

Description of a new natural fiber extracted from *Helianthus tuberosus* L. as a composite reinforcement material

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Research Article

Keywords: *Helianthus tuberosus* L., eco-friendly, natural fiber, material characterizations, cellulose, green composite

Posted Date: June 13th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1649460/v1>

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Abstract

Natural fiber-reinforced composites are generally believed as eco-friendly, long-lasting, and recyclable materials. Considering this trend, this study characterizes the *Helianthus tuberosus* L. fiber for polymer-based green composites for the first time. It has been found that *Helianthus tuberosus* L. fiber has many advantages as a reinforcement material in polymer-based composites. For example, the high roughness provided by the fiber surface in cellular morphology increases the locking into the composite body. One of the most critical advantages is its high thermal stability temperature of 247.3 °C. Also, other advantages of the *Helianthus tuberosus* L. fiber as a good reinforcement candidate for green composites can be listed as high cellulose content, high crystallinity, and high tensile strength. The hollow fiber structure can allow it to be used in materials used for insulation. Eventually, the high cellulose content of 62.65% supports its use in various industries, including paper and paperboard manufacturing.

1 Introduction

Global warming, severe pollution, and natural resource shortage pose a serious threats to future generations. Finding an alternative bio-based material obtained from a natural renewable resource is one method to reduce the deterioration of our planet's resources (Perumal & Sarala, 2020). Furthermore, the necessity to identify new alternatives for materials generated from nonrenewable resources is highly clear at the policy formation level (Vaisanen et al., 2017). Governmental considerations appear to be aligning to create an environment conducive to the development of more advanced products from various types of biomass. Natural fiber reinforced polymer composites (NFRPCs) are a type of fiber reinforced polymer composite that is made from natural fibers (Zhao et al., 2022). NFRPCs are frequently regarded as environmentally friendly, long-lasting, and recyclable materials (Parparita et al., 2015). In the circular economy, where future manufacturing processes will be designed to minimize and eventually remove waste from the system, recycling is becoming more important for materials (Moazzem et al., 2021).

Natural fibers for reinforcing polymers have many advantages over synthetic fibers such as glass or carbon fibers, including their "green" and sustainable nature, low cost, low abrasion, excellent stiffness to weight ratio and biodegradability (Liu et al., 2020; Zhao et al., 2020). Suffocation, carcinogenic, pulmonary toxicity, lung cancer, cell mutagenicity, and oxidative DNA damage to field workers may result from unprotected handling of synthetic fibers (Indran et al., 2014; Manimaran et al., 2018). NFRPC materials are used in various applications in modern technology, including aircraft (fuel tanks, wings), naval (moderate loadbearing structures), automobiles (seat, dial and switch housing panels, clutch plates, bumpers, headrests, fuel lines, door panel, upholstery, grills, and mats), sports equipment, liquid storage tanks, electronic, construction, food packaging, and furniture (Karthi et al., 2020; Kilinc et al., 2016; Kulandaivel et al., 2020; Perumal & Sarala, 2020; Sanjay et al., 2019; Seki et al., 2019a; Senthamaraikannan & Kathiresan, 2018). Natural fibers offer promising alternatives to synthetic fibers, such as being non-harmful, low density, biodegradable, non-polluting, have good thermo-mechanical properties, are abundant, renewable, and cost-effective (Madhu et al., 2020; Perumal & Sarala, 2020). Polyolefins (e.g., polypropylene (PP) and polyethylene (PE)), polyvinyl chloride (PVC), polyamides (e.g.,

nylon), and, more recently, biobased polylactic acid (PLA) are the most common thermoplastics used for NFRPCs (Zhao et al., 2022). Although natural fibers are sustainable and biodegradable, current natural fiber resources are insufficient to meet the industry's sustainable fiber needs. As a result, natural fiber resources must be diversified (Ganapathy et al., 2019; Gedik, 2021). Accordingly, new natural fibers introduced to the literature recently. can be listed as *Yucca aloifolia* L. (do Nascimento et al., 2021), *Derris scandens* (Perumal & Sarala, 2020), *Trachelospermum jasminoides* (Gedik, 2021), *Furcraea foetida* (Manimaran et al., 2018), *Centaurea solstitialis* (Keskin et al., 2020), *Chrysanthemum morifolium* (Dalmis et al., 2020a), *Hierochloe Odarata* (Dalmis et al., 2020b), *Conium maculatum* (Kilinc et al., 2018b), roots of banyan tree (Ganapathy et al., 2019), and *Althea Officinalis* L. (Kilinc et al., 2018a). Furthermore, numerous modification studies have been conducted to provide these fibers the best properties possible for use as reinforcements (Seki et al., 2018; Seki et al., 2019b). Many natural fiber-reinforced polymer-based green composites, such as Coir, Sisal, Jute, and banana, have been developed (Senthilkumar et al., 2019; Siakeng et al., 2019). Because of the environmental and ecological benefits of green composites, finding natural fibers suitable for them is critical. Considering this tendency, the current research intends to describe the *Helianthus tuberosus* L. fiber for the first time for polymer-based green composites.

Helianthus tuberosus L. (also known as Jerusalem Artichoke) is a member of the Asteraceae family of plants and is regarded to be one of North America's earliest agricultural crops (Ozgoren et al., 2019). It has a fast growth rate, a great tolerance for frost, drought, and poor soil, a strong resistance to pests and plant diseases, and requires little to no fertilizer (Ozgoren et al., 2019). *Helianthus tuberosus* L. is grown mainly because of its edible tubers with high inulin content (Ozgoren et al., 2019; Swanton et al., 1992). Some are small, spherical, and knobby, like potatoes, while others are long, slender, and smooth. The tubers have an artichoke flavor (thus the common name) and can be eaten raw or cooked like potatoes (Swanton et al., 1992). The stem part other than the root, which has this economic value, has no value at present. That's why we suggest a new *Helianthus tuberosus* L. fiber for the economic value of the fibers extracted from the stem, which is the waste of this vegetable. Accordingly, the study aims to reveal whether the fibers obtained from the stem of the *Helianthus tuberosus* L. vegetable can be used in polymer-based composites or in other areas of use. Morphological, thermal, chemical, structural and mechanical properties of the *Helianthus tuberosus* L. fibers were characterized.

2. Materials And Methods

2.1 Fiber extraction

The *Helianthus tuberosus* L. plants (can be observed in Fig. 1) were gathered in the Bahadirli village of Çanakkale, Turkey. The fiber extraction stages of the *Helianthus tuberosus* L. are summarized in Fig. 1. The branches and leaves of the harvested *Helianthus tuberosus* L. plants were roughed up. The separated stems were rinsed in distilled water to remove any debris and dust before being cut into 300 mm pieces. The fibers of *Helianthus tuberosus* L. were separated from the stem using the traditional water retting method. For simple separation of fibers, stem sections were soaked in a plastic tub filled with tap water for 4 weeks to allow microbial deterioration. Fibers were then manually separated from the

stem using a metal comb. Finally, the fibers were rinsed in distilled water and dried for an overnight period at 60°C to remove moisture.

2.2 Characterization methods

2.2.1 Chemical analysis

Before chemical analysis, the fiber samples were oven-dried at 105°C. The cellulose and hemicellulose contents of *Helianthus tuberosus* L. fiber were determined in accordance with the previous work after the excess moisture was removed from the fiber sample (Kilinc et al., 2018b).

2.2.2 Fourier Transform Infrared analysis

The Perkin Elmer Spectrum BX equipment was used to determine functional groups of *Helianthus tuberosus* L. fibers using Fourier Transform Infrared (FTIR) analysis. Data were collected at a scan rate of 40 scans per minute with a resolution of 2 cm⁻¹ in the wavenumber range of 650 to 4000 cm⁻¹.

2.2.3 Thermogravimetric analysis

Thermogravimetric analysis was used to study the thermal stability of *Helianthus tuberosus* L. using Shimadzu DTG-60H equipment. The experiment was carried out at a pace of 10°C/min from room temperature to 800°C. The analysis was carried out in a nitrogen environment with a flow rate of 100 ml/min to avoid oxidation. For the experiment, 10 mg of *Helianthus tuberosus* L. fiber was employed.

2.2.4 X-ray photoelectron spectroscopy analysis

With the use of a Thermo Scientific device, the chemical states and surface components of *Helianthus tuberosus* L. fibers were determined. With a resolution of 1 eV, an Al-K α (1486.7eV) X-ray source was used in the range of 1350 and 10 eV. Before the analysis, the sample's surface was sputtered with ionic Ar gas.

2.2.5 X-ray diffraction analysis

The data collected from the X-Ray diffraction pattern of the fibers was used to calculate the crystallinity index and crystallite size using the Rigaku Ultima 3 devices with Cu – K radiation (λ -K α_1 = 1.54 Å). Fibers were chopped into small pieces to fit onto the specimen holder. Scanning was done between 5-80° with a 2°/min scan rate using an XRD instrument set to 40 kV and 30 mA power.

Segal et al. used an empirical formula (Eq. 2) to calculate the crystallinity index (CI) (Segal et al., 1959).

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

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where I_{am} is the least intensity value between the highest two peaks, which is at a 2θ angle between 18° and 19° and corresponds to the (200) lattice plane between 22-23°. The I_{200} is the peak at maximum

intensity between 22-23° that corresponds to the (200) lattice plane (Seki et al., 2013). Scherrer's Eq. (3) was used to compute the crystallite size (L) of fibers acquired from the XRD pattern (Warren, 1990).

$$L = \frac{K\lambda}{\beta \cos \theta}$$

3

where L represents the crystallite size, K represents the Scherrer constant (0.94), λ is the X-ray beam wavelength, and β is the peak full width half maximum (FWHM) in radians and θ is the diffraction angle.

2.2.6 Single fiber tensile test

Helianthus tuberosus L. tensile tests were performed on INSTRON 4411 universal testing equipment with a 1 kgf load cell. With a gauge length of 20 mm, the loading rate was 1 mm/min. Pneumatic grips at a pressure of 0.5 MPa were used to clamp the fiber. The tensile characteristics of *Helianthus tuberosus* L. fiber were determined using ten fiber samples. All tests were carried out in accordance with the ASTM D 3822 standard at standard atmospheric circumstances (20°C ambient temperature and 65 percent relative humidity).

2.2.8 Morphological characterization

The surface and cross-sectional morphologies of *Helianthus tuberosus* L. fibers were studied using a Zeiss Sigma 500 field emission scanning electron microscope (SEM). Secondary electron images were captured with a 20 kV accelerating voltage. Before characterization, *Helianthus tuberosus* L. fibers were sputter coated with Au-Pd alloy to prevent electron charging effects during the investigation.

3. Results And Discussion

3.1 Morphological characterization

Longitudinal and cross-section SEM images of the *Helianthus tuberosus* L. fiber are presented in Fig. 2. General images (taken at lower magnifications) are placed in the upper right part of the images at higher magnifications to clarify morphological explanations. Fiber morphology is of great importance in determining the application area of new natural fiber (Maache et al., 2017). For example, high surface roughness is needed for good composite reinforcement usage to increase contact surface area with the matrix in composite manufacturing (Indran & Raj, 2015). When the longitudinal fiber surface is examined (see Fig. 2 (a)), cellular fiber morphology is observed. Rectangular cell shapes with an average width of about 20 μm and a length of 50 μm reveal very distinctive surface morphology. The protruding structure of the cell walls and the recessed structure of the interior cause a rough fiber surface. As mentioned before, increased surface roughness is a big advantage for composite systems by providing better adherence between the fiber and matrix (Indran & Raj E., 2015). According to Zhang et al., rough surfaces can promote interfacial adhesion between fiber and matrix by mechanical interlocking (Zhang et al., 2018). Non-cellulosic materials present at the fiber surfaces lead to cleaner and smoother surfaces, as

can be observed on the lignocellulosic jute and banana fibers, also at cotton fibers (Kambli et al., 2016). Such fiber needs application surface modification for composite use (do Nascimento et al., 2021).

Helianthus tuberosus L. fiber takes the shape of several multiple elementary fibers called fibrils or fiber-cells connected together in the direction of their length of fibers, as can be observed from Fig. 2 (b). An empty space can be observed in the center of the elementary fibrils (Amroune et al., 2015). It is known as the lumen where water and nutrients flow occur along the fiber. (Sanjay et al., 2018). Such a hollow structure in natural fibers is responsible for the low density characteristic. Furthermore, the porous structure endorses high insulation and absorbance properties to the fiber (Asmanto & Chafidz, 2018). Fibril cells are almost spherical in shape and compactly arranged (Manimaran et al., 2018). However, it can be seen that its shape is slightly distorted as it deforms during the cutting process. While elementary fibrils have a diameter of 9.2 μm , wall thickness is around 2 μm and lumen diameter is about 5.2 μm according to the cross-sectional SEM images in Fig. 2 (b). Since the morphologies of natural fibers are similar, it is the lumen diameter and wall thickness parameters that make the difference. For example, high strength and Young's modulus are associated with the low lumen area and high cell-wall thickness (Fidelis et al., 2013). Accordingly, the introduced new *Helianthus tuberosus* L. fiber has a lower lumen diameter and thicker cell wall than currently used Jute and Sisal fibers (Fidelis et al., 2013). Morphological examinations of the *Helianthus tuberosus* L. fiber revealed that it has advantages such as high surface roughness and wall thickness; and low lumen diameter.

3.2 Thermal analysis

The thermal properties of a new natural fiber are very crucial for usage in composite systems. Natural fibers are preferred in polymer-based composites which are produced generally at relatively high temperatures. The thermal behavior of the natural fiber should be put forward to use its properties at a maximum rate without any degradation. Thermogravimetric (TG) and Differential Thermogravimetry Analysis (DTA) were conducted in this respect and obtained TG and DTG curves of the *Helianthus tuberosus* L. fiber are presented in Fig. 3. Generally speaking, it is seen that the fiber undergoes three fundamental degradations. The first weight loss is observed between 25 and 100°C with 6.3% ratio related to the evaporation of physical water. Also, it is mentioned that the degradation of the hemicellulose occurred in this temperature range (Ridzuan et al., 2016). The second weight loss step starts at 247.3°C and finishes at about 310°C with a ratio of 33.2%. The starting temperature of the second step indicates the onset temperature of the *Helianthus tuberosus* L. fibers (Yao et al., 2008), and is also known as the thermal resistance temperature of the fiber. *Helianthus tuberosus* L. fibers more thermally stable (with onset temperature of 247.3°C) than popular natural fibers such as jute (205.1), hemp (205.1°C) and kenaf (219°C) (Yao et al., 2008).

The third weight loss (about 31.7%) occurs between 310 and 367°C. The second and third weight loss steps are associated with the decomposition of cellulose and lignin in fibers (Baskaran et al., 2018; Mahmood et al., 2016; Saravanakumar et al., 2013). The finishing temperature of the third weight loss known as maximum degradation temperature found as 367°C. In this respect, the thermal analysis showed that *Helianthus tuberosus* L. fiber has an advantage with higher maximum decomposition

temperature than popular natural fibers including sisal (340°C), jute (365°C), and flax (345°C); and than recently characterized cellulosic fibers such as *Chloris Barbata* (324.6°C), *Heteropogon Contortus* (337.7°C), *Acacia Leucophloea* (346.8°C) and *Thespesia populnea* (323.8°C) (Alvarez et al., 2006; Balasundar et al., 2018; Indran & Raj E., 2015; Manfredi et al., 2006; Saravanakumar et al., 2013).

A mass loss of 7.82% from 367° to 800° is also due to the residual content in the fiber (Balasundar et al., 2018). The thermal results showed that due to the high onset temperature, fibers can be used as a reinforcement material in a polymer matrix composites without any degradation (Belouadah et al., 2015; Sarikanat et al., 2014). The high thermal degradation temperatures (247.3 °C) of *Helianthus tuberosus L.* endorse usage in thermoplastics used for NFRPCs are polyolefins like polypropylene (PP) and polyethylene (PE), polyvinyl chloride (PVC), polyamides (nylon), and, recently, biobased polylactic acid (PLA) due to their low processing temperature (< 225 °C) (Zhao et al., 2022).

3.3 Chemical and structural characterizations

3.3.1 Chemical composition

Lignocellulosic fibers like *Helianthus tuberosus L.* consist of cellulose, hemicellulose and lignin basically (Rowell and Stout, 2006). Chemical content of the *Helianthus tuberosus L.* fiber is given in Fig. 4 as a pie chart. *Helianthus tuberosus L.* fiber consists of 62.65% cellulose, 17.36% hemicellulose, 18.49% lignin and other contents 1.5%. Extraction methods, soil properties, age and origin of the plant may affect the chemical composition of cellulosic fibers (Baskaran et al., 2018).

Table 1. Chemical content of the *Helianthus tuberosus L.* fiber and, its place between traditional and up-to-date fibers according to the Cellulose contents.

Fibers		Contents (%)			References
		Cellulose	Hemicellulose	Lignin	
Tradational Fibers	<i>Jute</i>	64.4	12	11.8	(Indran & Raj, 2015)
	<i>Flax</i>	64.1	16.7	2.0	(Indran & Raj, 2015)
	<i>Helianthus tuberosus L.</i>	62.65	17.36	18.49	current study
	<i>Banana</i>	56–63	20–25	7–9	(Indran & Raj, 2015)
	<i>Kenaf</i>	45–57	8–13	21.5	(Indran & Raj, 2015)
	<i>Coir</i>	32–43	0.15–0.25	40–45	(Indran & Raj, 2015)
Up-to-date Fibers	<i>Hierochloe Odarata</i>	70.4	21.5	8.1	(Dalmis et al., 2020b)
	<i>Thespesia populnea</i>	70.27	12.64	16.34	(Kathirselvam et al., 2019)
	<i>Derris scandens</i>	63.3	11.6	15.3	(Perumal & Sarala, 2020)
	<i>Helianthus tuberosus L.</i>	62.65	17.36	18.49	current study
	<i>Cereus Hildmannianus</i>	58.4	17.14	10.36	(Subramanian et al., 2019)
	<i>Curcuma longa L.</i>	56.5	12.4	14.8	(Ilangovan et al., 2018)
	<i>Ficus religiosa</i>	55.58	13.86	10.13	(Moshi et al., 2020)
	<i>Conium maculatum</i>	49.5	32.2	8.6	(Kilinc et al., 2018b)
	<i>Chrysanthemum morifolium</i>	32.9	13.8	53-others	(Dalmis et al., 2020a)
	<i>Tridax procumbens</i>	32.0	6.8	3	(Vijay et al., 2019)

The place of the *Helianthus tuberosus L.* fiber between traditional and up-to-date fibers according to the cellulose content is presented in the Table 1. Cellulose chains cause increase crystallinity and thus enhance mechanical properties of the fibers due to the extensive hydrogen bonds (Silva et al., 2019). Cellulose stands out as the most important chemical component in natural fibers. The high amount of

cellulose content ensures high mechanical properties including strength, toughness, and rigidity to natural fibers (Perumal & Sarala, 2020). *Helianthus tuberosus L.* has a lower cellulose content (with a cellulose ratio of 62.65%) than Jute and Flax while higher than Banana, Kenaf, and Coir among traditional natural fibers. It draws attention with its higher cellulose ratio than up-to-date natural fibers such as *Cereus Hildmannianus*, *Curcuma longa L.*, *Ficus religiosa*, *Conium maculatum*, *Chrysanthemum Morifolium* and *Tridax procumbens*.

Hemicellulose part is related to the moisture content of the fiber due to its amorphous structure. *Helianthus tuberosus L.* fiber appears to contain hemicelluloses content comparable to the natural fibers such as Flax, Banana, and *Cereus Hildmannianus*. It can be seen as an advantage that it does not have high hemicellulose ratios such as 30–40% as the large amount of hemicellulose existence diminishes the strength of the fiber (Manimaran et al., 2018). The lignin influences structural properties, moisture resistance, bonding nature, and morphology of the fiber. Moreover, it behaves as a protection shield against fungal or bacterial attacks (Balaji & Nagarajan, 2017; Binoj et al., 2018; Perumal & Sarala, 2020). Therefore, a low amount of lignin content causes the disintegration of cellulose microfibrils (Indran & Raj, 2015). However, as can be seen in the Table 1, the *Helianthus tuberosus L.* fiber has the highest lignin ratio in the table, excluding the coir. So, it can be said that the structural integrity of the newly proposed natural fiber is quite good. the ratio of remaining fiber components like oils and waxes was determined as 1.5%. As a result, the fiber can be assumed as a strong natural fiber promising high mechanical strength with its relatively low hemicellulose content as well as high cellulose and lignin ratios. In addition, introduced fiber can find an application area use of cellulose within different industries, as Moran et. al obtained nano-cellulose from Sisal fiber containing 50–74% cellulose (Moran et al., 2008).

3.3.2 FTIR analysis

FT-IR spectroscopy was used to characterize the primary components of natural fiber including lignin, cellulose, and hemicellulose, as well as their functional groups like ester, ketone, and alcohol (De Rosa et al., 2010; Fan et al., 2011). Figure 5 shows the functional groups of *Helianthus tuberosus L.* fibers, with a range of 4000 – 650 cm^{-1} . The spectrum shows a large peak at 3346 cm^{-1} attributable to cellulose's distinctive O-H stretching vibrations (Porrás et al., 2015). The C-H stretching vibrations of CH and CH₂ in cellulose and hemicellulose are assigned to the peak at 2920 cm^{-1} (Oh et al., 2005). The peak at 1734 cm^{-1} was associated with the stretching vibration of the C = O group in the ester group of hemicellulose or carboxylic acid in lignin.

Table 2. FTIR peak results of *Helianthus tuberosus L.* according to the associated bonds and chemical component kinds

Absorbsion wavelength (cm^{-1})	Associated bonds	Related natural fiber components		
		Cellulose	Hemisellulose	Lignin
3346	O-H strecthing	+	-	-
2920	C-H strecthing	+	+	-
1734	C = O stretching	-	+	+
1628	H-O-H bending	+	-	+
1508	C = C strecthing	-	-	+
1422	C-H bending	+	-	-
1372	C-H bending	+	-	+
1334	C-O strecthing/bonding	+	-	-
1234	C-O strecthing	-	-	+
898	C–O–C stretching	+	-	-

The H-O-H bending vibration of water in lignin or cellulose is responsible for the pronounced absorption peak at 1630 cm^{-1} (De Rosa et al., 2011; De Rosa et al., 2010). The C = C stretching of aromatic lignin in the fiber correlates to the minor peak at roughly 1508 cm^{-1} (Kilinc et al., 2018b). The peak at 1422 cm^{-1} corresponds to cellulose's C-H symmetric bending of CH_2 (Sgriccia et al., 2008). The absorption peak at 1372 cm^{-1} is related to the C-H bending bond of cellulose and hemicellulose (El Oudiani et al., 2017). The peak at 1332 cm^{-1} corresponds to C–O stretching and bending in cellulose's CH plane (do Nascimento et al., 2021; El Oudiani et al., 2017). The peak at 1234 cm^{-1} is related to the C–O stretching vibration of the acetyl groups in lignin (Tawakkal et al., 2016). The C-O and O-H stretching vibrations in fiber are responsible for the sharp peak near 1034 cm^{-1} (Dalmis et al., 2020b). The band at 896 cm^{-1} is associated with C–O–C asymmetrical stretching bonds of b-glycosidic amorphous cellulose (Chimeni et al., 2016; Mwaikambo & Ansell, 2002). All these FTIR results according to the associated bonds and chemical component kinds are summarized in Table 2.

As can be understood from Table 2, basic components of natural fiber including lignin, cellulose, and hemicellulose are present in the *Helianthus tuberosus L.* fiber similar to the most commonly used natural fiber (Keshk et al., 2006; Saha et al., 2010; Sawpan et al., 2011).

3.3.3 XPS analysis

XPS was used to analyze the chemical states and composition of *Helianthus tuberosus L.* fiber. As can be seen from general XPS survey in Fig. 6 (a) the main component of the fiber surface is Carbon (C) that is followed by Oxygen (O). Small amounts of Silicon (Si) and Nitrogen (N) elements were also detected.

The elemental compositions of the *Helianthus tuberosus L.* fiber together with some other natural fibers are presented in Table 3. Carbon and Oxygen concentrations were found to be 69.39% and 25.85%, while Si and N concentrations were detected as 3.91 and 2.53, respectively. Small amounts of Si and N atoms typically emerge from the soil, and natural contaminants stick to the fiber's external surface (Perumal & Sarala, 2020).

Figure 6 (b) and (c) show the high-resolution XPS spectra of the C1s and O1s peaks, respectively. Deconvolution analysis was performed in order to determine the content of the functional groups. The most significant signal for C1s, at 285.52 eV, represents C-C and C-H bonds, which can suggest the existence of cellulose or ether (Pandey et al., 2020). The O1s peak at 532.25 eV is of cellulosic or cyanoethyl cellulose, which has a C-O-C bond and indicates the existence of cellulose in the substance (Pandey et al., 2020).

Table 3
Elemental composition of the *Helianthus tuberosus L.* fiber and some other fibers

Natural Fibers	Elemental composition (%)				O/C	C/O	References
	C1s	O1s	N1s	Si2p			
<i>Helianthus tuberosus L.</i>	69.39	25.85	2.79	1.96	0.37	2.68	Current study
<i>Conium maculatum</i>	69.22	15.05	2.53	3.91	0.21	0.22	(Kilinc et al., 2018b)
<i>Hierochloe Odarata</i>	63.80	30.45	1.38	2.49	0.47	0.48	(Dalmis et al., 2020b)
<i>Chrysanthemum morifolium</i>	66.33	27.45		6.52	0.41	2.40	(Dalmis et al., 2020a)
<i>Centaurea solstitialis</i>	59.08	32.17		8.75	0.54	1.83	(Keskin et al., 2020)
<i>Derris scandens</i>	80.16	19.33		0.32	0.24	4.14	(Perumal & Sarala, 2020)
Jute	64.3	29.7	1.8	2.8	0.46	2.09	(Bulut & Aksit, 2013)
Kenaf	62.34	27.96	2.68	4.26	0.45	2.38	(Sgriccia et al., 2008)
<i>Flax</i>	83.88	16.12			0.15	5.20	(Sgriccia et al., 2008)
<i>Hemp</i>	76.79	20.48	2.19		0.27	3.74	(Sgriccia et al., 2008)

Carbon/Oxygen (C/O) and Oxygen /Carbon (O/C) ratios of fibers are used to determine the surface hydrophilic or hydrophobic characteristics. Therefore, the O/C and C/O data of the *Helianthus tuberosus L.* and some current and conventional natural fibers along are gathered in Table 3. The low O/C ratio of fibers indicates that there is less wax and lignin on the fiber surface (Perumal & Sarala, 2020). When we look at the O/C ratios, it can be seen from Table 3 that *Helianthus tuberosus L.* has lower value than

many other fibers, except for a few fibers including *Conium maculatum*, *Derris scandens*, Flax, and Hemp. The hydrophobic surface characteristic of fibers is generally associated with a high C/O ratio, and this parameter is crucial for cellulose-based fiber-reinforced composite materials (Sernek et al., 2004). When we look at the C/O ratios, *Helianthus tuberosus* L. has lower than only *Derris scandens*, Flax, and Hemp fibers. *Helianthus tuberosus* L. fiber is suitable for use as a reinforcement in many polymer-based composites because it has a higher C/O value than all the remaining fibers in Table 3.

3.3.4 XRD analysis

The X-ray diffraction pattern of the *Helianthus tuberosus* L. fiber is presented in Fig. 7 together with the simulated cellulose I β pattern from the Mercury software. As can be seen from Fig. 7, the *Helianthus tuberosus* L. fiber has diffraction peaks at the following Bragg angles 14.98°, 16.58°, 22.14° and 34.78° corresponding to the (1 1 0), (110), (200) and (004) planes, respectively (del Cerro et al., 2020; French, 2014). The minimum intensity between the (110) and (200) peaks represents the amorphous content (Segal et al., 1959). The minimum intensity at 18.52° is utilized to the determination of the I_{am} value which is used for the calculation of the crystallinity index (CI). The basic XRD peak at 22.14° (related to the 200 plane) which is characteristic of cellulosic materials, also helps to find the I_{200} required in the CI formula.

Natural fibers' crystallinity is proportional to their mechanical properties. The cellulose chains become more consistently aligned as crystallinity increases, which serves to improve the tensile strength of the fibers (Ehrenstein, 2012). As a result, when natural fibers are intended to be used as reinforcement in polymeric matrix composites, these characteristics might be extremely desirable (do Nascimento et al., 2021). Increased crystallinity as a reinforcement aids in the manufacture of high-strength composites. Moreover, high CI helps to improve thermal degradation temperature of natural fibers (Kim et al., 2010). The crystallinity index of *Helianthus tuberosus* L. fiber is 63.11% according to the Segal formula (2). High crystallinity index of *Helianthus tuberosus* L. fiber is suitable with the high maximum degradation temperature of fibers (Jonoobi et al., 2009). Crystallite size (L) of the *Helianthus tuberosus* L. fiber was calculated by the Scherrer's Eq. (3) found as 21.8 Å. The percentage of amorphous structure decreases as crystallite size grows, raising the cellulose's CI (Kim et al., 2010).

3.4 Mechanical properties

Natural fibers' mechanical characteristics are heavily influenced by their structure and chemical content. When the literature is examined, it is clear that the claimed mechanical properties of cellulose-based fibers have a diverse variety. Diversity can be attributed to a variety of factors, including test settings, plant features, extraction, maturity, growth conditions, harvesting period, degree of retting, irregular cross-section, section measurements, and imperfections on the fiber surface, among others (Fidelis et al., 2013; Kilinc et al., 2018b; Owonubi et al., 2019). High cellulose content, on the other hand, is known to improve tensile strength and modulus values because cellulose has special properties such as a high degree of polymerization and a linear orientation (Baskaran et al., 2018; Senthamaraikannan et al., 2019; Thakur &

Singha, 2010). Apart from reinforcing fiber mechanical characteristics, it is well known that the mechanical properties of fiber-reinforced composites are influenced by other factors such as matrix composition, matrix mechanical properties, fiber orientation angle, fiber-matrix shear strength, and adhesion, and so on (Amroune et al., 2020; Goda et al., 2009; Saheb & Jog, 1999; Shesan et al., 2019).

Table 4
Mechanical properties of *Helianthus tuberosus* L. together with some natural fibers

Fiber Name	Cellulose content (%)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Reference
Banana	62.4	529–759	8–20	1–3.5	(Prasad & Rao, 2011)
Cotton	89	500	8	7	(Fiore et al., 2014)
<i>Trachelospermum jasminoides</i>	62.7	404.0	32.3	1.8	(Gedik, 2021)
<i>Sansevieria ehrenbergii</i>	80	343.67 ± 242.99	3.29 ± 1.79	9.05 ± 2.61	(Sathishkumar et al., 2013)
<i>Conium maculatum</i>	49.5	327.89 ± 67.41	15.77 ± 3.15	2.67 ± 0.53	(Kilinc et al., 2018b)
Jute	67	325	37.5	2.5	(do Nascimento et al., 2021)
<i>Helianthus tuberosus</i> L.	62.65	144.11 ± 94.2	2.58 ± 2.77	6.92 ± 2.18	Current study
<i>Centaurea solstitialis</i>	57.20	111.85 ± 24.97	3.41 ± 0.62	3.32 ± 0.67	(Keskin et al., 2020)
<i>Hierochloe Odarata</i>	70.4	105.73 ± 35.42	2.56 ± 0.98	2.37 ± 0.95	(Dalmis et al., 2020b)
<i>Palm leaf stalk fibre (WLF)</i>	77.94 ± 0.87	65.67 ± 21	3.64 ± 1.11	1.8 ± 0.623	(Mayandi et al., 2015)
<i>Grewia tilifolia</i>	62.8	65.2	4.57	1.6	(Jayaramudu et al., 2010)
<i>Chrysanthemum morifolium</i>	32.9	65.12 ± 25.04	1.55 ± 0.76	4.51 ± 0.95	(Dalmis et al., 2020a)
<i>Veldt-grape stem fibre (VSF)</i>	81.38 ± 1.61	61.42 ± 17.3	1.1 ± 0.315	5.6 ± 1.37	(Mayandi et al., 2015)
<i>Catharanthus roseus</i>	47.3	27.02 ± 1.1	1.23 ± 0.04	2.15 ± 0.1	(Vinod et al., 2019)
<i>Tridax procumbens</i>	32.0	25.75	0.94 ± 0.09	2.77 ± 0.27	(Vijay et al., 2019)

Mechanical properties of the *Helianthus tuberosus* L. and some lignocellulosic fibers together with their cellulose content are listed in Table 4. Natural fibers are listed according to their tensile strength values in Table 4. As can be observed from Table 4, *Helianthus tuberosus* L. fiber has a higher tensile strength than

most of the fibers in the list. When the values are compared, it can be seen that while the cellulose content of *Helianthus tuberosus L.* is lower than Hierochloe Odarata, Palm leaf stalk (WLF) and Veldt-grape stem (VSF) fibers it has higher tensile strength values. The exceptional strength of the fibers despite their low cellulose percentage can be attributed to the more regular production of cellulosic chains (Ehrenstein, 2012). It can be said that Young's modulus of the fiber is lower than the others and the elongation at the break value is higher, in general (see Table 4). Its high strength and elongation value show that the fiber can be easily used in polymer-based natural composites.

Conclusion

Helianthus tuberosus L. fiber has a morphological advantage with its cellular structure for composites by providing better adhesion. Thus, the fiber can be used as reinforcement in composites without any surface modification. The high thermal degradation temperature (247.3 °C) of *Helianthus tuberosus L.* endorses utilization in thermoplastic-based composites due to their low processing temperature. *Helianthus tuberosus L.* fiber has 62.65% cellulose, 17.36% hemicellulose, 18.49% lignin and 1.5% others. These components were proved by the FTIR results. Due to the high cellulose content, it can find use in many industries such as paper and paperboard productions. *Helianthus tuberosus L.* fiber shows another superiority with a high C/O value for usage as a reinforcement in green composites. The crystallinity index of *Helianthus tuberosus L.* fiber was found as 63.11% while crystallite size was 21.8 Å. The *Helianthus tuberosus L.* fiber outperformed many natural fibers with its 144.11 MPa tensile strength. Consequently, *Helianthus tuberosus L.* fiber is a very good reinforcement candidate for green composites with high surface roughness, high thermal resistance, high cellulose content, high crystallinity and high tensile strength.

Declarations

Acknowledgement

I would want to express my gratitude to the Center for Fabrication and Application of Electronic Materials at Dokuz Eylul University.

References

1. Alvarez V, Rodriguez E, Vazquez A (2006) Thermal degradation and decomposition of jute/vinylester composites. J Therm Anal Calorim 85(2):383–389
2. Amroune S, Belaadi A, Dalmis R, Seki Y, Makhoulouf A, Satha H (2020) Quantitatively Investigating the effects of fiber parameters on tensile and flexural response of flax/epoxy biocomposites. Journal of Natural Fibers, 1–16
3. Amroune S, Bezazi A, Belaadi A, Zhu CC, Scarpa F, Rahatekar S, Imad A (2015) Tensile mechanical properties and surface chemical sensitivity of technical fibres from date palm fruit branches (*Phoenix dactylifera L.*). Compos Part a-Applied Sci Manuf 71:95–106

4. Asmanto S, Chafidz A (2018) Banana pseudo-stem fiber: Preparation, characteristics, and applications. in: *Banana Nutrition-Function and Processing Kinetics*, IntechOpen
5. Balaji AN, Nagarajan KJ (2017) Characterization of alkali treated and untreated new cellulosic fiber from Saharan aloe vera cactus leaves. *Carbohydr Polym* 174:200–208
6. Balasundar P, Narayanasamy P, Senthamaraikannan P, Senthil S, Prithvirajan R, Ramkumar T (2018) Extraction and Characterization of New Natural Cellulosic Chloris barbata Fiber. *J Nat Fibers* 15(3):436–444
7. Baskaran PG, Kathiresan M, Senthamaraikannan P, Saravanakumar SS (2018) Characterization of New Natural Cellulosic Fiber from the Bark of Dichrostachys Cinerea. *J Nat Fibers* 15(1):62–68
8. Belouadah Z, Ati A, Rokbi M (2015) Characterization of new natural cellulosic fiber from Lygeum spartum L. *Carbohydr Polym* 134:429–437
9. Binoj JS, Raj RE, Indran S (2018) Characterization of industrial discarded fruit wastes (Tamarindus Indica L.) as potential alternate for man-made vitreous fiber in polymer composites. *Process Saf Environ Prot* 116:527–534
10. Bulut Y, Aksit A (2013) A comparative study on chemical treatment of jute fiber: potassium dichromate, potassium permanganate and sodium perborate trihydrate. *Cellulose* 20(6):3155–3164
11. Chimeni DY, Toupe JL, Dubois C, Rodrigue D (2016) Effect of hemp surface modification on the morphological and tensile properties of linear medium density polyethylene (LMDPE) composites. *Compos Interfaces* 23(5):405–421
12. Dalmis R, Kilic GB, Seki Y, Koktas S, Keskin OY (2020a) Characterization of a novel natural cellulosic fiber extracted from the stem of Chrysanthemum morifolium. *Cellulose* 27(15):8621–8634
13. Dalmis R, Koktas S, Seki Y, Kilinc AC (2020b) Characterization of a new natural cellulose based fiber from Hierochloe Odarata. *Cellulose*
14. De Rosa IM, Kenny JM, Maniruzzaman M, Moniruzzaman M, Monti M, Puglia D, Santulli C, Sarasini F (2011) Effect of chemical treatments on the mechanical and thermal behaviour of okra (Abelmoschus esculentus) fibres. *Compos Sci Technol* 71(2):246–254
15. De Rosa IM, Kenny JM, Puglia D, Santulli C, Sarasini F (2010) Morphological, thermal and mechanical characterization of okra (Abelmoschus esculentus) fibres as potential reinforcement in polymer composites. *Compos Sci Technol* 70(1):116–122
16. del Cerro DR, Koso TV, Kakko T, King AWT, Kilpelainen I (2020) Crystallinity reduction and enhancement in the chemical reactivity of cellulose by non-dissolving pre-treatment with tetrabutylphosphonium acetate. *Cellulose* 27(10):5545–5562
17. do Nascimento HM, dos Santos A, Duarte VA, Bittencourt PRS, Radovanovic E, Favaro SL (2021) Characterization of natural cellulosic fibers from Yucca aloifolia L. leaf as potential reinforcement of polymer composites. *Cellulose* 28(9):5477–5492
18. Ehrenstein GW (2012) Polymeric materials: structure, properties, applications. Carl Hanser Verlag GmbH Co KG

19. El Oudiani A, Msahli S, Sakli F (2017) In-depth study of agave fiber structure using Fourier transform infrared spectroscopy. *Carbohydr Polym* 164:242–248
20. Fan M, Dai D, Huang B (2011) Fourier Transform Infrared Spectroscopy for Natural Fibres. in: *Fourier transform-materials analysis*, pp. 45–68
21. Fidelis M, Pereira T, Gomes O, Silva F, Toledo Filho R (2013) The effect of fiber morphology on the tensile strength of natural fibers. *J Mater Res Technol* 2:149–157
22. Fiore V, Scalici T, Valenza A (2014) Characterization of a new natural fiber from *Arundo donax* L. as potential reinforcement of polymer composites. *Carbohydr Polym* 106:77–83
23. French AD (2014) Idealized powder diffraction patterns for cellulose polymorphs. *Cellulose* 21(2):885–896
24. Ganapathy T, Sathiskumar R, Senthamaraikannan P, Saravanakumar SS, Khan A (2019) Characterization of raw and alkali treated new natural cellulosic fibres extracted from the aerial roots of banyan tree. *Int J Biol Macromol* 138:573–581
25. Gedik G (2021) Extraction of new natural cellulosic fiber from *Trachelospermum jasminoides* (star jasmine) and its characterization for textile and composite uses. *Cellulose* 28(11):6899–6915
26. Goda K, Takagi H, Netravali AN (2009) Fully biodegradable green composites reinforced with natural fibers. in: *Natural Fibre Reinforced Polymer Composites*, Old City Publishing pp. 329–360
27. Ilangovan M, Guna V, Hu C, Nagananda GS, Reddy N (2018) *Curcuma longa* L. plant residue as a source for natural cellulose fibers with antimicrobial activity. *Ind Crops Prod* 112:556–560
28. Indran S, Raj E., R (2015) Characterization of new natural cellulosic fiber from *Cissusquadrangularis* stem. *Carbohydr Polym* 117:392–399
29. Indran S, Raj RE (2015) Characterization of new natural cellulosic fiber from *Cissus quadrangularis* stem. *Carbohydr Polym* 117:392–399
30. Indran S, Raj RE, Sreenivasan VS (2014) Characterization of new natural cellulosic fiber from *Cissus quadrangularis* root. *Carbohydr Polym* 110:423–429
31. Jayaramudu J, Guduri BR, Rajulu AV (2010) Characterization of new natural cellulosic fabric *Grewia tilifolia*. *Carbohydr Polym* 79(4):847–851
32. Jonoobi M, Harun J, Shakeri A, Misra M, Oksman K (2009) CHEMICAL COMPOSITION, CRYSTALLINITY, AND THERMAL DEGRADATION OF BLEACHED AND UNBLEACHED KENAF BAST (*Hibiscus cannabinus*) PULP AND NANOFIBERS. *BioResources* 4(2):626–639
33. Kambli N, Basak S, Samanta KK, Deshmukh RR (2016) Extraction of Natural Cellulosic Fibers from Cornhusk and Its Physico-Chemical Properties. *Fibers Polym* 17(5):687–694
34. Karthi N, Kumaresan K, Sathish S, Gokulkumar S, Prabhu L, Vigneshkumar N (2020) An overview: Natural fiber reinforced hybrid composites, chemical treatments and application areas. *Materials Today: Proceedings*
35. Kathirselvam M, Kumaravel A, Arthanarieswaran VP, Saravanakumar SS (2019) Isolation and characterization of cellulose fibers from *Thespesia populnea* barks: A study on physicochemical and

- structural properties. *Int J Biol Macromol* 129:396–406
36. Keshk S, Suwinarti W, Sameshima K (2006) Physicochemical characterization of different treatment sequences on kenaf bast fiber. *Carbohydr Polym* 65(2):202–206
 37. Keskin OY, Dalmis R, Kilic GB, Seki Y, Koktas S (2020) Extraction and characterization of cellulosic fiber from *Centaurea solstitialis* for composites. *Cellulose* 27(17):9963–9974
 38. Kilinc AC, Atagur M, Ozdemir O, Sen I, Kucukdogan N, Sever K, Seydibeyoglu O, Sarikanat M, Seki Y (2016) Manufacturing and characterization of vine stem reinforced high density polyethylene composites. *Compos Part B-Engineering* 91:267–274
 39. Kilinc AC, Koktas S, Atagur M, Seydibeyoglu MO (2018a) Effect of Extraction Methods on the Properties of *Althea Officinalis* L. Fibers. *J Nat Fibers* 15(3):325–336
 40. Kilinc AC, Koktas S, Seki Y, Atagur M, Dalmis R, Erdogan UH, Goktas AA, Seydibeyoglu MO (2018b) Extraction and investigation of lightweight and porous natural fiber from *Conium maculatum* as a potential reinforcement for composite materials in transportation. *Compos Part B-Engineering* 140:1–8
 41. Kim UJ, Eom SH, Wada M (2010) Thermal decomposition of native cellulose: Influence on crystallite size. *Polym Degrad Stab* 95(5):778–781
 42. Kulandaivel N, Muralikannan R, KalyanaSundaram S (2020) Extraction and Characterization of Novel Natural Cellulosic Fibers from Pigeon Pea Plant. *J Nat Fibers* 17(5):769–779
 43. Liu C, Luan PC, Li Q, Cheng Z, Sun X, Cao DX, Zhu HL (2020) Biodegradable, Hygienic, and Compostable Tableware from Hybrid Sugarcane and Bamboo Fibers as Plastic Alternative. *Matter* 3(6):2066–2079
 44. Maache M, Bezazi A, Amroune S, Scarpa F, Dufresne A (2017) Characterization of a novel natural cellulosic fiber from *Juncus effusus* L. *Carbohydr Polym* 171:163–172
 45. Madhu P, Sanjay MR, Jawaaid M, Siengchin S, Khan A, Pruncu CI (2020) A new study on effect of various chemical treatments on *Agave Americana* fiber for composite reinforcement: Physico-chemical, thermal, mechanical and morphological properties. *Polymer Testing*, **85**
 46. Mahmood H, Moniruzzaman M, Yusup S, Akil HM (2016) Pretreatment of oil palm biomass with ionic liquids: a new approach for fabrication of green composite board. *J Clean Prod* 126:677–685
 47. Manfredi LB, Rodriguez ES, Wladyka-Przybylak M, Vazquez A (2006) Thermal degradation and fire resistance of unsaturated polyester, modified acrylic resins and their composites with natural fibres. *Polym Degrad Stab* 91(2):255–261
 48. Manimaran P, Senthamaraiannan P, Sanjay MR, Marichelvam MK, Jawaaid M (2018) Study on characterization of *Furcraea foetida* new natural fiber as composite reinforcement for lightweight applications. *Carbohydr Polym* 181:650–658
 49. Mayandi K, Rajini N, Pitchipoo P, Sreenivasan VS, Jappes JTW, Alavudeen A (2015) A comparative study on characterisations of *Cissus quadrangularis* and *Phoenix reclinata* natural fibres. *J Reinf Plast Compos* 34(4):269–280

50. Moazzem S, Wang LJ, Daver F, Crossin E (2021) Environmental impact of discarded apparel landfilling and recycling. *Resources Conservation and Recycling*, **166**
51. Moran JI, Alvarez VA, Cyras VP, Vazquez A (2008) Extraction of cellulose and preparation of nanocellulose from sisal fibers. *Cellulose* 15(1):149–159
52. Moshi AAM, Ravindran D, Bharathi SRS, Indran S, Saravanakumar SS, Liu YC (2020) Characterization of a new cellulosic natural fiber extracted from the root of *Ficus religiosa* tree. *Int J Biol Macromol* 142:212–221
53. Mwaikambo LY, Ansell MP (2002) Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization. *J Appl Polym Sci* 84(12):2222–2234
54. Oh SY, Yoo DI, Shin Y, Seo G (2005) FTIR analysis of cellulose treated with sodium hydroxide and carbon dioxide. *Carbohydr Res* 340(3):417–428
55. Owonubi JS, Agwuncha CS, Anusionwu GC, Revaprasadu N, Rotimi SE (2019) Improving the Mechanical Properties of Natural Fiber Composites for Structural and Biomedical Applications. in: *Renewable and Sustainable Composites IntechOpen*
56. Ozgoren E, Isik F, Yapar A (2019) Effect of Jerusalem artichoke (*Helianthus tuberosus* L.) supplementation on chemical and nutritional properties of crackers. *J Food Meas Charact* 13(4):2812–2821
57. Pandey R, Sinha MK, Dubey A (2020) Cellulosic fibers from Lotus (*Nelumbo nucifera*) peduncle. *J Nat Fibers* 17(2):298–309
58. Parparita E, Uddin MA, Watanabe T, Kato Y, Yanik J, Vasile C (2015) Gas production by steam gasification of polypropylene/biomass waste composites in a dual-bed reactor. *J Mater Cycles Waste Manage* 17(4):756–768
59. Perumal CI, Sarala R (2020) Characterization of a new natural cellulosic fiber extracted from *Derris scandens* stem. *Int J Biol Macromol* 165:2303–2313
60. Porras A, Maranon A, Ashcroft IA (2015) Characterization of a novel natural cellulose fabric from *Manicaria saccifera* palm as possible reinforcement of composite materials. *Compos Part B-Engineering* 74:66–73
61. Prasad AVR, Rao KM (2011) Mechanical properties of natural fibre reinforced polyester composites: Jowar, sisal and bamboo. *Mater Design* 32(8–9):4658–4663
62. Ridzuan MJM, Majid MSA, Afendi M, Kanafiah SNA, Zahri JM, Gibson AG (2016) Characterisation of natural cellulosic fibre from *Pennisetum purpureum* stem as potential reinforcement of polymer composites. *Mater Design* 89:839–847
63. Saha P, Manna S, Chowdhury SR, Sen R, Roy D, Adhikari B (2010) Enhancement of tensile strength of lignocellulosic jute fibers by alkali-steam treatment. *Bioresour Technol* 101(9):3182–3187
64. Saheb DN, Jog JP (1999) Natural fiber polymer composites: A review. *Adv Polym Technol* 18(4):351–363

65. Sanjay MR, Madhu P, Jawaid M, Senthamaraikannan P, Senthil S, Pradeep S (2018) Characterization and properties of natural fiber polymer composites: A comprehensive review. *J Clean Prod* 172:566–581
66. Sanjay MR, Siengchin S, Parameswaranpillai J, Jawaid M, Pruncu CI, Khan A (2019) A comprehensive review of techniques for natural fibers as reinforcement in composites: Preparation, processing and characterization. *Carbohydr Polym* 207:108–121
67. Saravanakumar SS, Kumaravel A, Nagarajan T, Sudhakar P, Baskaran R (2013) Characterization of a novel natural cellulosic fiber from *Prosopis juliflora* bark. *Carbohydr Polym* 92(2):1928–1933
68. Sarikanat M, Seki Y, Sever K, Durmuskahya C (2014) Determination of properties of *Althaea officinalis* L. (Marshmallow) fibres as a potential plant fibre in polymeric composite materials. *Compos Part B-Engineering* 57:180–186
69. Sathishkumar TP, Navaneethakrishnan P, Shankar S, Rajasekar R (2013) Characterization of new cellulose *sansevieria ehrenbergii* fibers for polymer composites. *Compos Interfaces* 20(8):575–593
70. Sawpan MA, Pickering KL, Fernyhough A (2011) Effect of various chemical treatments on the fibre structure and tensile properties of industrial hemp fibres. *Compos Part a-Applied Sci Manuf* 42(8):888–895
71. Segal L, Creely JJ, Martin AE, Conrad CM (1959) An empirical method for estimating the degree of crystallinity of native cellulose using the X-ray diffractometer. *Text Res J* 29(10):786–794
72. Seki Y, Kilinc AC, Dalmis R, Atagur M, Koktas S, Goktas AA, Celik E, Seydibeyoglu MO, Onay AB (2018) Surface modification of new cellulose fiber extracted from *Conium maculatum* plant: a comparative study. *Cellulose* 25(6):3267–3280
73. Seki Y, Kilinc AC, Dalmis R, Koktas S, Celik E (2019a) Characterization of Flax, Jute, and Sisal Fibers after Sodium Perborate Modification. *Aatcc J Res* 6(6):25–31
74. Seki Y, Koktas S, Kilinc AC, Dalmis R (2019b) Green alternative treatment for cellulosic fibers: ionic liquid modification of *Abelmoschus esculentus* fibers with methyl-tri-n-butyl ammonium methyl sulphate. *Materials Research Express*, 6(8)
75. Seki Y, Sarikanat M, Sever K, Durmuskahya C (2013) Extraction and properties of *Ferula communis* (chakshir) fibers as novel reinforcement for composites materials. *Compos Part B-Engineering* 44(1):517–523
76. Senthamaraikannan P, Kathiresan M (2018) Characterization of raw and alkali treated new natural cellulosic fiber from *Coccinia grandis*. *L Carbohydr Polym* 186:332–343
77. Senthamaraikannan P, Sanjay MR, Bhat KS, Padmaraj NH, Jawaid M (2019) Characterization of natural cellulosic fiber from bark of *Albizia amara*. *J Nat Fibers* 16(8):1124–1131
78. Senthilkumar K, Saba N, Chandrasekar M, Jawaid M, Rajini N, Alothman OY, Siengchin S (2019) Evaluation of mechanical and free vibration properties of the pineapple leaf fibre reinforced polyester composites. *Constr Build Mater* 195:423–431
79. Sernek M, Kamke FA, Glasser WG (2004) Comparative analysis of inactivated wood surfaces. *Holzforschung* 58(1):22–31

80. Sgriccia N, Hawley MC, Misra M (2008) Characterization of natural fiber surfaces and natural fiber composites. *Compos Part a-Applied Sci Manuf* 39(10):1632–1637
81. Shesan OJ, Stephen AC, Chioma AG, Neerish R, Rotimi SE (2019) Improving the Mechanical Properties of Natural Fiber Composites for Structural and Biomedical Applications. in: *Renewable and Sustainable Composites*, IntechOpen
82. Siakeng R, Jawaaid M, Ariffin H, Sapuan SM, Asim M, Saba N (2019) Natural fiber reinforced polylactic acid composites: A review. *Polym Compos* 40(2):446–463
83. Silva AMBd, Luz SMD, Siva I, Jappes JTW, Amico SC (2019) An Overview on Plant Fiber Technology: An Interdisciplinary Approach. in: *In Sustainable Polymer Composites and Nanocomposites*. Springer, pp 977–999
84. Subramanian S, Rajkumar G, Ramkumar R, T (2019) Characterization of Natural Cellulosic Fiber from *Cereus Hildmannianus*. *Journal of Natural Fibers*
85. Swanton CJ, Cavers PB, Clements DR, Moore MJ (1992) The Biology of Canadian Weeds. 101. *Helianthus-Tuberosus* L. *Can J Plant Sci* 72(4):1367–1382
86. Tawakkal ISMA, Cran MJ, Bigger SW (2016) Interaction and quantification of thymol in active PLA-based materials containing natural fibers. *Journal of Applied Polymer Science*, **133**(2)
87. Thakur VK, Singha AS (2010) Natural fibres-based polymers: Part I-Mechanical analysis of Pine needles reinforced biocomposites. *Bull Mater Sci* 33(3):257–264
88. Vaisanen T, Das O, Tomppo L (2017) A review on new bio-based constituents for natural fiber-polymer composites. *J Clean Prod* 149:582–596
89. Vijay R, Singaravelu DL, Vinod A, Sanjay MR, Siengchin S, Jawaaid M, Khan A, Parameswaranpillai J (2019) Characterization of raw and alkali treated new natural cellulosic fibers from *Tridax procumbens*. *Int J Biol Macromol* 125:99–108
90. Vinod A, Vijay R, Singaravelu DL, Sanjay MR, Siengchin S, Moure MM (2019) Characterization of untreated and alkali treated natural fibers extracted from the stem of *Catharanthus roseus*. *Materials Research Express*, **6**(8)
91. Warren BE (1990) X-ray Diffraction. Courier Corporation
92. Yao F, Wu QL, Lei Y, Guo WH, Xu YJ (2008) Thermal decomposition kinetics of natural fibers: Activation energy with dynamic thermogravimetric analysis. *Polym Degrad Stab* 93(1):90–98
93. Zhang K, Wang FX, Liang WY, Wang ZQ, Duan ZW, Yang B (2018) Thermal and Mechanical Properties of Bamboo Fiber Reinforced Epoxy Composites. *Polymers*, **10**(6)
94. Zhao XH, Copenhaver K, Wang L, Korey M, Gardner DJ, Li K, Lamm ME, Kishore V, Bhagia S, Tajvidi M, Tekinalp H, Oyedeji O, Wasti S, Webb E, Ragauskas AJ, Zhu HL, Peter WH, Ozcan S (2022) Recycling of natural fiber composites: Challenges and opportunities. *Resources Conservation and Recycling*, **177**
95. Zhao XH, Li K, Wang Y, Tekinalp H, Richard A, Webb E, Ozcan S (2020) Bio-treatment of poplar via amino acid for interface control in biocomposites. *Composites Part B-Engineering*, **199**

Figures



Figure 1

Graphical abstract showing the fiber extraction stages from the harvesting of the *Helianthus tuberosus* L. plant. The tuber part of the plant, which has nutritional value, was separated and the remaining stem part of the plant was used for fiber production.

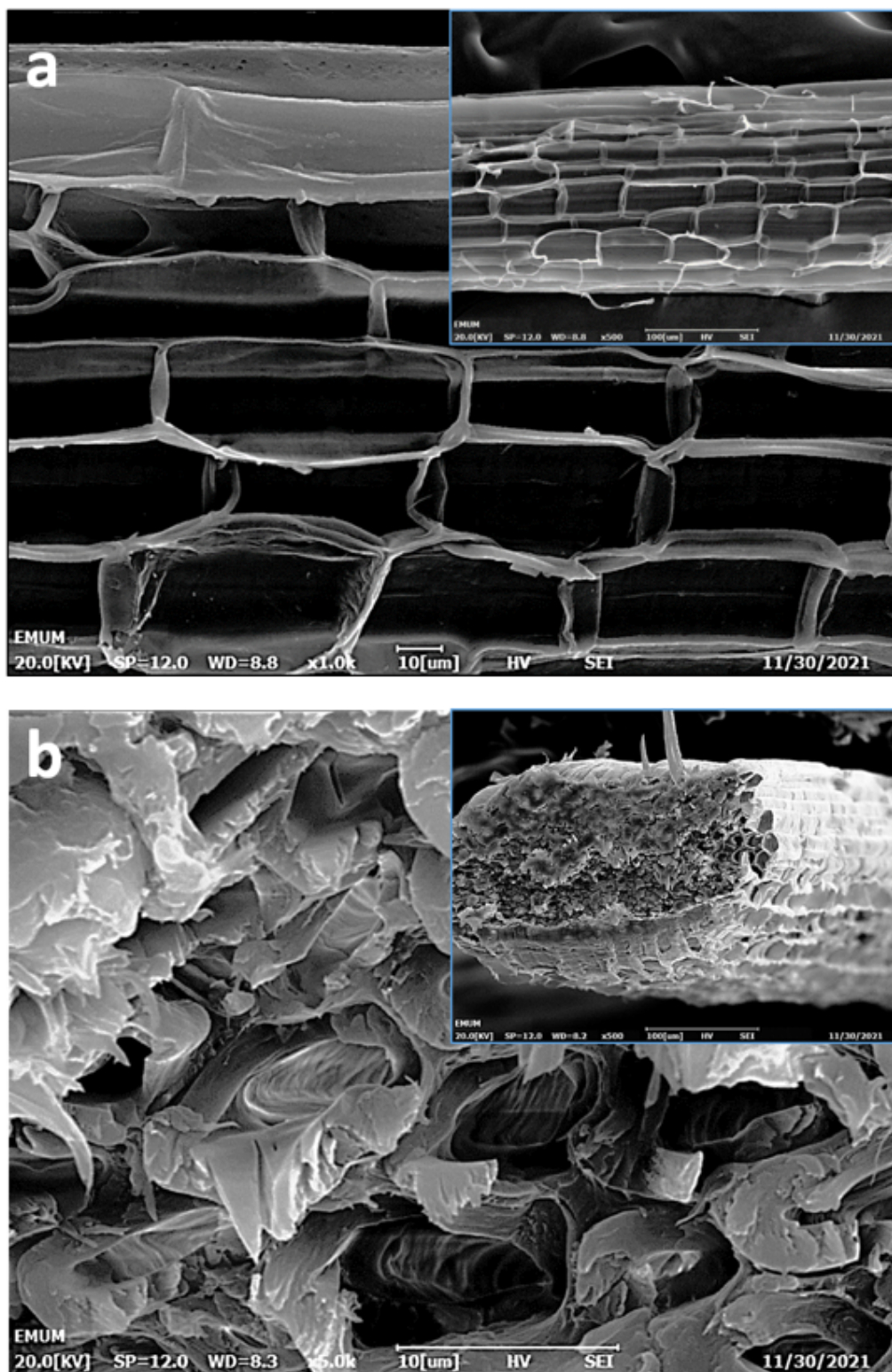


Figure 2

SEM images of the *Helianthus tuberosus* L. fiber in the view of (a) longitudinal and (b) cross-sectional

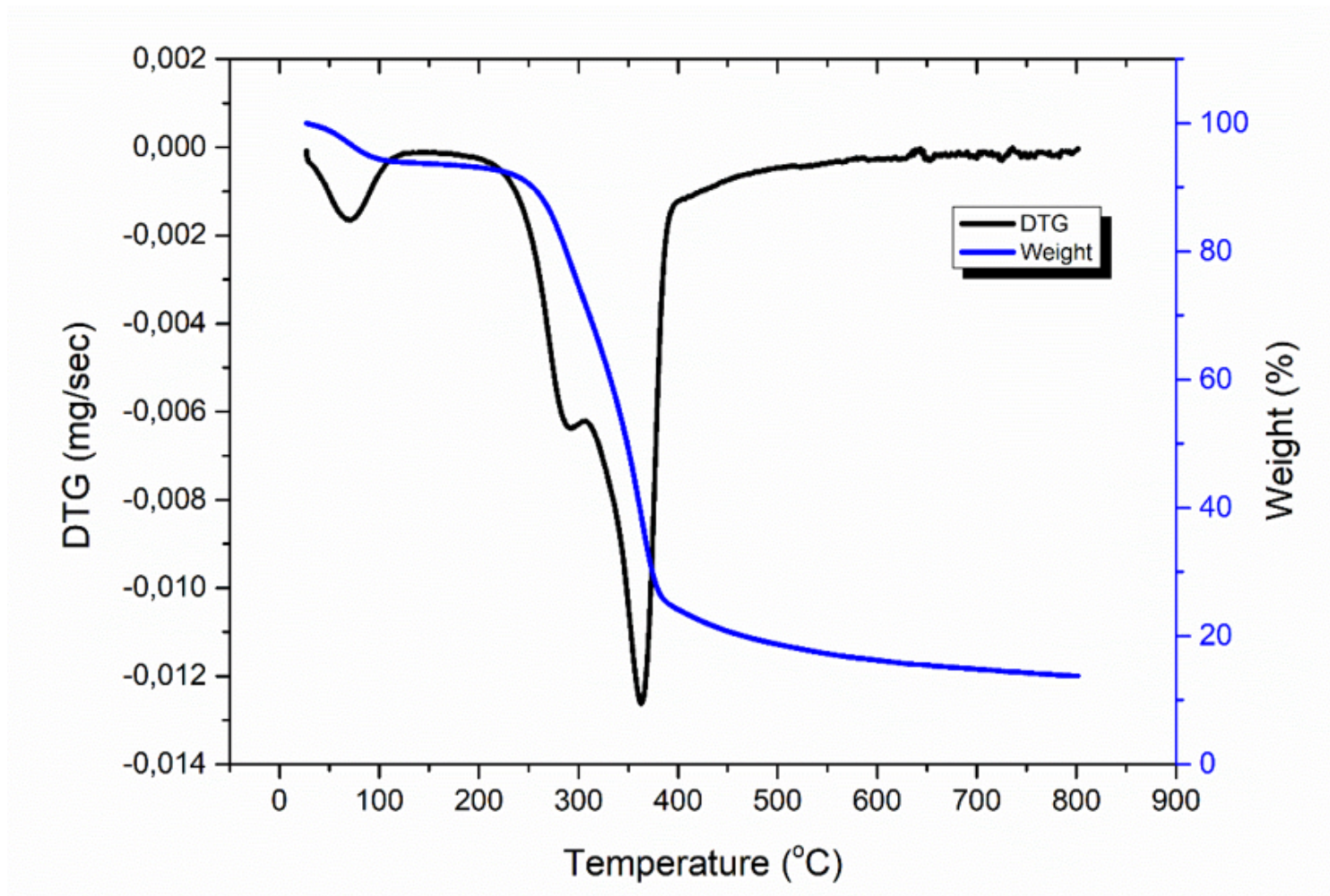


Figure 3

TG and DTG curves belong to the *Helianthus tuberosus* L. fibers

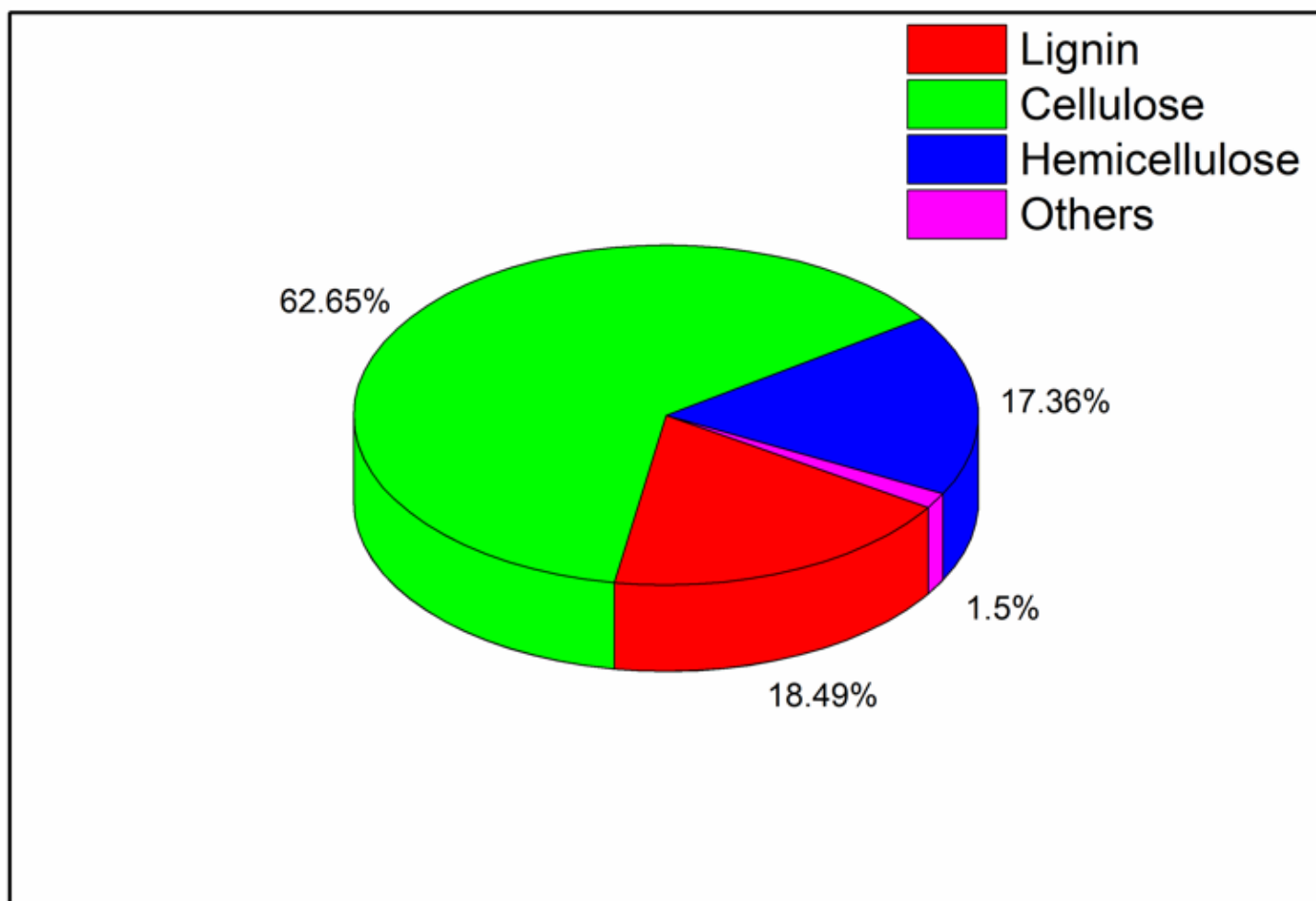


Figure 4

Chemical content distribution of the *Helianthus tuberosus* L. fiber as a pie chart

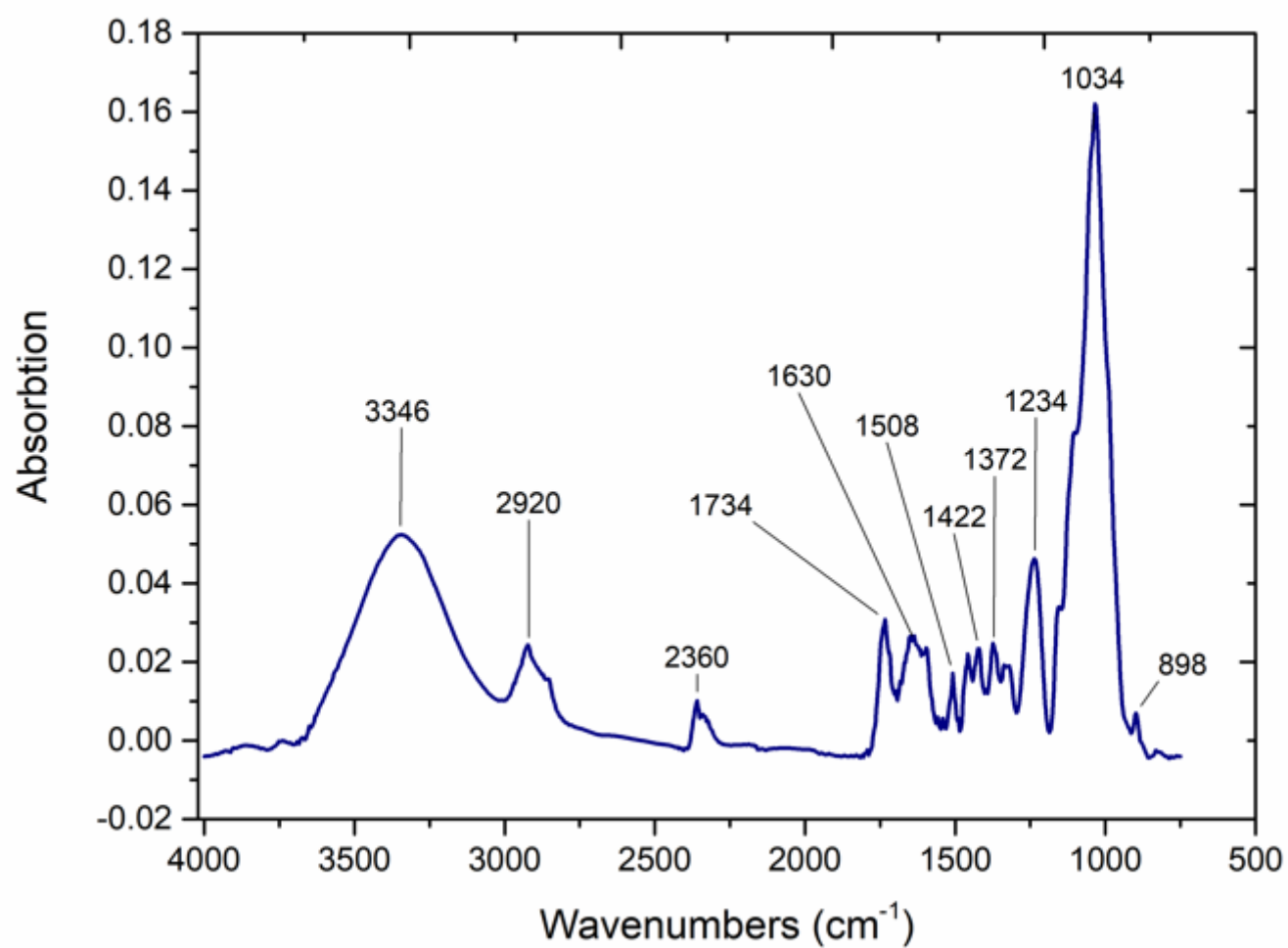
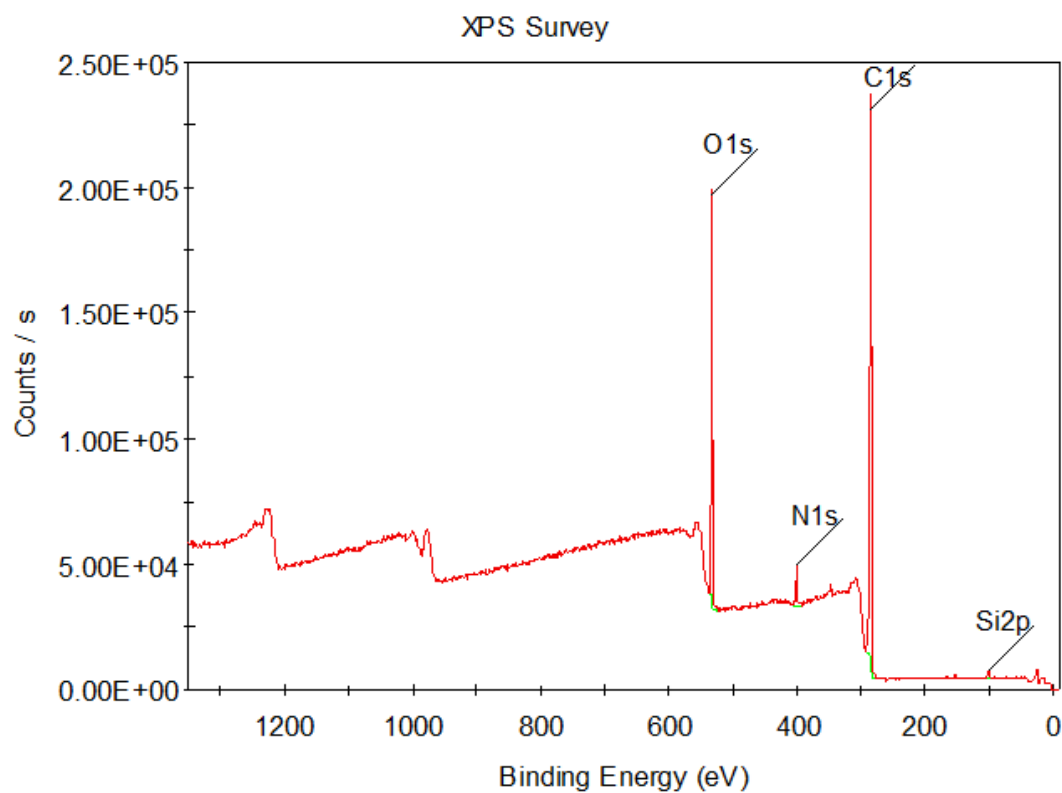
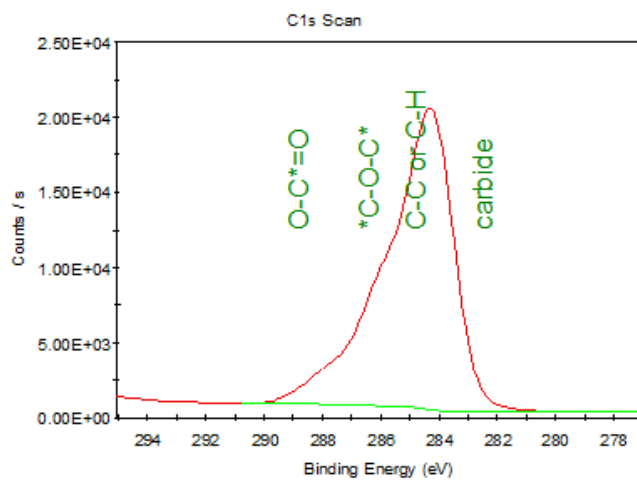


Figure 5

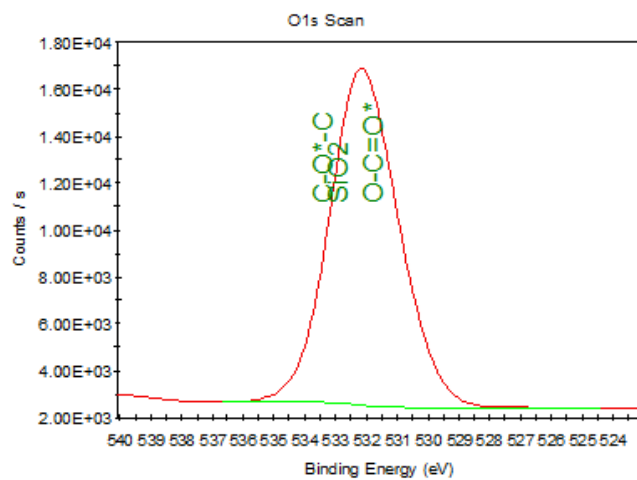
FTIR spectrum of the *Helianthus tuberosus* L. fiber



(a)



(b)



(c)

Figure 6

(a) General XPS survey and, the high-resolution XPS spectra of (a) C1s and (b) O1s peaks of the *Helianthus tuberosus* L. fiber

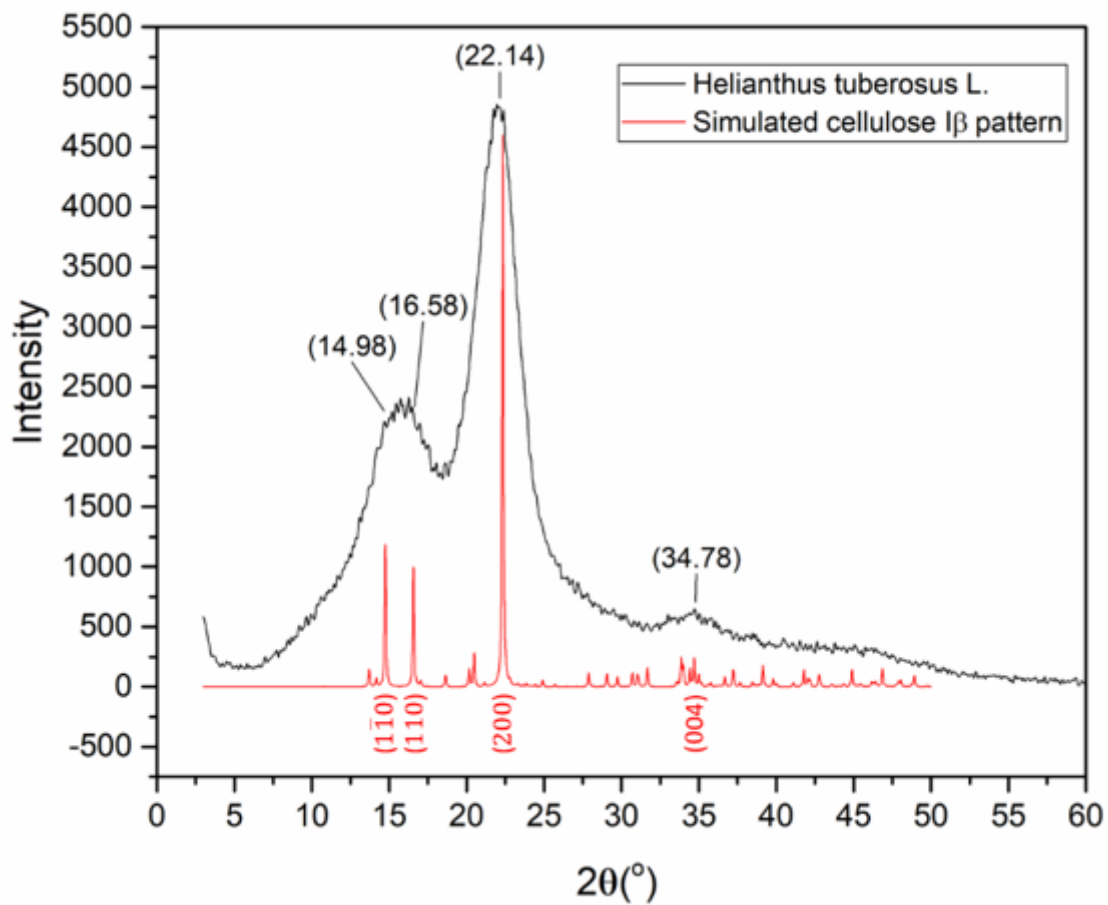


Figure 7

XRD pattern of the *Helianthus tuberosus* L. Fiber together with the simulated cellulose I β pattern