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Arracacha (*Arracacia xanthorrhiza*) Starch can Produce Foam Trays with Low Density

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Abstract: Arracacha starch, Sugarcane Bagasse (SB) and Asparagus Peel (AP) were used to produce foam trays by baking process. The incorporation of SB or AP fiber up to 15% does not affect the density of the trays. Incorporation of the fiber SB and AP improved the flexural strength of the trays. The microstructure has large internal air cells, product of the good expansion of the starch. The incorporation of the fiber affected the thermal stability of the trays, degrading at a higher rate than the foam trays control. The DRX patterns of the trays showing a semicrystalline structure, with predominance in the amorphous zone. The results suggest that those trays had low density and good mechanical properties and they able to be used as substitutes for expanded polystyrene to pack dry foods.

Key words: Arracacha starch, Asparagus, sugarcane bagasse, biodegradable material, expanded polystyrene, results

INTRODUCTION

The study, development and characterization of biomaterials to be used as substitutes for conventional polymers is of great interest (Kaisangsri *et al.,* 2014). Starch has been used to produce starch-based foam trays due to their swelling properties, low cost, renewable, biodegradability and abundance (Gao *et al*., 2015; Mello and Mali, 2014; Pushpadass *et al*., 2010). Arracacha (*Arracacia xanthorrhiza*) is a tuber of high production in Peru, currently producing 22.8 mil tons per year (MAI., 2016). Of the total carbohydrates, the main part (about 80%) belongs to starch (Sales, 2014). However, there is no record of using arracacha starch to make biodegradable foam trays made by thermoforming (baking a water/starch mixture at high temperatures) (Shogren *et al*., 2002).

Foam trays made from native starch have limitations on yield, poor mechanical properties and high hydrophilicity (Matsuda *et al*., 2013), limiting its scope of application.

Vegetable fibers as reinforcements in biopolymers have been studied by several authors due to their excellent specific properties such as high strength, low weight and good barrier properties (Cinelli *et al*., 2006; Lawton *et al*., 2004; Glenn and Orts, 2001). Sugarcane bagasse fiber contains approximately 40-50% cellulose (Sun *et al*., 2004) and many authors have used it in different proportions to reinforce starch-based foam trays (Vercelheze *et al*., 2012, 2013; Benezet *et al*., 2012; Mali *et al*., 2010). Asparagus is of great economic importance cultivated in Peru, being the second largest producer after China (Vazquez-Rowe *et al*., 2016). During the process of canned Asparagus, the peeling stage generates a residue called Asparagus peel which could constitute up to 40-50% of the fresh weight of Asparagus (Espina *et al*., 2016).

The aim of this research was to develop foam trays Arracacha-starch based and evaluate the effect of adding of sugarcane bagasse and Asparagus peel fiber in their physicochemical and mechanical properties.

MATERIALS AND METHODS

Materials: The Agro-industrial Processes Engineering Laboratory (National University of Trujillo, Peru) provided Arracacha starch, Sugarcane Bagasse fiber (SB) and Asparagus Peel fiber (AP). The starch contained 31.89±2.20% amylose, 13.01±0.27% moisture and 0.40±0.05% protein. The SB fiber contained 8.05±0.12 moisture, 23.69±0.39 cellulose, 19.29±1.34 hemicellulose, 1.50±0.24 soluble lignin and 17.93±1.08 insoluble lignin. The AP fiber contained 14.48±0.08 moisture, 16.18±0.67 cellulose, 20.33±1.39 hemicellulose, 2.36±0.09 soluble lignin and 19.35±0.66 insoluble lignin. The fiber samples were ground in a knife mill and sieved (50 mesh, Tyler series, 300 μm).

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Table 1: Compositions of the mixtures used to prepare Arracacha-starch based foam trays sugarcane bagasse and Asparagus peel fiber

Starch/fiber ratio	Water (g)	Amount in mixture (g)
100/0	100	50
95/5SB	100	45
90/10SB	100	45
85/15SB	105	45
80/20SB	105	45
95/5AP	100	40
90/10AP	100	40
85/15AP	100	40
80/20AP	102.5	42.5

Foam tray manufacturing: Sugarcane Bagasse (SB) and Asparagus Peel fiber (AP) were used to make Arracacha-starch based foam trays by thermopressing using four formulations for each fiber type (Table 1). To prepare each formulation, the proportion of starch, fiber (SB or AP), water, glycerol (7% w/w) used as plasticizer and magnesium stearate (3%) used as the release agent was mixed for 10 min with a mechanical stirrer at 1500 rpm (Imaco, China). Then 42-60 g of each formulation were homogeneously placed in a Teflon mold (27×20 cm× 25× 3.0 mm thick) in a compression molding machine (RELES, Lima, Peru) at 140°C for 18 min and 60 bar. Finally, the trays were removed, demolded and stored for 4 days at 25°C and 60% relative humidity prior to characterization.

Foam tray characterization: The density of foam tray (g/cm^{-3}) was calculated according to Shogren *et al*. (1998). The reported density values were the averages of 12 samples per formulation.

SEM analyses were performed with a Tecsan VEGA 3 LM with a gold coating system SPI 11430-AB (TESCAN USA, EE.UU). The foam pieces were mounted for cross-section visualization on bronze stubs using double-sided tape. Images were taken using an acceleration voltage of 20 kV in all cases.

The thermal decomposition of the starch foam was measured under a nitrogen atmosphere (100 mL/min^{-1}) using a SETSYS Evolution TGA-DTA/DSC (SETARAM Instrumentation, France) equipment in the temperature range of 25-600°C at a heating rate of 10°C/min^{-1} (Pornsuksomboon *et al*., 2016). Sample masses: ~6 mg. Sample pan type: alumina/referent pan: empty alumina.

A texture analyzer model TA.HDPlus (Stable Micro System, Surrey, UK) with a 10N load cell was used to determine the mechanical properties of the foam samples. Tensile tests were performed with strips measuring 100 mm by 25 mm with an initial grip separation of 80 mm and with a crosshead speed of 2 mm/sec. Each formulation was assayed 12 times and the reported values are the averages of these determinations.

Tray samples were pulverized and sieved (particles <300 μm) and diffraction analysis was performed on a Miniflex 600 diffractor model (Rigaku, Japan) using copper kα radiation (λ = 1.5418 Å) and a voltage of 40 kV and an operating current of 15 mA. The analyzes were performed with a ramp of 1°/min between $2\theta = 10°$ and $2\theta = 60°$.

Statistical analysis: Analysis of Variance (ANOVA), Tukey's test to compared the formulations (ratios starch/fiber) and Tukey's test to compared both types of fiber in baked foams ($p = 0.05$) were performed with the Statistica Software Version 7.0 (Statsoft®, USA).

RESULTS AND DISCUSSION

Density and mechanical properties: Table 2 shows the density, flexural strength and elongation of Arracacha-starch based foam trays and Sugarcane Bagasse fiber (SB) or Asparagus Peel fiber (AP). The density of the trays does not vary significantly until a fiber incorporation of 15% and there is no significant difference between SB and AP fibers. Trays with 20% fiber presented higher densities (both fibers), probably to an interference of the fiber in the capacity of expansion of the starch, generating trays of greater density (Salgado *et al*., 2008). The density values obtained in this study were higher as compared to the density values obtained for EPS foam trays (thickness of 2.53 mm and density of 0.041 g/cm^{-3}) but the density values were lower to reported by other researchers for foam trays made of cassava starch and SB fibers: 0.194-0.330 g/cm^{-3} (Vercelheze *et al*., 2012, 2013; Mali *et al*., 2010).

The incorporation of SB fiber improves the flexural strength of the Arracacha-starch based foam trays. The fibers used in this study (SB and AP) probably did not interfere in the direct interactions and in the proximity between the starch chain, so, under tensile forces, the force was transmitted to the fibers which caused the increase of the resistance of the trays. The incorporation of SB fiber resulted in trays with greater flexural strength than trays with AP fiber. This behavior is probably related to a higher content of cellulose in the SB fiber.

The elongation of arracacha-starch based foam trays and SB fiber was not significantly affected until a fiber incorporation of 15%. Some authors report an inverse relationship between flexural strength and trays elongation (Mello and Mali, 2014) which justifies the behavior of trays with 20% of SB fiber and trays with 5-15% AP fiber. At 20% AP fiber, the foam trays increase their elongation, probably due to the fiber ability to absorb water which functions as a plasticizer increasing its elongation.

The mechanical properties of EPS were flexural strength of 0.83±0.11 MPa and strain at break of 2.82+0.38%. These values revealed that the composite

Table 2: Density, flexural strength and elongation of foam trays made of arracacha starch and Sugarcane Bagasse (SB) or Asparagus Peel (AP) fibers

	Density (g/cm^{-3})		Flexural strength (MPa)		Elongation (%)	
Starch/fiber ratio	SB	AP	SB	AP	SB	AP
100/0	0.144±0.012^{b}	0.144±0.012^{a}	0.45±0.07^{b}	0.45±0.07^{b}	0.90±0.02^{a}	0.90±0.02^{a}
95/5	0.145±0.002^{b,A}	0.145±0.002^{a,A}	0.65± 0.13^{a,A}	0.56±0.01^{a,b}	0.90±0.01^{a,A}	0.70±0.01^{a,A}
90/10	0.145±0.016^{b,A}	0.145±0.016^{a,A}	0.69±0.13^{a,A}	0.52±0.01^{a,b}	0.90±0.01^{a,A}	0.80±0.01^{a,A}
85/15	0.144±0.014^{b,A}	0.144±0.014^{a,A}	0.78±0.04^{a,A}	0.59±0.02^{a,b}	0.90±0.01^{a,A}	0.80±0.02^{a,B}
80/20	0.172±0.019^{a,A}	0.172±0.019^{a,A}	0.76±0.02^{a,A}	0.58±0.04^{a,b}	0.70±0.01^{b,B}	0.90±0.02^{a,A}

$^{a, b}$Mean with different lower case letter in the same column indicates significant difference between the trays with different fiber concentrations according to Tukey's test, $p<0.05$. $^{A, B}$Mean with different upper case letter in the same line indicates significant difference between starch/SB and starch/PA foam tray for each analyzed parameter according to Tukey's test, $p<0.05$

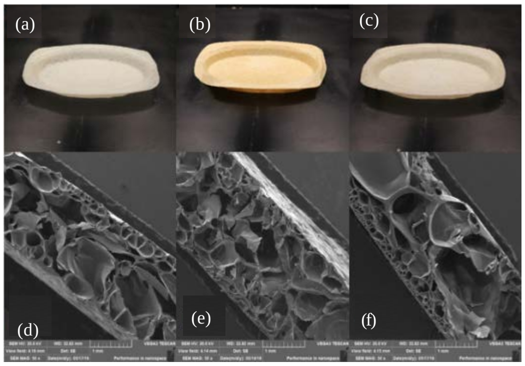

Fig. 1: a-c) Appearance of trays made from cassava starch and malt bagasse; d-f) SEM of cross-sections of the trays; a and d) control; b and e) starch/AP fiber; c and f) starch/SB fiber. Magnification: 50×

arracacha starch foam tray produced in this study have low densities and good mechanical properties and can be considered a promising material that could replace EPS.

Microstructure: Figure 1 depicts the SEM micrographs of the cross-sections of the control (100/0, 2D), the starch/AP (95/5, 2E) and the starch/SB (95/5, 2F) trays which presented lower densities and higher flexural strength. Foam trays made from arracacha starch, SB and AP fiber show a sandwich structure with dense outer layers that enclose small cells while the internal structure is less dense with large cells. A larger size of internal air cells is explained by an improved starch expansion capacity (Machado *et al*., 2017) which is in agreement with the low density values of the trays (Table 2).

Thermal properties of the starch foams: We analyzed the foams trays (control, starch/PA 95/5 and starch/SB 95/5) by thermogravimetry to investigate their thermal stability and to find out how interactions among the components affected the degradation of arracacha starch-based foam trays (Fig. 2).

The decomposition course was similar for all three foams. A first stage corresponding to the evaporation of water and phenolic compounds is given up to 150°C for foams with SB and AP fiber and up to 250°C for control foam (100/0), similar to that reported by Pornsuksomboon *et al.* (2016). The results suggest that foams without fiber addition have a more compact and less porous structure which prevents water from evaporating easily. The control tray (100/0) had a higher thermal stability (Fig. 2b) and a lower decomposition rate (Fig. 2a) than foam trays incorporated with SB and AP fiber. This would indicate that the fibers destabilized the bonds between the starch and the glycerol, negatively affecting the thermal stability of the materials. Therefore, foam trays with SB fiber, AP fiber and control were degraded at 230, 237 and 330°C, respectively. The control foam (100/0) made of arracacha starch being more thermally stable. The mass loss observed for the starch/SB and starch/AP trays between 150 and 350°C

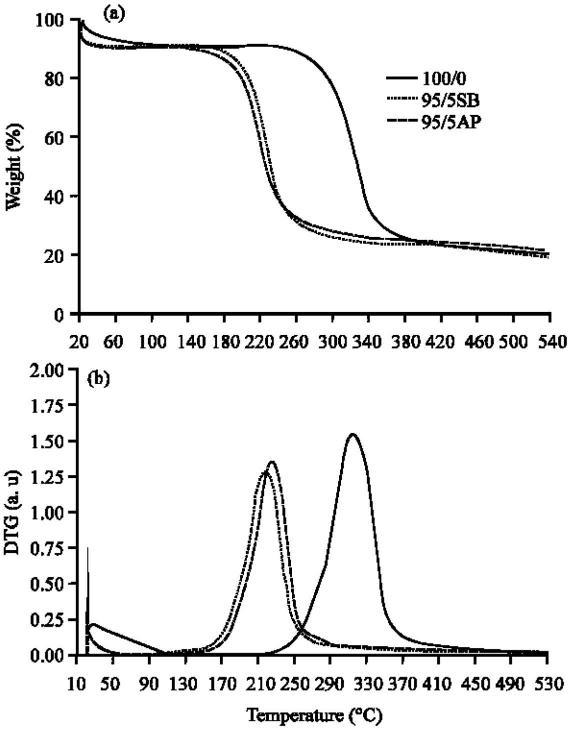

Fig. 2: TG analysis of cross-sections of the trays: a) TGA and b) DTG

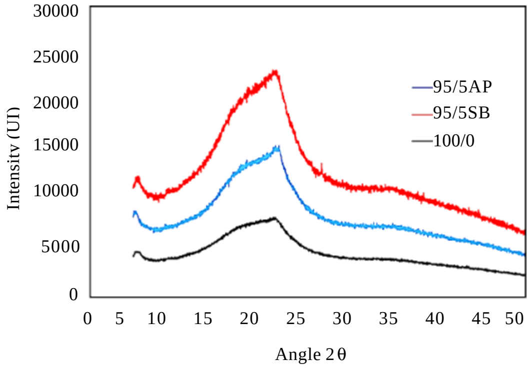

Fig. 3: X-ray diffraction patterns of foam trays arracacha-starch based

was due to degradation of cellulose by dehydration, depolymerization or decomposition of glycosyl units, followed by formation of a carbonized residue (Kaewtatip *et al.*, 2014) and to degradation of saccharide rings (Sanyang *et al.*, 2016). The third stage is ascribed to the partially decomposed starch underwent oxidation, to generate solid residues such as ashes and inorganic materials (around 20% of the initial mass) and also may be ascribed to the degradation of lignin which is present in the SB and AP fibers (Martelli-Tosi *et al.*, 2017).

X-ray diffraction: Figure 3 shows the XRD patterns of the arracacha-starch bases foam trays (control, 100/0), SB fiber (95/5SB) and AP fiber (95/5AP). According to data from the literature (Santacruz *et al.*, 2002), arracacha starch has a type B crystallinity with peaks at $2\theta = 5.5$, 12, 15, 17, 20 and 22°.

However, these peaks disappeared in the foam trays, because during the cooking process the gelatinization of the starch occurred, giving rise to semicrystalline materials whose diffraction patterns are predominantly in the amorphous region. A similar behavior was observed for cassava starch and malt bagasse (Mello and Mali, 2014) and in cassava starch and sesame cake foam trays (Machado *et al.*, 2017).

CONCLUSION

Arracacha starch, sugarcane bagasse and Asparagus peel fiber were used to prepare trays by thermoforming. The trays produced had low values of density and high values of flexural strength which is favorable in the development of these containers. The thermal stability of the trays was affected by the incorporation of fiber increasing the speed of degradation. The foam trays were semi-crystalline compounds with diffraction patterns in the amorphous zone. The results suggest that these foams can be used as substitutes for EPS and thus, mitigate its environmental impact.

RECOMMENDATION

It is recommended to test new reinforcement materials that improve the properties of the trays and their thermal stability.

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