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Linhu Ding

Nanjing Forestry University

Xiaoshuai Han (✉ hxs141424@163.com)

Nanjing Forestry University

Huiling Li

Nanjing Forestry University

Jingquan Han

Nanjing Forestry University

Lihua Cao

Nanjing Forestry University

Yiming Chen

Nanjing Forestry University

Zhe Ling

Nanjing Forestry University

Shuijian He

Nanjing Forestry University

Shaohua Jiang

Nanjing Forestry University

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Characterization of novel natural fiber from manau rattan (*Calamus manan*) as a potential reinforcement for polymer-based composites

Linhu Ding^a, Xiaoshuai Han^{a*}, Huiling Li^a, Jingquan Han^a, Lihua Cao^a, Yiming Chen^a, Zhe Ling^b, Shuijian He^a, Shaohua Jiang^{a*}

^a Jiangsu Co-Innovation Center of Efficient Processing and Utilization of Forest Resources, International Innovation Center for Forest Chemicals and Materials, College of Materials Science and Engineering, Nanjing Forestry University, Nanjing, 210037, China.

^b Jiangsu Co-Innovation Center of Efficient Processing and Utilization of Forest Resources, College of Chemical Engineering, Nanjing Forestry University, Nanjing 210037, China.

Email: 2215617702@qq.com (L. Ding), 1932651941@qq.com (H. Li), hjq@njfu.edu.cn (J. Han), 541004274@qq.com (L. Cao), 747883685@qq.com (Y. Chen), jjling19@njfu.edu.cn (Z. Ling), shuijianhe@njfu.edu.cn (S. He)

*hxs141424@163.com (X. Han)

*shaohua.jiang@njfu.edu.cn (S. Jiang)

Abstract

The study on novel natural fibers in polymer-based composites will help promote the invention of novel reinforcement and expand their possible applications. Herein, novel cellulosic fibers were extracted from the stem of manau rattan (*Calamus manan*) by mechanical separation. It is the first time to comprehensively analyze and study the chemical, thermal, mechanical and morphological properties of manau rattan fibers by Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Photoelectron Spectroscopy (XPS), X-Ray Diffraction Analysis (XRD), Thermogravimetric Analysis (TGA), single fiber tensile test and Scanning Electron Microscopy (SEM). Component analysis results showed the cellulose, hemicellulose and lignin contents of manau rattan fibers were 42, 20, and 27%, respectively. The surface of the rattan fiber was hydrophilic according to the oxygen/carbon ratio of 0.49. Manau rattan has a high crystalline index of 48.28%, inducing a high maximum degradation temperature of 332.8 °C. This reveals that it can be used as a reinforcement for thermoplastic composites whose operating temperature is below 300 °C. The average tensile strength can reach 273.28 MPa, which is beneficial to improve the mechanical properties of rattan fiber reinforced composites. SEM images displayed the rough surface of the fiber, which helps to enhance the interfacial adhesion between the fibers and matrices in composites. This work was also in comparison with some other natural fibers. The above analysis and

research showed the great potential of manau rattan fibers as the reinforcement in polymer-based composites.

Keywords: *Manau rattan (Calamus manan), Natural fiber, Reinforcement, Composite*

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Introduction

Nowadays, with the development of modern civilization, environmental problems, depletion of oil resources and global waste issues are becoming more and more serious. Natural fibers have attracted increased research interest of many researchers due to their environmental friendliness, abundant reserves, renewability, biodegradability, light weight, high strength, etc. (Porras et al. 2015). Synthetic fibers commonly used today like glass fiber, aramid, carbon fiber, etc. are costly, not biodegradable and harmful to human in long-term exposure (Dris et al. 2018). Therefore, the development of new natural fibers or the search for new high-strength natural fibers to replace synthetic fibers are expected to solve the above problems. Natural fiber reinforced composites have gained greater demand in the manufacturing industry, especially in the automotive industry. Now composites made of abaca, flax and hemp fibers with thermoplastic matrices gradually replace the applications of glass fibers in door liners, seat backs, headrests, engine shields, etc. These composites contribute to the lightweight of the car and can reduce skin irritation caused by the use of synthetic materials (Akil and Zamri 2014). Under these circumstances, it is significant to make use of novel materials that contain natural ingredients, such as cellulosic natural fibers. Today, natural fiber reinforced composites have been applied in various areas like sports equipment, construction materials, aircraft parts, naval applications, household appliances and auto parts (Senthamaraikannan and Kathiresan 2018). The prevalent applications encouraged boffins to study novel

natural cellulosic fibers.

Numerous boffins have characterized natural fibers as reinforcement of composites like cornstalks (Reddy and Yang 2005), Date Palm Fibers (Al-Khanbashi et al. 2005), sisal (Silva et al. 2008), mulberry (Li et al. 2009), okra (*Abelmoschus esculentus*) (De Rosa et al. 2010), *Luffa cylindrica* (Seki et al. 2012). Recently, on account of the increasing demand for plant fibers in industry, researchers have sought and studied new natural fibers such as *Heteropogon Contortus* (Hyness et al. 2017), *Conium maculatum* (Kılınç et al. 2018), *Catharanthus roseus* (Vinod et al. 2019), *Thespesia populnea* (Kathirselvam et al. 2019b), *Chrysanthemum morifolium* (Dalmis et al. 2020), *Hierochloe Odarata* (Dalmis et al. 2019). Furthermore, numerous physical or chemical treatments have been applied to make these fibers have better performance and can be used as reinforcement in composites. In this trend, a novel natural fiber originating from the stem of manau rattan (*Calamus manan*) was extracted and its properties were studied comprehensively for the first time. Manau rattan is a tropical climbing palm (subfamily *Calamiodeae* of the family *Arecaceae*) with no branches or seasonal rings (Zampieri et al. 2005). It is native to Sumatra and Indonesia, with an average diameter around 4 cm while its metaxylem micro-vessels can reach several meters in length. As is known to all, it is one of the most commercially valuable and commonly used rattan palms in the furniture manufacturing industry. There are currently very few characterizations of manau rattan (*Calamus manan*). Rizkiansyah et al. (2016) extracted microcrystalline cellulose from manau rattan (*Calamus manan*) through alkalization and acid hydrolysis and investigated the influence of concentration of sulfuric acid and hydrolysis time on crystallinity and thermal resistance of it.

Our research is more practical than previous research and can further promote the understanding of rattan, especially its potential of reinforcement in polymer-based thermoplastic composites. This could potentially help the development and research of new materials used in industry, especially the

automotive and aerospace industries. Herein, mechanical separation was utilized to extract fibers from the rattan stem. For the purpose of determining its feasibility as a reinforcing phase in composites, manau rattan fibers were characterized by chemical composition analysis, Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Photoelectron Spectroscopy (XPS), X-Ray Diffraction Analysis (XRD), Thermogravimetric Analysis (TGA), single fiber tensile test and Scanning Electron Microscopy (SEM).

Materials and methods

Materials

Manau rattan (*Calamus manan*) was harvested from Indonesia with an air-dry density of about 0.45 g/cm³. Its stem is cylindrical with diameter of about 40 mm (Fig. 1).

Methods

Fiber extraction

The stem of manau rattan was cut into 250 mm length approximately followed by decortication, and then soaked in deionized water and washed to remove dust and impurities. It was dried at 60 °C for 3 days to get rid of water. It was split into thin plates by using a knife and cut into thin strips via scissors. Later it was torn apart by hand. At this time, the preliminarily obtained rattan fibers were passed through the screen and drawn out from the mesh opening. In this experiment, a 100-mesh screen was used, and the corresponding aperture was 0.15 mm. Manau rattan fibers were sanded with fine sandpaper to remove burrs. Finally, the fibers were washed with deionized water and oven-dried at 60 °C overnight. In this way, manau rattan fibers were obtained (Fig. 1).

Fig. 1 Stem of manau rattan with its extracted fiber

Chemical composition

The rattan fibers were ground into powder followed by drying in a oven at 105 °C for 4 hours to get rid of water. It was put in a drying apparatus at last. Cellulose content of manau rattan fiber was measured in accordance with Kurshner and Hoffer's method, while hemicellulose content was evaluated as per the NFT 12-008 standard. The lignin content of manau rattan (Klason lignin) was obtained according to the standard TAPPI T 222 om-2 method.

Fourier Transform Infrared Spectroscopy (FTIR)

The Fourier transform infrared spectroscopy technique was utilized to recognize the chemical functional groups of the rattan fiber. A certain amount of fiber samples were powdered, then mixed with KBr, and pellets were prepared by a press. A FTIR spectrometer (VERTEX 80v, Bruker, Germany) was used to record the FTIR spectrum in the wavenumber range between 500 and 4000 cm^{-1} .

X-Ray Photoelectron Spectroscopy (XPS)

Surface chemistries of manau rattan fibers were studied through XPS analysis. The spectra were obtained

through X-ray photoelectron spectroscopy (AXIS Ultra, USA), equipped with a monochromatic Al-K α (1486.7 eV) radiation source and a beam diameter of 400 nm. Spectra data was acquired with the vacuum pressure lower than 10⁻⁹ Torr. X-ray source was used in the region between 1350 and 10 eV. Pass energy and energy step size were determined as 150 eV and 1 eV, respectively.

X-Ray Diffraction (XRD)

X-ray diffraction was conducted on the device of an X-ray diffraction analyzer (Ultima IV, Rigaku, Japan) with Cu-K α radiation (λ -K α_1 = 1.54 Å) at room temperature. At 40 kV and 30 mA, the spectrum was recorded in steps of 0.02° between 5° and 90° (2 θ angular ranges). The crystallinity index (*CI*) of manau rattan fibers was obtained by the subsequent expression (Segal et al. 1959):

$$CI = \frac{(I_{200} - I_{am})}{I_{200}} \times 100 \quad (1)$$

where I_{200} refers to the crystalline peak corresponding to the intensity between 22° and 23°, while I_{am} is the amorphous fraction corresponding to the intensity of about 18° lying between the highest two peaks.

The crystallite size (*L*) of manau rattan was computed via the Scherrer's expression (Indran and Raj 2015):

$$L = \frac{K\lambda}{\beta \cos \theta} \quad (2)$$

where *K* is the Sherrer's constant of 0.89, λ is the wavelength of the radiation, β is the peak's full-width at half-maximum (FWHM) in radians and θ is the corresponding Bragg angle.

Thermogravimetric Analysis (TGA)

Thermo gravimetric analysis is a method of measuring the relationship between the mass of the sample and temperature or time under the control of the programmed temperature. Approximately 3.1 mg samples were studied through a thermal analyzer (STA 449F3, NETZSCH, Germany). The sample was gradually heated from 30 °C to 800 °C with the heating rate of 10 °C/min. Nitrogen atmosphere remained

unchanged during the whole experiment at a flow rate of 20 mL/min. The kinetic activation energy (E) was computed to understand the kinetic parameters of rattan fiber by the Broido's equation (Broido 1969):

$$\ln[\ln(\frac{1}{y})] = -\left(\frac{E}{R}\right) \left[\left(\frac{1}{T}\right) + K\right] \quad (3)$$

where y is the normalized weight (w_t/w_0), w_t is the weight of the sample at any time t and w_0 represents the initial weight of the sample, R signified the universal gas constant (8.314 J/mol K), T symbolizes the temperature in Kelvin, and K is constant.

Single fiber tensile test

The tensile test was performed on 3365 universal testing machine (Instron Test Equipment Trading Co., Ltd., China) at room temperature (25 °C) with the relative humidity of about 65%. 20 samples were used in this experiment and they were all dried at 60 °C for 6 hours before testing. The sizes of all samples were determined via a vernier caliper (± 0.01 mm). The load cell was 1 kN and the crosshead speed was 2 mm/min with the gauge length of 10 mm. The tensile strength, Young's modulus and elongation at break of manau rattan fibers were obtained from this test. The microfibril angle (α) represents the angle between the microfibril and the fiber axis, which was evaluated from the next formula (Hyness et al. 2017):

$$\varepsilon = \ln\left(1 + \frac{\Delta L}{L_0}\right) = -\ln(\cos \alpha) \quad (4)$$

Where ε is the strain, α is the microfibril angle (°), L_0 is the gauge length (mm), and ΔL is the elongation at break (mm).

Scanning Electron Microscopy (SEM)

Manau rattan fiber's morphologies were observed by a scanning electron microscope (PhenomScientific XL G2, China) at an accelerating voltage of 5 kV. Before scanning, gold was plated on the fiber surface by sputtering coating to prevent the electron beam charging effect in the observation process. The surface

morphologies of manau rattan fibers were observed under different magnifications.

Results and discussion

Chemical composition analysis

The chemical content of manau rattan fiber seriously affects its mechanical properties, flame retardancy, biodegradability, etc. Lignocellulose fibers are mainly composed by cellulose, hemicellulose and lignin (Han et al. 2021). Table 1 lists the chemical composition of manau rattan fiber and some other lignocellulosic fibers for comparison. The cellulose content of manau rattan fiber is 42%, which is higher than *Curcuma longa* L. (Ilangovan et al. 2018) and comparable to *Arundo Donax* L. (Fiore et al. 2014), but is lower than Linden (Seki et al. 2014), *Thespesia populnea* (Kathirselvam et al. 2019b), *Ferula communis* (Seki et al. 2013), etc. The hydrogen bonds among the cellulose chains can augment crystallinity thereby improving the mechanical properties of manau rattan fiber. Therefore, a higher cellulose content can increase the stiffness of the fiber, which is beneficial to the reinforcement of the composite material. The content of hemicellulose in rattan fiber is 20%, which is equivalent to some other natural fibers, such as *Hydrangea macrophylla* (Cárdenas-R et al. 2018), Date Palm (Al-Khanbashi et al. 2005) and *Arundo Donax* L. (Fiore et al. 2014). Higher content of hemicellulose can cause disintegration of cellulose microfibrils, thereby reducing mechanical properties. Compared with other lignocellulosic fibers, the lignin content of rattan fibers is relatively high, which is 27%. Higher content of lignin is conducive to resist the attack from biology. The other chemical components in the fiber are wax, pectin, oil, ash, etc.

Table 1 Chemical composition of manau rattan and some other lignocellulosic fibers

Fiber	Cellulose (%)	Hemicellulose (%)	Lignin (%)	References
Manau rattan	42	20	27	This work
Mulberry barks	37	25	10	(Li et al. 2009)

<i>Fagus sylvatica</i>	39	29	25	(Patt et al. 2005)
<i>Phragmites</i>	40	24	24	(Jiménez et al. 2008)
<i>Curcuma longa</i> L.	31	26	18	(Ilangovan et al. 2018)
<i>Hydrangea</i> <i>macrophylla</i>	50	19	18	(Cárdenas-R et al. 2018)
Linden	62	4	34	(Seki et al. 2014)
<i>Thespesia</i> <i>populnea</i>	70	13	16	(Kathirselvam et al. 2019b)
<i>Ferula communis</i>	53	9	1	(Seki et al. 2013)
Date Palm	46	18	20	(Al-Khanbashi et al. 2005)
<i>Arundo</i> <i>Donax</i> L.	43	21	17	(Fiore et al. 2014)

FTIR analysis

The FT-IR spectrum of rattan fiber is shown in Fig. 2. The peak observed at 3429 cm⁻¹ is connected with the characteristic of O-H stretching vibration and hydrogen bond of the hydroxyl groups (Manimaran et al. 2018). The peak at 2923 cm⁻¹ is in connection with C-H stretching vibration from CH and CH₂ in cellulose and hemicellulose (Indran and Raj 2015). The peak at 1740 cm⁻¹ is associated with stretching vibration of the C=O group in the ester group of hemicellulose or carboxylic acid in lignin (De Rosa et al. 2010). The wavenumber around 1629 cm⁻¹ belongs to the carbonyl groups (C=O) of lignin and hemicellulose (Belouadah et al. 2015). The peak at 1506 cm⁻¹ indicates C=C stretching of aromatic lignin (Seki et al. 2014). The presence of peak around 1426 cm⁻¹ is related to the symmetric bending of CH₂ in cellulose (Manimaran et al. 2018). A peak detected at 1376 cm⁻¹ is attributed to C-H groups of cellulose (Belouadah et al. 2015). Vibration peak of 1246 cm⁻¹ means C-O stretching vibration of the acetyl groups

in lignin (Dalmis et al. 2020). The peak at 1164 cm^{-1} is ascribed to C-O-C groups of cellulose and hemicellulose (De Rosa et al. 2010). The wavenumber at 1050 cm^{-1} manifests the existence of C-O groups of cellulose (Manimaran et al. 2018). The peak around 897 cm^{-1} is associated with the β -glycosidic linkages between the monosaccharides (Dalmis et al. 2020). The little peak located at 604 cm^{-1} represents the C-OH bending (De Rosa et al. 2010). These results proved the existence of the main components (cellulose, hemicellulose and lignin) in manau rattan fibers according to the above analysis.

Fig. 2 FTIR spectra of manau rattan fibers

XPS analysis

The atomic concentrations and O/C ratios for rattan fiber is given in Table 2. The relative surface composition of rattan fiber is 63.44% C, 31.08% O, 1.64% N and 3.85% Si. O/C ratio of rattan fiber is obtained as 0.49, which is higher than many other mostly utilized lignocellulosic fibers such as Linden (0.13) (Seki et al. 2014), *Conium maculatum* (0.21) (Kılınç et al. 2018), *Henequen* (0.25) (Sgriccia et al. 2008), hemp (0.27) (Sgriccia et al. 2008), *Chrysanthemum morifolium* (0.41) (Dalmis et al. 2020), Kenaf (0.45) (Sgriccia et al. 2008) and *Hierochloe Odarata* (0.48) (Dalmis et al. 2019). However, the value is

lower than that of *Luffa cylindrica* (0.61) (Seki et al. 2013) and oil palm mesocarp fiber (1.00). Generally, a high C/O ratio is related to the hydrophobic surface properties of the fiber, which is significant for cellulosic fiber-reinforced composites. Compared with common fibers such as jute with a surface C/O ratio of 2.09, manau rattan fiber has the potential to become a reinforcing material in composites with a comparable C/O ratio (2.04).

Table 2 Elemental composition of manau rattan fibers

	C1s (%)	O1s (%)	N1s (%)	Si2p(%)	O/C
Manau rattan	63.44	31.08	1.64	3.85	0.49

Deconvolution of C1s and O1s peak were conducted to have a knowledge of the amount of functional groups. The curves are shown in Fig. 3 and the peak distributions and concentrations of related functional groups are shown in Table 3. The peaks at 284.33 eV, 286.16 eV and 287.82 eV can be ascribed to C-C/C-H groups, C-OH/C-O-C groups and C=O groups respectively with the proportion of 40.52%, 49.54% and 9.94%, while the peaks at 531.75 eV and 532.58 eV belongs to O=C groups and O-C groups with the proportion of 32.31% and 67.69% (Seki et al. 2012). The above functional groups also prove the presence of cellulose, hemicellulose and lignin in manau rattan fibers. Carbonyl groups in lignocellulosic fibers are present in hemicellulose and lignin. Such high carbonyl content confirms the high content of hemicellulose and lignin as shown in Table 1.

Table 3 The concentrations of the functional groups on the surface of manau rattan fibers

	C-C/C-H	C-OH/C-O-C	C=O	O=C	O-C
	C1s			O1s	
eV	284.33	286.16	287.82	531.75	532.58
%	40.52	49.54	9.94	32.31	67.69

Fig. 3 High resolution XPS spectra showing the deconvoluted C1s (a) and O1s (b) envelope

XRD analysis

XRD is a technique that uses x-rays to diffract a sample to analyze its structure. Fig. 4 shows the XRD graph of manau rattan fibers. Two peaks at 16.02° and 21.94° by the planes (1 $\pm$ 10 and 200) are relevant peaks of cellulose I and IV respectively (Seki et al. 2012). The crystalline peak of (1 $\bar{1}$ -10) and (110) at

16.02° overlap owing to the small crystallite size (French 2013). The peak located around 17.78° corresponds to the amorphous component. The crystallinity index (*CI*) of manau rattan computed via Eq. (1) is 48.28%, higher than date palm (20%) (Abdal-hay et al. 2012). However, the *CI* of manau rattan fibers is less than many other natural fibers like *Conium Maculatum* (56%) (Kılınc et al. 2018) and *Sansevieria cylindrica* (60%) (Belouadah et al. 2015). The high amount of non-cellulosic materials may account for this. The crystallite size (*L*) of manau rattan fibers calculated from Eq. (2) is 1.91 nm. The *L* of some other natural fibers are flax fibers (2.8 nm) (Reddy and Yang 2005) and Funacel (4.5 nm) (Kim et al. 2010). It is precisely because of the small crystallite size that the number of amorphous structures has increased, which makes the *CI* value of manau rattan fibers relatively small (Kim et al. 2010).

Fig. 4 XRD graph of manau rattan fibers

TGA analysis

Generally, high temperatures are required to manufacture fiber-reinforced thermoplastic composite materials. The thermogravimetric (TG) and its derivative thermogravimetric (DTG) curves for manau

rattan fibers are given in Fig. 5a. Three main weight loss steps are observed. The initial step (2.29%) is seen between 50 °C and 100 °C, which represents the evaporation of moisture (Kılınç et al. 2018). The second weight loss with 13.51% occurs between 100 °C and 280 °C, which corresponds to the decomposition of hemicellulose and the glycosidic linkages of cellulose (Indran and Raj 2015). The maximum weight loss of manau rattan fibers is seen between 280 °C and 360 °C, and it is also the third weight loss stage with a weight loss of 62.24%. It is associated with the decomposition of cellulose I and α -cellulose (Fiore et al. 2014). Then comes the decomposition of lignin. Finally, 17.35% of the initial weight is kept at 800 °C. DTG data shows that the maximum degradation rate of rattan fiber occurs at 332.8 °C. Similar peak related to the decomposition of cellulose were reported for various fibers such as *Lygeum spartum* (338.7 °C), *Cissus quadrangularis* root (328.9 °C), *Chloris Barbata* (324.6 °C) and *Thespesia populnea* (323.8 °C) (Belouadah et al. 2015; Indran and Raj 2015; Kathirselvam et al. 2019b). The kinetic activation energy (E) calculated from the Broidio's plot (Fig. 5b) of $(\ln [\ln (1/y)])$ verses $(1/T)$ is 81.68 kJ/mol. The kinetic activation energy of rattan fiber is in the range of 60-170 kJ/mol which specifies the activation energy margin of woods decomposition, indicating that rattan fiber has heat resistance when preparing fiber-reinforced polymer composites and can withstand the temperature during the polymerization process (Saravanakumar et al. 2013). The kinetic activation energy (E) of manau rattan fiber is higher than *Lygeum spartum* (68.77 kJ/mol), *Furcraea foetida* (65.64 kJ/mol) and close to *Prosopis juliflora* (76.72 kJ/mol), *Cissus quadrangularis* root (74.18 kJ/mol) (Belouadah et al. 2015; Indran and Raj 2015; Manimaran et al. 2018; Saravanakumar et al. 2013). As shown in Fig. 5a, manau rattan fibers are thermally stable up to 220 °C. The above results confirm that rattan fiber is suitable to be a reinforcement in composites, especially in polymer-based composites owing to its relatively high onset temperature.

Fig. 5 TGA/DTG curves of manau rattan fibers (a) and Broido's plot of manau rattan fibers (b)

Single fiber tensile properties

Fig. 6a shows three representative stress-strain curves of rattan fiber. It can be seen that when fiber failure occurs, it exhibits brittle behavior (De Rosa et al. 2010). Rattan fibers exhibit an initial linear deformation of the strain under tensile load, followed by nonlinear deformation. Young's modulus was obtained according to the slope of the line in the first stage. The nonlinear deformation is caused by the delamination between fiber cells and the collapse of the weaker primary cell wall (Belouadah et al. 2015).

Fig. 6b displays the mechanical properties of manau rattan fibers. The tensile strength, Young's modulus and elongation at break of manau rattan fibers with some other natural fibers are shown in Table 4. The tensile strength of rattan fiber is 273.28 ± 52.88 MPa, higher than *Catharanthus roseus* (Vinod et al. 2019) and lower than *Ferula communis* (Seki et al. 2013). Young's modulus is 7.80 ± 1.70 GPa while the elongation at break is 9.40 ± 3.67 %. The deviation value of tensile properties of rattan fiber are slightly high. This is caused by the following factors: the position of the fiber in the plant (Kılınç et al. 2018), the presence of defects (Silva et al. 2008), the hypothesis of circular cross-section of fiber (Fiore et al. 2014).

Fig. 6 (a) Tensile stress-strain curve of manau rattan fiber and (b) its corresponding mechanical properties

Table 4 Mechanical properties of manau rattan fibers as compared with some cellulosic fibers

Fiber	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	References
Manau rattan	273.28 ± 52.88	7.80 ± 1.70	9.40 ± 3.67	This work
Sisal	274	7	2	(Silva et al. 2008)
Areca palm leaf stalk	365	9	3	(Shanmugasundaram et al. 2018)
<i>Ferula communis</i>	476	53	4	(Seki et al. 2013)
<i>Catharanthus roseus</i>	27	1	2	(Vinod et al. 2019)
Elephant Grass	292	10	3	(Belouadah et al. 2015)
Date Palm	170	5	10	(Al-Khanbashi et al. 2005)
<i>Arundo Donax</i>	248	9	3	(Fiore et al. 2014)
<i>Juncus effusus</i> L.	113	4	3	(Dalmis et al. 2019)
Oil palm	248	3	25	(Indran and Raj 2015)
<i>Sansevieria cylindrica</i>	658	7	12	(Indran and Raj 2015)

The microfibril angle (α) of rattan fiber calculated from Eq. (4) is $23.47 \pm 3.97^\circ$. The value is lower than that found in Coir (30.45°) (Sathishkumar et al. 2013) and *Rhctophyllum camerunense* ($40.1 \pm 0.5^\circ$) (Béakou et al. 2008) while higher than *Thespesia populnea* ($13.94 \pm 1.21^\circ$) (Kathirselvam et al. 2019a) and *Heteropogon contortus* ($14.53 \pm 0.53^\circ$) (Hyness et al. 2017). Large microfibril angle indicates an important strain value, which is associated with the reorientation of the microfibrils along the fiber axis in the tensile test. The smaller angle contributes to higher strength and stiffness, while a larger angle can provide higher ductility. The microfibril angle of rattan fiber is at a medium level, giving it great strength together with good toughness. In addition, the composition of the fiber also has a great influence on its mechanical properties. High cellulose content can increase tensile strength and Young's modulus for the reason that cellulose has specific characteristics like high degree of polymerization and linear orientation. Relatively high cellulose content (42%) makes the rattan fibers have good mechanical properties. Fibers rich in cellulose and small microfibril angles are considered to be important features of composite reinforcement. Therefore, manau rattan fiber has great potential to become a reinforcement for green composite materials in the future.

SEM analysis

The surface morphology of a fiber significantly affects its capacity of reinforcement in polymer-based composites. It can be clearly seen from longitudinal image of rattan fiber in Fig. 7a and its enlarged graph Fig. 7b that fine grains are on the rough surface of manau rattan fiber, which may be wax or lignin. Further, these particles increase the surface roughness of the fiber. The surface roughness of the fiber improves the interface adhesion between the fiber and the matrix in polymer-based composites (Alavudeen et al. 2015). Fig. 7c with its enlarged graph Fig. 7d shows the fracture surface picture of rattan fiber after tensile test which reveals that rattan fiber consists of several elementary fibers with a

fiber diameter of about 11 μm , cell wall thickness of about 3 μm and circular lumen diameter of about 5 μm . These elementary fibers bonded together by pectin and other non-cellulosic compounds like other natural fibers. The elementary fibers were not broken in the same plane, which may be caused by defects in the cell wall. In addition, The fiber cells did not separate from each other after fracture, confirming the brittle fracture behavior of the fibers discussed above.

Fig. 7 SEM micrographs of manau rattan fiber

Conclusion

The research shows the extraction and characterization of novel natural fibers from the stem of manau rattan (*Calamus manan*) to evaluate their potential to become a reinforcement in composites. Main components of manau rattan fiber like cellulose, hemicellulose and lignin were decided through FTIR along with XRD. Chemical analysis revealed cellulose, hemicellulose and lignin content of manau rattan fiber were 42%, 20%, and 27%, respectively. Surface C/O ratio was 2.04 comparable to commonly used fiber like jute (2.09). Manau rattan fiber presents 48.28% crystallinity index with the crystallite size of 1.91 nm. Thermogravimetric analysis manifested that manau rattan fibers are thermally stable up to

220 °C with the kinetic activation energy of 81.68 kJ/mol. The maximum degradation temperature was 332.8 °C which contributes to manufacturing thermoplastic polymer-based composites. The tensile strength, Young's modulus and elongation at break values were 273.28 ± 52.88 MPa, 7.80 ± 1.70 GPa, and $9.40 \pm 3.67\%$, respectively. It was observed by SEM that manau rattan fibers consisted of elementary fibers aligned and bound together by non-cellulose components. The rough fiber surface morphology was observed by SEM, which is conducive to the binding of fiber and polymer matrix in composite materials. In conclusion, manau rattan fibers are good candidate for reinforcement especially in polymer-based thermoplastic composites owing to its high thermal stability, good mechanical properties and rough surface. What's more, surface treatment can be used for increasing the interface adhesion between the hydrophilic natural fibers and the hydrophobic polymer matrices to expand the application of manau rattan fiber as a reinforcement.

Declarations

Conflict of interest

All authors declare that they have no conflict of interest.

Human and animal rights

The paper does not contain any research on humans or animals by the authors.

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Figures

Figure 1

Stem of manau rattan with its extracted fiber

Figure 2

FTIR spectra of manau rattan fibers

Figure 3

High resolution XPS spectra showing the deconvoluted C1s (a) and O1s (b) envelope

Figure 4

XRD graph of manau rattan fibers

Figure 5

TGA/DTG curves of manau rattan fibers (a) and Broido's plot of manau rattan fibers (b)

Figure 6

(a) Tensile stress-strain curve of manau rattan fiber and (b) its corresponding mechanical properties

Figure 7

SEM micrographs of manau rattan fiber