# Influence of Proportion and Size of Sugarcane Bagasse Fiber on the Properties of Sweet Potato Starch Foams

J P Cruz-Tirado<sup>a</sup>, Delia R Tapia-Blácido<sup>b</sup>, Raúl Siche<sup>a,\*</sup>

<sup>a</sup>Facultad de Ciencias Agropecuarias, Universidad Nacional de Trujillo, Av. Juan Pablo II s/n, Trujillo, Peru.

<sup>b</sup> Departamento de Química, Faculdade de Filosofia, Ciências e Letras, Universidade de São Paulo, Av. Bandeirantes, 3900, CEP 14040-901, RibeirãoPreto, SP, Brazil

\* Corresponding author. Tel.: (+51) 44 294778

E-mail address: rsiche@unitru.edu.pe

**Abstract:** The objective of this work was the proportion and size of cane bagasse fiber in the physical (density and thickness), mechanical (flexural strength and tensile at break) and thermal (TG and DTG) properties of trays made from sweet potato starch. A fiber size of 75-45  $\mu$ m and a 2.5% ratio allowed to obtain trays with low thicknesses and densities, but with more compact structures that improved the mechanical properties of trays made from sweet potato starch alone. In addition, higher thermal stability and lower decomposition rate are shown for trays with fiber size 75-45  $\mu$ m and ratios of 2.5% and 5%. These results show that the smaller fiber size improves the properties of the sweet potato starch trays and that these trays can be used to replace the expanded polymer (EPS) for use in dry foods.

Keywords: Size fiber, sugarcane bagasse, new biodegradable material, sweet potato, starch.

#### 1. INTRODUCTION

Petroleum-based packaging has been used because of its high specific strength, durability, resistance to moisture, low cost and adaptability to the product. However, these products are not biodegradable [1], so biodegradable substitutes such as starch-based biopolymers have been studied [2]. Baked starch foams can be obtained by the thermoforming process [3]. However, starch-based foams have poor mechanical and hydrophilic properties, so that different additives (fiber, glycerol, nano-clay, nanofibers, etc.) are incorporated into the polymer matrix to improve their properties [4]-[6]. The cane bagasse fiber (20-50% cellulose) [7] has been used by different authors in different proportions (1 - 50%) and in different sizes (120 - 700  $\mu$ m) as reinforcement in trays made of starch [5], [8], [9] due to its ease of adhesion with polar matrix materials such as biopolymer matrices [5]. The authors agree that fiber proportions above 20% generate less

flexible and more fragile foams because the starch increases its resistance to expansion producing more porous trays [1]. However, the authors used different fiber sizes, which could influence the physical and thermal properties of the baked foams, since a smaller fiber size could have a better distribution in the polymer matrix [10]. The objective of this work was to evaluate the effect of the size and proportion of cane bagasse fiber on the physical and thermal properties of trays made from sweet potato starch.

### 2. MATERIALS AND METHODS

### 2.1 Materials

Sweet potato (*Iponomeabatata*, pink variety) starch and sugarcane bagasse fiber were provided by Laboratory of Agro-industrial Process Engineering of the National University of Trujillo (Trujillo, Perú). Starch contained 42.65  $\pm$  0.85% amylose, 0.30  $\pm$  0.07% protein and 9.27  $\pm$ 0.38% moisture. The sugarcane bagasse fiber (SB)(size > 300 µm) contained 8.05  $\pm$  0.12 moisture, 23.69  $\pm$  0.39 cellulose, 19.29  $\pm$  1.34 hemicellulose, 1.50  $\pm$  0.24 soluble lignin and 17.93  $\pm$  1.08 insoluble lignin. The fiber was ground in a knife mill and sieved through 50, 80, 100, 200 and 325-mesh sieves to obtain fiber distribution of 300-180 µm, 180-150 µm, 150-75 µm and 75-45 µm.Glycerol and magnesium stearate were purchased from Su Man (Pflücker e Hijos S.A., Lima, Peru).

# 2.2 Starch foam trays preparation by thermopressing

The starch/SB foam trays were prepared by thermopressing as shown in Table 1. The proportions of starch, fibers and other ingredients were based on previous results (not published).

| Fibersize (µm) | Starch/fiberratio* | Water (g/100 g solids) | Batter (g) |
|----------------|--------------------|------------------------|------------|
| Control        | 100/0              | 76.25                  | 53         |
|                | 97.5/2.5           | 76.25                  | 53.5       |
| 180 -300       | 95/5               | 78.75                  | 54         |
|                | 90/10              | 81.25                  | 55         |
|                | 97.5/2.5           | 76.25                  | 54         |
| 150 - 180      | 95/5               | 78.75                  | 55         |
|                | 90/10              | 81.25                  | 56         |
|                | 97.5/2.5           | 76.25                  | 54         |
| 75 - 150       | 95/5               | 77.5                   | 55         |
|                | 90/10              | 78.75                  | 56         |
|                | 97.5/2.5           | 78.75                  | 54         |
| 45 -75         | 95/5               | 80                     | 55         |
|                | 90/10              | 81.25                  | 56         |

**Table 1.**Compositions of the batters used to prepare the trays based on sweet potato starch added of sugarcane bagasse fiber.

\* The starch/fiber ratios represent the percentage of starch and fiber content in the batter.

To prepare each formulation, the proportion of starch, fiber, water, glycerol (plasticizer, 7.5%) and magnesium stearate (release agent, 5%) were mixed for 10 min using a mechanic stirrer at 1500 rpm (Imaco, China). After, 53 - 56 g of each formulation was homogeneously layered on a teflon mold (27 cm × 20 cm × 25 mm, 3.0 mm in thickness) in a compression molding machine (RELES, Lima, Peru) at 160 °C for 10 min and 60 bar. Finally, the trays were removed, unmolded and stored for 4 days at 25 °C and 60% relative humidity before characterization.

# 2.3 Tray characterization

The density was calculated as the relationship between weight and volume [3]. Twelve simple were tested for each sample. The thickness was measured with a vernier digital (Stainless Hardened, China) [9]. Twelve specimens were tested for each sample.

The thermal decomposition of the samples was measured under a nitrogen atmosphere (100 mL min<sup>-1</sup>) using a SETSYS Evolution TGA-DTA/DSC (SETARAM Instrumentation, France) equipment in the temperature range of 0 - 600 °C at a heating rate of 10 °C min<sup>-1</sup>. Sample masses: ~6 mg. Sample pan type: alumina/referent pan: empty alumina.

Mechanical properties were measured using a texture analyzer model TA.HD Plus (Stable Micro System, Surrey, UK) with a 100-kg load cell. Tensile tests (flexural strength and strain at break) were performed according to ASTM method D790M-91 (1991)[11] with modifications. Strips measuring 100 mm by 25 mm were used with an initial grip separation of 80 mm and a crosshead speed of 2 mm/s.

# 2.4 Statistical analysis

Analysis of variance (ANOVA) and Tukey's test were performed to compare the formulations: fiber proportion and size fiber, with significance set at p < 0.05. Statistica software version 7.0 (Statsoft®, USA) was employed.

# 3. RESULTS AND DISCUSSION

# 3.1 Physical properties

The thickness of the trays varied from 2.588 to 2.654 mm, and the mean densities ranged from 0.144 to 0.212 g cm<sup>-3</sup> (Figure 1). The fiber size significantly influences the thickness and density of the trays. When the starch/fiber ratio is 97.5/2.5, the sweet potato starch tray showed a low thickness, which leads to a low density, quite the opposite when the fiber size was 300 - 180  $\mu$ m (Figure 1A). This behavior could be attributed to the high viscosity of the pulp when the fiber is 45-75  $\mu$ m, which reduces the foaming capacity of the starch paste, generating trays with smaller

thickness[1]. Figure 1A also shows that a higher starch / fiber ratio leads to an increase in tray thickness, similar to that reported by [5] and [12]. However, fiber size does not influence significantly when the starch/fiber ratio is 90/10, probably because the fibers agglomerate at high concentrations [13]. The density of the trays was higher when 300-180  $\mu$ m fiber was used compared to trays with 75-45  $\mu$ m fiber (Figure 1B), which shows that a smaller fiber size is better distributed in the polymer matrix, since that the density of the foams is known to be inversely proportional to their expansion capacity [2]. It is possible that the 75-45  $\mu$ m fiber will act as reinforcing fillers which improved the foaming ability of the starch paste, resulting in more expandable materials of lower density. These results were similar to those reported in cassava starch trays reinforced with cane bagasse and Na-MMT fiber [5]. The density values recorded in the present study were high compared to expanded polystyrene (EPS) (2.530 mm thickness and 0.041 g cm<sup>-3</sup> density). However, the values found for fiber size of 75-45  $\mu$ m and a starch/fiber ratio of 97.5/2.5 (0.185 g cm<sup>-3</sup>) present a promising option for the use of these materials.



Figure 1. Thickness and density of composite trays based on sweet potato starch and sugarcane bagasse fiber.

# 3.2 Mechanical properties

El flexural strength (MPa) and elongation at break (%) for the trays of sweet potato starch and cane bagasse fiber is shown in Figure 2. A reduction in fiber size of 300-180  $\mu$ m at 75-45  $\mu$ m leads to an increase in the flexural strength of the sweetpotato trays when compared to the control (100/0) (from 0.52 MPa to 0.84 MPa) (Figure 2A). A higher value of flexural strength was found for the tray with 2.5% fiber 75-45  $\mu$ m (1.04 MPa), which could be explained as a better distribution of fiber in the matrix, without significant interference between the connections of the

molecules of starch [3], allowing starch to expand to form a more compact structure [14]. The same test used to evaluate the trays was used to evaluate the mechanical properties of expanded polystyrene (EPS) ( $0.83 \pm 0.11$  MPa,  $2.82 \pm 0.38\%$ ). The results of the present study suggest that baked fiber-reinforced sweet potato starch foams of size 75-45 µm can be used as a substitute for EPS trays. An increase in the fiber ratio (from 2.5% to 10%) increases the flexural strength of the trays when the fiber size is 300-180 µm, 180-150 µm and 150-75 µm. On the other hand, when the fiber size is 75-45 µm, the flexural strength decreases with the increase in the proportion of fiber, almost agreeing on the same value as registered for the other fiber sizes. This is probably because when we increase the fiber we decrease the content of starch, hence the content of amylose [15], so under stress forces, the stress is transferred to the fiber and therefore the resistance depends more on the proportion That of the distribution. In addition, at 10% the densities of the trays with different fiber sizes have close values, so the flexural strength values are also close, since there is a direct relationship between density and flexural strength [15].

The strain at break of the trays (% elongation) increases with the decrease in fiber size, showing higher values (1.52% - 1.68%) for the fiber size 75-45 µm when compared to the control (100/0). Although these trays had the lowest density values, their structure should be more compact, so that it would not only prevent the ingress of water molecules but also retain it inside the matrix, forming hydrogen bonds with the compounds Present and the water acting as plasticizer [16], an increase in the elongation of the trays is justified.



Figure 2. Mechanical properties of the trays based on sweet potato starch and sugarcane bagasse fiber.

#### 3.3 Thermal properties

The behavior during the thermal degradation of the sweetpotato starch trays with different sizes and proportions of cane bagasse fiber is detailed through the TG and DTG curves (Figure 3).The decomposition of the trays takes place in three stages. The first stage up to around 200 ° C was associated with the loss of free and bound water absorbed by the trays [17]-[18]. A higher water loss rate is observed for the larger fiber trays (300 - 180  $\mu$ m) (Figure 3A), probably due to a less compact and more porous structure that allows the exit of the water molecules [10]. The second stage showed the initiation of the decomposition of the phase rich in glycerol and starch (210 °C - 370 °C), with the thermo-oxidation of cellulose, hemicellulose and lignin [16], with a loss of surrounding mass of 70%. Trays with fiber size of 75-45  $\mu$ m and proportions of 2.5% and 5% showed a higher thermal stability with a lower decomposition rate than the other samples (Figure 3B), which is due to stronger interactions within the mixture [14]. The thermal data are in agreement with the physical and mechanical properties of the starch foams. The third stage shows the oxidation of partially decomposed starch, which generates solid waste such as ash and inorganic material (about 20% of the initial mass) [10], [19].





#### 4 CONCLUSIONS

Trays of sweetpotato starch reinforced with fiber of different sizes and in different proportions were prepared by thermopressing. The results showed that a size reduction of 300-180  $\mu$ m at 75-45  $\mu$ m produces less dense but more compact trays with better mechanical properties when compared to the non-fiber tray. Flexural strength values higher than those of expanded

polystyrene were found for trays with fiber of 75 - 45  $\mu$ m in 2.5% proportion. Likewise, the results show that when the fiber is in a proportion of 10% in the mixture, the physical and mechanical properties of the tray are independent of the fiber size. The addition of 75-45  $\mu$ m fiber in ratios of 2.5% and 5% improves the thermal stability of the trays, which could expand the use of these materials. This work provides information that allows the researcher a correct selection of fiber size for use as reinforcement in polymeric materials. In future work, the behavior of these materials should be analyzed under different relative humidity conditions and baked foams made from another type of starch.

### ACKNOWLEDGEMENTS

This work was supported by the ProgramaNacional de Innovación para la Competitividad y Productividad (INNÓVATE PERÚ) Contract 407-PNICP-PIAP-2014.

#### REFERENCES

[1] Soykeabkaew, N., Thanomsilp, C.andSuwantong,O. A review: Starch-based composite foams. Composites Part A: Applied Science and Manufacturing. 78(2015) 246-263.

[2] Espina, M., Cruz-Tirado, J.P., Siche, R.Mechanical properties of trays based on starch of native plant species and fiber of agroindustrial wastes. Scientia Agropecuaria. 7(2016) 133-143.

[3] Salgado, P.R., Schmidt, V. C., Molina Ortiz, S. E., Mauri, A. N., and Laurindo, J. B. Biodegradable foams based on cassava starch, sunflower proteins and cellulose fibers obtained by a baking process. Journal of Food Engineering. 85(2008) 435-443.

[4] Mello, L.R.P.F. and Mali, S. Use of malt bagasse to produce biodegradable baked foams made from cassava starch. Industrial Crops and Products. 55 (2014) 187-193.

[5] Vercelheze, A. E. S., Fakhouri, F. M., Dall'Antônia, L. H., Urbano, A., Youssef, E. Y., Yamashita, F., and Mali, S. Properties of baked foams based on cassava starch, sugarcane bagasse fibers and montmorillonite. Carbohydrate Polymers. 87(2012) 1302-1310.

[6] Marengo, V.A., Vercelheze, A.E.S., and Mali, S., Biodegradable composites based on cassava starch and waste from agro-industry. Quimica Nova. 36(2013) 680-685.

[7] Satyanarayana, K.G., Arizaga,G.G.C., and Wypych, F. Biodegradable composites based on lignocellulosic fibers-An overview. Progress in Polymer Science (Oxford). 34(2009) 982-1021.

[8] Mali, S., Debiagi, F., Grossmann, M. V. E., and Yamashita, F. Starch, sugarcane bagasse fibre, and polyvinyl alcohol effects on extruded foam properties: A mixture design approach. Industrial Crops and Products. 32(2010) 353-359.

[9] Bénézet, J.-C., Stanojlovic-Davidovic, A., Bergeret, A., Ferry, L., andCrespy, A. Mechanical and physical properties of expanded starch, reinforced by natural fibres. Industrial Crops and Products. 37(2012) 435-440.

[10] Gutiérrez, T. J., Morales, N. J., Pérez, E., Tapia, M. S., andFamá, L.Physico-chemical properties of edible films derived from native and phosphatedcush-cush yam and cassava starches. Food Packaging and Shelf Life. 3 (2015) 1-8.

[11] ASTM, American Society for Testing and Materials (ASTM), in Method D790M-91: Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials. (1991). Annual Book of ASTM Standards: Philadelphia.

[12] Matsuda, D. K. M., Verceheze, A. E. S., Carvalho, G. M., Yamashita, F., and Mali, S. Baked foams of cassava starch and organically modified nanoclays. Industrial Crops and Products. 44 (2013) 705-711.

[13] Hajiha, H. and M. Sain, 17 - The use of sugarcane bagasse fibres as reinforcements in composites, in Biofiber Reinforcements in Composite Materials. Woodhead Publishing. (2015) 525-549.

[14] Pornsuksomboon, K., Holló, B. B., Szécsényi, K. M., andKaewtatip, K. Properties of baked foams from citric acid modified cassava starch and native cassava starch blends. Carbohydrate Polymers. 136 (2016) 107-112.

[15] Yildirim, N., Shaler, S. M., Gardner, D. J., Rice, R., and Bousfield, D. W. Cellulose nanofibril (CNF) reinforced starch insulating foams. Cellulose. 21 (2014) 4337-4347.

[16] Martelli-Tosi, M., Assis, O. B. G., Silva, N. C., Esposto, B. S., Martins, M. A., and Tapia-Blácido, D. R. Chemical treatment and characterization of soybean straw and soybean protein isolate/straw composite films. Carbohydrate Polymers. 157 (2017) 512-520.

[17] Ayala, G., Agudelo, A., and Vargas R. Effect of glycerol on the electrical properties and phase behavior of cassava starch biopolymers. DYNA (Colombia). 79 (2012) 138-147.

[18] Kaewtatip, K., Poungroi, M., Holló, B., andSzécsényi, K. M. Effects of starch types on the properties of baked starch foams. Journal of Thermal Analysis and Calorimetry. 115 (2014) 833-840.

[19] García, N. L., Famá, L., Dufresne, A., Aranguren, M., and Goyanes, S. A comparison between the physico-chemical properties of tuber and cereal starches. Food Research International. 42(2009) 976-982.