

Extraction, Chemical Composition, and Characterization of Potential Lignocellulosic Biomasses and Polymers from Corn Plant Parts

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Corn is a plant that can be used as a potential source of biomass for various biomaterial applications. Thermoplastic corn starch and corn hull, husk, and stalk fibers were extracted from different corn plant parts. The chemical composition, physical properties, thermal stability, crystallinity index, and surface morphology of the extracted samples were characterized on a powder basis. The corn husk and corn starch revealed an excellent combination of properties. Corn husk provided the highest cellulose content as well as the most favorable surface morphology. Corn starch revealed acceptable amylose content and tolerable thermal stability. The cellulose and starch demonstrated an excellent correlation between the function and structure of biomolecules. Hence, both corn starch and husk have potential for use in many applications of the biomaterial.

Keywords: Corn biomasses; Chemical composition; Physical; Thermal; Morphological properties

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INTRODUCTION

Contemporary environmental concerns, such as non-biodegradable disposal materials, plant wastes, and rising mountains of garbage are increasingly documented as environmental barriers (Ibrahim *et al.* 2019). The area for landfills is limited, and further incineration capacities require high capital investment and cause additional environmental threats. These issues have prompted the design and manufacture of eco-friendly materials from renewable sources to replace conventional non-biodegradable materials. Reducing the dependence on synthetic plastic and petroleum products is one reason for investigating biomasses in reinforcing polymer composites (Mori *et al.* 2018). Furthermore, the use of biomasses as reinforcement in composites would lead to partial degradation of wastes, which in turn contributes to the solution of environmental complications.

Corn (maize) is one of the most abundant sources of plant residues, which as biomass provides multiple advantages such as high concentration of starch, excellent consistency, cost-effectiveness, availability, and biodegradability (Mendes *et al.* 2016). According to Sandhu *et al.* (2004), corn is among the most abundant agriculture cereals planted on earth. There are typically six common sorts of maize, namely dent, flint, pop, pod, flour, and sweet corn. These sorts vary remarkably in their physiochemical characteristics due to environmental influences. The production of corn in 2014 was estimated at 1.04 billion tons, which corresponded to 31% of the global cereal production;

therefore, corn became the third most important food grain (Singh *et al.* 2016). The corn plant consists of one stem or more associated with a combination of short roots. The stem branches at each node and ends with inflorescences. After harvest, the corn parts are turned into residues that are disposed (Weatherwax 1950).

Corn is a vital source of commercial starch, which is a type alpha-linked glucose that is used extensively in food factories as a gelling, water retention, and bulking agent (Zobel 1988). More than 70% of corn kernel composition is starch, and the rest is sugar, protein, oil, and ash. However, many natural fibers can be extracted from corn plant parts including the stalk, straw, leave, and husk. Compared with other agricultural bioproducts, corn fiber offers distinct features such as saving 90% of the cost and being more accessible than other natural fibers (McAloon *et al.* 2000).

The use of natural fibers as reinforcing materials in polymers and composites is a major area of research interest. The chemical composition, morphological structure, and thermal stability of biomass are essential criteria to select the best lignocellulosic material (Brinchi *et al.* 2013). To date, there is insufficient research on the applications of corn polymers, fibers, and composites, with no study conducted on the physical, morphological, and thermal properties of corn biomass. This study considers the physiochemical composition, thermal characteristics, and crystallinity index and morphological properties of corn biopolymers and biofibers with the aim of exploring their potential in the development of biocomposites.

EXPERIMENTAL

Materials

Corn was collected from a local farm in Malaysia. Corn starch and corn hull fiber were extracted from the granules of a fresh sweet corn ear. Corn stalk and husk were obtained from the stems and leaves of corn plants, respectively. All samples were characterized in a powder basis.

Starch and Fiber Extraction Processes

The isolation of corn starch was carried out in accordance with Ali *et al.* (2016). Corn grains (1 kg) were steeped in distilled water (4 L) for 12 h at 4 °C. The purpose of the steeping is to increase grain moisture to facilitate grinding process. After the water was evacuated, the grains were crushed in a lab electric blender (wet milling) until the minimum likely fraction was achieved. The crushed fractions were sifted through a 75 µm mesh sieve and then left to sediment for 8 h. The supernatant liquid was discarded, and the sedimented particles were suspended in distilled water to remove any residual protein from the starch. The slurry of starch and water was separated by centrifugation at 3000 rpm for 20 min. The obtained corn starch was dehydrated at 50 °C for 12 h in an air circulation oven (type Venticell 22, Planegg, Germany); the dried corn starch was blended and sieved to achieve uniform particle size distribution.

Corn hull fiber was obtained *via* the wet milling process during starch isolation. The industrial production of corn starch involves the elimination of proteins and separation of fibers resulting in purified starch and solid residues called de-starched corn hull fiber which exists in corn grain pericarp. Subsequently, the remaining fiber was washed many times with hot distilled water to remove starch molecules and then was separated by centrifugation. Either by drying in an oven or direct sunray, the hull fiber was dehydrated

and converted to powder form *via* grinding and sieving processes.

Corn husk fiber was obtained according to Sari *et al.* (2016). Husks surrounding the ear of corn were soaked in condensed water for 3 days to remove the residuals and dust. The husks were thoroughly washed by fresh water and brushed with a soft plastic comb. The husks were air-dried, ground, and screened through a sieve to be in powder form. The extraction of corn stalk fiber was performed as described by Baranitharan and Mahesh (2014). Raw corn stalks were cleaned thoroughly and chopped into specific sizes; they were completely dehydrated in an oven for 12 h at 60 °C. The outer skins of the dried corn stems were separated manually. The corn stalk fiber appeared light white in color and was directly converted into powder.

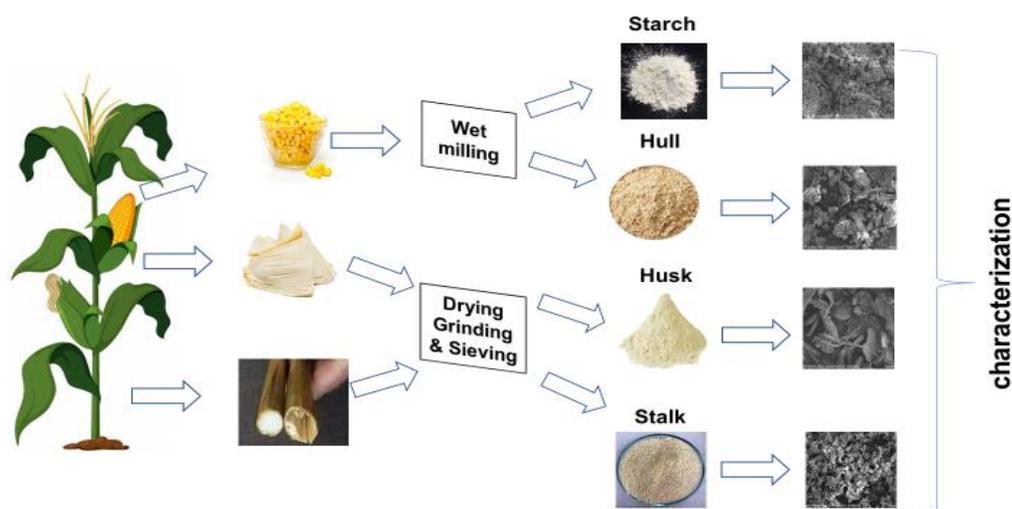


Fig. 1. Extraction and preparation of corn biomass

Chemical Composition

The chemical composition of the corn samples was measured according to published methods (Razali *et al.* 2015; Alzorqi *et al.* 2017). These methods were employed to examine on dry matter the percentages of cellulose, hemicellulose, lignin, and ash of corn fibers. The amylose and amylopectin contents of starch were obtained (James 2013).

Physical Properties

Density (ρ)

A gas pycnometer AccuPyc II 1340 (Micromeritics Instrument Corp., Norcross, USA) was used to obtain the density and volume of known weight powder samples. Helium gas was used as a replacing fluid to measure volume because it has the ability to penetrate and expand through the pores into a chamber containing the sample. Density (ρ) is defined as the ratio of mass m (g) to volume v (m³) of material, as expressed by Eq. 1.

$$\rho \text{ (g/m}^3\text{)} = m / v \quad (1)$$

Moisture content (MC)

The moisture content of the material is defined as the amount of the water that could be removed from the material without changing the chemical composition for the main weight of the material (Jindal and Siebenmorgen 1987). The powder samples were weighed

individually and then kept on an oven for 24 h at 110 °C. The weight differences before (w_1) and after (w_2) drying were used to obtain the MC for each sample indicated by percentage or gram/100 g as shown in Eq. 2.

$$MC (\%) = ((w_1 - w_2) / w_1) \times 100 \quad (2)$$

Water-holding capacity (WHC)

Water-holding capacity of a substance is expressed by the ability of the material to hold over water and is indicated by the quantity of water seized by 1 g of the dehydrated material. The water-holding capacity of the maize samples was measured by a similar method explained by Kirwan *et al.* (1974) with insignificant modifications. A powder sample (3 g) in a pre-weighed centrifugal tube (M_{initial}) was submerged in 25 mL of distilled water. After centrifuging at 3000 rpm for 25 min the supernatant was disposed, and the residue was dehydrated in an air circulation oven at 50 °C for 30 min and weighed again (M_{final}). The test was repeated several times until the tested specimen reached a constant mass. Hence, the WHC percentage was obtained from the average of several measurements according to Eq. 3.

$$WHC (\%) = ((M_{\text{final}} - M_{\text{initial}}) / M_{\text{initial}}) \times 100 \quad (3)$$

Particle size distribution (PSD)

A Mastersizer 2000 E Ver. 5.52 (Malvern Instruments Ltd., Worcestershire, UK) was used to find out the PSD for the samples *via* a built in Q-space powder feeder. The particle size for tested samples was examined through a 1000 μm sieve prior to distribution analysis.

Thermal Gravity Analyzer (TGA)

A thermogravimeter analyzer (Q500 V20.13 Build 39, Bellingham, USA) was used to record the specimens' thermal properties. Samples with mass ranging 5 to 10 mg were placed in platinum crucibles and exposed to a temperature varied from room temperature to 450 °C at a rate of 10 °C/min⁻¹ and under a nitrogen atmosphere. TGA measures the mass loss over time as a function of temperature.

Morphological and Structural Properties

Scanning electron microscopy (SEM)

A scanning electron microscope (Hitachi S-3400N, Nara, Japan) was employed to study the surface morphology of the samples. Before the test, the sample was soaked in nitrogen liquid and covered by a golden layer. A 20 kV voltage was applied through a high vacuum to generate a beam of electrons. The applied electrons interacted with the sample atoms creating signals containing information about surface topography and producing images with high resolution.

Fourier transform infrared spectroscopy (FT-IR)

An infrared spectrometer (Bruker vector 22, Lancashire, UK) was used to obtain the FT-IR spectrum of samples at a frequency over a broad spectral range of 4000 to 400 cm⁻¹ with a spectral resolution of 4 cm⁻¹. The tested samples preparation was conducted *via* KBr pressed-disc technique. Using 16 scans per specimen.

X-ray diffraction (XRD)

The XRD analysis was performed using a 2500 X-ray diffractometer (Rigaku, Tokyo, Japan) with a scattering speed of $0.02 (\theta) \text{ s}^{-1}$ within an angular range from 5° to 60° (2θ). The operating voltage and current were set to 40 kV and 35 mA, respectively.

RESULTS AND DISCUSSION

Chemical Composition

Table 1 reveals the chemical composition of corn starch. The comparative analysis of composition indicated that corn starch is characterized by a relatively high concentration of polysaccharides, (amylopectin and amylose), while the amounts of extractives, such as crude fats, protein, and ash, were quite low. This formulation is consistent with the standard chemical structure of the native starch as mentioned in the previous report (Lu *et al.* 2009). The amylose content, the main compound of native starches, was 24.6 g/100 g. This amount is roughly equivalent to 25 g/100 g obtained in an earlier study by Chinnaswamy and Hanna (1988). Also, this amount was found within the normal range (14% to 29%) of the amylose content of all native plant starch (Bertoft 2017).

Table 1. Chemical Composition and Physical Properties of Corn Starch

Content	Amount	Units
Amylose	24.64	g/100 g
Amylopectin	75.36	g/100 g
Crude fats	7.13	g/100 g
Crude proteins	7.70	g/100 g
Ash	0.62	g/100 g
Phosphor	0.09	%
Moisture content	10.45	%
Density	1.4029	g/cm ³

Table 2. Comparison of Chemical Composition and Physical Properties of Corn Fibers with Selected Natural Fibers

Material	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	Moisture (%)	Density (g/cm ³)	Reference
Hull	15.30	40.4	2.87	0.88	8.59	1.3231	Current study
Husk	45.7	35.8	4.03	0.36	7.81	1.4913	Current study
Stalk	10.8	60.3	1.98	1.97	11.1	1.4164	Current study
Juta	61 to 71.5	13.6 to 20.4	12 to 13	0.5 to 2	12.6	1.3 to 1.46	(Mohanty <i>et al.</i> 2001; Li <i>et al.</i> 2007)
Hemp	57	14	3.7	0.8	10.8	1.48	(Mohanty <i>et al.</i> 2001; Razali <i>et al.</i> 2015)
Sisal	67	10	8	0.6	11	1.33	(Mohanty <i>et al.</i> 2001)

Table 2 displays the chemical composition of maize fibers with a comparison to selected natural fibers. The natural fibers are composed primarily of carbohydrate polymers (cellulose and hemicellulose), aromatic polymers (lignin), and ash. Typically, cellulose acts as a primary constituent for fiber structure and plant strength (Chen 2014). Of the three fibers, corn husk contained the highest concentration of cellulose at 45.7%. This amount was slightly higher than the 43% previously discovered by Youssef *et al.* (2015). Corn hull cellulose content from the current study was to some extent lower than the 16% cellulose content detected by Sugawara *et al.* (1994). The lignin, which is responsible for flexibility and stiffness of the fiber wall (Varanasi *et al.* 2013), was found to be present in the corn husk at a more remarkable percentage than in the corn hull and stalk counterparts. A minor concentration of ash was observed in the composition of corn hull and husk fibers, while the ash concentration reached a noticeable amount of about 10.7 g/100g on a corn stalk.

Density (ρ) and Moisture Content (MC)

The density of each specimen was measured among the average of five replicates. As shown in Tables 1 and 2, the density values of corn starch, husk, and stalk were roughly the same at around 1.4 g/cm³, while the corn hull recorded a lower value at about 1.3 g/cm³. However, the density values obtained in this study were within the range of various natural fiber densities between 0.81 and 1.450 g/m³, as indicated in the literature (Rao and Rao 2007). The low-density of biomaterials made it more attractive for manufacturing of bio-composites in comparison with artificial composite materials, such as fiberglass (2.5 g/m³) (Mendes *et al.* 2015).

The moisture content of the samples was measured and included in Tables 1 and 2. Cornstalk contained the highest moisture content and reached 11.1 g/100g. Ashori *et al.* (2014) attributed that to the presence of the hydroxyl group in cellulose and lignin of corn stalk, whereas corn husk achieved the lowest quantity at 7.81 g/100g. However, a similar result of corn hull moisture content (8.59 g/100g) from this study was detected by Yadav *et al.* (2007) when the corn hull fiber was extracted through the wet milling process it was found that the moisture content reached 8.41 g/100g.

Water-Holding Capacity (WHC)

The ability of the material to absorb water is an important criterion when manufacturing composite materials because it has a great influence on dimensional stability, porosity, tensile strength, and swelling behavior of natural composite materials (Jawaid and Khalil 2011). Based on the data, corn starch, which has a hygroscopic nature, retained the lowest amount of water (22%) as compared to the fiber samples, which are characterized by a high hydrophilic nature (Munthoub and Rahman 2011). Cornstalk offered the highest amount of water retention with a value of 93.7%, while corn husk and hull counterparts recorded 78.8% and 37.4%, respectively; this observation refers to the low amount of cellulose content in the composition of the corn stalk (Ashori *et al.* 2014). Cellulose decreases the free volume in the fiber intermolecular chain and leads to a reduction of water penetration (Razali *et al.* 2015). This conclusion is compatible with its chemical composition shown in Table 2.

Particle Size Distribution (PSD)

The strength of composite materials depends on the efficiency of transferred stress between matrix and fillers. Parameters, such as particle size distribution, particle loading, and particle/matrix interfacial strength, are strongly affected on the composite strength (Fu

et al. 2008). Thus, the PSD of corn starch is presented in Fig. 2a. The histogram displays that the highest percentage (43%) of starch particles had sizes of less than 10 μm , followed by 24% for the sizes within 10 to 20 μm . Nonetheless, the vast majority (89%) of the corn starch particles had sizes less than 40 μm ; such results are identical to the findings of Han *et al.* (2009). On the other hand, corn husk and stalk exhibited a similar distribution of particle sizes. As revealed in Fig. 2c and d, both fibers showed a large particle size of 200 to 300 μm making up 42% and 39% of the total particles, respectively. Meanwhile, corn hull had larger particles with 35% having a particle size of 300 to 400. This observation is due to the presence of non-removed starch particles attached to hull fiber during the extraction process. Nevertheless, the diminishing size of fiber particles enhances the biodegradability and tensile characteristics of the composite material (Radford 1971; Zhao *et al.* 2013).

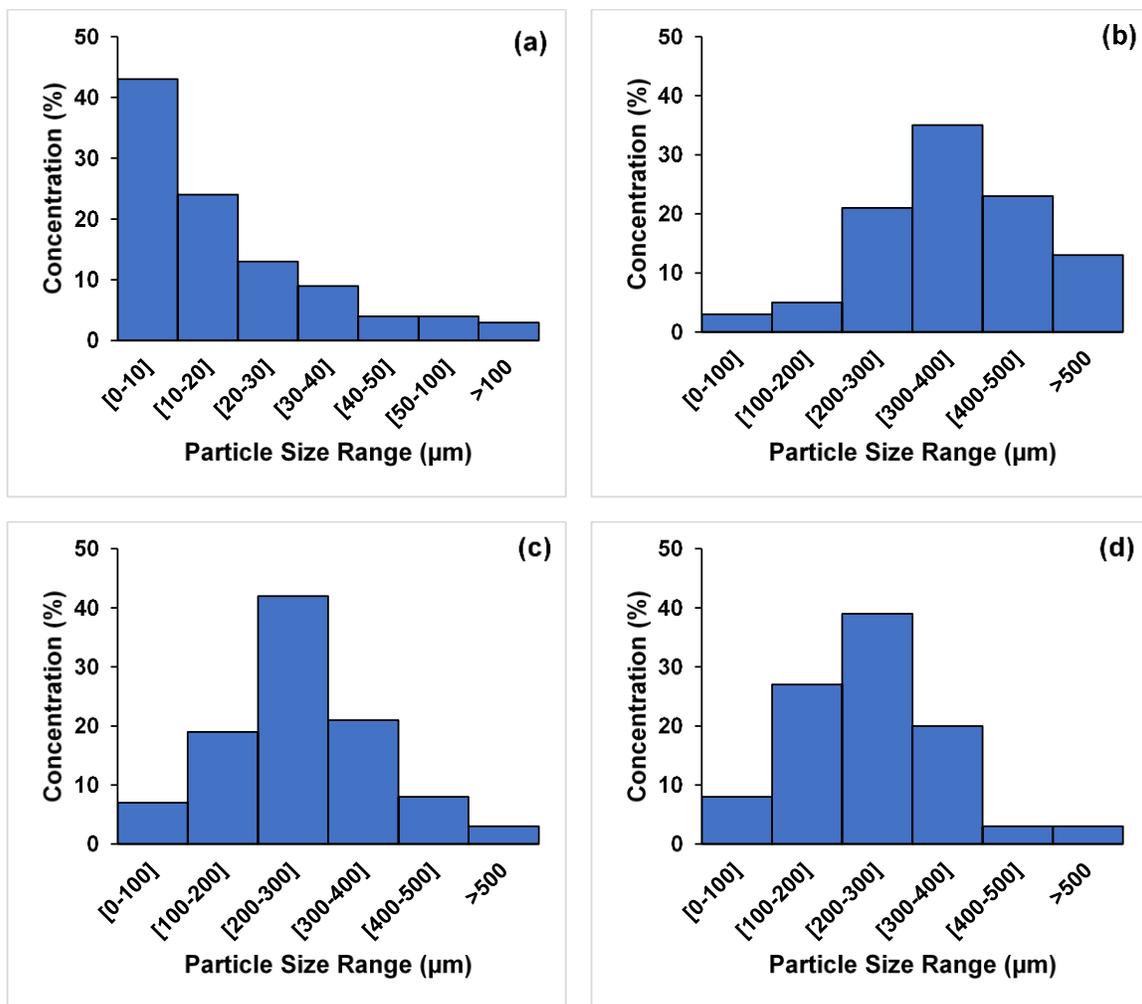


Fig. 2. PSD of a) corn starch, b) corn hull, c) corn husk, and d) corn stalk

Thermal Gravity Analyzer (TGA)

Thermogravimetric analysis (TGA) and differential thermogravimetry (DTG) are accurate techniques used extensively to investigate the thermal stability and evaluate the weight loss of composite materials (Guinesi *et al.* 2006). The TGA and DTG curves in Fig. 3a and b reveal three distinct phases of weight loss represented in the prominent peaks on

the DTG curve. The first phase exhibits the loss of weight due to dehydration of water content, the second phase presents the weight loss resulting from the decomposition of the material side chains, and the third phase displays the weight loss due to the decomposition of the main chains of the material (Othman *et al.* 2011). For the corn starch, the first loss of weight occurred immediately after the dehydration began at a temperature slightly below 100 °C. The weight loss in this phase relies on the moisture content of the starch as a higher moisture content results in higher weight loss. The second phase began with decaying of the water-soluble amylopectin at an onset temperature (T_0) corresponding to 161.2 °C and continued until 281.1 °C, resulting in 66.3% weight loss. The highest rate of thermal degradation of corn starch occurred at about 450 °C leaving 16.2% residue of ash. These findings were closer to what was previously obtained by other authors (Liu *et al.* 2009). Regarding corn (hull, husk, and stalk) fibers, the first weight loss occurred approximately at the same temperature for the three samples at slightly above 100 °C, as shown in Fig. 3. In the second stage, the fiber material degradation took place due to the decomposition of hemicellulose and cellulose. For all different plant fibers, cellulose content begins to deteriorate at a temperature exceeding 300 °C and dissolves into its components at about 400 °C (Yang *et al.* 2007). The corresponding data are shown in Table 3.

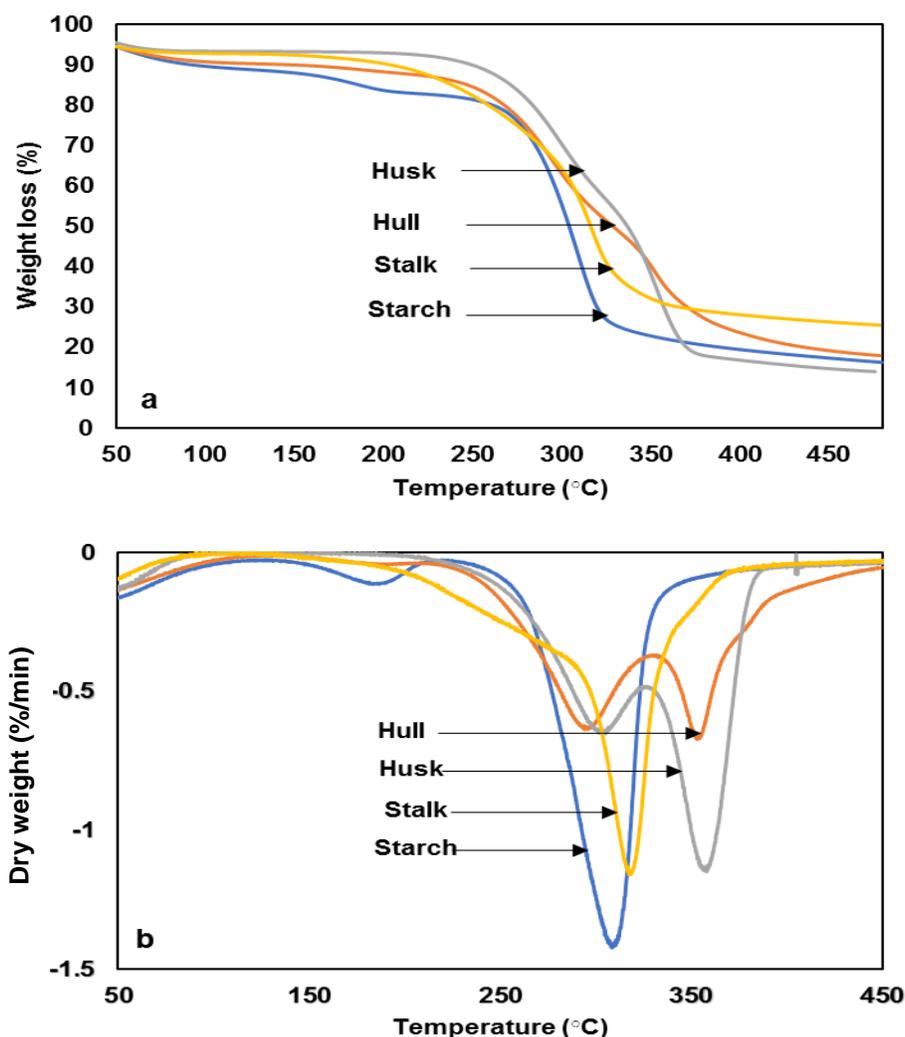
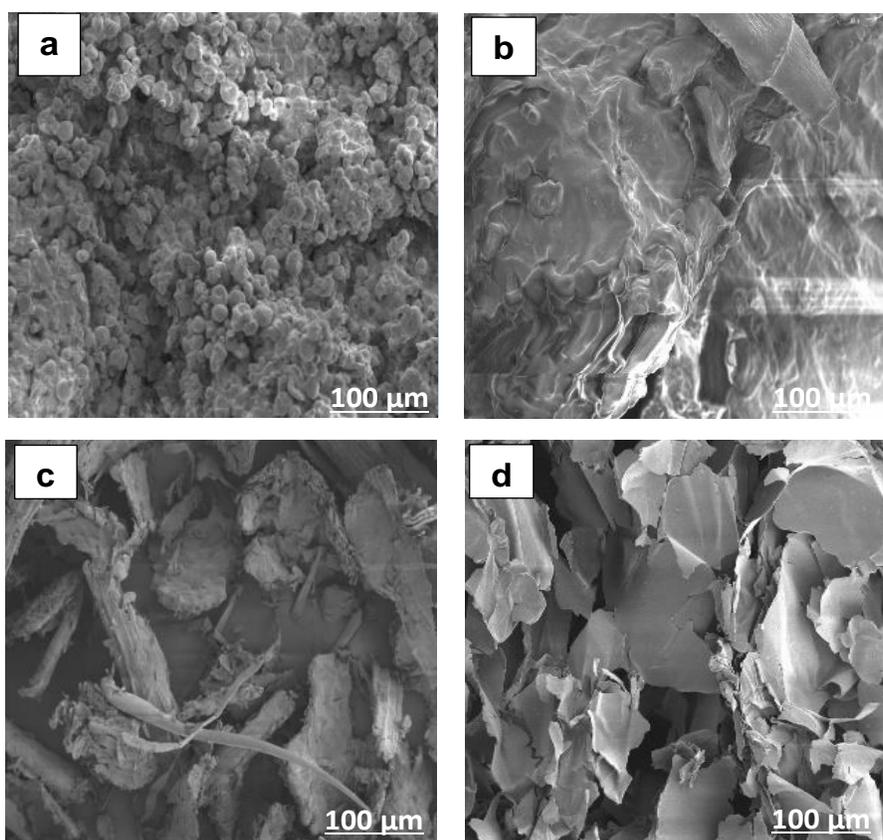


Fig. 3. a) TGA and b) DTG of corn starch, hull, husk, and stalk

Table 3. Thermal Degradation of Corn Starch, Hull, Husk and Stalk, Comparison with Cassava Biomass

Material	Degradation Temperatures (°C)			Mass Residue (%) above 400 °C	DTG Peak Temperature (°C)
	T_{onset}	$T_{25\%}$	$T_{50\%}$		
Starch	161.20	281.08	303.79	16.24	310
Hull	258.94	278.58	343.38	17.87	352
Husk	264.27	289.57	340.19	13.86	350
Stalk	274.94	278.74	315.35	25.42	318

The onset decomposition temperatures achieved in this study suggest that the use of corn fibers as fillers for polymer composites production is possible because the majority of polymer composites are processed at above of 180 °C (Mendes *et al.* 2015). In the final stage, the highest rate of thermal degradation occurred above 400 °C as a result of lignin decomposition. However, the results are well in agreement with the thermal decomposition of natural fibers, which begins with the decaying of hemicellulose (200 °C to 260 °C), cellulose (240 °C to 350 °C), and lignin (280 °C to 500 °C) (Lomelí-Ramírez *et al.* 2014).

**Fig. 4.** SEM of a) corn starch, b) hull, c) husk, and d) stalk

Scanning Electron Microscopy

Figure 4a shows the surface morphology of corn starch. The remarkable shape of the starch granules was found to be varied from aspherical to polyhedral shapes with solid structure, and most granule sizes were less than 40 µm. Moreover, the view showed smooth scratched surfaces with slight porosity, which is usually related to the starch genotype as

well as to extraction and storage conditions (Leach and Schoch 1961). The surface fracture of corn hull as displayed in Fig. 4b reveals a fiber with starch particles covering the surfaces. The observed surface of the hull granules was found to be smooth and relatively cohesive, which could be ascribed to the remains of corn starch molecules from the detaching process. Also, the corn hull visualization shows wrinkled spongy surfaces that may lead to weak interfacial adhesion between matrix and filler. Therefore, hull fiber could not afford an effective stress transfer from the matrix (Tabari *et al.* 2011). Figure 4c illustrates the morphological structure of corn husk. The images exhibited husk particles with a nonuniform cross section and irregular surfaces. Also, some impurities were noticed on the structure, which is undesirable for composites integrity. Moreover, corn husk appeared to have rough surfaces with some pores that could be allow for better adhesion during the mixing process. This description is well aligned with the findings reported by Mendes *et al.* (2015). The surface fracture of the corn stalk is visualized in Fig. 4d. The typical view showed a fibrous and porous structure with an irregular cross section. Also, relatively smooth surfaces with some defects were detected, which may influence negatively on cohesion bonds between matrices and fillers. Similar results were observed in the prior study performed by Kaliyan and Morey (2010).

Fourier Transform Infrared Spectroscopy

The interpretation of the leading bands of corn starch was carried out by dividing the FT-IR spectra curve into four main zones. The first zone was at wavenumbers below 800 cm^{-1} , the second zone was at wavenumbers between 800 and 1500 cm^{-1} , the third zone was within the C-H stretch region from 2800 to 3000 cm^{-1} , and the last zone was the O-H stretch area above 3000 cm^{-1} (Kizil *et al.* 2002). Consequently, the FT-IR spectrum of corn starch as shown in Fig. 5 revealed an oscillatory behavior in the region below 800 cm^{-1} . This behavior is related to vibrations of glucose pyranose units (Kizil *et al.* 2002). In the second region, starch appeared to have complex spectra with remarkable overlapping originating from C-O vibrational stretching of the monomer glucose unit. Also, the presence of the C-O-H bending mode caused the appearance of the band at 1076 cm^{-1} , whereas the coupling modes of C-O and C-C stretching showed up in the peak at 1149 cm^{-1} . However, the infrared wavenumbers at the peak at 1335 cm^{-1} were attributed to CH_2 bending modes (Cael *et al.* 1975). Additionally, the vibrations of water fragments in the amorphous region of starch granules resulted in the emergence of broad infrared bands at peaks at 1640 cm^{-1} and 1709 cm^{-1} (Santha *et al.* 1990). In the third area between 2800 and 3000 cm^{-1} , and the presence of the C-H stretching vibration generated the peaks at 2853 cm^{-1} and 2923 cm^{-1} . Finally, the fourth vibration region of the O-H stretch hydroxyl groups led to the creation of the last band at 3285 cm^{-1} (Pi-Xin *et al.* 2009).

The FT-IR analysis of corn husk and stalk fiber is displayed in Fig. 5. It can be seen that both fibers exhibited roughly the same trends. The main differences between husk and stalk were the position and width of the bands at 1635 cm^{-1} , 2917 cm^{-1} , and 3333 cm^{-1} for the corn husk had shifted to 1604 cm^{-1} , 2897 cm^{-1} , and 3339 cm^{-1} for the corn stalk counterpart. These differences are related to the variances in the chemical composition, particularly cellulose, hemicellulose, and crude protein contents. Furthermore, both husk and stalk in the aromatic region, which correlates to lignin (Ali *et al.* 2001), recorded the same peaks at 1159 cm^{-1} , 1370 cm^{-1} , and 1515 cm^{-1} . Likewise, both husk and stalk fibers stretched at the peak at 897 cm^{-1} which was assigned to the C-O-C stretching of glycosidic linkages in cellulose (Jonoobi *et al.* 2009; Yılmaz 2013). However, almost the same peaks were observed by Husseien *et al.* (2009) who recorded peaks at 3415 cm^{-1} , 1638 cm^{-1} , and

900 cm^{-1} for corn stalk. Similarly, Yılmaz (2013) found peaks at 3400 cm^{-1} , 2923 cm^{-1} , and 897 cm^{-1} for corn husk. Regarding corn hull, it was observed that corn hull offered additional sharp bands at peaks at 2921 cm^{-1} and 2852 cm^{-1} . The prominence of these peaks was attributed to the presence of starch residues attached to hull fiber from the extraction process.

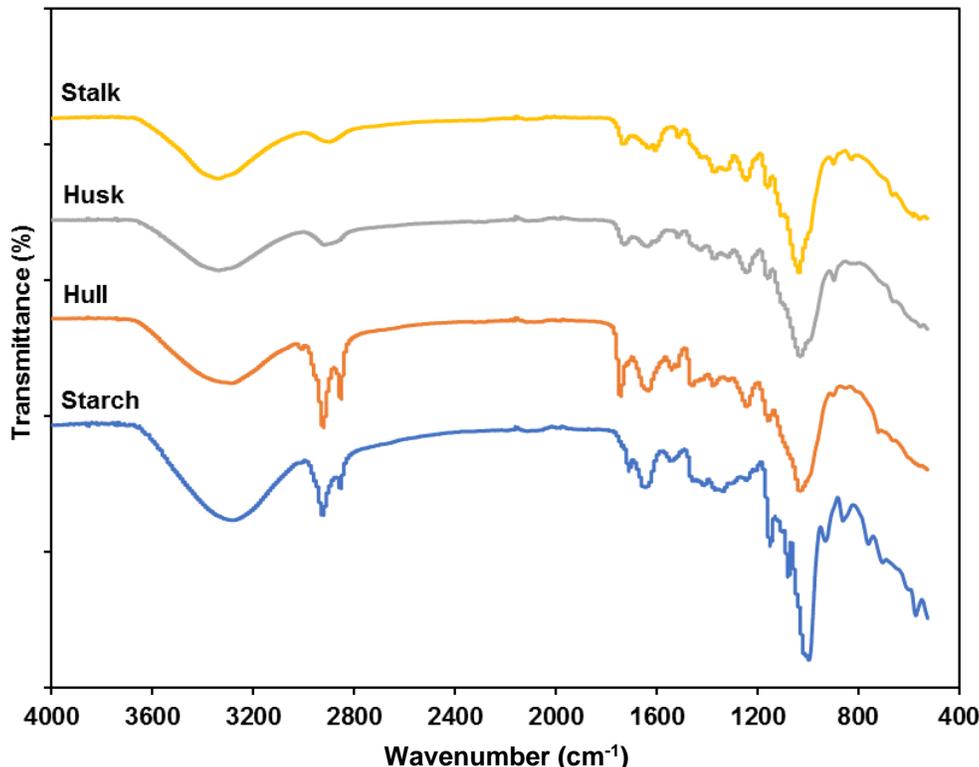


Fig. 5. FT-IR spectroscopy of corn starch, hull, husk, and stalk

X-ray Diffraction

The XRD structure of native corn starch as illustrated in Fig. 6 shows five 2θ diffraction angles focused at peaks at 15.14°, 17.4°, 18.6°, 20.11°, and 22.8°. These peaks represent the A-type starch semi-crystallinity structure, which is the typical pattern of all cereal starches (Shamai *et al.* 2003). The peaks obtained from the current study are effectively compatible with those introduced by Paraginski *et al.* (2014) for native corn starch with the peaks being found at 15°, 17°, 18°, 20°, and 23°. These are also mostly comparable to those revealed by Koo *et al.* (2010) at peaks at 15.02°, 17.18°, and 23.73°.

The corresponding spectrum of corn hull fiber peaks of crystalline and amorphous regions appeared at the following 2θ angles; a minor peak at 18° and a high peak at close to 20°. These peaks are related to the remains of corn starch in the hull fiber. However, the morphological properties of maize fiber composites can be attributed to the distinctive diffraction behavior of corn hull to disordered regions and scattering of crystallinity to this material (Sisson 1938). As for the XRD patterns of corn husk and stalk, the results showed that the main peaks for corn husk and corn stalk were located at positions 21.75° and 21.43°, respectively. Likewise, both fibers revealed a minor broad peak at 2θ equivalent to 15.88° for corn husk and at 15.76° for the corn stalk counterpart. These observations are similar to those of the corn stalk obtained by Zhao *et al.* (2013) and those of the corn husk in the study of Mendes *et al.* (2015).

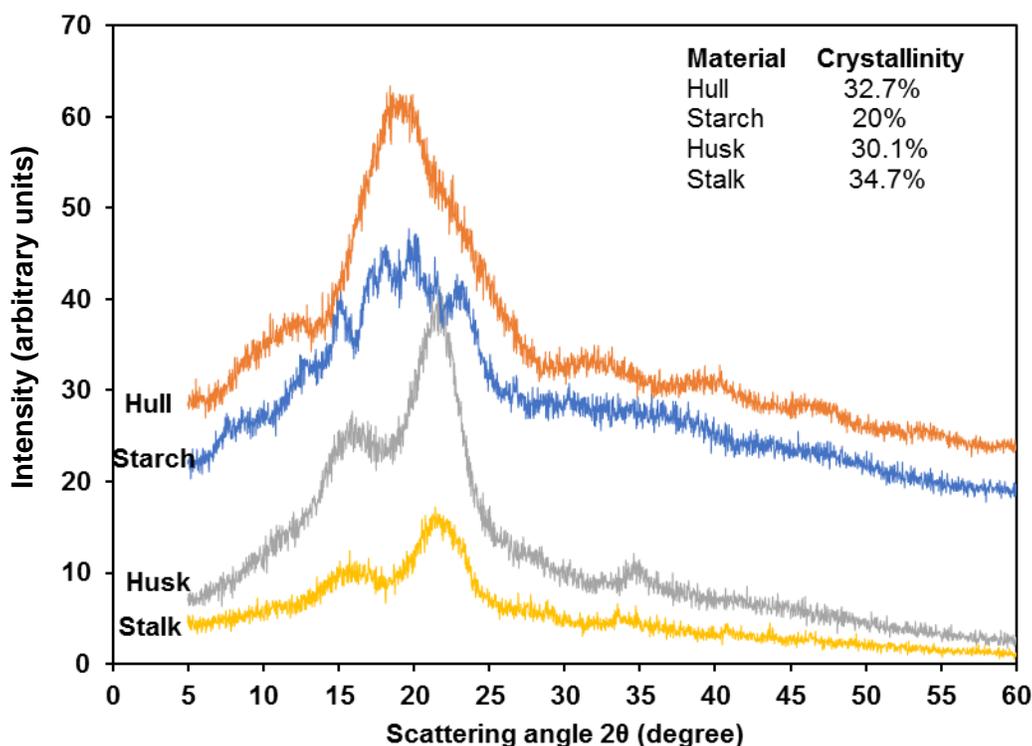


Fig. 6. X-ray diffractogram of corn starch, hull, husk, and stalk

CONCLUSIONS

1. Three lignocellulosic fibers (hull, husk, and stalk) along with thermoplastic starch polymer have been isolated and characterized with the aim of obtaining biomasses for biomaterial applications.
2. The highest concentrations of cellulose and lignin were found in corn husk. The largest amount of hemicellulose was obtained in corn stalk fiber.
3. Thermal results revealed that corn starch degraded at 161.2 °C, while hull, husk, and stalk fibers began decomposing above 260 °C. That made the use of corn fibers as fillers for polymer composites production possible because the majority of polymer composites are processed at above 180 °C.
4. The morphological analysis exhibited aspherical to polyhedral shapes for corn starch molecules. The husk showed an irregular shape with a coarse surface which could lead to better adhesion, stalk displayed a fibrous surface with little porosity, and hull depicted smooth spongy surfaces.
5. Corn starch and the fiber extracted from corn husk were found to provide the most favorable collection of characteristics in the present research. Thus, they are likely to be used as a sustainable biomass for various applications, especially as an alternative to synthetic plastic uses such bio-films making and packaging.

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