of reddish shell bean fiber was calculated with Eq. 3.

$$\varepsilon = \ln\left(1 + \frac{\Delta L}{L_0}\right) = -\ln(Cos\alpha) \quad (3)$$

In this equation, ε, L_0, ΔL, and α is global deformation, gage length (mm), elongation at break (mm), and microfibril angle (°deg), respectively [19].

3 Results and discussion

3.1 Fiber diameter

Fiber diameter is an important factor affecting the mechanical behavior of polymer matrix composites. Because there is a lot of specific contact area between the small fiber diameter and the polymer matrix, the mechanical strength of the material can be increased. Additionally, during composite manufacture, the high volume of natural fiber in polymer composites is supported by the small diameter of the fiber [20]. Moreover, the average fiber diameter was determined to be 785.87 µm utilizing the presented image processing approach. Figure 3 shows the diameter histogram of the reddish shell bean fiber.

3.2 Fiber surface morphology

The morphological structure of reddish shell bean fiber was investigated using SEM analysis, and micrographs are given in Fig. 4. Scanning electron microscope images show that the fiber surface has a cellular structure. It is deemed that the cellular structure gains a reddish shell bean fiber rough surface at fiber longitude. The rough surface of fiber can be an advantage in utilizing reddish shell bean fiber as a significant

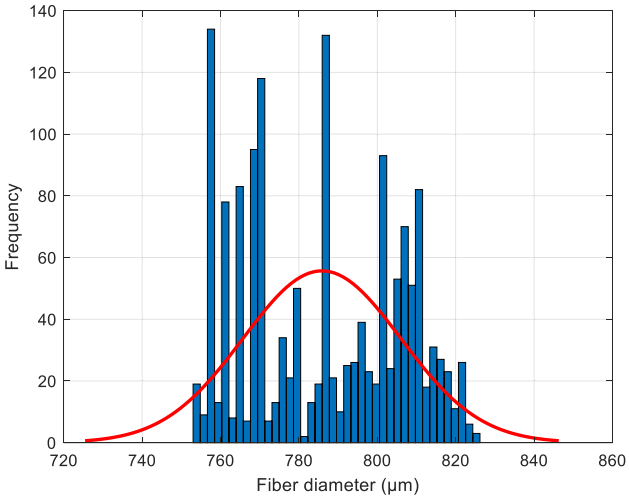


Fig. 3 The diameter histogram of reddish shell bean fiber

reinforcement in polymer matrix composites to increase the adhesion behaviors of matrix and fiber [20].

3.3 Energy-dispersive X-ray analysis

The EDX spectrum indicating the distribution of elements on reddish shell bean fiber is given in Fig. 5. The results show that reddish shell bean fiber consists of 50.67 wt.% oxygen, 47.89 wt.% carbon, and 1.52 wt.% calcium. The EDX spectrum proves the existence of high-intensity peaks of oxygen and carbon, which are the main elemental components of cellulose. The increase in the amount of hemicellulose and lignin in the fiber structure causes the amount of carbon to be higher than the amount of oxygen. The amorphous components of fiber, such as wax, lignin, and other impurities, are represented by the other element, like calcium, which has discernible peaks [21].

3.4 Fourier transform infrared analysis

The functional groups of reddish shell bean fiber were determined with FTIR analysis. The FTIR spectrum is given in Fig. 6.

According to the FTIR spectrum, it was concluded that reddish shell bean fiber has similar characteristic functional groups and peaks with other plant-based fibers. The FTIR spectrum results of reddish shell bean fiber prove that the fiber consists of cellulose, hemicellulose, lignin, and moisture. In the FTIR spectra, the peak at 3340.1 cm^{-1} presences hydroxyl group (-OH) existing of cellulose and hydroscopic moisture in reddish shell bean fiber. The peak at 2918.7 cm^{-1} is responsible for C-H stretching which corresponds to cellulose and hemicellulose. The reddish shell bean fiber spectrum at 1642.1 cm^{-1} refers to C = O carbonyl stretching

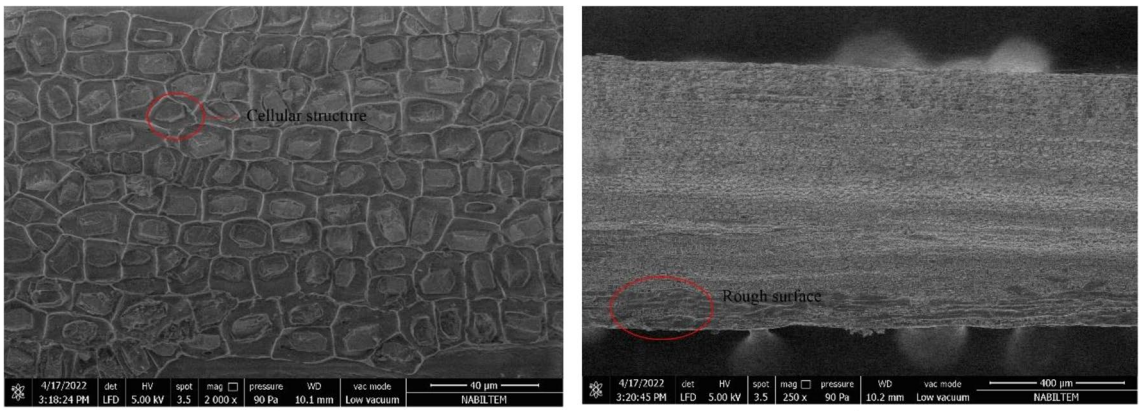
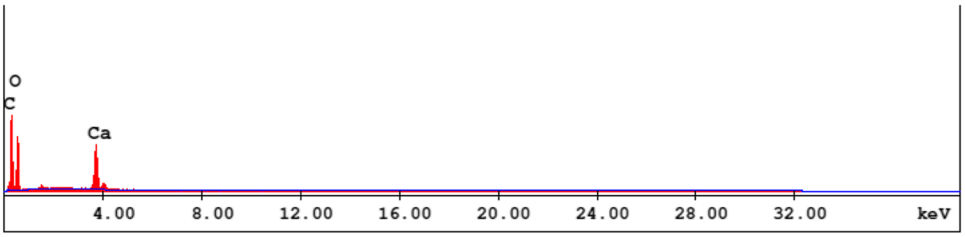


Fig. 4 SEM micrographs of reddish shell bean fiber (a. SEM micrographs of reddish shell bean fiber at 2000× magnification, b. SEM micrographs of reddish shell bean fiber at 250× magnification)

Fig. 5 EDX spectrum indicating the distribution of elements on reddish shell bean fiber



EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Element	Wt %	At %	K-Ratio	Z	A	F
C K	47.80	55.39	0.2490	1.0081	0.5166	1.0004
O K	50.67	44.08	0.0920	0.9939	0.1827	1.0000
CaK	1.52	0.53	0.0199	0.9253	1.4122	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
C K	591.43	9.82	1.22	60.20
O K	585.25	11.01	1.23	53.15
CaK	846.79	38.71	1.04	21.88

responding from aldehyde and acetyl groups of hemicellulose and lignin. The peak is seen at 1234.3 cm^{-1} response to C-O stretch in lignin structure. The absorption peak was determined at 1023.6 cm^{-1} associated with C-O and -OH groups of secondary alcohol responding from hemicellulose. The peak at 655.7 cm^{-1} belongs to carboxylic acid (COOH) [22, 23]. The functional group peak positions and related chemical compositions are given in Table 1.

3.5 X-ray diffraction analysis

The XRD pattern of reddish shell bean fiber is given in Fig. 7. The XRD pattern consists of two main peaks at $2\theta = 22^{o}$ (2 0 0) and $2\theta = 14.65^{o}$ (1 -1 0) which are generally found in natural cellulosic fiber. The crystallinity index of reddish shell bean fiber was calculated as 57%. The maximum diffraction peak displays all crystalline materials, whereas the amorphous structure is shown by the lowest intensity between the main peaks. Although it was observed that some of the intensity at the 18° minimum is due to the overlap of the broad crystalline peaks that come from the microscopic crystals, Segal method allows for the determination of the crystalline index. In addition, the orientation of macromolecule chains improves in fiber as the crystallinity index increases [26, 27]. In addition, cellulose chains become more consistently oriented, improving the mechanical behaviors and making them appropriate for bio-composites at high crystallinity [15].

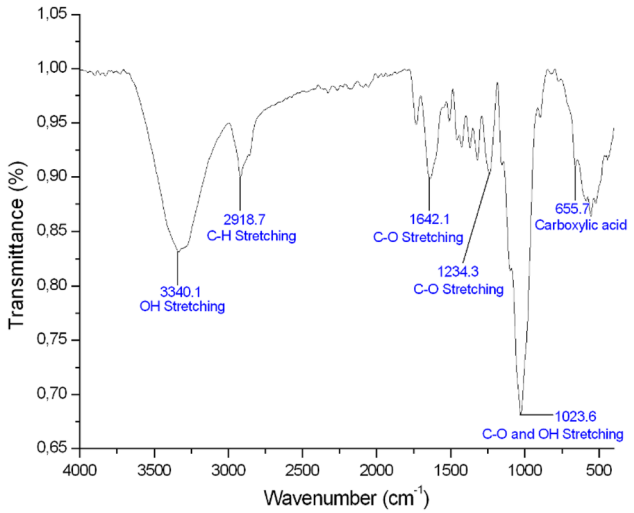


Fig. 6 FTIR spectra of reddish shell bean fiber

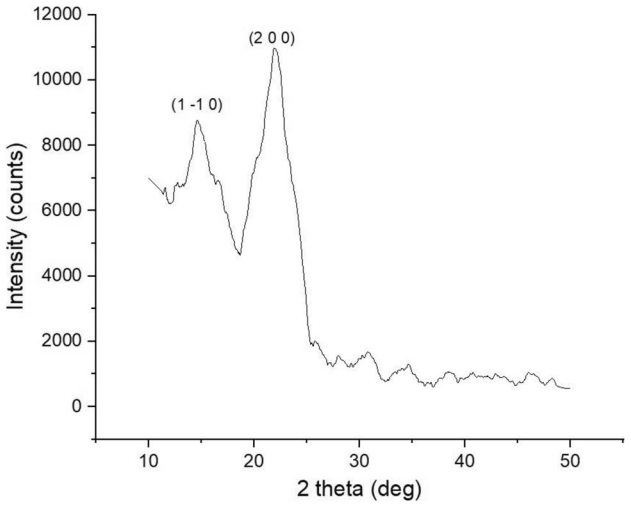


Fig. 7 XRD pattern of reddish shell bean fiber

The crystalline size of the reddish shell bean fiber was calculated as 3.9 nm. It is known that high crystalline size causes an increase in the arrangement of macromolecule chains, resulting in an increase in the crystalline region in fiber. As the crystalline size of fiber increases, mechanical behaviors improve, whereas the hydrophilic character and chemical responsiveness of fiber decrease [15]. The comparison between the crystallinity properties of reddish shell bean fiber and some novel cellulose-based fibers is indicated in Table 2.

3.6 Thermogravimetric analysis

The derivative thermogravimetric and TGA curves of reddish shell bean fiber are shown in Fig. 8. According to Fig. 8, the thermal degradation of reddish shell bean fiber consists of three stages. In the TG curves, the first degradation of reddish shell bean fiber is determined at 59.74°C with a weight loss of 5.53% which represents the water evaporation in the nature of fiber [11]. The important degradation was determined between 59.74°C and 328.23°C calling as the second phase. The weight loss of the sample was obtained as 63.43% responsible for hemicellulose in this phase. Another significant peak at 328.23°C and 469.14°C points out volatile material and cellulose decomposition with 30.47% of mass loss [11]. The peaks between 200°C and 800°C indicate the decomposition of the aromatic structure of lignin. According to the literature, similar peaks are determined in TGA analysis of many different plant-based fibers. The thermal stability of plant-based fiber is a very important parameter for the usage and processing of these materials. The TG and DTG analyses of reddish shell bean fiber show that the fiber can be accepted as a reinforcement in polymer matrix composites. The comparison between the maximum thermal degradation temperature of reddish shell bean fiber and other plant-based fibers is shown in Table 2.

Kinetic activation energy (E_a) is an important factor to specify the thermal stability of plant-based fiber which is interpolated from Broido's plot (Fig. 9). In literature, it is reported that kinetic activation energy of plant-based fibers ranges from 20 to 210 kJ/mol [12]. The kinetic activation energy of reddish shell bean fiber was predicted as 103.61 kJ/mol. The TGA/DTG curves show that reddish shell bean fiber is a sustainable reinforcement that is stable up to 328.23°C for polymer matrix composites.

Table 1 Functional groups peak positions and related chemical compositions

Peak positions (Wavenumber (cm^{-1})	Functional group	Related chemical composition	References
3340	O-H stretching	Cellulose	[24]
2918	C-H stretching	Cellulose and hemicellulose	[24]
1642	C=O stretching	Hemicellulose and lignin	[25]
1234	C-O stretching	Lignin	[22]
1023	C-O and O-H stretching	Hemicellulose	[22]

Table 2 Comparison between crystallinity properties of reddish shell bean fiber and some novel cellulose-based fibers

Fiber	Crystallinity index (%)	Crystallinity size (nm)	Thermal stability (°C)	References
Fragrant Screw Pine Prop Root	64.8	25.71	341.8	[28]
Careya Arborea	85.05	7.40	385	[29]
Cryptostegia Grandiflora	62	20.6	340	[30]
Ziziphus jujuba	35.70	16.30	335	[31]
Bauhinia vahli	57.71	-	345	[32]
Abutilon Indicum	77.35	2.20	302.6	[16]
Ageratina Adenophora	68.98	17.01	244	[33]
Leucaena Leucocephala	63.10	2.33	188.20	[21]
Ficus Carica	41.42	5.51	225	[34]
Strelitzia reginae	70	14.8	233	[8]
Bark of Vachellia	13	31.89	324	[35]
Acacia nilotica L.	44.82	3.21	339	[19]
Taraxacum Sect. Ruderalia	69.59	-	272	[36]
Cocos nucifera Peduncle	52	6.5	290	[37]
Aleo Vera Cactus Leaves	52.6	5.6	355	[38]
Dracaena reflexa	57.32	19.01	230	[39]
Carica papaya bark	56.34	15.4	322.1	[40]
Redish shell bean	57	3.9	328.23	Recent study

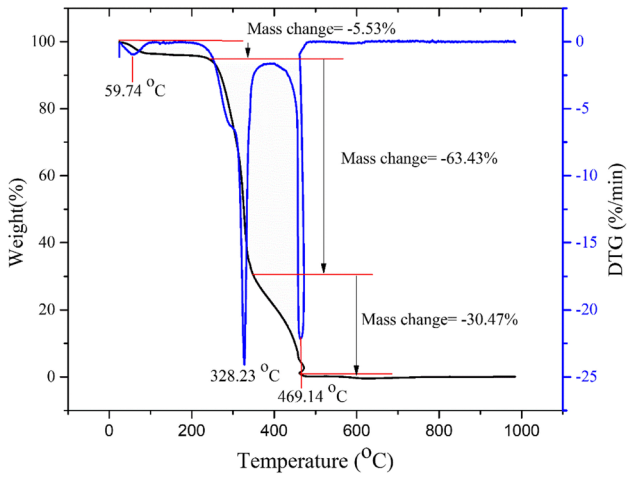


Fig. 8 The TGA/DTG graphs of reddish shell bean fiber

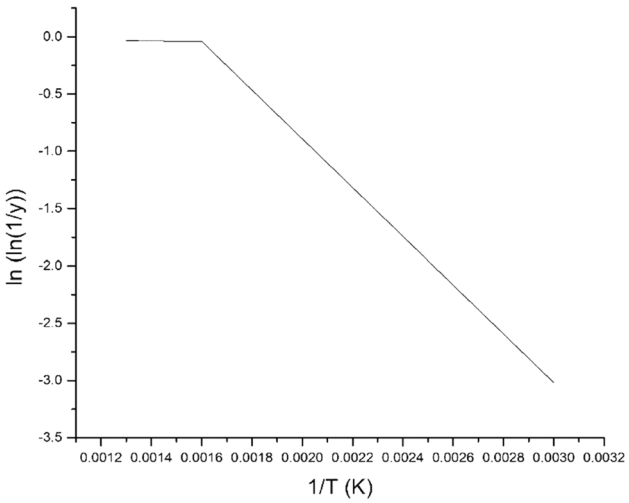


Fig. 9 Broido's plot of reddish shell bean fiber

3.7 Mechanical properties analysis

Mechanical behaviors are a significant characteristic of plant-based fibers. Mechanical behavior determination of plant-based fibers is fundamental to specify their sustainability for different structural practices. A tensile test was performed on reddish shell bean fiber with 20 mm length with the use of a universal testing machine. In literature, it is reported that 20 mm of gage length indicates maximum tensile strength, and the test was achieved with 20 mm of gage length [12]. The ultimate tensile strength of reddish shell bean fiber corresponding to 20 mm length was calculated as 111 MPa which is equiparable with *Kigelia Africana* [41], *Sansevieria ehrenbergii* [42], *Alcea rosea* L [43], and *Atriplex halimus* [44]. The elongation at break and estimated values of Young's modulus of reddish shell bean fiber are 1.83% and 6.11 GPa. Reddish shell bean fiber density, diameter, tensile strength, elongation at break, and Young's modulus are given in Table 3 compared with some other plant-based fibers.

Mechanical behaviors of fibers are an essential parameter that determines whether fibers are suitable or unsuitable for fiber-reinforced composites. High tensile strength of fibers

Table 3 Physical and mechanical properties of some novel plant-based fibers

Fiber	Density (kg/m^3)	Diameter (μm)	Tensile strength (MPa)	Young's modules (GPa)	Elongation at break (%)	References
Fragrant Screw Pine Prop Root	1410	-	619	23	3.84	[28]
Cryptostegia Grandiflora	1020	117	791	-	3.1	[30]
Bauhinia vahli	-	-	62.28	3.22	2.25	[32]
Abutilon Indicum	1170	175	-	-	-	[16]
Ageratina adenophora	1320	-	123	7.69	1.6	[33]
Leucaena Leucocephala	1470	-	415	9.90	4.33	[21]
Strelitzia reginae	1113	200	271.79	9.89	3.3	[8]
Acacia caesia	1290	128.6	-	-	-	[44]
Vachellia farnesiana	1270	231	33.075	-	-	[35]
Acacia nilotica L.	1165	-	-	-	-	[19]
Cocos nucifera Peduncle	1360	380	184	5.5	3.3	[37]
Aleo Vera Cactus Leaves	1325.1	91.15	621.8	40.03	2.47	[38]
Taraxacum Sect. Ruderalia	1397	233	60	-	-	[36]
Dracaena reflexa fiber	790	176.2	829.6	46.37	2.95	[39]
Carica papaya bark	943	-	530	-	1.62	[40]
Areca palm leaf	1090	285-330	334.66	7.64	4.38	[45]
Coccinia grandis. L	1243	27.33	173	-	-	[46]
Dichrostachys Cinerea	1240		873	-	-	[47]
Arial roots of banyan tree	1234	0.09-0.14	19.37	0.70	1.8	[48]
Tithonia diversifolia	-	56.09	258	10.54	2.71	[14]
Ficus benjamina L.	886	331.95	233.87	2.72	2.73	[15]
Abutilon Indicum	1170	175	-	-	-	[16]
Bauhinia Vahlii	1470	15.77	187	-	4.4	[17]
Lavender	870	295	226.65	7.68-4.82	2.94–4.69	[10]
Reddish shell bean	1580	785.87	111	6.11	1.83	Recent study

gains high strength for polymer matrix composites. Mechanical behaviors of any plant-based fiber belong to structure, chemical composition (presence of hemicellulose, cellulose, and lignin), growing condition, extraction method, fiber diameter, plant age, plant resource, fiber microstructure, and harvesting time. In addition, tensile strength and Young's modulus values vary from (i) plant parameters (plant age, cultivation region, and method), (ii) fiber parameters (fiber cell number and fiber extraction method), and (iii) tensile test parameters.

Reddish shell bean fiber diameter is higher than that of many plant-based fibers. It is deemed that higher diameter of fiber is related to the structure of the reddish shell bean. The investigated reddish shell bean fiber was determined to have an average density of 1580 kg/m^3 which is importantly lower than widely used synthetic fibers such as carbon fiber (1800 kg/m^3) and E-glass (2560 kg/m^3) [23].

Microfibril angle of fiber is a significant factor affecting strain behaviors. As microfibril angle of a fiber increases, the ductility of fiber improves. A decrease in microfibril angle of a fiber causes an increase in strength. In this study, the microfibril angle of reddish shell bean fiber for 20 mm gage length was calculated as 16°. In fiber-reinforced composite production, fibers with a small microfibril angle are commonly preferred [40, 49].

4 Conclusion

The determined physicochemical characterization results of reddish shell bean fibers have comparable density, better elemental composition, high crystallinity index, high thermal behaviors, high surface roughness, and good mechanical properties. The density of the fiber was obtained as 1580 kg/m^3, and the diameter was predicted as 785.87 μm, making reddish shell bean fiber suitable for lightweight applications. The reddish shell bean fiber crystallinity index was calculated as 57% with 3.9 nm crystal size. FTIR spectra of fiber show the chemical ingredients in comparison to other plant-based fibers. Furthermore, TGA analysis results show that the fiber is stable up to 328.23^{o}C and can be used as reinforcement in composite materials that can endure greater temperatures because of the fiber's lower weight loss. SEM images indicated that the reddish shell bean fiber

has a rough surface due to its original nature. The ultimate tensile strength of reddish shell bean fiber corresponding to 20 mm length was calculated as 111 MPa. The obtained results show that reddish shell bean fiber can be utilized as reinforcement in polymer matrix composites and textile materials. Furthermore, reddish shell bean fiber can be used as a natural substitute for synthetic reinforced fibers.

Author contribution S.E. carried out physico-chemical analysis of reddish shell bean fiber and interpreted the results. C.E. developed and implemented an image processing method to determine the average fiber diameter of reddish shell bean fibers. N.M. extracted the reddish shell bean fiber from plant stem. All authors wrote and reviewed the main manuscript.

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Data availability The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Declarations

Ethics approval The authors confirm that there were no ethical in preparing this manuscript.

Consent to participate All authors consent to participating in this work.

Competing interests The authors declare no competing interests.

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