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Research article

Effect of size and amount of sugarcane fibers on the properties of baked foams based on plantain flour

José L. Román-Moreno [a], Guadalupe P. Radilla-Serrano [a,d], Alejandra Flores-Castro [a], José De J. Berrios [b], Gregory Glenn [b], Areli Salgado-Delgado [c], Heidi M. Palma-Rodríguez [d], Apolonio Vargas-Torres [d,*]

[a] Tecnológico Nacional de México/Instituto Tecnológico de Acapulco, Depto. de Ingeniería Química y Bioquímica, Av. Instituto Tecnológicos s/n, Crucero de Cayaco, C.P.39905, Acapulco Gro, Mexico
[b] USDA-ARS-Western Regional Research Center, 800 Buchanan Street, Albany, CA 94710, USA
[c] Tecnológico Nacional de México/ Instituto Tecnológico de Zacatepec, Calzada Tecnológico No. 27, C.P.62780, Zacatepec de Hidalgo, Morelos, Mexico
[d] Universidad Autónoma del Estado de Hidalgo, Instituto de Ciencias Agropecuarias (ICAP), Av. Universidad km 1, Rancho Universitario, C.P.43600, Tulancingo de Bravo, Hidalgo, Mexico

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ABSTRACT

Baked foams made with plantain flour (PF) and sugarcane fiber (SF) were characterized by calorimetric, mechanical, physicochemical and structural techniques in order to assess the results induced by different sugarcane concentrations and fiber size on the structure of baked foams. The addition of SF to the baked samples increased their hydrophobic properties. Thermal conductivity (TC) decreased when the concentration of SF was 10 g and 7.5 g in the baked foams. The density of the biodegradable baked foams (BBFs) decreased with decreasing concentrations of SF, observing an inverse behavior in water vapor permeability (WVP) and solubility properties. The mechanical properties of the baked foams were more influenced by the concentration of SF than by the size of SF, obtained from different sieves. The scanning electron microscopy cross-sectional images of the BBFs showed that the size of SF affected the size and number of the internal cells in the BBFs.

1. Introduction

Nowadays, one of the most abundant and visible plastic environmental pollutant is expanded polystyrene, a foamed plastic material derived from petroleum and used in food containers and construction materials. Due in part to the large volume of non-biodegradable plastic used globally, researchers are looking for renewable and degradable materials that can replace plastics. This is particularly true in the manufacture of household items such as plates, packaging foams, cups and containers (Du et al., 2012; Palma-Rodríguez et al., 2016; Vargas--Torres et al., 2017). One of the most biodegradable, inexpensive, and abundant renewable polymer available for use in making containers is starch (Du et al., 2012; Mello and Mali, 2014; Palma-Rodríguez et al., 2016; Shey et al., 2006; Shogren et al., 1998). However, packaging made only from starch has poor mechanical properties and moisture resistance. Therefore, starch alone, is not a well-suited material for food packaging. Particularly for foods with high moisture content. Adding malt bagasse to a foam material is reported to improve mechanical properties and increase moisture resistance (Mello and Mali, 2014). Vargas-Torres et al. (2017) reported that adding increasing concentrations of plantain flour to formulations based on chayotextle starch, used as a reinforcement material in baked foams, increased the hydrophobic properties of the foam, decreased its solubility and water vapor permeability, and improved its mechanical properties. Pelissari et al. (2013) reported that the mechanical properties and water solubility of films improved when made with formulations containing banana flour compared to films that were made only with plantain starch. These studies indicate that starch obtained from unconventional sources such as unripe plantain flour is a good alternative for making biodegradable materials. Furthermore, unripe plantain flour is cheaper than commercial starches.

The production of plantains represents 2.7% of the perennial crops in Mexico. From 2013 to 2016, the production of plantain increased to 270,000 tons, a 12.9% increase in a four-year period (SIAP, 2017). Due to the increased production of plantain, there is interest in finding value-added uses for plantains that will benefit growers and, ultimately, the national economy. In their green or immature state, banana fruits

* Corresponding author.
E-mail address: apolonio@uaeh.edu.mx (A. Vargas-Torres).

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have up to 70% of starch (dry basis) (Flores-Gorosquera et al., 2004; Rodríguez-Ambriz et al., 2008). The use of plantain flour in biodegradable materials can help reduce crop loss. Furthermore, it is an excellent raw material for making biodegradable films and baked foams.

There is an increasing interest in using natural fibers to reinforce polymers due to their positive effect on mechanical properties, significant processing advantages, low cost and low density (Carr et al., 2006). Several studies have shown that the use of natural fibers improves the physical and mechanical properties of starch-based biodegradable materials (Mali et al., 2010; Müller et al., 2009; Vercelheze et al., 2013). The water resistance and mechanical properties of a fiber used to reinforce a polymer composite depend on many factors, including fiber-matrix adhesion, volume fraction of fiber, fiber aspect ratio (l/d), alignment and size of the fiber size (Joseph et al., 2000; Matsui et al., 2004). The waste produced by the agricultural sector, such as sugarcane fiber, can be used as a reinforcing material in biodegradable composite materials. The objective of this study was to determine whether the sugarcane fiber size and concentration could beneficially modify the mechanical, physicochemical and structural properties of biodegradable baked foams.

2. Materials and methods

2.1. Materials

Unripe plantains (*Musa paradisiaca* L.) were collected in Tetitlán, Guerrero, México. The sugarcane fiber was donated by the sugar mill of Zacatepec, Morelos, México. Magnesium stearate (MgStr) was purchased from Aldrich (México).

2.2. Plantain flour processing

Unripe plantains (*M. paradisiaca* L.) were peeled, cut into 3 mm thick slices and dipped into sodium bisulfate solution (3%) for 1 min to prevent enzymatic browning of the PF. The treated slices were placed in a forced-air drying oven (Hamilton Beach 32100) and dried at 45 °C for 12 h or until the moisture was reduced to <5%. The dried plantain slices were initially crushed using a commercial blender to obtain a coarse material (approximately 5–10 mm particle size), and subsequently milled into flour in a UDY Mill equipped with a sieve (~0.05 mm) (UDY Corp., Fort Collins, CO). The PF was placed in a zip-lock bag and stored at room temperature for subsequent use.

2.3. Sugarcane fiber processing

The sugarcane fiber was previously washed with alcohol (80%) under constant stirring for 4 h. It was then washed with distilled water and dried at 60 °C for 12 h. The dried sugarcane fiber was ground using a commercial blender and sieved using three mesh sizes; 30 mesh (0.595 mm), 45 mesh (0.354 mm), and 70 mesh (0.210 mm).

2.4. Dough preparation

Sugarcane fiber (SF), PF, magnesium stearate and water (1/2 of the quantity shown in Table 1) were placed in the metal mixing bowl of a Hobart laboratory mixer (Model N-50, Hobart Mfg., Troy, OH) and mixed at medium speed for 5 min. The remaining water was added slowly until an homogeneous blend was obtained. The blend was further mixed at the highest speed for 10 min to ensure adequate SF dispersion.

2.5. Baking process (thermopressing)

A laboratory-baking machine (ZQe Mini Hebenstreit GmbH, Germany) was used to bake rectangular BBF samples (~0.2 cm thick, 16.5 cm long, and 11.1 cm width). The baking mold was preheated and maintained at 200 °C. Foam panels were made by placing a dough sample (30 g) in the center of the mold, quickly closing it and baking it for 1 min and 30 s. Afterwards, the BBFs were removed from the baking machine and stored in sealed plastic bags at room conditions (25 ± 2 °C) for later use.

2.6. Contact angle measurement

To determine the hydrophilicity of the foams, their water contact angle was measured using a goniometer designed at the Zacatepec Technological Institute, Mexico. The test was carried out at 35 °C. A drop of water was placed on the foam film surface and the evolution of the droplet shape was recorded for 5 min (taking readings every minute) with an optical video camera (Steren 1003) equipped with AVACAM software, which allowed the internal contact angle to be determined. The contact angles were measured on both sides of the droplet and their values averaged. A minimum of 6 measurements were recorded for each sample.

2.7. Scanning electron microscopy

Scanning Electron Microscopy was used to study the internal structure of the samples. Aluminum specimen stubs were used to mount the BBF samples, using double-sided carbon tape (Ted Pella, Redding, CA). All specimens were coated with gold-palladium for 45 s using a Denton Desk II sputter coating unit (Denton Vacuum, Moorestown, NJ). The coated specimens were observed using a field emission scanning electron microscope (SEM) (JEOL, Japan) at 2 kV.

Table 1. Formulations containing plantain flour (PF) and sugarcane fiber (SF) for the fabrication of biodegradable baked foams.

Sample ID	Plantain flour (g)	Sugar cane fiber (g)	Mesh number▲	Water (mL)	Magnesium stearate (g)
Control	100	–	325	100	1
PF95/SF5-30	95	5	30	140	1
PF92.5/SF7.5-30	92.5	7.5	30	140	1
PF90/SF10-30	90	10	30	140	1
PF95/SF5-45	95	5	45	120	1
PF92.5/SF7.5-45	92.5	7.5	45	120	1
PF90/SF10-45	90	10	45	120	1
PF95/SF5-70	95	5	70	100	1
PF92.5/SF7.5-70	92.5	7.5	70	100	1
PF90/SF10-70	90	10	70	100	1

PF = Plantain flour; SF = Sugar cane fiber.
▲ Mesh used to sieve the sugarcane fiber and plantain flours.

2.8. Measurement of thermal conductivity

In preparation for thermal conductivity (TC) tests, the BBFs were conditioned at 37% rh (25 °C) for 48 h. The TC tests were performed following the method of Salgado-Delgado et al. (2016). A hot plate system, based on the ASTM C177-19 (2019), was used. The components of the hot plate system consisted of a heating plate, two cold plates located on each side of the system, a mounting system, an isolation chamber, and accessory devices for tuning and measuring TC (Pérez Sánchez et al., 2002). The main particular specifications of the guideline are as follows: the method must be applied to materials with thermal conductivities of up to 0.62 kcal/m °C; the testing temperature throughout the run must be kept between 10 and 90 °C; the external insulation surrounding the guard ring must have a thermal resistance of at least twice that of the material that is being tested; the thermocouples must be made from wires with a diameter no greater than 0.57 mm; the hot and cold faces of the sample must have at least 22 °C of temperature difference.

2.9. Density

The test was carried out at 35 °C and at approximately 0% RH. Density (g/cm^3) was calculated from the mass (g) and volume (cm^3) of each sample. Density tests were performed on rectangular foam strips measuring 2 × 3 cm. Each sample was weighed, and the length, width and thickness of the samples were multiplied to calculate the volume. Density values are presented as the average of three replicate per treatment.

2.10. Solubility

Samples of 2 cm × 3 cm were cut and stored for 7 days in a desiccator (approximately 0% RH). The samples were weighed and placed in glass vessels with 80 mL of deionized water. The samples were kept at 25 °C for 1 h, under constant agitation, followed by drying at 60 °C, until a constant weight was obtained. The percentage of total soluble material was calculated with Eq. (1):

$$\%Solubility = \frac{(Initial\ \ weight - Final\ \ dry\ \ weight)}{Initial\ \ dry\ \ weight} \times 100 \quad (1)$$

The samples were analyzed with three replicates.

2.11. Thickness

The thickness of the baked foams was measured at 10 random places using a digital micrometer (Mitutoyo, No. 293-831-30). The mean thickness values were used to estimate the mechanical properties and water vapor permeability (WVP) of the foams.

2.12. Water vapor permeability

A water vapor permeability (WVP) test was conducted using the ASTM standard method E96/E96M (ASTM, 2016) with some modifications. Each sample was sealed over a circular opening of 0.000282 m^2 in a permeation cell and stored at 25 °C in a desiccator. The RH in the desiccator/storage was maintained at 75% RH by placing silica gel (0% RH) inside the cell and a saturated solution of sodium chloride (75% RH) in the desiccator. Water vapor transport was determined from the weight gained in the permeation cell. After a steady-state condition was reached (at approximately 2 h), eight weight measurements were taken over an 8 h period. The changes in cell weight were recorded as a function of time and the data gathered was plotted. All the weights were measured to the nearest 0.0001 g. A linear regression ($r^2 > 0.98$) was generated from the slope of each line. The water vapor transmission rate (WVTR) was calculated from the slope of the straight line (g/s) divided by the cell area (m^2). After the permeation test was done, the thickness and WVP (g/Pa h m) of the baked foams were measured. The Eq. (2) to calculate WVP is shown below:

$$WVP = WVTR = \frac{Thickness(m)}{\Delta Pressure(Pa)} \quad (2)$$

2.13. Mechanical properties

The mechanical properties tested included load tensile strength (Ts), percent elongation at break (Eb) and elastic modulus (Em). The maximum breaking force, deformation at break (extension at the moment of rupture in mm), and elastic modulus were obtained from the force versus deformation curves using a universal testing machine (Instron, Model 4500, Canton, MA), equipped with a 50-kg load cell. Following the ASTM D638 (ASTM, 2014) standard protocol, typical type I tensile bars were prepared by cutting from panels, using a band saw. The tensile tests were performed at a deformation rate of 1 mm/min. The mean values from 10 replicates were reported for each BBF sample prepared.

2.14. Statistical analysis

Analysis of variance was used to determine whether a significant size and concentration effect could be detected. All data were properly organized and statistically analyzed using statistical software (Sigma-Stat version 11.0). The means were compared using Tukey's multiple comparison test ($\alpha = 0.05$).

3. Results and discussion

3.1. Microstructural properties

The control baked samples (made only with PF) show greater thickness (Table 2) than those BBFs reinforced with fiber (Figure 1). The size of the cells in top and bottom in the control foam was also larger (See Figure 1). The micrographs showed that the reduction in the SF contain in the matrix of BBFs produce an increase in the irregularity and cell size as observed in Figure 1B vs 1D; 1E vs 1G and 1H vs 1J. Lawton et al. (1999) reported similar pattern in in baked starch foam reinforced with aspen fibers. Shogren et al. (1998) mention that drying temperature; starch type and water content play an important role in the formation of the internal structure of baked foam samples.

The BBFs added with higher fiber load showed a more compact internal structure (smaller cell size or less damaged cells). This characteristic view of the internal structure of the baked samples may be associated to the even distribution of SF throughout the baked matrix. Similar conclusion was reported by Mello and Mali (2014). They reported that it is due to a good addition between the fibers and starch. The control baked samples (made only with PF) show greater thickness (Table 2) than that BBFs reinforced with fiber (Figure 1). The size of the cells in top and bottom in the control foam was also larger (See Figure 1). The observed increase in size and number of internal cells could have influenced the results of the characterization study shown in Table 2, such as water vapor permeability, contact angle, thickness, and mechanical properties.

3.2. Physicochemical and thermal characterization of baked foams

The contact angle (CA) of the biodegradable baked foams (BBFs) can is presented in Figure 2; the corresponding values are shown in Table 2. It is important to mention that the CA was read every minute for 5 min. Only the readings from minute one and minute five are reported. It is observed that the contact angle decreased every minute in all the samples (values not shown), which was more notable in the control sample, as can be seen in Figure 2A, 2A-5 and Table 2. Furthermore, the hydrophilicity of the samples was increased with a reduction of SF content in the BBFs. This effect was evidenced by the decrease in CA values, showing values of

Table 2. Characterization of contact angle, thermal conductivity, density, solubility, and thickness properties of biodegradable baked foams.

Sample ID	Contact angle (°)[Δ]	Contact angle (°) (five minutes later)[Δ]	Thermal conductivity (W/m °K)[Δ]	Density (g/cm^3)[Δ]	Solubility (%)[Δ]	Thickness (mm)[*]
Control	67.83 ± 0.41^{a}	36.03 ± 0.99^{a}	0.0140 ± 0.0004^{a}	0.2321 ± 0.0005^{a}	19.59 ± 0.24^{a}	1.901 ± 0.004^{a}
PF95/SF5-30	84.77 ± 0.50^{b}	95.21 ± 0.73^{b}	0.0103 ± 0.00009^{b}	0.3138 ± 0.0004^{b}	11.650 ± 0.030^{b}	1.585 ± 0.001^{b}
PF92.5/SF7.5-30	97.38 ± 0.22^{c}	101.11 ± 0.88^{c}	0.0093 ± 0.00007^{c}	0.3235 ± 0.0004^{b}	8.275 ± 0.025^{c}	1.519 ± 0.006^{b}
PF90/SF10-30	110.85 ± 0.38^{d}	105.18 ± 1.01^{c}	0.0083 ± 0.0004^{d}	0.4385 ± 0.0033^{c}	6.295 ± 0.245^{d}	1.597 ± 0.005^{b}
PF95/SF5-45	80.81 ± 0.44^{e,g}	75.78 ± 0.71^{d}	0.0110 ± 0.00002^{e}	0.3138 ± 0.0012^{b}	12.310 ± 0.190^{e}	1.685 ± 0.016^{c}
PF92.5/SF7.5-45	93.14 ± 0.54^{c}	82.22 ± 0.44^{e}	0.0096 ± 0.00003^{c}	0.3193 ± 0.0022^{b}	8.749 ± 0.173^{f}	1.636 ± 0.008^{c}
PF90/SF10-45	108.62 ± 0.36^{d}	88.70 ± 0.66^{f}	0.0088 ± 0.0002^{d}	0.3339 ± 0.0004^{b,d}	6.577 ± 0.182^{d}	1.643 ± 0.009^{c}
PF95/SF5-70	78.31 ± 0.34^{g}	49.75 ± 0.51^{g}	0.0109 ± 0.00008^{e}	0.2968 ± 0.0009^{e}	15.609 ± 0.233^{g}	1.745 ± 0.002^{d}
PF92.5/SF7.5-70	88.03 ± 0.26^{f}	58.54 ± 0.65^{h}	0.0099 ± 0.00001^{c}	0.3135 ± 0.0035^{b}	9.402 ± 0.389^{h}	1.679 ± 0.002^{d,c}
PF90/SF10-70	103.12 ± 0.15^{d}	64.57 ± 0.33^{i}	0.0091 ± 0.0004^{b}	0.3105 ± 0.0004^{b}	7.809 ± 0.558^{i}	1.711 ± 0.004^{d}

For sample identification, see Table I.
PF = Plantain flour; SF = Sugar cane fiber.
[Δ] Average of three replicates ±standard error.
[*] Average of ten replicates ±standard error. Means in the same column followed by different superscript letters are significantly different ($\alpha < 0.05$).

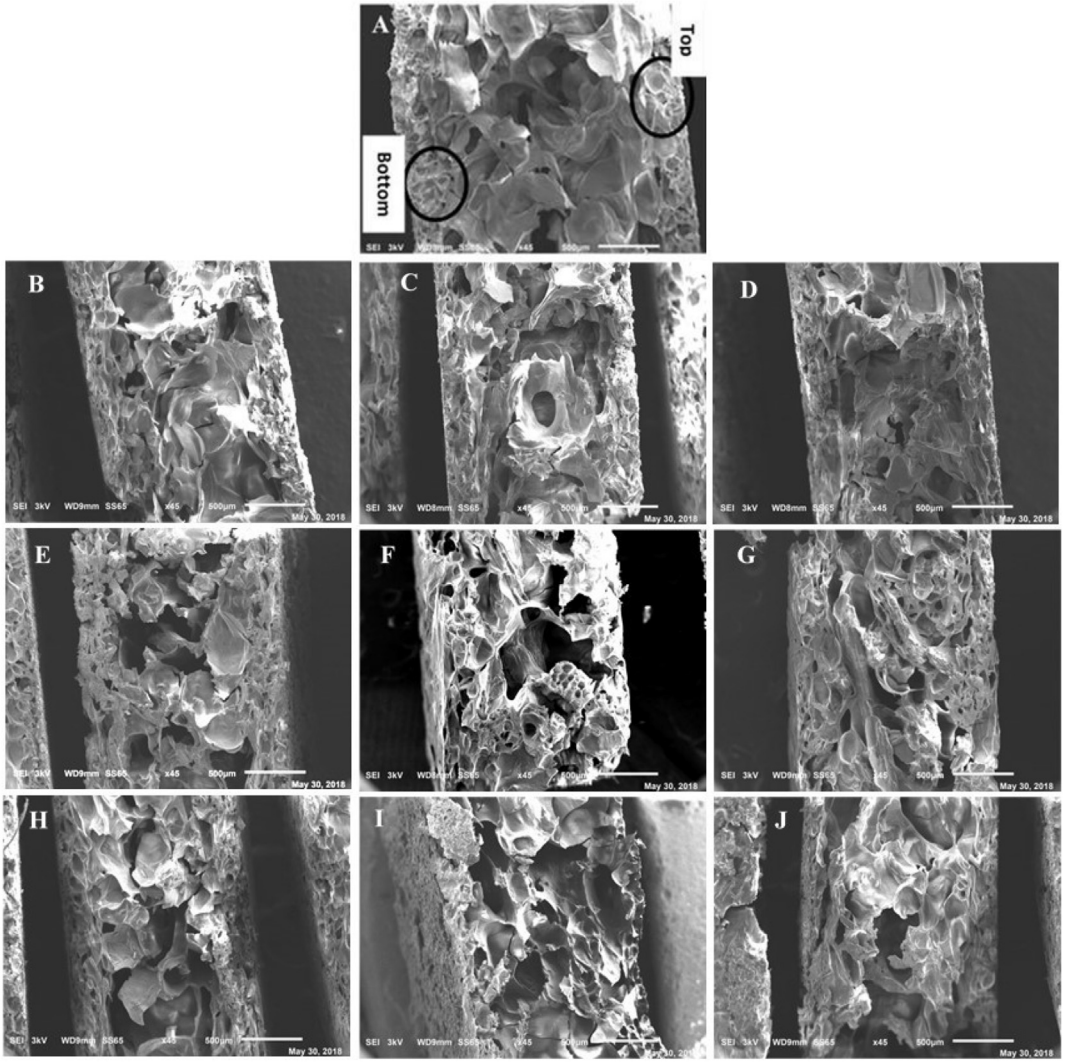

Figure 1. Scanning electron micrographs of cross-section of BBFs; A) Control; B) PF95/SF5-30; C) PF92.5/SF7.5-30; D) PF90/SF10-30; E) PF95/SF5-45; F) PF92.5/SF7.5-45; G) PF90/SF10-45; H) PF95/SF5-70; I) PF92.5/SF7.5-70; J) PF90/SF10-70.

10.85 (º), 97.38 (º) and 84.77 (º) at concentrations of 10, 7.5 and 5 g of SF respectively, only with mesh number 30, but similar behavior was showed by mesh number 45 and 70 (Table 2). The increase of the wood fiber content in the baked foams increases the crystalline portion of the foams, which in turn increased their hydrophobicity causing greater resistance to water permeability (Vargas-Torres et al., 2017). In the

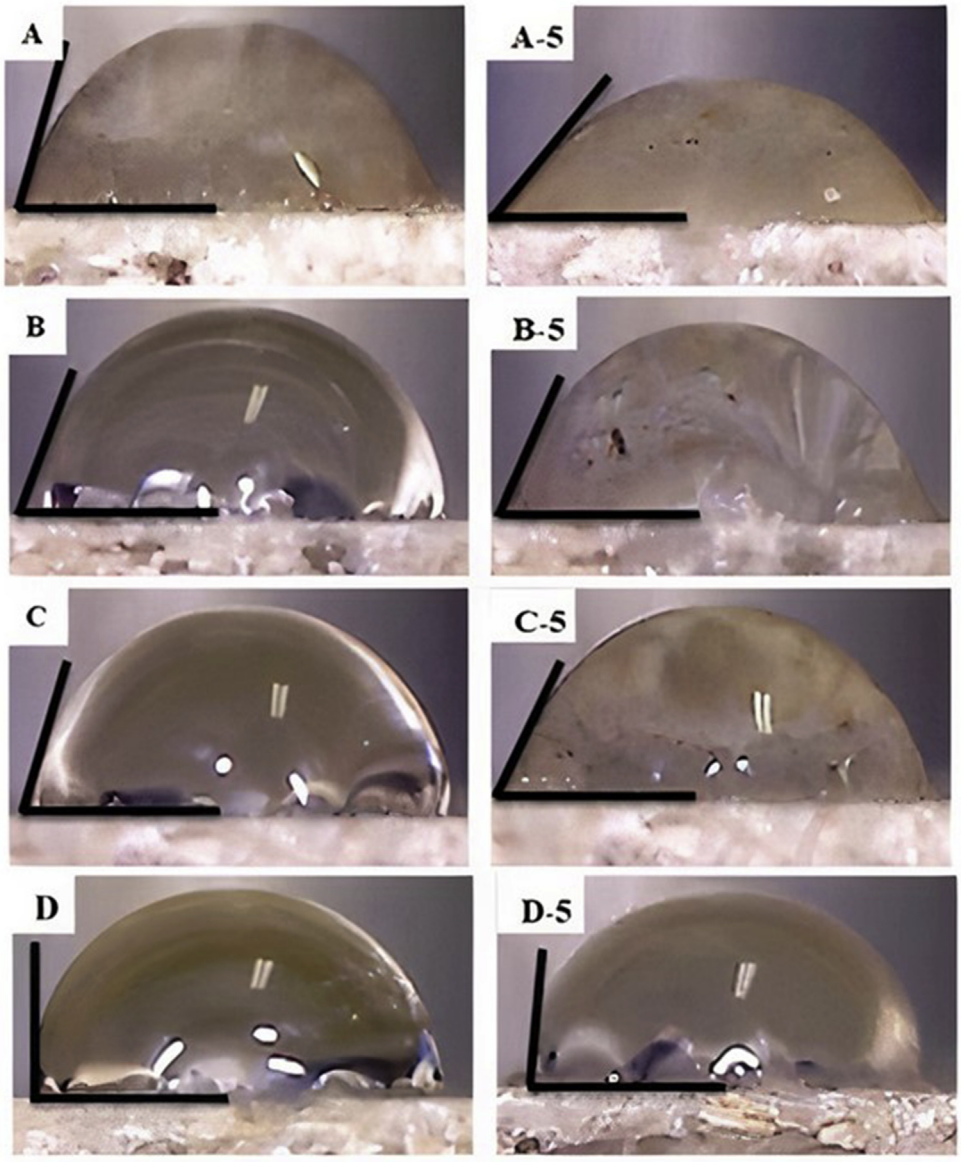

Figure 2. Water drop on the surface of biodegradable baked foams (BBFs). Pictures taken at the initial time and 5 min later. A) Control; B) PF90/SF10-30; C) PF92.5/SF7.5-45; D) PF95/SF5-70.

present study, a similar phenomenon was observed. However, the statistical analysis ($\alpha = 0.05$) showed that the concentration of SF had a greater effect on CA than the fibers obtained from the different sieves (different mesh numbers) used. Thus, the use of SF decreased the hydrophilic character of BBFs and improved their hydrophobic properties. This is important because SF improved the integrity of the material, which is beneficial when using it as packaging in the food industry.

The control samples and the PF95/SF5-30, PF95/SF5-45 and PF95/SF5-70 samples had the highest values of heat conductivity (Table 2), indicating that the starch present in PF may play an important factor in the observed changes in thermal conductivity. Drouzas and Saravacos (1988) reported thermal conductivity values of starch from 0.065 to 0.220 W/m°K, and mentioned that moisture influenced this parameter. However, the thermal conductivity that has been reported for sugarcane fiber is slightly lower (~0.045 W/m°K) (Manohar et al., 2006), which could explain why TC increased when the concentration of SF in baked samples decreased. The decrease in TC as the concentration of SF was increased indicates that SF provides higher resistance to heat transmission. Other studies report that the rate of heat transfer also depends on a better distribution of the fibers and the size of the cell in the matrix of the cooked foam materials (Vargas-Torres et al., 2017). In the present study, the statistical analysis ($\alpha = 0.05$) showed that the concentration of SF influenced the rate of heat transfer through the different BBF samples.

Density values (Table 2) showed an inverse pattern to that of thermal conductivity. This is, higher concentrations of SF was associated with increased density and thickness values, observing a more compact structure in the micrographs. The control sample (without SF) showed low density values (0.2321 g/cm^3). Shogren et al. (1998) and Lawton et al. (2004) reported that density values were influenced by the starch solids level. Results of the study carry out here, confirmed those observations. Since, the increase in concentration of SF (solids) in the formulations had an influence on density values. Mello and Mali (2014) and Avella et al. (2012) reported a similar behavior in biodegradable baked foam supplemented with malt bagasse and cellulose fibers, respectively. These authors mentioned that by increasing the amount of filler material in the foam's composite, the particle density of the foam also increased. Similarly, in the present study it was determined that samples with larger sizes of SF showed high density values.

The addition of SF showed to be associated to the solubility of the baked foams and to the increase in the crystalline portion of the foams. Wang and Wang (2003) have previously reported such association. Moreover, Fiedorowicz & Para (2006) mentioned that the crystalline portion of polymers plays an important role in water uptake. Results of the present study revealed that solubility values were associated with the CA. The samples with the highest SF content (PF90/SF10-30, PF90/SF10-45, PF90/SF10-70) showed higher CA values and lower solubility values, confirming that the crystalline portion of SF plays an important role in water uptake. Studies have reported up to ~74% crystallinity in cellulose fibers (Philipp et al., 1947). The control sample (100 % plantain flour) showed the highest percentage of solubility (19.59), followed by those samples with lower content of SF in the BBF samples. Vargas-Torres et al. (2017) mentioned that the solubility of baked foams is an important parameter that indicates the biodegradability of these kind of materials. In the present study, the statistical analysis ($\alpha = 0.05$) showed that the concentration of SF influenced the solubility of BBF samples. It also indicated that the fiber obtained with the different sieves did not influence this parameter.

The thickness of the foams ranged from 1.521 to 1.901 mm (Table 2). The statistical analysis ($\alpha = 0.05$) of the data showed that the addition of SF obtained from different sieves significantly reduced the thickness of BBFs. With respect to the sieving effect of SF on BBS, it was determined that the BBFs reinforced with SF obtained with mesh number 70 showed slightly higher thickness values than BBFs-45, and these showed a greater thickness than BBFs-30. The control BBF showed the highest thickness values, as this sample was obtained with a mesh number 325. This result indicated that SF, obtained under different mesh numbers, played an important role in the thickness of the samples as can be observed in the micrographs shown in Figure 6.

3.3. Water vapor permeability

Figure 3 shows that the addition of SF caused a notable decrease in water vapor permeability (WVP) compared with the control sample. Furthermore, a decrease in the concentration of SF in the baked samples led to an increase in the WVP rate. However, the baked samples PF95/SF5-30, PF95/SF5-45 and PF95/SF5-70 presented higher WVP rate. While samples reinforced with SF at concentrations of 10 and 7.5 showed a low WVP rate. This could indicate that the concentration of fiber has more influence on WVP than fiber size, showing statistically significant differences ($\alpha = 0.05$). Aila-Suárez et al. (2013) studied the use of cellulose nanoparticles (9 nm) and cellulose (20 mm) in films made from chayotextle starch and found a correlation between increasing concentrations of fiber and decreasing rate of WVP. This behavior was attributed to the increase in the crystalline portion of the films. This phenomenon could have occurred in the baked material with higher SF content that was evaluated in the present study. However, the increase in SF could have produced a highly constrained route for the water molecules, hampering their diffusion through the baked material, as observed in SEM. The internal structure in micrographs 1B, D, F, containing 10 g of SF, showed a more compact internal structure which could be influencing the WVP rate. Bras et al. (2010) and Curvelo et al. (2001) reported that the increase in the crystallinity of composite materials made them more hydrophobic, reducing their uptake of water molecules.

3.4. Mechanical properties

The tensile strength (Ts), elongation at break (Eb), and Young modulus (Ym) are shown in Figures 4, 5, and 6, respectively. The inclusion of SF (10 g) in the baked matrix resulted in greater values of Ts and Ym values (Figures 4 and 6) but the inverse behavior was observed in Eb (Figure 5). However, the statistical analysis ($\alpha = 0.05$) showed that the concentration of SF had more influence on the mechanical properties of the foams than the size of the fibers, obtained from different size

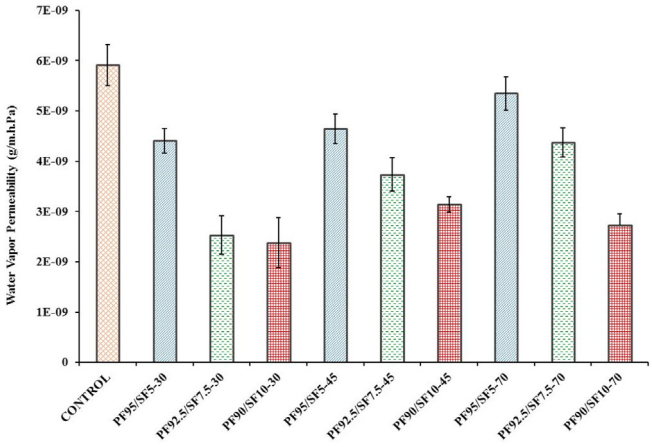

Figure 3. WVP of BBFs containing different concentrations of PF or SF. Average of five replicates ±standard error. For sample identification, see Table I.

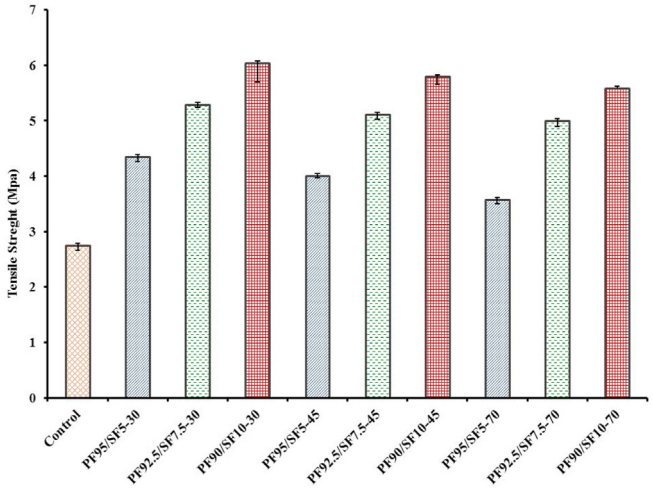

Figure 4. Effect of the different concentrations of PF or SF on the tensile strength of BBFs. Average of 10 replicates ±standard error. For sample identification, see Table I.

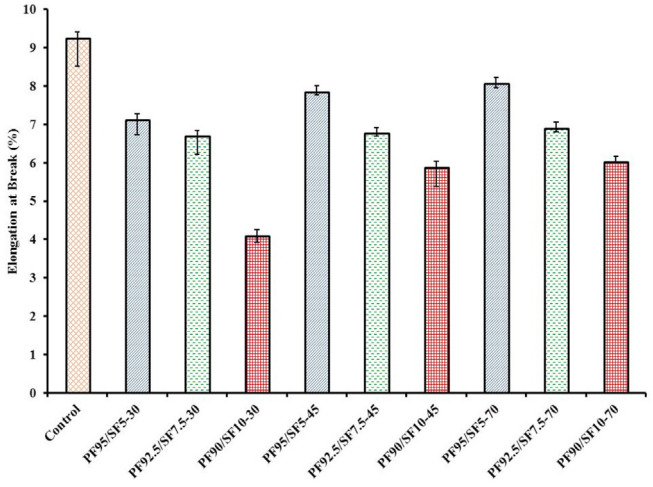

Figure 5. Effect of different concentrations of PF or SF on the elongation at break of BBFs. Average of 10 replicates ±standard error. For sample identification, see Table I.

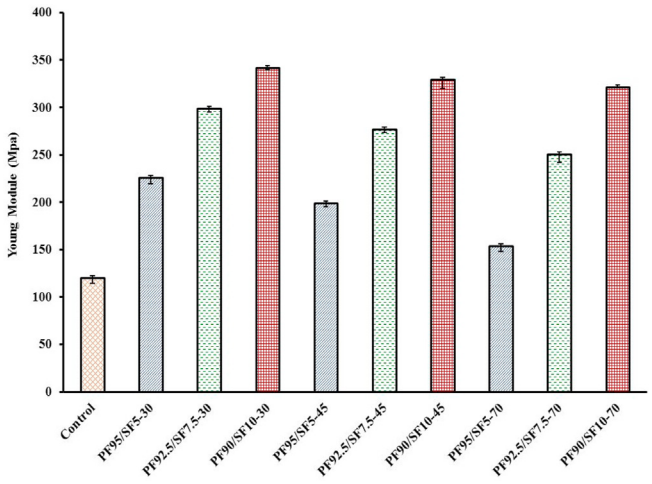

Figure 6. Effect of different concentrations of PF or SF on the Young's modulus of BBFs. Average of 10 replicates ±standard error. For sample identification, see Table I.

sieves. Similar behavior was reported by Gentile et al. (2018), when the concentration of microfibrillated cellulose in the foam matrix increased.

The values of Ts and Ym showed a slight increase in the baked samples PF90/SF10-30, PF90/SF10-45 and PF90/SF10-70, compared with the rest of samples. This behavior could be explained by the reported for Aila-Suárez et al. (2013); Sadegh-Hassani and Nafchi (2014) and Lopez et al. (2014). Who mention the mechanical properties are influenced by interfacial addition, intermolecular hydrogen bonding (-OH) groups inside the BBFs matrix, leading to the formation of baked materials with greater mechanical resistance but little Eb. Therefore, longer fibers could be generating more chemical interaction. Based on the information presented in Figure 5, the data resulted in this present study confirm this observation. Glenn et al. (2001) reported that the mechanical properties of the foams are associated with the internal microstructure and moisture content in the baked matrix. Cooked samples 1-D, G and J (SEM), which were reinforced with 5 g of SF (least quantity) showed irregular cell shape and size, probably as a result of a slight increase in Eb values compared with BBFs added with 10 g of SF (Figure 1B, E and H).

4. Conclusions

The addition of sugarcane fiber in formulations based on PF increased the hydrophobic character of BBFs. Conversely, by increasing the PF concentration in the formulations of BBFs, resulted in an increase in the solubility and WVP values in the baked foams. The contact angle showed that SF has a more hydrophobic character than PF. The mechanical properties of the foams were improved by the addition of SF into the matrix of the baked foams. The statistical analysis showed that increased concentration of SF in the BBFs played a more important role than the size of the fibers in the mechanical properties of BBFs. Additionally; it also showed that these properties can be improved by thde use of SF.

Declarations

Author contribution statement

José L. Román-Moreno, Guadalupe P. Radilla-Serrano: Performed the experiments.

Alejandra Flores-Castro, Areli Salgado-Delgado: Contributed reagents, materials, analysis tools or data.

José De J. Berrios, Gregory Glenn: Analyzed and interpreted the data.

Heidi M. Palma-Rodríguez: Conceived and designed the experiments.

Apolonio Vargas-Torres: Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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