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RESEARCH ARTICLE

Biodegradable trays made from *Poraqueiba sericea* Tulasne seed starch and *Zea mays* cob flour

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Abstract

The environmental impact of polystyrene and other petrochemical packaging has increased interest in researching biodegradable materials as alternatives. The main objective of this research was to develop biodegradable trays from five formulations of *Poraqueiba sericea* Tulasne (known as umari) seed starch and corn cob meal. The trays were produced using the thermoforming process applying temperatures of 135 °C and 145 °C for each side of the tray for a time of 6.5 min. Physical analysis of the trays showed that the increase in the percentage of corn cob flour caused changes in color (L*: 68.69 - 64.94), thickness (2.20 - 3.17 mm), density (0.251 - 0.414 g/cm^3), moisture (3.85% - 5.68%), water absorption (21.86% - 39.05%), volatile solids (95.33% - 98.31%). Regarding mechanical properties, it was also evidenced the increase in hardness (67.70 - 90.97 N), fracturability (1.43 and 3.19 mm), tension (2.84 to 3.43 MPa) and elongation (1.54% to 2.04%). The formulation of 87.5% umari seed starch and 12.5% corncob flour presented more favorable physical and mechanical properties. Further analysis of this formulation was performed by Fourier transform infrared spectroscopy (FTIR), which identified bands characteristic of starch (1055 and 1027 cm^{-1}); X-ray diffraction (XRD), which revealed characteristic peaks (2θ = 16.83° and 2θ = 22.69°) associated with cellulose crystallinity in the biodegradable tray; and scanning electron microscopy (SEM), which revealed cellulosic voids with irregular distribution due to the addition of fibers. Future research should examine the potential applications of these biodegradable trays for the packaging of raw materials in the food industry.

Keywords: biodegradable tray; corn cob; umari seed; starch; fiber.

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1. Introduction

The effects related to the use of plastics represent a growing environmental threat; annually, it is estimated that the marine environment is contaminated with 0.7 to 0.8 million tons of plastic waste that alters the habitat of aquatic species (Meijer et al., 2021). Plastics break down into microplastics that contaminate water (ocean and riverbanks) and enter the food chain (Zhu et al., 2022). On the other hand, the incineration of this plastic waste causes air pollution which produces toxic compounds harmful to the respiratory system of living beings (Aguilar et al., 2018; Pandey et al., 2023). To minimize their negative ecological impact, several countries have

developed legislation for the controlled use of petroleum-derived plastics, while promoting the use of biopolymers (Moshood et al., 2022). In this sense, multiple research projects are being carried out to replace the use of petroleum-derived polymers in the production of packaging; these substitutes are of greater interest when they are derived from raw material residues that are mostly obtained from agribusiness (Tapia-Blácido et al., 2021). Biodegradable plastics have a much shorter half-life than conventional plastics after being used, since they have the property of decomposing due to the natural effect of temperature, humidity, heat, microorganisms, carbon dioxide, among others (Emadian et al., 2017; El Menofy & Khattab, 2023; Cheng et al., 2024). The global bioplastics market will grow at more than 15% per year; however, bioplastics still account for less than 1% of total plastics production (Ediyilyam et al., 2021). Starch is considered the material par excellence for the development of biodegradable materials, as it has a low acquisition cost and suitable chemical properties (Onyeaka et al., 2022). Another interesting material for the development of trays is found in natural fibers whose chemical, physical and mechanical properties give them significant improvements with respect to shape, texture, length, strength and elasticity to the product (Li et al., 2020). Several research have considered the integration of natural fibers and proteins to improve stiffness, water absorption and elongation, increasing of biodegradability of trays (Bergel et al., 2017; Zwawi, 2021). The production of biodegradable trays uses the thermoforming technique, which is a manufacturing process in which a plastic or composite mixture is heated to make it malleable, molding with pressure and heat, and then cooled to solidify it (Aguirre et al., 2023).

The umari (*Poraqueiba sericea* Tulasne), belongs to the Icacinaceae family, and is a very aromatic edible fruit that is composed of a pulp composed in 7.98 ± 0.08 % of proteins; 25.25 ± 0.28% of lipids and 57.22% of total carbohydrates, being widely consumed by the Amazonian population (Peru and Brazil), mainly in its fresh form (Freitas et al., 2024; Berto et al., 2015; Silva, 1997). The consumption of umari fruit pulp generates seed residues of approximately 74% with respect to the fruit (Ordoñéz et al., 2001). These seeds contain a high starch content (approximately 98%), which makes it attractive for the development of new products, less than 5% of this seed consists of a mixture of cellulose, proteins, hemicellulose and remaining starch (Ordoñéz et al., 2001). Corn is a crop of high production and demand worldwide, of the total production 2023/2024, the majority are in countries such as: USA (32%), China (24%) and Brazil (10%); while in Peru 1, 575, 000 Metric Tons were produced, which represents 0.1% of world production (USDA, 2024). The corn cob that is discarded by farmers at the time of grain extraction represents about 20% by weight of the stubble, presenting itself as a residual material of low utility; on the other hand, corn cob presents abundant lignocellulosic biomass produced in the corn processing industry and contains a considerable amount of hemicellulose, which constitutes more than one third of its dry weight (Bovo et al., 2022; Ismail et al., 2022). Therefore, since umari seeds and corn cobs with high starch, fiber and cellulose content are waste materials, this work developed biodegradable trays from these waste raw materials, using the thermoforming process. Consequently, the chemical, physical and mechanical characteristics of the developed biodegradable trays were evaluated to select and propose a formulation with promising characteristics.

2. Methodology

2.1. Raw materials and reagents

Umari fruits (50 kg), obtained from the department of Loreto, Maynas province and Fernando Lores district (4°00'11"S 73°09'37"W), were used. The shelled coronta cobs (10 kg) were obtained from hard yellow corn (*Zea mays* L. var. Indurata), obtained from the department of Ancash, Casma province, San Rafael Valley district (9°26'65"S 78°12'12"W). Magnesium stearate, glycerol and guar gum (Merck Laboratory, Germany) were used to make biodegradable trays. The raw materials were processed at the Instituto de Investigación Tecnológica Agroindustrial (IITA) of the Universidad Nacional del Santa (UNS), Chimbote, Ancash, Peru.

2.2. Methodology for obtaining starch from umari seeds and corn cob flour

The extraction of starch from umari seeds is presented in Figure 1a. After selection and cleaning, the seeds were manually opened on the lateral side with a stainless-steel knife; subsequently, a bleaching process was carried out with a bisulfite solution (0.75%), with a raw material / bisulfite solution ratio of 2/1 (w/v). The raw material was crushed in the bisulfite solution and the liquid rest in which the starch is found was filtered, by means of a gravity sedimentation process during 24 h at refrigeration temperature (4 °C), the starch was separated from the liquid rest, to guarantee an adequate separation, four washes were performed and finally the starch was dried on trays in an industrial rotary oven (NOVA, MAX-1000, Peru) at a temperature of 40 °C for 24 hours.

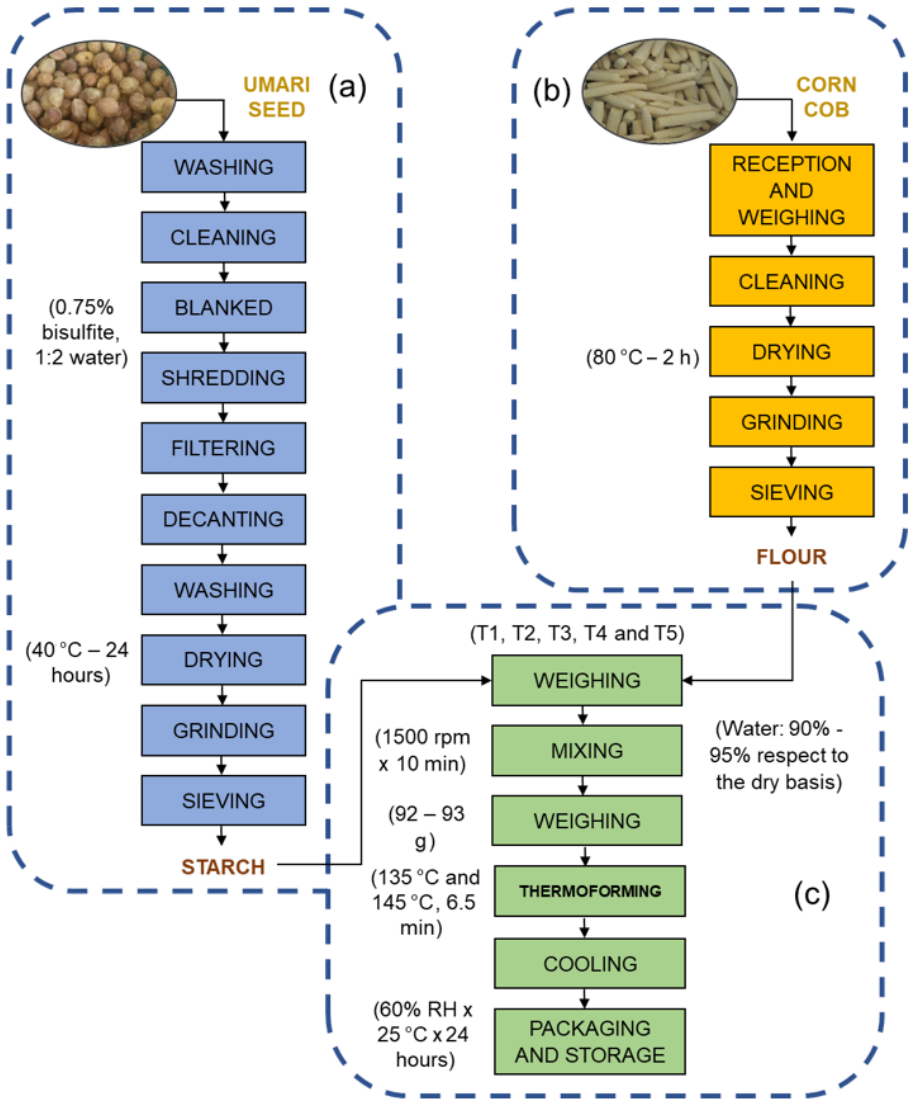

Figure 1. Process for obtaining (a) umari seed starch, (b) corn cob flour and (c) biodegradable trays.

The dry starch was ground in a hammer mill (TORRH, MDNT-60XL, Peru) and finally sieved through a 100-mesh sieve (CORMAC, ASTM standard, Peru). The methodology for obtaining corn cob flour is presented in Figure 1b, basically consisted of receiving and cleaning of foreign matter; the cobs were then taken to tray drying (TORRH, SBT-10x10, Peru) for 4 hours at a temperature of 80 °C. The dried cobs were subjected to the milling process in the hammer mill (RETSCH, ZM 200, Peru). The dried cobs were subjected to the grinding process in the hammer mill (RETSCH, ZM 200, Peru). Finally, the corn cob flour was sieved on an 80-mesh sieve.

2.3. Production of biodegradable trays

We estimated different formulations of umari seed and corn cob starch for the preparation of trays as detailed in Table 1. The formulations and inputs (6% magnesium stereate, 7% glycerol and 1% guar gum) were weighed on the analytical balance (Precisa Gravimetrics AG., LX320A, USA), the formulations and inputs were mixed with a hand mixer (IMACO, HM 505, Peru), until a homogeneous mass was achieved.

The thermoforming process (Figure 1c) used approximately 93 g of homogeneous dough to place it in a thermopress (Reles, MS3 Digital, Peru) at a temperature of 145 °C (bottom plate) and 135 °C (bottom plate) for a tray forming time of 6.5 min. The formed trays were cooled for a time of 24 h, room temperature (25 °C), relative humidity of 60% and stored in properly heat-sealed high-density polypropylene bags (Retail, MSLL 300, Peru)

Table 1
Formulations for the production of biodegradable trays from umari seed starch and corn cob flour

Formulation	Umari seed starch (%)	Corn cob flour (%)
T1	85.00	15.00
T2	90.00	10.00
T3	86.25	13.75
T4	88.75	11.25
T5	87.50	12.50

2.4. Chemical characterization of raw materials

The moisture percentage was determined using the oven (POL-EKO-Aparatura, SLW 115STD, USA), according to AOAC 931.04 (JAOAC, 1931). Fat determination was carried out according to AOAC method. 920.39 (AOAC, 2005b). Ash was determined using the muffle (Thermolyne, 347034984, USA), at 600 °C for 2 hours, according to AOAC 923.03 (AOAC, 1997). Crude fiber was determined according to AOAC method. 962.09 (AOAC, 2005b). Protein content was determined using AOAC method. 920.87 (AOAC, 2005a). The carbohydrate content was determined by difference: % carbohydrate = 100% - % moisture - % ash - % protein - % fat - % fiber.

2.5. Characterization of biodegradable trays

The color attributes of the trays were assessed utilizing a color meter (Hunterlab, MiniScan XE147, USA), based on the CIElab scale which comprises L* for lightness, a* for redness/greenness, and b* for yellowness/blueness. The total color deviation ($\Delta E^* = \sqrt{(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})}$) was determined considering the white background values (L* = 93.49, a* = 0.77 and b* = 1.40). For each analysis the area of each sample was 4 x 3 cm, in triplicate. The thickness of the trays was measured with a hand-held micrometer (Mitutoyo, model 1402, Peru) capable of measuring within the range of 0 to 150 millimeters. The bulk density (g/cm^3) of the trays was calculated following the approach outlined by Aguirre et al. (2023). The moisture content of the trays was assessed using the oven-drying technique, where 5 grams of crushed tray material was subjected to 105 °C heat for 3 hours. The water absorption capacity was assessed following the procedure outlined in ABNT NBR NM ISO 535 (2014). Volatile solids were measured utilizing method 2540G (Standard Method, 1997). Tensile and elongation tests were conducted in accordance with the ASTM D828 method as described by Mello & Mali (2014) using a texture analyzer (TA. HD Plus; Stable Micro System, Surrey, UK). Hardness and fracturability tests are conducted using the HDP/FSR holder positioned at the bottom of the texture analyzer. The penetration speed is set at 1 m/s, and a spherical probe P/0.5S with a deformation distance of 15 mm is employed.

2.6. Fourier Transform Infrared Spectroscopy (FTIR)

Molecular vibrations of the chemical compounds within the trays were examined utilizing an FTIR instrument (Thermo Scientific, Nicolet™ iS20, USA) paired with a single reflection attenuated total reflectance (ATR) accessory. The assessments were conducted within the mid-infrared spectrum, ranging from 4000 to 500 cm^{-1}, with a resolution of 4 cm^{-1}.

2.7. X-Ray Diffraction (XRD)

XRD analyses were conducted employing a diffractometer (Bruker, D8 Advance, USA) at ambient temperature (T = 25 °C), applying a voltage of 30 kV and intensity of 10 mA. The instrument emitted Kα copper radiation through a deflection window featuring a 0.06 mm slit positioned in the trajectory of the incident beam, with a wavelength of λ=1.54060 Å. The diffraction pattern was obtained between 2θ = 10º - 60º, with a ramp rate of 1◦/min.

2.8. Scanning Electron Microscopy (SEM)

Morphological analyses of the trays were performed on a SEM (Tescan, VEGA-3 LMU, Czech Republic) equipped with a gold coating system SPI 11430-AB (Tescan, USA). The components of the trays were fixed with double-sided adhesive tape to bronze stubs for cross-sectional observation. A thin layer of gold (40-50 nm) was applied to the surfaces. All samples were inspected at an accelerating voltage of 20 kV, following the methodology described by Cruz-Tirado et al. (2019), within an angular range of 5-60° on a 2θ scale with a step size of 0.02°.

2.9. Statistical analysis

The Statgraphics Plus v. 4 package (Manugistics Inc., USA) was used, employing a Simplex-Lattice mixture design. Analysis of variance (ANOVA) was performed at 95% confidence level, for multiple comparison of the prepared tray formulations, Tukey's test was performed ($p < 0.05$).

3. Results and discussion

3.1. Raw material characterization

Table 2 displays the chemical composition of corn cob flour and umari seed starch. The raw materials exhibited notable distinctions in their chemical makeup ($p < 0.05$). Approximately, 87% of corn cob flour presented carbohydrates and fibers as main components, this flour is constituted by 33% to 43% of cellulose, 26% to 36% of hemicellulose and 17% to 21% of lignin (Bhatia et al., 2020; Gandam et al., 2022). Regarding moisture in flour and starch, the

content varies according to the drying time prior to milling. Kumar et al. (2021) performed kinetics and modeling of corn cob drying, indicating that increasing the drying temperature caused a reduction in drying time. Umari starch presented a purity of 97.62%, similar to the 98.95% presented by Ordoñéz et al. (2001), on a dry basis.

Table 2
Proximal chemical composition of corn cob flour and umari seed starch dried (g/100 g)

Analysis	Umari seed starch	Corn cob flour
Moisture	0.82 ± 0.13^{a}	5.77 ± 0.09^{b}
Ashes	0.09 ± 0.01^{a}	1.85 ± 0.04^{b}
Fats	0.07 ± 0.01^{a}	0.71 ± 0.01^{b}
Proteins	1.35 ± 0.19^{a}	4.08 ± 0.06^{a}
Crude fiber	0.07 ± 0.03^{a}	20.80 ± 0.28^{b}
Carbohydrates	97.62 ± 0.03^{a}	66.79 ± 0.16^{b}

Different Letters between samples present significant difference ($p < 0.05$).

3.2. Characterization of biodegradable trays

3.2.1. Physical properties

Color parameters (L*, a* and b*) varied significantly with the addition of corn cob flour. The brightness (L*) of the trays was reduced with the addition of fibre in the formulations, which in turn caused an increase in the parameters a*, b* causing a reddish hue (a+) and a more accentuated yellowish hue (b+) (Figure 2), and also increased the total colour differential ΔE (Table 3). This behavior has been reported by several authors for fiber-reinforced starch trays (Vercelheze et al., 2013; Mello & Mali, 2014; Aguirre et al., 2023). Furthermore, several investigations linked the Maillard reaction to the darkening of the trays due to the resulting proteincarbohydrate reaction during thermoforming (Cruz-Tirado et al., 2017; Machado et al., 2017).

Table 4 shows the physical analysis of the trays prepared. It was determined that the thickness decreased as the percentage of fiber in the mixture increased, interfered in the foaming and starch swelling processes, which prevented a homogeneous expansion. A significant difference was found between treatments ($p < 0.05$).

The thickness of the trays was lower than those presented by Machado et al. (2017) and Ferreira et al. (2020) who found 3.30 - 4.60 mm and 3.50 - 4.21 mm, respectively. The density values of treatments T2, T4 and T5 decreased significantly compared to the control tray (only umari seed starch), this indicated that the density of starch foams decreases with the addition of fibers; On the other hand, the density values presented were higher than those reported by Bergel et al. (2018) and Machado et al. (2020) who used potato starch, cassava starch and peanut skin, respectively. The moisture content of the trays decreased significantly ($p < 0.05$), this is attributed to the hydrophobic characteristics of the fiber, and its percentage increase in the treatments, decreasing the affinity of the trays for moisture. Cruz-Tirado et al. (2019) used elaborated biodegradable trays using formulations with the addition of arracacha, oca and sweet potato fiber, whose results were superior in moisture (11.79%, 11.97% and 11.87%, respectively). The water absorption capacity decreased as the formulations presented higher corn cob flour addition, trend from 42.325% to 21.863%, Vercelheze et al. (2012) and Kaisangsri et al. (2014) observed that increasing the fiber concentration decreased the water absorption capacity in starch-based foams, which can be explained by the chemical nature of cellulose, which is partially insoluble in water. Proteins (amino acids) influence water absorption capacity (Días & Acuña, 2022).

Table 3
Average color parameters L*, a*, b*, and color difference (ΔE*) of biodegradable trays

Formulation	L*	a*	b*	ΔE*
Control	68.69±0.79^{c}	9.25±0.58^{a}	17.17±1.09^{a}	26.88±1.46^{a}
T1	64.94±0.80^{a}	10.12±0.44^{ab}	20.32±0.40^{b}	31.57±0.29^{c}
T2	67.80±0.93^{bc}	11.20±0.32^{c}	17.21±0.30^{a}	28.06±0.39^{ab}
T3	65.56±1.60^{a}	10.53±0.66^{bc}	19.41±1.00^{b}	30.67±1.53^{c}
T4	66.39±0.45^{ab}	10.72±0.24^{bc}	18.80±1.47^{ab}	29.82±0.94^{bc}
T5	65.94±1.44^{ab}	10.29±0.81^{bc}	19.70±1.27^{b}	30.62±2.01^{c}

Different Letters between formulations present significant difference ($p < 0.05$).

Table 4
Physical properties of biodegradable trays made of corn cob flour and umari seed starch

Formulation	Thickness (mm)	Density (g/cm^3)	Moisture (%)	Water absorption (%)	Volatile solids (%)
Control	3.08±0.14^{d}	0.33±0.02^{abc}	6.48±0.19^{e}	42.33±0.67^{e}	99.03±0.72^{c}
T1	2.47±0.11^{b}	0.41±0.09^{c}	3.85±0.03^{a}	33.23±1.05^{c}	97.70±0.15^{bc}
T2	2.20±0.07^{a}	0.30±0.02^{ab}	5.68±0.17^{d}	39.05±1.07^{d}	97.33±0.27^{b}
T3	2.81±0.03^{c}	0.35±0.00^{bc}	4.02±0.17^{a}	23.07±0.05^{ab}	97.15±1.23^{b}
T4	2.27±0.02^{a}	0.27±0.01^{ab}	4.98±0.10^{c}	24.08±0.34^{b}	95.33±0.09^{a}
T5	3.17±0.03^{d}	0.25±0.00^{a}	4.31±0.10^{b}	21.86±0.93^{a}	98.21±0.21^{bc}

Different letters between formulations present significant difference ($p < 0.05$).

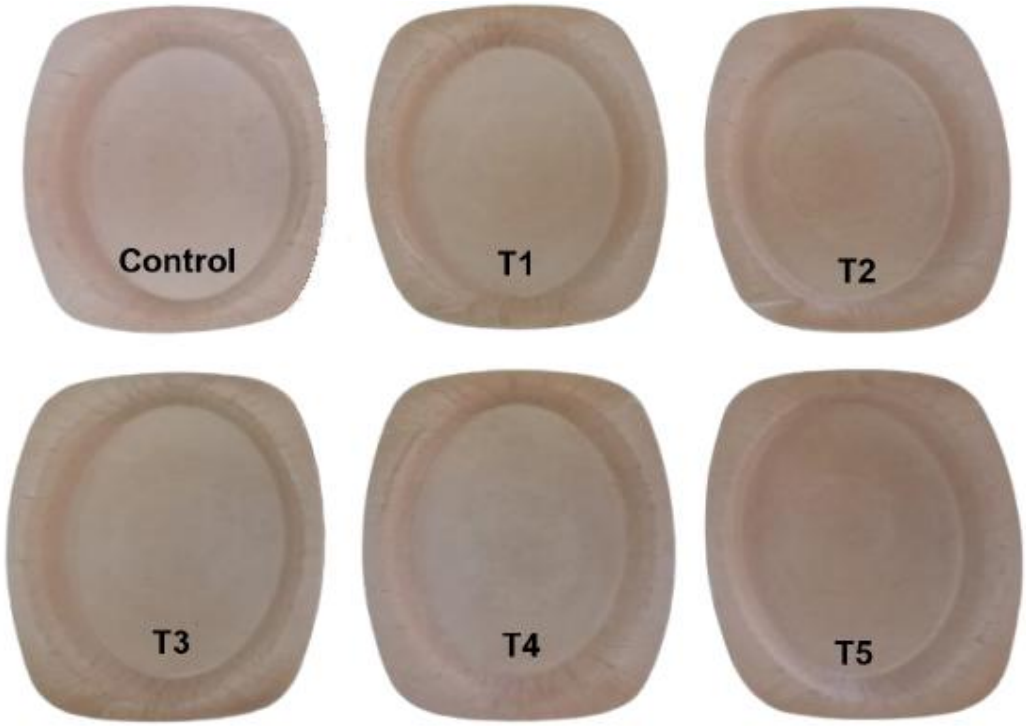

Figure 2. Biodegradable trays made from umari starch seeds (A) and corn cob flour (B) in different formulations. Control: umari seed starch only, T1: 85%A+15%B, T2:90%A+10%B, T3: 86.25%A+13.75%B, T4: 88.75%A+11.25%B and T5: 87.50%A+12.50%B.

Table 5
Mechanical properties of biodegradable trays made of corn cob flour and umari seed starch

Formulation	Tension (MPa)	Elongation (%)	Hardness (N)	Fracturability (mm)
Control	3.31±0.63^{a}	2.18±0.36^{b}	81.46±19.56^{ab}	2.90±1.53^{a}
T1	2.87±0.22^{a}	1.60±0.04^{a}	73.42±4.76^{ab}	1.63±0.68^{a}
T2	3.32±0.23^{a}	1.70±0.08^{a}	67.44±18.05^{a}	3.19±1.87^{a}
T3	2.84±0.24^{a}	1.54±0.08^{a}	77.86±9.55^{ab}	1.58±0.93^{a}
T4	3.43±0.11^{a}	2.04±0.12^{b}	67.70±7.31^{a}	1.43±0.60^{a}
T5	3.23±0.50^{a}	1.68±0.21^{a}	90.97±11.70^{b}	2.46±1.38^{a}

Different letters between formulations present significant difference ($p < 0.05$).

Volatile solids exceeded and complied with the minimum content of 50% volatile solids specified in NTP 900.080, the values presented in Table 4 exceeded those presented by Aguirre et al. (2023), who formulated trays with cassava starch and corn husk flour (65.34 - 74.76% volatile solids), where the 2540G (Standard Method) was also used.

3.2.2. Mechanical properties

The mechanical properties are presented in Table 5, the tensile strength of the trays did not present significant difference ($p < 0.05$); however, these values were higher than those obtained by Cruz-Tirado et al. (2019) (1.32 MPa) and lower than those of Oliveira et al (2018) (6.1 - 11.5 MPa), from these results we can infer that the addition of fiber > 11.25%, generates a reduction in tensile strength; this was probably caused by agglomeration, breaking of starch chains, affecting the expansion capacity during the thermoforming process (Cruz-Tirado et al., 2019). The elongation of the trays is in a range of 1.54 to 2.04%, these values do not exceed the control treatment due to the decrease in the percentage of starch, which led to a decrease in amylose and the interaction of fibers agglomerating in the matrix, resulting in less elastic trays (Cruz, 2021); however, the values obtained in the present study were higher than those obtained by Cabanillas et al. (2019) (1.16% to 1.38%) and Cruz-Tirado et al. (2019) (arracacha: 1.13%, oca: 1.10%, sweet potato: 1.03%). The hardness values present the T5 formulation with the highest average values, surpassing the control treatment by approximately 10 N. The fracturability of the biodegradable trays varies between 1.43 to 3.19 mm, these values were lower than desired compared to the 5.54 mm polystyrene trays (Cabanillas et al., 2019). The addition of fiber (> 10%) caused a decrease in the fracturability distance, since, its incorporation reduces water absorption (Cruz, 2021), according to Lawton et al.

(1999), the fiber content should be low, since increasing the fiber content in the mixture will lead to a more heterogeneous starch mass, resulting in a product with lower mechanical strength. According to the analyses performed we observed that the T5 formulation obtained the best mechanical properties.

3.2.3. Molecular vibration

The FTIR examination revealed the molecular vibrations of functional groups found in umari seed starch, corn cob flour, and additives, as depicted in Figure 3. The analysis was conducted under T5 (optimal) conditions and the control treatment. Within the spectrum, a band spanning 3200 - 3500 cm^{-1} was detected, attributed to the O-H stretching within hydrogen bonds of water molecules. Additionally, a band near 1645 cm^{-1} was observed, indicating O-H bending of water molecules, suggesting interaction with other components in the mixture (Marengo et al., 2013; Ferreira et al., 2020). The band located between 2800 - 3000 cm^{-1} a lower intensity and sharp stretching vibration of the C-H bond can be seen, corresponding to lipids. In general, the intensity of the control trays was higher than those of T5. There was variation in the 1055 and 1027 cm^{-1} peaks (carbohydrate vibrations) because in the starch structure they are considered sensitive to molecular changes (Villanueva et al., 2023). The decrease of peak intensities could be caused by the absorbance of cellulose molecules, to the decrease of the amount of starch in the matrix and to the destruction of covalent bonds in thermoforming.

3.2.5. Analysis of the crystalline structure

The RDX diffractogram of the T5 treatment identified the crystal structure (Figure 4). In general, two narrow peaks were observed at 2θ =16.83° and 2θ = 22.69°, with the second one having the most pronounced peak. The peaks are more pronounced at high fiber levels, probably due to the crystallinity of cellulose in the fiber (Cabanillas et al., 2019); it is also attributed to the crystallinity of amylose, which indicates that gelatinization of the tray starch is incomplete. Mello & Mali (2014) state that, if the peaks do not appear in a pronounced form or are of less intensity and width, it is due to the gelatinization that occurs during the cooking process, they are called semi-crystalline, predominating in the amorphous region. Starch trays with avocado seeds presented similar behavior (De Dios-Avila et al., 2022).

3.2.5. Morphology analysis

Figure 5 shows the results of the SEM analysis performed on the T5 formulation tray and the control. It was observed that in the cross section, cellulosic sandwich-type air cavities were formed, with two dense outer layers comprised on the tray surfaces.

These cellulosic cavities are formed due to the contact of the dough with the hot mold, supersaturating with water vapor, until gelation and drying of the dough (Aguirre et al., 2023; Cruz, 2021). The control tray presented a lower thickness, inside it showed the two thin outer layers, the cellulosic cavities are relatively smaller in quantity, large and fusiform, due to the amount of water that comes out during thermoforming and cell rupture (Cabanillas et al., 2019). In the T5 treatment, there was a partial reduction in the size of the cellulosic voids, attributed to an increase in quantity and irregular distribution due to fiber addition. This phenomenon, as noted by Ferreira et al. (2020) and Silva et al. (2020), is caused by fiber interference in the matrix, resulting in higher density and thickness observed in the structures' walls. Increasing fiber content, according to these studies, leads to a decrease in internal porosity.

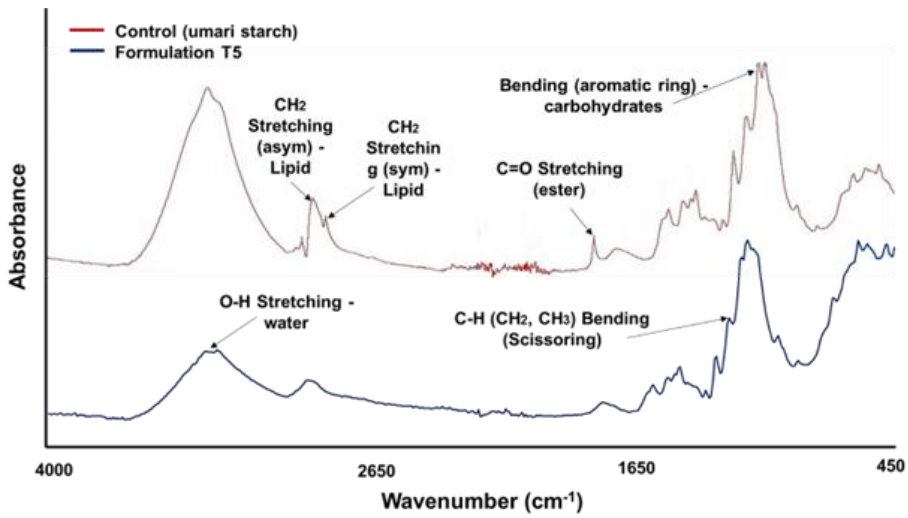

Figure 3. Molecular vibrational spectra measured in FTIR for biodegradable trays of the control (umari seed starch only) and Formulation T5 (87.50% umari seed starch +12.50% corn cob flour).

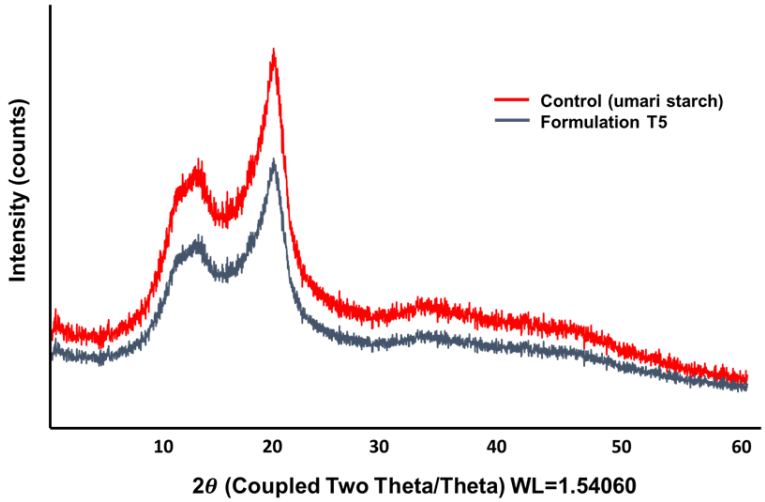

Figure 4. X-ray diffraction (XRD) of biodegradable tray of control (umari seed starch only) and Formulation T5 (87.50% umari seed starch +12.50% corn cob flour).

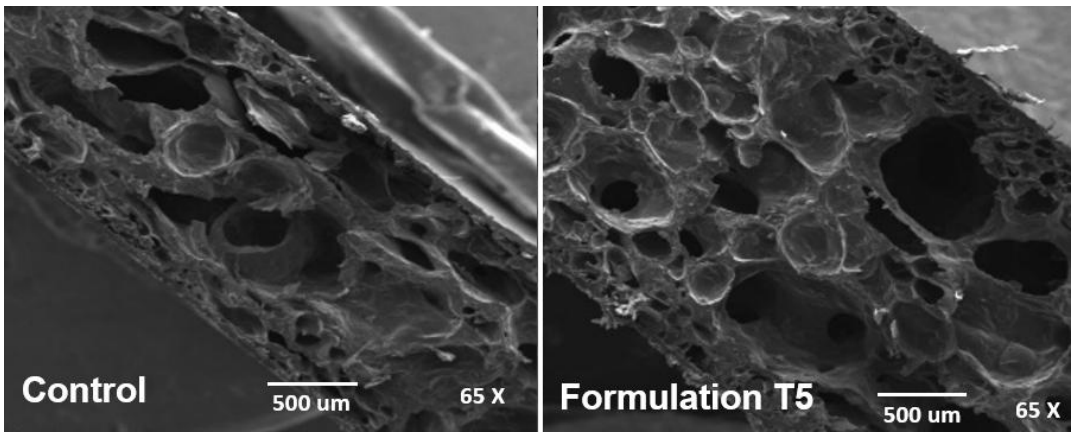

Figure 5. Micrographs obtained by SEM for biodegradable trays of control (umari seed starch only) and T5 formulation (87.50% umari seed starch +12.50% corn cob flour).

4. Conclusions

The present research has demonstrated the feasibility of developing biodegradable trays using waste materials such as umari seeds and corn cob. Using the thermoforming technique, a formulation composed of 87.50% umari seed starch and 12.50% corn cob meal was found to exhibit favorable chemical, physical and mechanical characteristics, suggesting its potential as a substitute for plastic or other petroleum-derived materials.

Future research could analyze the formulations proposed in this study, to explore the possible applications of these biodegradable trays in the packaging of fruits, vegetables, tubers, cereals, legumes, flours, meats, as well as processed foods, where criteria such as shelf life, sensory acceptability, preservation of nutritional and bioactive properties are evaluated, without ruling out the use of these trays in non-food industries.

Declarations conflict of interest

None of the authors has any conflict of interest in this research.

Author Contribution

Alexandra Huertas: Methodology, Formal analysis, Investigation. **Presly Barrios:** Methodology, Formal analysis, Investigation. **María de Fátima Arevalo-Oliva:** Resources, Investigation, Methodology. **Any Córdova – Chang**: Investigation, Data curation. **Beetthssy Z. Hurtado-Soria:** Validation, Writing – original draft. **Eudes Villanueva:** Supervision, Visualization, Writing—review and editing. **José González-Cabeza:** Methodology, Investigation. **Gilbert Rodríguez:** Investigation, Conceptualization. **Elza Aguirre:** Supervision, Funding acquisition, Project administration.

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