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ORIGINAL RESEARCH

Characterization of a novel natural cellulosic fiber extracted from the stem of *Chrysanthemum morifolium*

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Abstract Natural fiber reinforced green composites have been attracting high attention nowadays, as the green movement in the world forced companies to use green materials instead of synthetic fibre reinforced composites. In this respect, the aim of the study is to investigate usage possibility of undervalued *Chrysanthemum morifolium* stem fibers as a new reinforcement of composite materials. Chemical, thermal, crystallographic, density, mechanical and morphological characterizations of the *C. morifolium* fibers were examined. Crystallinity Index, density and tensile strength values were found as 65.18%, 1.33 g/cm^3 and 65.12 MPa, respectively. *Chrysanthemum morifolium* has a low cellulose content of 32.9% while the thermal resistance temperature was determined as 267.5 °C. Although its cellulose content is low, *C. morifolium* fiber can be a good alternative for many other reinforcement plant fibers in terms of tensile strength. The high tensile strength of the fiber can be attributed to the high crystallinity index and fiber morphology advantage (low lumen diameter and thick cell wall). Hollow fiber morphology can increase the insulation and absorption properties of the fibers and can also create a usage area in lightweight composites by providing low density. This study suggests a novel sustainable ecological reinforcement fiber for green polymer composites with low density, reasonable tensile strength, high surface hydrophobicity and high surface roughness.

Keywords *Chrysanthemum morifolium* · Natural fiber · Green composites · XPS · SEM

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Introduction

Since the early ages, metallic materials based on ferrous and non-ferrous have been used in the production of advanced technology vehicles such as aircraft from the simplest equipment. The need for lighter and stronger materials led to the development of composite materials after the discovery of polymers with low-density (Karthi et al. 2020).

The green movement in the world forced automotive companies to use bio-composite green materials instead of synthetic fibre reinforced composites (Ganapathy et al. 2019; Senthamaraikannan and Kathiresan 2018). Due to high cost-effectivity, sustainability, recyclability of the natural fiber-reinforced composites, high demand occurred in the last 20 years for natural fiber-reinforced polymeric composites in the fields of building and industrial panels, false ceilings, storage devices, automobile body panels,

interiors and partition boards (Karthi et al. 2020; Kilinc et al. 2016; Seki et al. 2019a).

Natural fiber reinforced green composites provide biodegradable nature, lightweight, low tool wear, less energy utilization during processing and machining, less hazardous and easy to fabrication properties compared to traditional composites reinforced by artificial fibers (Senthamaraikannan and Kathiresan 2018). Thanks to these features, green composites used in many applications including sports equipment, building materials, aircraft parts, naval applications, household appliances and automobile parts (Senthamaraikannan and Kathiresan 2018). These popular applications forced researchers to explore new natural fibres with appropriate properties (Ganapathy et al. 2019). Accordingly, new natural fibers such as *Conium maculatum* (Kilinc et al. 2018b), *Hierochloe Odarata* (Dalmis et al. 2020), *Furcraea foetida* (Manimaran et al. 2018b), aerial roots of banyan tree (Ganapathy et al. 2019), *Coccinia grandis.L* (Senthamaraikannan and Kathiresan 2018), *Lygeumspartum L.* (Belouadaha et al. 2015) *Cissusquadrangularis* (Indran and Raj 2015) *Althea Officinalis L.* (Kilinc et al. 2018a) and *Phoenix dactylifera L* (Alotaibi et al. 2019) fibers were characterized. In addition, many modification studies have been carried out to give optimum properties to these fibers for possible utilization as reinforcement (Seki et al. 2018, 2019b). Many polymer-based green composites reinforced with natural fibers including coir, sisal, jute, and banana have being developed (Senthilkumar et al. 2019; Siakeng et al. 2019). Due to environmental and ecological advantages of green composites, it is very important to find alternative natural fibers suitable for them (Amroune et al. 2019; Saaidia et al. 2015; Sanjay et al.2019; Senthilkumar et al. 2018). Under the light of this trend, the characterization of the *Chrysanthemum morifolium* fiber for the polymer-based green composites is aimed in the present study for the first time.

C. morifolium is known as an important horticulture crop belongs to the Asteraceae family, among the 30 flowering species in the *C.* genus (Nissim-Levi et al. 2019). *C.s* are native to Asia and north-eastern Europe and are grown for flowering pots and cut for flower industry (Nissim-Levi et al. 2019). *C. morifolium* has a very important state in the world flower industry due to the fact that this plant is one of the ten most popular traditional flowers in China and one of the four most popular cut flowers in the world (Sun et al. 2010a, b; Wang et al. 2014). Taking advantage of the stem of such a popular flower will provide great economic value.

In this respect, the aim of the study is to characterize *C. morifolium* stem fibers as a novel natural fiber for the green polymeric composites. Structural, morphological and mechanical properties of the *C. morifolium* fibers are characterized by the help of Fourier Transform Infrared Spectroscopy (FTIR), X-Ray Photoelectron Spectroscopy (XPS), Thermogravimetric Analysis (TGA), X-Ray Diffraction Analysis (XRD), Scanning Electron Microscope (SEM), Archimedes density method, determination of chemical composition, and single fiber tensile tests.

Materials and methods

Fiber extraction

Chrysanthemum morifolium plants presented in Fig. 1 were harvested from Bahadırlı village of Çanakkale which is located about the northwest part of Turkey. The harvested *C. morifolium* plants were roughly cleaned from their branches and leaves. Separated stems were washed in distilled water to clean any dirt and dust afterward cut into parts of about 300 mm. The conventional water retting process was carried out for separation of *C. morifolium* fibers from the stem. In order to let microbial degradation, stem parts were immersed in a plastic tub filled by tap water and kept for 4 weeks for easy separation of fibers. Then, fibers were manually separated from the stem by brushing with a metal comb. Finally, the obtained fibers were washed with distilled water and dried in an oven at 60 °C for overnight to depart moisture.

Characterization methods

Density measurement

As the density measurement method, ASTM D8171-18, based on Archimedes Law (Method B) was used. Approximately 1 g of specimen was measured with 3 replications. Eq. (1) shows the density measurement formula.

Fig. 1 **a** Plant and **b** fiber images of the *Chrysanthemum morifolium*

$$d = \frac{W_d}{W_d - W_s} \quad (1)$$

where d represents the density, W_d and W_s are dry weight, and the effective mass of samples submerged in deionized water, respectively.

Chemical analysis

The fiber samples were oven-dried at 105 °C before chemical analysis. After removing the excess moisture from the fiber sample, cellulose and hemicellulose contents of *Chysantemum* fiber were determined in accordance with the previous study (Kilinc et al. 2018b).

Fourier transform infrared analysis

Fourier Transform Infrared (FTIR) analysis was used to identify functional groups of *C. morifolium* fibers with the aid of the Perkin Elmer Spectrum BX instrument. Data was recorded with a scan rate of 40 scans per minute and at a resolution of 2 cm^{-1} in the range of 650–4000 cm^{-1} wavenumber.

Thermogravimetric analysis

To investigate the thermal stability of *C. morifolium,* thermogravimetric analysis was conducted by using a Shimadzu DTG-60H instrument. The investigation was performed from room temperature to 800 °C at a rate of 10 °C/min. To prevent oxidation, the analysis was conducted under a nitrogen atmosphere with a flow rate of 100 ml/min. 10 mg of *C. morifolium* fibers were used for the test.

X-ray photoelectron spectroscopy analysis

The chemical states and surface compositions of *C. morifolium* fibers were determined with aid of Thermo Scientific instrument. Al-Kα (1486.7 eV) X-ray source was applied in the range of 1350 and 10 eV with a resolution of 1 eV. The surface of the sample was sputtered with ionic Ar gas before the analysis.

X-ray diffraction analysis

Crystallinity index and crystallite size calculations were performed by the help of the data obtained from X-Ray diffraction pattern of the fibers by using Rigaku Ultima 3 device with Cu–Kα radiation (λ-$K\alpha_1$ = 1.54 Å). In order to put fibres on specimen holder, fibres were cut into small pieces. XRD device was set to 40 kV and 30 mA power, and scanning was done between 5° and 80° range with 2°/min scan rate.

The crystallinity index (CI) was determined by using the empirical formula [Eq. (2)] by Segal et al. (Segal et al. 1959).

$$CI = \frac{(I_{200} - I_{am})}{I_{200}} \times 100 \quad (2)$$

where I_{200} represents the peak at the maximum intensity that relates to the (200) lattice plane between 22° and 23°, and I_{am} is the minimum intensity value between the highest two peaks, which is at a 2θ angle between 18° and 19° (French 2014; Seki et al. 2013). Crystallite size (L) of fibers were also obtained from the XRD pattern and calculated by using the Scherrer's Equation [Eq. (3) (Warren 1990)]

$$L = \frac{K\lambda}{\beta cos\theta} \quad (3)$$

where L is the crystallite size, K is the Scherrer constant (0.94), λ is the wavelength of the x-ray beam, and β is the peak full width half maximum (FWHM).

Single fiber tensile test

The tensile tests of *C. morifolium* were conducted using INSTRON 4411 universal testing machine equipped with 1 kgf load cell. The loading rate was 1 mm/min with a gauge length of 20 mm. Pneumatic grips which were used for clamping the fibre have of 0.5 MPa pressure. Ten fiber samples were tested to determine tensile properties of *C. morifolium* fiber. All tests were performed at standard atmospheric conditions (20 ± 2 °C ambient temperature and 65 ± 4% relative humidity) in accordance with ASTM D 3822 standard.

Morphological characterization

A JEOL-JJM 6060 model scanning electron microscope (SEM) was used for the characterization of the surface and cross-sectional morphologies of *C. morifolium* fibers. Scanning electron images were taken with an accelerating voltage of 5 kV. In order to obstruct electron charging effects during the examination, *C. morifolium* fibers were coated with Au–Pd alloy by sputter coating prior to characterization.

Results and discussion

Density results

The density of *C. morifolium* bast fibres was calculated by using Eq. (1) and found as 1.336 g/cm^3. It can be easily seen from Table 1, that the density of *C. morifolium* is very similar to the density of many common natural fibers like sisal, jute, and banana fibers. But there are also lighter fibers obtained from other plants, for example, *Hierochloe Oderata*, and coir. As lightweight is one of the main properties that a natural fiber needs to have, because of its low density *C. morifolium* becomes a good option for use in composites.

Chemical composition

Cellulose, hemicellulose and lignin are the chief components of the lignocellulosic fibers (Rowell and Stout 2006). The chemical composition of cellulosic fiber is reportedly affected by extraction methods, soil properties, age and origin of the plant (Baskaran et al. 2018). The chemical compositions of *C. morifolium* some recently characterized lignocellulosic fibers are compared from the available data and listed in Table 2.

Chemical analysis of *C. morifolium* showed low cellulose content of 32.9% in comparison with fibers from *Hierochloe Odarata, Sida Cordfolia, Epipremnum Aurem* and *Cereus Hildmannianus* (Dalmis et al. 2020; Maheshwaran et al.2018; Manimaran et al. 2018b; Subramanian et al. 2019). Besides, *C. morifolium* has comparable cellulose content with *Tridax Procumbens, Juncus Effusus*, coir and bagasse fibers (Justiz-Smith et al. 2008; Maache et al. 2017; Vijay et al. 2019). The extensive hydrogen bonds between cellulose chains may increase crystallinity and enhance mechanical properties of the fibers (Silva et al. 2019). The hemicellulose content (13.8%) is comparable with jute, flax and coir fibers (Bulut and Aksit 2013; Justiz-Smith et al. 2008; Nilsson and Gustafsson 2007). High level content of hemicellulose may lead to the disintegration of cellulose micro fibrils (Indran and Raj 2015). Hemicellulose is responsible from moisture content of the fiber possibly due to its amorphous region. The content of the rest of the components including lignin, oils, and waxes is experimentally 53.3%. To summarize, it is possible to indicate that *C. morifolium* can be a candidate as a

Table 1 The density values of different natural fibers

Plant Name	Fiber density (g/cm^3)	References
Chrysanthemum morifolium	1.30	Present study
Hierochloe Oderata	1.16	(Dalmis et al. 2020)
Coir	1.25	(Wambua et al. 2003)
Sisal	1.30	(Saheb and Jog 1999)
Jute	1.30	(Saheb and Jog 1999)
Banana	1.35	(Kulkarni et al. 1983)
Bamboo	1.40	(Madsen et al. 2013)
Kenaf	1.45	(Holbery and Houston 2006)
Hemp	1.48	(Wambua et al. 2003)
Flax	1.50	(Mohanty et al. 2005)
Cotton	1.51	(Wambua et al. 2003)

Table 2 Cellulose contents of *Chrysanthemum morifolium* and some recently characterized fibers

Fiber	Cellulose content (%)	References
Chrysanthemum morifolium	32.9	In current study
Hierochloe Odarata	70.4	(Dalmis et al. 2020)
Cereus Hildmannianus	58.4	(Subramanian et al. 2019)
Tridax procumbens	32.0	(Vijay et al. 2019)
Thespesia populnea	48.2	(Kathirselvam et al. 2019)
Curcuma longa L	50.0	(Ilangovan et al. 2018)
Epipremnum aurem	66.3	(Maheshwaran et al. 2018)
Conium maculatum	49.5	(Kilinc et al. 2018b)
Furcraea Foetida	52.6	(Manimaran et al. 2018b)
Nerium Oleander	43.4	(Jabli et al. 2018)
Sida cordifolia	59.6	(Manimaran et al. 2018a)
Juncus effusus	33.4	(Maache et al. 2017)

reinforcement fiber regarding to chemical composition data.

FTIR analysis

To clarify the main component of natural fiber (lignin, cellulose, and hemicellulose), and their functional groups (ester, ketone, and alcohol) FT-IR spectroscopy was utilized for characterization (De Rosa et al. 2010; Fan et al. 2011). The functional groups of *C. morifolium* fibers are given in Fig. 2 with the range of 4000–650 cm^{-1}. As seen from the spectrum a broad peak observed at 3340 cm^{-1} related to characteristic O–H stretching vibrations of cellulose (Porras et al. 2015). The peak located at 2922 cm^{-1} is assigned of the C–H stretching vibrations of CH and CH_2 in cellulose and hemicellulose (Oh et al. 2005). The peak located at 1737 cm^{-1} can be related to stretching

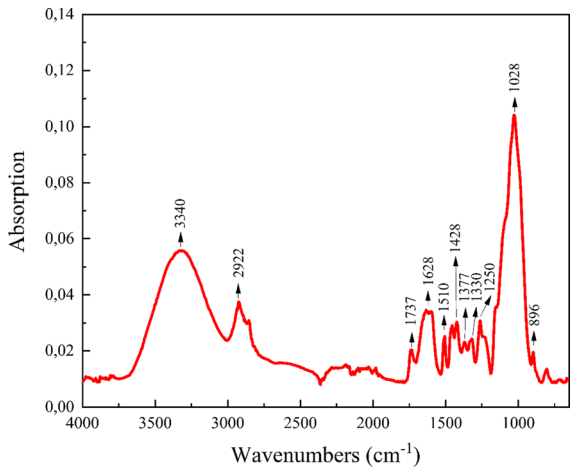

Fig. 2 FTIR spectrum of the *Chrysanthemum morifolium* fibers

vibration of the C=O group in the ester group of hemicellulose or carboxylic acid in lignin and the distinct absorption peak at 1628 cm^{-1} can be ascribed to H–O–H bending vibration of water in fiber (De Rosa et al. 2010, 2011). The small peak located at nearly 1510 cm^{-1} corresponds to the C= stretching of aromatic lignin in the fiber(Kilinc et al. 2018b). The peaks detected at 1428 cm^{-1} correspond to the symmetric bending of CH_2 in cellulose (Sgriccia et al. 2008b). The two peaks located at 1377 and 1330 C–H cm^{-1} can be associated with the C–O bending vibrations of aromatic rings of hemicellulose and lignin (Jonoobi et al. 2009; Sreenivasan et al. 2011). The peaks located at 1250 cm^{-1} are associated with C–O stretching vibration of the acetyl groups in lignin (Tawakkal et al. 2016). The intense peak nearly at 1028 cm^{-1} is related to the C–O and O–H stretching vibrations in fiber (Dalmis et al. 2020). The band at 896 cm^{-1} is related to the β-glycosidic linkages between the monosaccharides (Mwaikambo and Ansell 2002). These results can indicate the existence of the main components of natural fiber (lignin, cellulose, and hemicellulose) similar to the most utilized natural fibers such as jute (Saha et al. 2010), hemp (Sawpan et al. 2011), kenaf (Keshk et al. 2006).

Thermogravimetric analysis

Investigation of the thermal behavior of natural fiber is important because the fabrication of polymer composite generally executed at relatively high temperatures. To manufacture composite without any degradation of natural fiber at relatively high-temperature and to utilize its properties at a maximum rate we need to understand the thermal behavior of fibers. Natural fiber generally consists of lignin, cellulose, and hemicellulose, which can possibly affect the thermal stability of natural fibers. Finding the degradation temperature of *C. morifolium* fibers can help to learn about the thermal behavior these fibers (Belouadah et al. 2015; Sarikanat et al. 2014). In this respect, TGA analysis was used to investigate the thermal behavior of the *C. morifolium* fibers. TG/DTG curves of the fibers are given in Fig. 3. The first weight loss with 8.978% occurred between 25 and 100 °C due to the evaporation of water (Ridzuan et al. 2016). The next degradation was observed at 267.5 °C with the 16.3% weight loss which corresponds to the decomposition of hemicellulose in fibers (Saravanakumar et al. 2013). This temperature also indicates the decomposition onset temperature of fibers (Yao et al. 2008). The last degradation was recorded at 350 °C with major weight loss (48.12%) associated with the decomposition of cellulose and lignin in fiber (Baskaran et al. 2018; Mahmood et al. 2016) which indicates the maximum degradation temperature of *C. morifolium* fibers. Similar maximum decomposition temperatures related to the decomposition of cellulose were observed at different studies examining sisal, jute, and flax at 340 °C (Manfredi et al. 2006), 365 °C (Alvarez et al. 2006), and 345 °C (Manfredi et al. 2006), respectively (Indran and Raj E. 2015; Saravanakumar et al. 2013). Also, *C. morifolium* fibers decompose at higher temperatures as compared with some recently characterized cellulosic fibers such as *Chloris Barbata* (324.6 °C) (Balasundar et al. 2018), *Heteropogon Contortus* (337.7 °C) (Rajesh Jesudoss Hyness et al. 2018), *Acacia Leucophloea* (346.8 °C) (Arthanarieswaran et al. 2015) and *Thespesia populnea* (323.8 °C) (Kathirselvam et al. 2019).

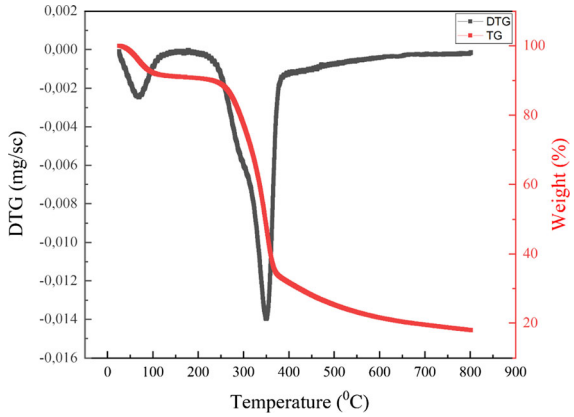

Fig. 3 TG/DTG curves of the *Chrysanthemum morifolium* fibers

Also, the high crystallinity index of *C. morifolium* fiber with 65.18% compatible with the high maximum degradation temperature of fibers (Jonoobi et al. 2009). The measurement was conducted to the 800 °C and after major decomposition, 8.54% weight loss recorded, which is related to the residual content in the fiber (Balasundar et al. 2018). Thermal analysis indicates that *C. morifolium* fiber is thermally stable up to 267.5 °C which is higher than the onset temperature of the most utilized natural fibers such as hemp (205.1 °C), kenaf (219 °C), jute (205.1 °C) (Yao et al. 2008). This result indicates that *C.*

morifolium fiber can be proper reinforcement for polymer matrix composites because of high onset temperature considering the manufacturing temperature of the polymer composite, without any degradation under its onset temperature (267.5 °C) (Belouadah et al. 2015; Sarikanat et al. 2014).

XPS analysis

The chemical states and surface compositions of *C. morifolium* fibers were investigated using XPS. The elemental compositions of *C. morifolium* fiber surface were listed in Table 3. The main component of the fiber surface is carbon that is followed by oxygen. Concentrations of carbon and oxygen were determined as 66.33% and 27.45%, respectively. To determine the surface hydrophilic or hydrophobic character of fibers, Carbon/Oxygen (C/O) and Oxygen /Carbon (O/C) ratios of fibers were calculated using XPS data. The O/C ratio of *C. morifolium* (0.41) is higher than the most known cellulosic fibers such as flax (0.156) (Csiszar et al. 2013), hemp (0.27), sisal (0.29) (Seki et al. 2019a, b) and Henequen fibers (0.25) (Sgriccia et al. 2008a). However, the value is lower than that of *Luffa Cylindrica* (0.61), oil palm mesocarp fiber (1.00) and oil palm kernel shell (1.07) (Sabil et al. 2013). In general, a high C/O ratio is associated with the hydrophobic surface characteristic in fibers and this parameter is important for cellulose-based fiber-reinforced composite materials (Sernek et al. 2004).

As compared to common fibers such as such as jute (2.09) and kenaf (2.38) (Sgriccia et al. 2008a) taking into account surface C/O ratio, *C. morifolium* can be used as a reinforcement in green composites with a high C/O ratio (2.40).

In order to determine the content of the functional groups, deconvolution analysis was used for C1s and O1s peaks. The high-resolution XPS spectra of C1s and O1s peaks are given in Fig. 4. The main peak at 285.52 eV is the most prominent peak in all represents C–C, C–H bonds which can indicate the presence of cellulose or ether (Pandey et al. 2020). The 532.25 eV peak is of cellulosic or cyanoethyl cellulose peak which is having C–O–C bond and signifies the presence of cellulose in material (Pandey et al. 2020).

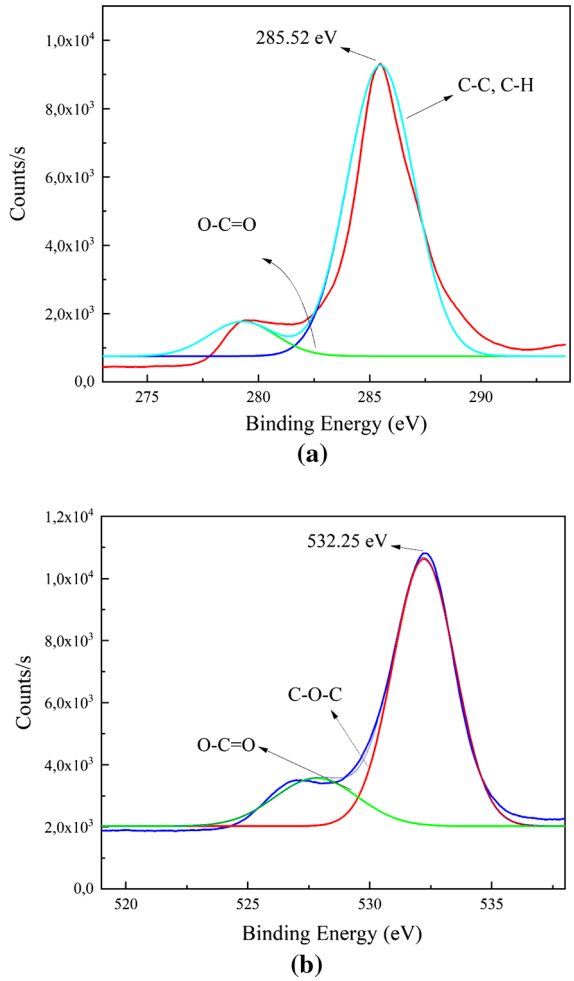

Fig. 4 The high-resolution XPS spectra of **a** C1s and **b** O1s peaks belong to the *Chrysanthemum morifolium* fiber

XRD analysis

The XRD pattern of *C. morifolium* is shown in Fig. 5. There is a broad amorphous part showing peak intensities between 13.36° and 18.66°, which is

Table 3 Elemental composition of the *Chrysanthemum morifolium* fibers

	C1s	O1s (%)	Si2p (%)	O/C	C/O
Chrysanthemum morifolium	66.33	27.45	6.52	0.41	2.40

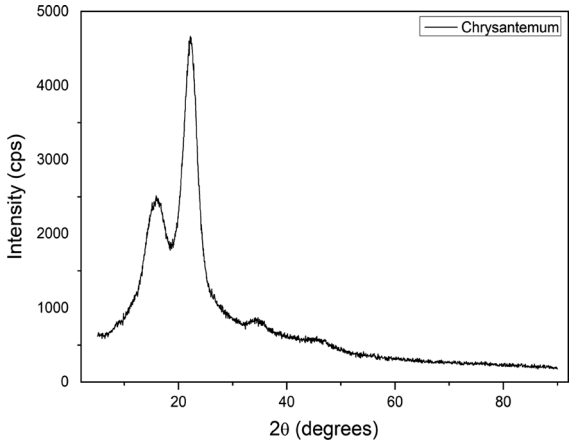

Fig. 5 XRD pattern of the *Chrysanthemum morifolium fiber*

contributed to the two peaks of cellulose-I, that (110) and (1$\bar{1}$0) lattice planes overlap (Manimaran et al. 2018b). At 18.72° the minimum intensity between these peaks can be seen for measuring the crystallinity index. The main peak seen in XRD pattern is related with cellulose (200) lattice plane, which is at 21.94°. Also a weak peak at 34° can be assigned to the (004) plane (Oh et al. 2005). Crystallinity Index (CI) of *C. morifolium* fibers calculated by Segal formula is 65.18%, which is comparatively higher than many natural fibers extracted from different plant sources (see Table 4). With increasing crystallinity, the cellulosic chains become more regularly aligned and helps to increase the tensile properties of the fibers (Ehrenstein2012). Therefore, as a reinforcement higher crystallinity helps the production of high-strength composites. Thermal degradation temperature of natural fibers is also improved with increasing crystallinity (Kim et al. 2010).

The crystallite size of *C. morifolium* fibers is shown in Table 4. Crystallite size is a measure of coherency of the related XRD peak which is (200) lattice plane of cellulose (French 2014). With the increasing crystallite size, the amount of amorphous structure becomes diminished and this increases the CI value of the cellulose (Kim et al. 2010).

Single fiber tensile properties

The mechanical properties of natural fibers highly depend on their structure and chemical composition. When the literature is analyzed, it is seen that there is a wide distribution for the reported mechanical values of cellulose-based fibers. This variability is due to some reasons such as test conditions, plant characteristics, extraction, maturity, growing conditions, harvesting period, degree of retting, irregular cross-section, section measurements, defects on the fiber surface and etc. (Fidelis et al.2013; Kilinc et al. 2018b; Owonubi et al. 2019). On the other hand, it is known that high cellulose content provides better tensile strength and modulus values because cellulose possesses specific characters such as high degree of polymerization and its linear orientation (Baskaran et al. 2018; Senthamaraikannan et al. 2019; Thakur and Singha 2010). The cellulose content and mechanical properties of *C. morifolium* and some lignocellulosic fibers are listed in Table 5. When the values are examined, it is seen that although the cellulose content of *C. morifolium* is lower than *Veldt-grape stem (VSF), Palm leaf stalk (WLF), banyan tree, Catharanthus roseus, coconut tree leaf sheath, and Grewia tilifolia fibers, C. morifolium* fibers have comparable and even higher tensile strength values (Ganapathy et al. 2019; Indran and Raj 2015; Jayaramudu et al. 2010; Mayandi et al. 2015; Vinod et al. 2019). The fact that the fibers exhibit high strength despite the low cellulose ratio can be attributed to the more regular formation of the cellulosic chains due to the high crystallinity as mentioned in the crystallinity

Table 4 Crystallinity index and crystallite size values of *Chrysanthemum morifolium* and some natural fibers

Fiber source	Crystallinity index (%)	Crystallite size (L) (nm)	References
Chrysanthemum morifolium	65.18	4.1	Present study
Funacel	54	4.5	(Kim et al. 2010)
Cotton	58	5.8	(Kim et al. 2010)
Halocynthia	74	10.6	(Kim et al. 2010)
Conium Maculatum	56	8	(Kilinc et al. 2018b)

Table 5 Mechanical properties of *Chrysanthemum morifolium* and some lignocellulosic fibers

Fiber name	Cellulose content (%)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	References
Chrysanthemum morifolium	32.9	65.12 ± 25.04	1.55 ± 0.76	4.51 ± 0.95	Current study
Napier grass	47.12 ± 0.76	88.40	13.1	0.99	(Kommula et al. 2013)
Veldt-grape stem fibre (VSF)	81.38 ± 1.61	61.42 ± 17.30	1.1 ± 0.315	5.6 ± 1.37	(Mayandi et al. 2015)
Palm leaf stalk fibre (WLF)	77.94 ± 0.87	65.67 ± 21.00	3.64 ± 1.11	1.8 ± 0.623	(Mayandi et al. 2015)
Banyan tree root	67.32	19.37 ± 7.72	1.8 ± 0.40	10.88 ± 1.20	(Ganapathy et al. 2019)
Catharanthus roseus	47.3	27.02 ± 1.10	1.23 ± 0.04	2.15 ± 0.1	(Vinod et al. 2019)
Hierochloe Odarata	70.4	105.73 ± 35.42	2.56 ± 0.98	2.37 ± 0.95	(Dalmis et al. 2020)
Sansevieria ehrenbergii	80	343.67 ± 242.99	3.29 ± 1.79	9.05 ± 2.61	(Sathishkumar et al. 2013)
Tridax procumbens	32.0	25.75	0.94 ± 0.09	2.77 ± 0.27	(Vijay et al. 2019)
Coconut tree leaf sheath	27	46.4	2.3	2.84	(Indran and Raj 2015)
Conium maculatum	49.5	327.89 ± 67.41	15.77 ± 3.15	2.67 ± 0.53	(Kilinc et al. 2018b)
Grewia tilifolia	62.8	65.2	4.57	1.6	(Jayaramudu et al. 2010)

characterizations (Ehrenstein 2012). Furthermore, the elongation values of *C. morifolium* is also quite good. It is known that the mechanical properties of fiber-reinforced composites depend on some other parameters such as matrix composition, mechanical properties of matrix, fiber orientation angle, fiber-matrix shear strength and adhesion and also mechanical properties of reinforcement fiber (Goda et al. 2009; Saheb and Jog 1999; Shesan et al. 2019). In addition, it is thought that this fiber can be a good alternative for green composites with reasonable mechanical properties and similar properties to other reinforcement plant fibers such as palm and coconut. The stress–strain curve of *C. morifolium* fiber is given in Fig. 6 that a sudden decrease in stress value indicates the nature of the brittle failure.

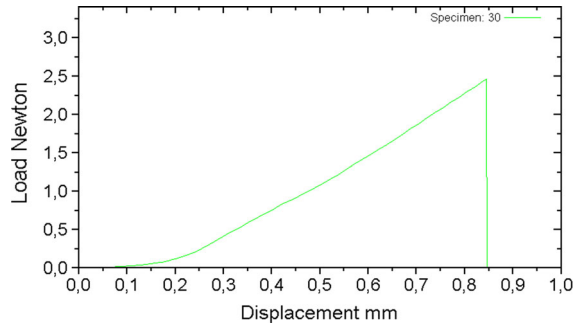

Fig. 6 Load–displacement graph of *Chrysanthemum morifolium* fiber

Morphological characterizations

The morphology of the *C. morifolium* fibers was examined according to Fig. 7, where the longitudinal and cross-sectional SEM images are presented. Surface morphology can be interpreted from the longitudinal fiber section in Fig. 7a. It is seen that the fiber sample has a diameter of about 118 μm. It can be concluded that *C. morifolium* fibers are thinner than Banana pseudo-stem, coir, sisal, and palmyra fibers while thicker than pineapple leaf fiber, considering the average diameter of the fibers (Asmanto and Chafidz 2018). It is very clear that *C. morifolium* fibers have many particles [might be wax, lignin or impurities (Senthamaraikannan and Kathiresan 2018)] and porosities on the surface. These irregularities increase

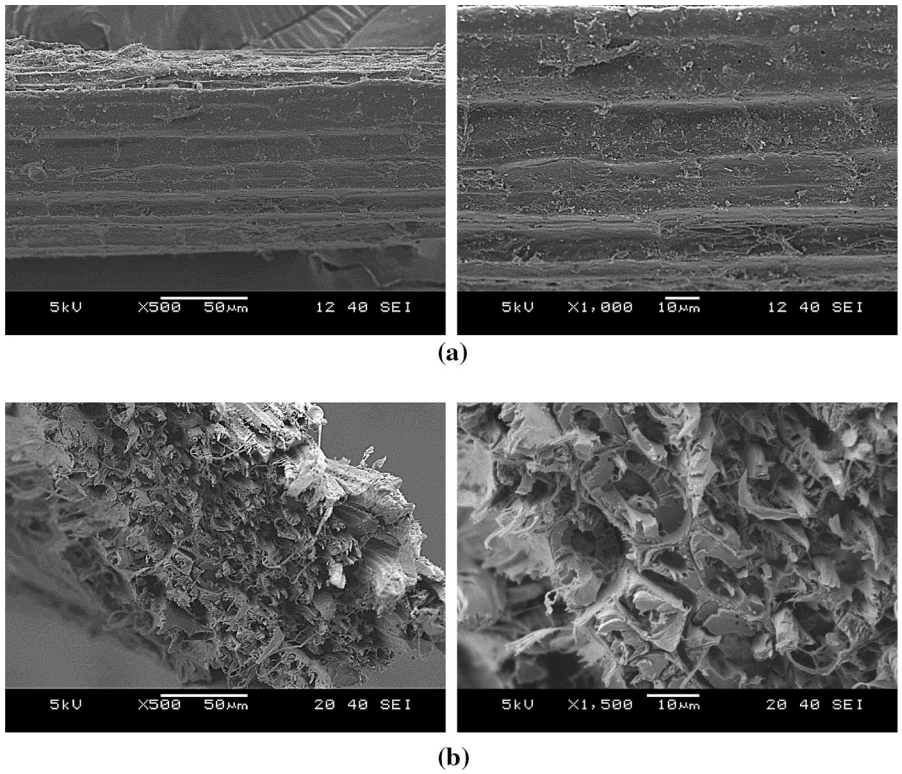

Fig. 7 **a** Longitudinal and **b** cross-sectional SEM images of the *Chrysanthemum morifolium* fibers

the surface roughness of the fibers. Increased surface roughness is a big advantage for composite systems due to providing better adherence to the fiber with the matrix (Indran and Raj 2015). Moreover, Zhang et al. (2018) have mentioned that rough surface can improve interfacial bonding between fiber and matrix by the means of mechanical interlocking.

When cross-sectional SEM images of the *C. morifolium* fibers are examined from Fig. 7b, elementary fibers can be observed. It can be concluded that similar to the other natural fibers, *C. morifolium* fibers consist of many several elementary fibers bound together by pectin or other non-cellulosic compounds (Kilinc et al. 2018b). Empty spaces (called lumen) in the center of the fibers corresponding to the channels, where nutrients and water flow take place throughout the fiber can be observed from cross-sectional images (Sanjay et al. 2018). The observed central hole explains why *C. morifolium* natural fiber has a low density. Furthermore, the hollow structure due to the lumen phenomenon, provides good insulation and absorbance properties to the fiber (Asmanto and Chafidz 2018). Cross-sectional SEM images showed up that elementary fibers have a diameter of 10 µm, while the cell wall thickness is about 3 µm and lumen diameter is about 4 µm. The natural fibers generally have similar morphology, but they differ from each other by factors including wall thickness, lumen, and fiber diameters. That's why it is important to compare some of these properties of the new fiber with popular natural fibers. For example, Fidelis et al. found that strength and Young's modulus could be increased by low lumen area and high cell-wall thickness (Fidelis et al. 2013). When compared to this study, the lumen diameter of the *C. morifolium* fiber is equal to that of the curaua fiber and smaller than the jute and sisal fibers (Fidelis et al. 2013). Also, *C. morifolium* fiber has higher cell wall thickness than jute and sisal fibers while lower than curaua fiber (Fidelis et al. 2013). In the previous section, it was stated that high crystallinity helps the *C. morifolium* fibers to have good strength despite low cellulose ratio. It is thought that morphological advantages of *C. morifolium* fiber such as low lumen range and thick cell wall contribute to this situation.

Conclusion

This study aimed to investigate whether *C. morifolium* fiber properties are suitable for use in green composites as a new potential reinforcement material. Thermal resistance temperature is analyzed to be 267.5 °C that can facilitate extrusion of polymer-based composites. Main components of *C. morifolium* fiber such as cellulose, hemicellulose and lignin was determined by FTIR and XPS analyses like other cellulosic fibers. Surface C/O ratio is found to be relatively high (2.4), which is a desired feature for the natural fiber reinforcements for helping to improve fiber/matrix compatibility. Cellulose content of *C. morifolium* fiber is analysed to be 32.9% which is quite low comparing with other fibers. Tensile strength as 65.12 MPa supports the claim that *C. morifolium* fiber can be a good alternative for many reinforcement fibers. The relatively high tensile strength of the fiber can be attributed to the high crystallinity index (65.18%) and characteristic fiber morphology (low lumen diameter and thick cell wall) associated with XRD and SEM results. In addition, hollow fiber morphology can increase the insulation and absorption properties of the fibers and can create an application area in lightweight composites by providing low density such as 1.33 g/cm^3. In summary, *C. morifolium* fiber is a good natural reinforcement candidate for green composites with high thermal resistance, high hydrophobicity, reasonable tensile strength, low density, and rough surface. The development of *C. morifolium* fiber-reinforced green composites can be aimed for future studies.

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