STRUCTURAL, PHYSICOCHEMICAL AND FUNCTIONAL PROPERTIES OF INDUSTRIAL RESIDUES OF PINEAPPLE (*Ananas comosus*)

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Pineapple residues can account for 50% of waste weight.The aim of this research was to study the structural, physicochemical and functional properties of the industrial residues of pineapple to obtain information for recommending their use as dietary fibre. The pineapple residues had a high concentration of cellulose and a low crystallinity index (21.47-30.4%; 14.90-25.86 cellulose I and II, respectively). Scanning electron microscopy (SEM) revealed helical tracheids (HT) and sclerenchymatic fibres (SF) in the shell and helical tracheids in the leaf bracts and various 'individual' fibres with a semi-helical cord (SHC) shape in the core. Additionally, the pineapple residues exhibited low concentrations of lignin, which is an advantage when they are subjected to chemical or enzymatic hydrolysis. Therefore, a new type of product based on these residues could be considered helpful for promoting the nutritional value of foods and extending the utilisation of residues.

Keywords:pineapple, total dietary fibre, scanning electron microscopy (SEM), crystallinity index

INTRODUCTION

Pineapple (*Ananas comosus*), native to the South American continent, is considered an exotic fruit due to its pleasant aroma and flavour, and contains water, carbohydrates, sugars, vitamins A, C and beta-carotene, protein, fat, ash, fibre and antioxidants, namely, flavonoids, in addition to citric and ascorbic acids.[1] In Mexico, pineapple cultivation has a long tradition and is of vital economicand cultural importance. Indeed, Mexico is the eighth largest producer of pineapples worldwide, with 701,746 metric tons (MT).[2] Unlike other fruits, pineapple has the advantage of being commercialised not only as fresh fruit but also in various products with high demand in the market, offering advantages such as added value uses anda greater market availability of products based on pineapple.[1] Pineapple products have been diversified over the past 30 years, and in Mexico, this fruit is commercially marketed as juice concentrates, slices, half slices or mixed with slices of other fruits.[2] The food industry processes this fruit by performing a series of steps during production, removing large amounts of residues such the seeds, shell, bracts and core.[3] Pineapple residues can account for 50% of waste weight, with approximately 10 tons/year of fresh fibre. Larrauri *et al*.[4] reported that the external part of the pineapple has a significant content of soluble carbohydrates (as the product of the pulp remaining after removal of the edible part) including 20% total dietary fibre (TDF), primarily composed of hemicelluloses. As the problems generated by natural resource depletion and global warning have motived every industry to be green and sustainable,[5] a good option is the utilisation of cellulose wastes.

Residual lignocellulosic fibres are polymeric materials of great industrial interest because they are renewable and biodegradable products. The chemical composition of fibres depends on their type and origin, containing different amounts of cellulose, hemicelluloses and lignin (dietary fibre).[6] In addition to the amount of dietary fibre present in plant tissues, other important aspects are their chemical (degree of lignification, type and crystallinity of cellulose) and physical (particle size and shape) properties because these have an effect on fermentation in the colonand speed of transit in the gastrointestinal tract.

According to Rodríguez *et al.*[7], the beneficial effects that fibre has on health depends on, among other properties, such characteristics as hydration, ion exchange and oil-holding capacities.Therefore, given the above conditions, the present study aimed to quantify the fibrous constituents of residues from the industrial processes of pineapples in Mexico. These residues were grouped as leaf bracts, shell and core to study the relationship between the native cellulose phases and the differences among these residues to thereby obtain information for recommending their use as dietary fibre.

EXPERIMENTAL

Raw materials: treatment and classification

The agro-industrial residues (leaf bracts, shell and core) were provided by a pineapple-in-syrup processing plant located in the city of Puebla, Mexico. The residues were collected during the production seasons of 2010 and 2011 and dehydrated in a horizontal drying chamber (Lumisell, Mexico city, Mexico) at 60°C; the moisture content was less than 10%. Size reduction was performed using a cyclone mill (Tecator Cyclotec, Höngänas, Sweden), followed by size classification: 500 g samples were sieved for 20 min through Tyler mesh sieves (OH, USA) number 40, 60, 80 and 100 (with aperture sizes of 0.335, 0.214, 0.163 and 0.112 mm, respectively) coupled in series with a sieve stack attached to shaker (Ro-Tap,OH, USA).

Proximate chemical analysis of raw materials

A proximate chemical analysis for pulp and residues (leaf bracts, shell and core) was performed using the methods of Association of Official Analytical Chemists (AOAC).[8] The moisture and ash contents were determined until no further decrease in weight (AOAC 942.05). The total crude protein was determined [%N × 6.25] using method 984.13, crude fat by ether extraction (method 945.16) and crude fibre using the acid-alkaline hydrolysis method (962.09). Total carbohydrates were determined by the following equation: 100 - % (CP + Ash + Crude fat + CF + M), whereCP = crude protein; CF = crude fibre and M = moisture.[9]

Physicochemical composition of pineapple residues

Determination of total dietary fibre: the insoluble (IDF) and soluble (SDF) dietary fibre contents were determined according to AOAC methods.[8]The samples were dried, defatted and freed from carbohydrate; prior to the analysis, a blank was run through the entire procedure along with the samples to measure any contribution of reagents to the residues. The dietary fibre contents were corrected for residual protein and ash. The total dietary fibre content (TDF) was calculated as the sum of IDF and SDF.

Hemicellulose: The determination of the neutral detergent fibre (NDF) content (Van Soest) was used to quantify the content of hemicelluloses.[10]The residue of NDF was utilised to determine the content of cellulose and lignin as acid detergent fibre (ADF), according to AOAC (978.19).[8]

Effect of particle size on functional properties of pineapple residues

As the physiological attributes of fibre largely depend on its physical characteristics, namely, the molecular structure and solubility, the effect of particle size (0.335, 0.214, 0.163 and 0.112 mm) and type of residue (leaf bracts, shell and core) on functional properties, such as swelling water capacity (SWC), water holding capacity (WRC), oil holding capacity (OHC) and cationic exchange capacity (CEC), was evaluated.

SWC. A 3 g sample was weighed precisely and transferred to separate calibrated cylinders (1.5 cm diameter), to which 10 mL of distilled water was added. After careful mixing, the sample was allowed to stand at room temperature (22 ºC) for 24 h. The bed volume was recorded, and the SWC was calculated as mL per g of dry sample.WRC was expressed as the amount of water (mL) per gram of dry sample (mL water/g dry sample). OHC was expressed as the amount (g) of olive oil retained per gram of dry sample (g oil/g dry sample). CEC was assessed according to Yeh *et al.*[11]

Statistical analysis of data: A completely randomised design (CRD) was used to evaluate the effect of particle size and the type of residue on the functional properties,with the following factorial arrangement:

$$Y_{ijk} = \mu + R_i + T_j + R \times T + \varepsilon_{ijk} \ldots$$

whereY_{ijk} = response variable (value of the functional property); μ = general average; T_j= effect of size; R_i = effect of the type of residue; R × T = interaction between the size and the type of residue and ε = random error associated with the response variable. An analysis of variance was used applying Tukey's test (α

= 0.05)[12] with Statistical Analysis System 8.0 (SAS Institute Inc., Cary, North California, USA) software.

Fourier transform-infrared spectroscopy (FTIR): FTIR was performed according to Gomez-Ordoñez and Ruperez[13] to investigate the differences in crystallinity and hydrogen bonding of the cellulose fibre. A Perkin Elmer (precisely, Salem, MA, USA) spectro-photometer was used with the attenuated total reflectance (ATR) technique as the sampling mode. The analysis was assessed in the mid-infrared region (700-4000 cm^{-1}) at a resolution of 4 cm^{-1} using Spectrum 5.3.0 software. To identify functional groups, standard samples of microcrystalline cellulose and lignin (435236 and 370959 Sigma-Aldrich®, Co. St. Louis, MO, USA) were used.

Scanning electron microscopy (SEM): Surface materials were examined by SEM to observe the morphology of fibres in the samples of pineapple residues. The samples were mounted on conductive adhesive tape, sputter coated with gold and observed usinga scanning electron microscope (JEOL JSM-6610-LV Low Pressure Tokyo, Japan) operating at 20 kV.

X-ray diffraction (XRD): XRD was used to reveal the supramolecular structure of cellulose following the method described by Dominique *et al.*[14] A 25 mg sample was placed into the sample holder of a diffractometer (Bruker D8 Discover Berlin, Germany) with an X-ray source of copper operating at 40kV and 40 mA and producing Cu-Kα radiation with a wavelength of 1.54 Å. Each sample was analysed for 30 minutes, with an incidence for 0.6 s for each fraction from an angle (φ) of 5-90º with a step size of 0.028º φ. The diffractogram was obtained using DIFFRAC plus XRD CommanderSoftware (Bruker Berlin, Germany). A standard sample of microcrystalline cellulose (435236, Sigma-Aldrich®, Co. St. Louis MO, USA) was analysed to confirm its identity in the pineapple residues.

RESULTS AND DISCUSSION

Proximate chemical analysis

Table 1 shows the proximate chemical composition of the pineapple pulp and residues (leaf bracts, shell and core). A statistical analysis revealed significant differences ($p \leq 0.05$) in the values of the total protein, ash and crude fat parameters. The total protein content ranged from 0.7 g/100 g of leaf bracts to 1.58 g/100 g of pulp; this total protein can be largely attributed to hydroxyproline-rich glycoprotein because Ai *et al*.[15] reported that the glycoproteins in the shells of fruits are embedded in the primary cell wall, forming a network of microfibrils with the cellulose. The protein content of the pineapple residues was compared with that of *Mangifera pajan*g Kort fibre.[16] The leaf bracts exhibited the highest ash content, which was twice that in the pulp, and the pulp ash values were higher than in mango fibre (3.0% pineapple and 0.8% mango fibre).[16] The carbohydrate content was determined by calculation and may include simple sugars, such as monosaccharides and disaccharides. The highest content of crude fat was found in the edible fraction of the pulp, followed by the core (in the case of the residue), whereas the lowest concentration of crude fat was in the leaf bracts.

The raw fibre contents ranged from 24.14% in the pulp to 65.0% in the leaf bracts. As shown in Table 1, the raw fibre content of the residue fractionwas found to be 2.5 times greater than the edible fraction (pulp); these values are similar to those found by Larrauri *et al.*,[4] who also studied pineapple shells.

Determination of soluble (SDF) and insoluble (IDF) dietary fibre

Table 2 shows the results obtained for the different dietary fibre fractions, with the statistical analysis showing significant differences ($p \leq 0.05$) among the leaf bracts, shell and core. The content of dietary fibre (TDF) in the residue depended on the source from which it was extracted, with the shell having the highest content (81.8 g/100 g of dry sample). Furthermore, the main fibre fraction found in the residues of the fibres studied was the IDF fraction, which represented 56-65% of the TDF. Larrauri *et al.*[4] reported similar values for pineapple shell. These results indicated that the samples tested were composed mainly of cellulose microfibrils containing hemicelluloses and lignin, as shown in Table 2. Because the insoluble fraction of fibre appears to be related to intestinal regulation,[17] the fibre obtained from pineapple residues could be recommended as source of DF to supplement food products low in fibre.[18] Pineapple residues are a major source of cellulose and hemicelluloses and could have promising applications, including uses as a low-cost animal feedstock, as raw material for the biological production of fuels, chemicals and even as cellular support in different bioprocesses.

Table 1
Proximate chemical composition of the leaf bracts, shell and core residues of pineapple compared with the pulp

Parameter (g/100 g)	Pulp	Leaf bracts	Shell	Core
Total protein	1.58±0.01[d]	0.70±0.01[a]	0.75±0.01[b]	0.85±0.01[c]
Ash	3.00±0.01[b]	7.37±0.00[d]	1.50±0.00[b]	1.30±0.00[a]
Crude fat	3.19±0.00[b]	3.50±0.01[c]	2.00±0.01[a]	3.17±0.01[b]
Crude fibre	24.14±0.01[a]	62.50±0.00[c]	65.00±0.00[c]	47.60±0.00[b]
NFE*	68.79±0.00	25.93±0.02	32.10±0.02	47.08±0.01

NFE=Nitrogen-free extract. The results are given on adry basis and correspond to the average from three independent determinations ± standard deviation. Means followed by at least one different letter within the same row indicate a statistically significant difference ($p \leq 0.05$) after applying Tukey's test

Table 2
Comparison of the chemical composition of the pineapple residues in terms of fibre fractions

Fibre % Dry weight	Leaf bracts	Shell	Core
IDF	43.53±0.93[a]	46.20±0.50[b]	42.92±0.09[a]
SDF	29.16±0.46[b]	35.67±0.37[c]	21.27±0.61[a]
TDF	74.69	81.8	64.19
Hemicellulose	21.88±0.22[a]	28.69±0.35[b]	28.53±1.37[b]
Cellulose	43.53±1.17[c]	40.55±1.02[b]	24.53±1.68[a]
Lignin	13.88±1.70[c]	10.01±0.3751[b]	5.78±0.429[a]
Pectin	2.32±0.37[b]	2.49±0.20[b]	1.58±0.17[a]

IDF = Insoluble dietary fibre; SDF = Soluble dietary fibre; TDF = Total dietary fibre. The results are given on a dry basis and correspond to the average from three independent determinations ± standard deviation. Means with different superscripts in the same row indicate a statistically significant difference ($p \leq 0.05$) with respect to each other after applying Tukey's test

Effect of particle size on the functional properties of pineapple residue

Table 3 shows the effect of particle size on the functional properties, including SWC, WHC and OHC. The particle sizes ranged from 0.335 to 0.112 mm. SWC and WHC were affected by particle size because 0.112 and 0.163 were significantly different ($p \leq 0.05$) from 0.214 and 0.335. The low values of SWC for 0.112 and 0.163 mm could be related to the IDF content, since Al-Sheraji *et al.*[16] reported that low swelling capacity values could be related to a high content of IDF. Hence, particle size is related to the chemical composition of fibres, most likely because a larger particle size results in a higher proportion of fibres, such as cellulose. Sangnark and Noomhorm[19] reported similar behaviours in different fruit residues and related their density and chemical composition to these properties. Based on these results, the cellulose and hemicellulose contents varied with respect to the particle size and the proportion of these components affected SWC and WHC. The OHC values were different depending on the particle size, of which the highest value was 0.163 mm. These results can be related to the composition of the fibre, with a potential higher proportion of cell wall. By analysing the effect of particle size on the functional properties of pineapple residue, we can recommend 0.163 mm as the optimum.

Effect of the type of residue on the functional properties of leaf bracts, shell and core

Table 4 shows the effect of the type of residue (leaf bracts, shell and core) on the functional properties mentioned above. The SWC values for the leaf bracts and shell were 7.5 and 9.15 g of water/g of fibre, respectively. The SWC value obtained for the pineapple shell was similar to that reported by Al-Sheraji[15] for *Mangifera pajang* Kort fruit pulp (8.81g/g). The pineapple shell exhibited the highest value of WHC (9.71 mL of water/g of dry fibre), followed by the core at 9.01 mL of water/g of dry fibre. These results agree with the value previously reported for pineapple cores.[4]

Table 3
Effect of particle size on the functional properties of pineapple residues

Functional properties	Particle size (mm)			
	0.335	0.214	0.163	0.112
Swelling water capacity (SWC) mL water g^{-1}	$8.70\pm0.29^{a, a, a}$	$8.40\pm0.44^{ba,ba,ba}$	$8.0\pm0.42^{bc,bc,bc}$	$7.79\pm0.27^{c,c,c}$
Water holding capacity (WHC)mL water g^{-1}	$8.70\pm0.23^{a, a, a}$	$8.43\pm0.14^{a, a, a}$	$7.01\pm0.15^{b,b,b}$	$6.84\pm0.23^{b,b,b}$
Oil-holding capacity (OHC) g oil g^{-1}	$2.70\pm0.20^{c,c,c}$	$2.72\pm0.15^{c,c,c}$	$4.34\pm0.64^{a,a,a}$	$3.61\pm0.25^{b,b,b}$

The results are given on adry basis and correspond to the average from three independent determinations ± standard deviation. Means followed by at least one different letter within the same row are significantly different ($p \leq 0.05$) after applying Tukey's test

Table 4
Influence of the type of residue (leaf bracts, shell and core) on functional properties

Functional properties	Leaf bracts	Shell	Core
Swelling water capacity (SWC) mL water g^{-1}	7.50 ± 0.41^{a}	9.15 ± 0.63^{b}	7.96 ± 0.53^{a}
Waterholding capacity (WHC) mL water g^{-1}	4.49 ± 0.48^{a}	9.71 ± 0.63^{b}	9.08 ± 0.59^{b}
Oilholding capacity (OHC) g g^{-1}	2.79 ± 0.22^{a}	3.75 ± 0.33^{b}	3.50 ± 0.38^{b}
Cation exchange capacity (CEC) mequiv g^{-1}	1.60 ± 0.10^{a}	1.50 ± 0.10^{a}	1.70 ± 0.10^{a}

The results are given on a dry basis and correspond to the average from three independent determinations ± standard deviation. Means with the different superscripts in the same row indicate a statistically significant difference ($p \leq 0.05$) with respect to each other after applying Tukey's test

These functional properties of residues are closely related to the viscosity that the residues confer to food; thus, considering these functional properties, the residues could be used as viscosity-increasing agents. Alternatively, these fibrous residues might be added to foods with low energy density.

The shell showed the highest values of OHC. This could be a positive feature from a technological point of view, high oil holding capacity is very important within meat industry where the products consist of prominent amount of fat. Therefore, high emulsifying and stabilizing properties of food ingredients are desirable.[18] Because pineapple residues have a high OHC, they will be useful for promoting the emulsification of some products.

The type of residue did not appear to affect CEC (Table 4). This parameter is an indicator of the ability of fibres to bind minerals, mainly zinc, iron and calcium: a lower CEC value indicates a lower affinity for cations.[11] One of the adverse effects of fibre intake is the scavenging of ions, such as Ca^{2+}, Mg^{2+} and Fe^{2+}, which diminishes their bioavailability. However, pineapple consumption would not have this adverse effect, and the bioavailability of minerals necessary for the appropriate functioning of humans and animals would be maintained, as Ojukuku *et al.*[9] and Yeh *et al.* reported.[11]

FTIR of cellulose and lignin samples obtained from pineapple residues

The FTIR spectra of cellulose and lignin were identified and compared with those of the samples of pineapple residues (leaf bracts, shell and core) in the range of 4000 to 750 cm^{-1}. In the cellulose spectrum (Fig. 1a), a signal in the range of 3600-3100 cm^{-1} is associated with the presence of O-H stretching vibration,[20] which provides considerable information concerning hydrogen bonds. The peaks characteristic of hydrogen bonds were sharper and with a lower intensity than amorphous cellulose.[21]

Signals between 1336 and 1314 cm^{-1} indicate the presence of crystalline cellulose type II. The band at 1157 cm^{-1} indicates the presence of C-O-C groups,[22] suggesting the presence of saturated ether groups and thus is the peak characteristic of amorphous cellulose. The signal at 896 cm^{-1} is associated with the vibration of the anomeric carbon group of carbohydrates, C-O-C, and is designed as an amorphous absorption band.[22]

In Figure 1b, the signal at 3223 cm^{-1} corresponds to an OH group, whereas the signal at 2935 cm^{-1} corresponds to the C-H stretching of methylene groups in a phenol ring.[23] According to Herrera *et al*.[24] and Reddy *et al.*,[25] the signal at 1594 $cm^{-1}$is characteristic of the elongation of the C=C bond in the aromatic ring of lignin. The signals in the regions of 820-855 cm^{-1} and 748-779 cm^{-1} that were observed are related to substitutions of the groups in the *ortho-* and *para-*positions of the aromatic ring, as reported for phenolic resins and vanillin extract.[24,26]

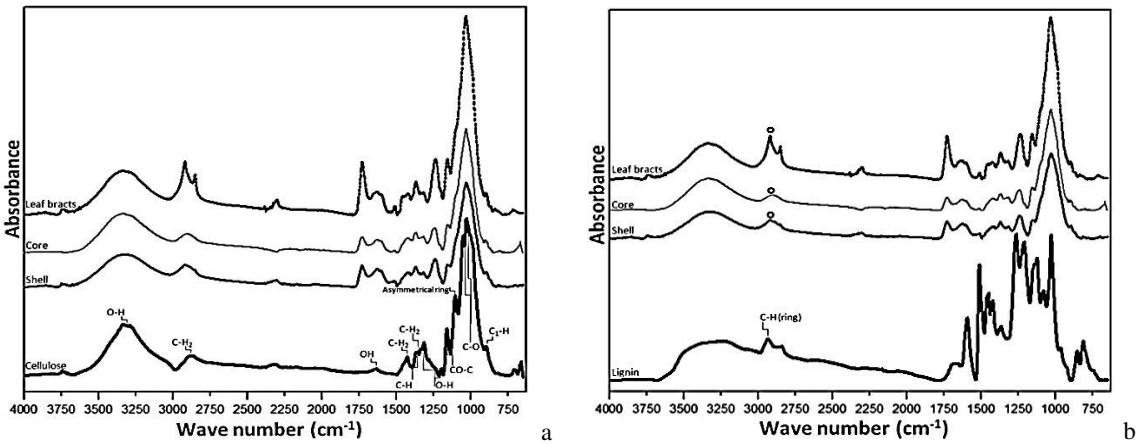

Figure 1:FTIR spectra of pineapple residues in the 4000-750 cm^{-1} range in comparison with the spectra of (a: cellulose, and b: lignin)

The cellulose, pectin and lignin spectra enabled the inference of the overlapping functional groups in the leaf bracts, shell and core, one of which is C-H, which occurred at frequencies of 2917, 2918 and 2923 cm^{-1}, respectively.These values are similar to the signal for methoxy groups in phenolic rings. The signal in the range of 2950-2800 cm^{-1}, the C-H stretchingof methylene groups, was found in different proportions: it was higher in leaf bracts, indicating a higher proportion. This result is in agreement with the concentration of lignin shown in Table 2. Moreover, most of the signals present in the lignin spectrum were observed in the spectra of the pineapple residues (leaf bracts, shell and core). Other signals associated with H-C and =C-H bonds were observed but at a lower intensity due to the low concentration of lignin in the residues.

Scanning electron microscopy (SEM)

Considering that particle size was found to affect the chemical composition of pineapple residue fibres, the 0.214 mm size was used for all measurements to study the possible structural changes in these fibres by SEM.

Figures 2a, 2b and 2c demonstrate the micro-morphology of the pineapple fibres (leaf bracts, shell, and core). The images show fibres in latticed and spiral-annular arrangements, with cellulose deposits in the form of helixes around the cellular axis.[27]

Figure 2a shows the shell sample at 500x magnification, and it is possible to observe a helical tracheid (HT) and a sclerenchymatic fibre (SF) with a sharp fusiform and sharp structure. These morphological characteristics are distinctive of cotton fibres, which are composed mainly of cellulose (99%).[27,28] These results were in agreement with the results for IDF.

Figure 2b shows a set of helical tracheids in the leaf bracts, *i.e*., there is a helical thickening that allows the cell wall to expand the fibre length. However, several long bundles were observed to unite in the form of a plate, which according to Paniagua,[29] is composed of alternating layers rich in lignin or cellulose. The structures linked to the cell wall are microfibrils,

which can be divided into two groups: xylary and extraxylary fibres. The latter are linked to primary membranes, such as cellulose, which is immersed in an amorphous matrix composed of non-cellulosic polysaccharides (hemicelluloses, pectin and lignin),[27,28] representing approximately 50% of the dry material, as determined by microanalysis of the composition of the amorphous or non-crystalline phase of the pineapple residues. The crystalline content differs with species, variety and age, modifying the composition, proportion and structure of fruit components.

In Figure 2c, various 'individual' fibres with a semi-helical cord shape (SHC) are observed in the core sample. Notable among them is a set of long fibres grouped into several, perfectly arranged packets with a slightly helical shape (SHS) due to the presence of cellulose.[29,30]

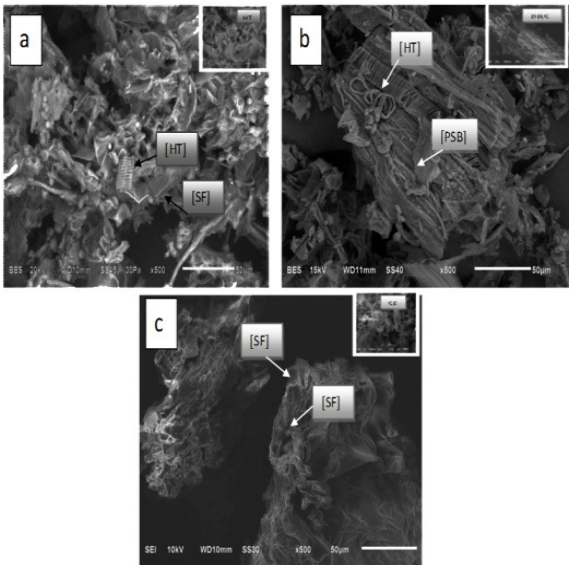

Figure 2: SEM images of pineapple residues; a: shell, b: leaf bracts and c: core (HT: helical tracheid; SF: sclerenchymatic fibre; PSB: plate-shaped bundles)

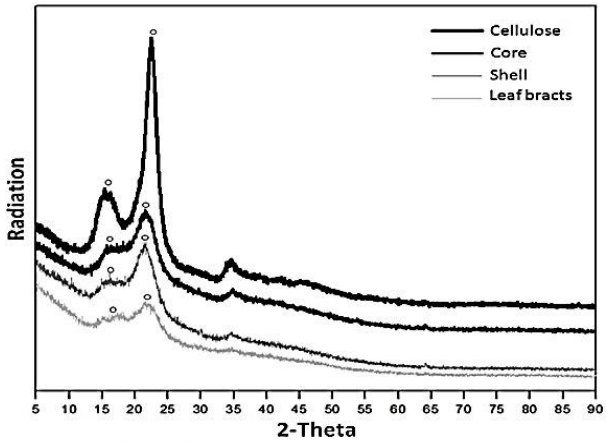

Figure 3: X-ray diffraction profiles of pineapple residues in comparison with the diffraction pattern of a commercial preparation

The cellulosic chains are regularly arranged parallel to the length of the microfibril-ordered lattices. When not present in these orderly regions, the cellulosic chains lose their regularity and form amorphous regions.[29] SEM revealed structural differences among the fibres in the pineapple residues, which is consistent with the results shown in Table 2. The analysed fibres,

despite originating from a monocot plant, were soft and had low lignin content, as corroborated using X-ray diffraction, which makes them useful in commercial applications.

X-ray diffraction (XRD)

The X-ray diffraction patterns of the analysed samples (leaf bracts, shell and core) are shown in Figure 3; these patterns were compared with the results of a cellulose standard. The diffractogram of cellulose showed well-defined signals, with the highest intensity at 2θ=23º. A flexion at 2θ=15º was observed, which is related to the presence of less-ordered zones of cellulose (amorphous cellulose that may be composed of hemicelluloses, lignin and pectin).[24,29] To evaluate the apparent crystalline nature of the samples, multiple strip resolution was used, in which the signal with the highest intensity known as the base signal corresponds to the diffractogram of cellulose, with 100% intensity for 2θ = 15º (signal 1) and 2θ = 23º (signal 2). Additionally, comparisons were made with respect to the other diffractograms, for which the following relative intensity percentage was assumed: 32% for the leaf bracts, 47% for the shell and 61% for the core.[22,25,26] In signal 1, width angle flexions were observed, which may be attributed to amorphous cellulose due to the scarcity of hydrogen bonds in this region; this is commonly observed in components linked to the cell wall.[23,25,30] In contrast, signal 2 appears to be more acute and intense, assigned to crystalline cellulose.

The core was observed to be a type of residue with the most intense signal. Nonetheless, the cellulose fibre is a polycrystalline aggregate that contains crystalline, non-crystalline and amorphous components, i.e., it is composed of amorphous or less crystalline regions. By observing the signals shown in Figure 4, the pineapple residues showed crystalline and amorphous regionsin the cellulose.Therefore, it was important to measure the extent of crystallinity, which was associated with diffraction zones of the diffractogram, by determining the ratio between the amounts of crystalline and amorphous materials and the total (integrated) intensity of the crystalline and amorphous components.

The crystallinity index values calculated according to Herrera *et al.*[24] indicated that the leaf bracts had a small amount of crystalline cellulose, with 21.47% cellulose I and 20.30% cellulose II. The shell contained 30.40% cellulose I and 14.90% cellulose II, whereas the core had 29.40% cellulose I and 25.86% cellulose II. Cellulose I and II correspond to native and crystalline cellulose, respectively. Therefore, the cellulose present in pineapple residues is largely amorphous, which means that the material can be degraded more easily because this type of cellulose is not resistant to processing.[22]

CONCLUSION

The agroindustrial pineapple residues studied had a greater fraction of fibre than the edible portion or pulp and even more than other agroindustrial residues. The amount of dietary fibre found in the pineapple leaf bracts, shell and core residues was relatively high, with the insoluble fraction being the main component. These residues are a good source of cellulose, hemicellulose and lignin. Based on their functional properties, pineapple residues may be used to modify food characteristics, such as viscosity. The analysis of the lignin-cellulose compounds in pineapple residues indicated that they have low lignin content and a high concentration of cellulose, mainly amorphous, indicating that these residues, in addition to their use as dietary fibre, can be employed for biofuel production.

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