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Research article

Physicochemical and sensory evaluation of sweet potato (*Ipomoea batatas* L.) restructured products produced in the Sinu Valley, Colombia

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ABSTRACT

The purpose of the food industry is to ensure the availability of safe and nutritious food ingredients for human consumption. Sweet potato is a crop with excellent industrialization possibilities for human food due to its important nutrient content. The objective of this study was to evaluate the effect of an alginate-calcium sulfate-tripolyphosphate (PPTS) gelling system on the physicochemical and sensory characteristics of restructured sweet potato products. Fifteen formulations with varied concentrations of alginate, calcium sulfate, and PPTS were elaborated and subjected to a ordered-preference test. The physicochemical composition and color parameters of the preferred samples were determined, and the consumer acceptance, intention to purchase, and acceptability index (AI) were assessed. The preferred formulations ($p \leq 0.05$) were F1, F6, F10, F11, and F14, and the gel formation was efficient at retaining water and preventing the restructured products from absorbing fat during frying. The restructured products with the highest water retention and lowest fat absorption were F11 (46.75%), F10 (44.53%), and F14 (43.29%). In the acceptance test, no differences ($p \geq 0.05$) were found in the attributes softness, crunchiness, and sweet potato flavor. Formulations F6 and F14 obtained the highest acceptability index (AI), equal to or higher than 70%, indicating that they could represent viable alternatives for the industrial transformation of sweet potato for its possible commercialization.

1. Introduction

In the Sinú Valley (Colombia), sweet potato (*Ipomoea batatas* L.) is a species that is traditionally grown with little or no technology, generally as a cover crop for other crops, such as plantain, or in the backyards of rural families. However, this crop has great potential to become an economic and productive option for farmers. The applications of this tuber in the industry are increasing because its use has expanded significantly, and the sweet potato is fast becoming a complement or substitute for raw materials in food products, thanks to its nutritional and culinary characteristics [1].

In 2019, world sweet potato production records placed China as the leading producer with 51,793,916 t, followed by Malawi with 5,908,989 t, and Nigeria and United Republic of Tanzania, with production of 4,145,488 and 3,921,590 t, respectively [2].

The uses of sweet potato include the production of flours, starches, bakery products, and noodles, as well as the preparation of brines from the root. Sweet potato can also be cured (preserved by adding salt), dehydrated in pieces, canned, frozen, flaked, cooked in hamburgers, and added to yogurts. In addition, it can be pureed, roasted, or fried at home [1].

On the other hand, restructuring offers important advantages such as revaluation of low-quality raw materials, expansion of the range of products offered, exact and reproducible control of physical and sensory characteristics of the product, and formulation of products with guaranteed and adjusted composition. A product is considered to be restructured when it is made from one or several ingredients, generally from the meat, dairy, fruit and vegetable, fish and seafood, and bakery and confectionery sectors, obtained through a process of structural disintegration (chopping, dicing, etc.) to subsequently create a different structure with a new appearance and texture. The resulting foods are usually marketed as frozen or refrigerated, precooked, or cooked products [3].

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Gelation is the property of starch that allows it to form gels, which can be induced by heat or chemical means using gelling agents such as lecithin, pectin, alginates, carrageenans, and xanthates. In the case of alginates, which are part of the cell wall of algae (Phaeophyceae), their properties vary from one species to another, so harvesting is subject to both the availability of the species and the characteristics of the alginate it contains. Alginates are considered hydrocolloids thanks to their affinity for water and their rheological properties. In their natural state, they are found as a mixture of salts commonly found in seawater, such as Ca2+, Mg2+, and Na+ [4].

The objective of this research was to evaluate the effect of using an alginate-sulfate-phosphorus gelling system on the physicochemical and sensory properties of a restructured sweet potato product.

2. Materials and methods

The sweet potato variety Exportación was provided by the Centro de Investigación AGROSAVIA, Turipaná, located in Cereté, Córdoba, Colombia. Alginate, calcium sulfate di-hydrate and sodium tripolyphosphate (PPTS) were provided by the University of Córdoba.

2.1. Procurement of sweet potato flour

The production of sweet potato flour was carried out following the methodology of Trancoso et al. [5], the first stage consisted of washing the sweet potato, peeling it, and cutting it into 6-mm-thick slices that were subsequently subjected to cooking. The cooked slices were dried at 60 °C for 10 h in an oven with forced air circulation controlling the temperature. After dehydration, the slices were ground and passed through a 60-mesh sieve. The flour obtained was packed in hermetically sealed polyethylene bags and stored at 4 °C until use.

2.2. Preparation of sweet potato puree

The sweet potatoes were peeled and manually cut into 1-cm-thick slices. They were then steamed for 4 minutes and ground in a screw mill. The puree was conditioned in polyethylene bags and stored at −20 °C until use in the formulations, following the methodology described by De Paula [6].

2.3. Preparation of fried sweet potato restructured products

For the stage of elaboration of the restructured products, formulations were developed with variations in the concentrations of alginate (0.23–0.82 g/100 g), calcium sulfate di-hydrate (CaSO4.2H2O) (0.41–0.84 g/100 g), PPTS (0.06–0.18 g/100 g), and sweet potato puree to a total of 100 g for each formulation. The formulations can be seen in Table 1.

The production process of the restructured products was based on the methodology of De Paula [6] (adapted from that of Walter et al. [7]) and the design established in the flow chart in Figure 1. The ingredients were mixed for 1 min in a JAVAR mixer with a capacity of 20 L and a speed of 40 rpm. This procedure was repeated with the addition of each ingredient, thus obtaining a homogeneous mixture. After all ingredients were combined, the emulsion was introduced into sausage casings 2 cm in diameter, cut to form rolls approximately 20 cm long, and tied at the ends. The rolls were stored for 24 h at 4 °C, manually cut into 2 cm pieces, and stored at −20 °C until frying.

2.4. Sensory ordering-preference test

Fifty potential consumers of the product were selected [8, 9, 10], owing to the nature of the treatments, it was not possible to serve all 15 treatments in a single batch, because to do so would saturate the taste buds [11]. All participants signed an informed consent form to participate in the sensory tests. The samples were served completely at random, organized in three batches of five formulations each (Table 2), which were served in a balanced manner. For this test, the 50 tasters rated the samples on a scale from 1 (most liked) to 5 (least liked).

2.5. Physicochemical analysis and acceptance testing of the most preferred formulations

2.5.1. Physicochemical analysis

The physicochemical composition was determined by official AOAC methods [12]: moisture (AOAC 925.10), crude fat (AOAC 920.85), crude protein (AOAC 960.52), ash (AOAC 923.03), and crude fiber (AOAC 920.86). The factor 6.25 was used for the conversion of nitrogen to protein [13], and Atwater's factors were used to calculate the energy value [14]. The percentage of total carbohydrates was calculated by difference, by adding the previous analyses and subtracting this value from 100. The analyses were performed in triplicate.

Also, color was determined by the CIELAB method using a state-of-the-art Hunterlab ColorFlex EZ spectrophotometer with direct reflectance reading on the sample, in the chromaticity coordinates "L" (lightness), "a" (shades from red to green), and "b" (shades from yellow to blue), using the Hunter-Lab scale [15].

Table 1. Concentration of ingredients (g/100 g) for sweet potato products formulations.

Formulations	Alginate	$CaSO_4$	Sweet potato puree	Sacarosa	Sal	Flour	PPTS
1	0.35	0.50	86.06	4.0	1.0	8.0	0.09
2	0.70	0.50	85.71	4.0	1.0	8.0	0.09
3	0.35	0.75	85.81	4.0	1.0	8.0	0.09
4	0.70	0.75	85.46	4.0	1.0	8.0	0.09
5	0.35	0.50	85.97	4.0	1.0	8.0	0.18
6	0.70	0.50	85.62	4.0	1.0	8.0	0.18
7	0.35	0.75	85.72	4.0	1.0	8.0	0.18
8	0.70	0.75	85.37	4.0	1.0	8.0	0.18
9	0.23	0.63	86.00	4.0	1.0	8.0	0.14
10	0.82	0.63	85.41	4.0	1.0	8.0	0.14
11	0.53	0.41	85.92	4.0	1.0	8.0	0.14
12	0.53	0.84	85.49	4.0	1.0	8.0	0.14
13	0.53	0.63	85.78	4.0	1.0	8.0	0.06
14	0.53	0.63	85.63	4.0	1.0	8.0	0.21
15	0.53	0.63	85.70	4.0	1.0	8.0	0.14

Source: De Paula [6], adapted of Walter et al. [7].

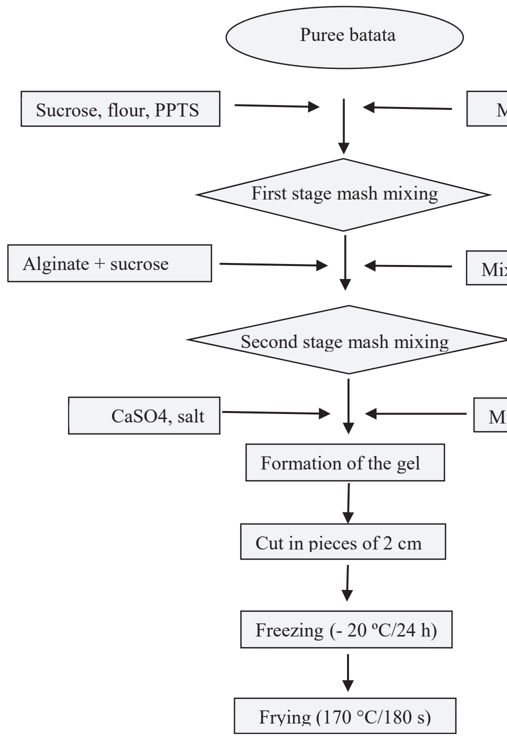

Figure 1. Production flow chart of sweet potato fried restructured products. Source: De Paula (2009) [6], adapted of Walter et al. [7].

Table 2. Batches for the presentation of the restructurings for the Ordering-Preference test.

Formulations					
Batch 1	F5	F15	F4	F8	F11
Batch 2	F2	F7	F13	F1	F10
Batch 3	F3	F12	F9	F14	F6

2.5.2. Instrumental texture and firmness analysis

Instrumental texture and firmness were determined using a Shimazu AZ texture analyzer with a 50 cm plate, a double uniaxial compression test up to 30% of the initial height of the sample with a speed between 1 and 2 mm/s and a waiting time of 5 seconds [16]. The texture parameters analyzed were hardness, adhesiveness, gumminess, chewiness, and elasticity. The analyses were performed in triplicate.

2.5.3. Sensory acceptance test

The preferred samples from the previous stage were tested for acceptability with the participation of 50 verbally recruited potential consumers of the product [8, 9, 10]. A nine-point mixed hedonic scale was used, where 1 meant "I extremely dislike it" and 9 "I extremely like it, " evaluating the attributes of softness, crunchiness, a sensation of oiliness, and sweet potato flavor. Moreover, purchase intention was determined on a five-point scale, where 1 meant "I would not buy it" and 5 "I would buy it".

The Acceptability Index (AI) [17] was determined for each attribute according to Eq. (1):

$$AI(\%) = \frac{A \times 100}{B} \left\{ \begin{array}{l} A = \text{Average grade obtained for the product} \\ B = \text{Maximum grade given to the product} \end{array} \right. \quad (1)$$

2.6. Data analysis

A completely randomized experimental design with three replications was used, for a total of 45 experimental units. The results obtained for the order-preference test were analyzed employing Friedman's test [18] ($p \leq 0.05$). The results of the physicochemical analysis and the acceptance test were analyzed by analysis of variance (ANOVA) ($p \leq 0.05$) and Tukey's post hoc test ($p \leq 0.05$) using the SAS System for Windows, version 9.0.

3. Results

3.1. Sensory ordering-preference test

The control treatment could not be included in the analysis because a gel was not formed in the frying process with the ingredients of the formulation, as the restructured ingredients disintegrated during the frying process.

Table 3 presents the results obtained in the ordering-preference test. The tasters selected formulations F1, F6, F10, F11, and F14 as the preferred.

3.2. Physicochemical analysis and acceptance testing of the most preferred formulations

3.2.1. Physicochemical analysis

Table 4 shows the results for the physicochemical composition of the selected formulations. Significant differences ($p \leq 0.05$) were found in the moisture, ash, and fat contents. With respect to moisture content, formulation F11 did not differ from F10 and F14 ($p \geq 0.05$), which presented the highest moisture values, while F1, F6, and F7 (equal to each other) presented the lowest values.

The ash content of F14 was significantly higher than those of the other formulations ($p \leq 0.05$). This result was similar to those reported

Table 3. Sensory test results Ordering-Preference*.

Lot 1		Lot 2		Lot 3	
Formulations	Results	Formulations	Results	Formulations	Results
F5	163a	F2	183a	F3	184a
F15	160a	F7	172a	F12	180a
F4	158a	F13	161a	F9	159a
F8	157a	F1	117b	F14	113b
F11	112b	F10	115b	F6	110b

* Means with the same letter in the columns do not differ from each other at the 5% probability level for the Friedman test. (DMS = 44).

Table 4. Results of the physicochemical characterization of the most preferred fried sweet potato restructured.*

Formulations	Moisture	Ash	Fat	Protein	Fiber	Carbohydrate	VCT
F1	39.94 ± 2.38bc	1.89 ± 0.22d	30.70 ± 0.01b	3.64 ± 0.09a	3.91 ± 0.23a	19.90 ± 2.34a	370.50a
F6	39.54 ± 1.18c	2.75 ± 0.02b	28.51 ± 0.02c	4.04 ± 0.02a	3.94 ± 1.12a	21.21 ± 1.54a	357.63a
F7	41.48 ± 2.92bc	2.69 ± 0.08bc	32.06 ± 0.02a	3.19 ± 0.62a	4.13 ± 1.31a	16.43 ± 4.81a	321.03a
F10	44.53 ± 1.03ab	2.62 ± 0.16bc	25.72 ± 0.75e	3.94 ± 0.17a	4.37 ± 0.61a	18.47 ± 0.21a	321.12a
F11	46.75 ± 0.73a	2.32 ± 0.20c	27.51 ± 0.05d	3.96 ± 0.48a	4.65 ± 1.12a	14.79 ± 1.23a	322.42a
F14	43.29 ± 0.20abc	3.23 ± 0.06a	26.38 ± 0.36e	4.10 ± 1.05a	4.48 ± 0.55a	18.15 ± 1.05a	326.42a

*Average of three replicates ± standard deviation. Different letters in the same column denote significant statistical differences ($p \leq 0.05$).

by Serrano [19] (restructured meat with nut incorporation 3.51%). F1, in contrast, differed in ash content from the other formulations but presented the lowest value ($p \leq 0.05$).

Regarding the fat absorption capacity of the restructured products, formulations F10 (25.72%) and F14 (26.38%) stood out with the lowest fat content, equal to each other ($p \geq 0.05$), and also differing ($p \leq 0.05$) from the other formulations. F7, with the highest fat absorption value, differed from the other formulations ($p \leq 0.05$) and those with moderate absorption were F1 and F6 ($p \leq 0.05$) (30.70% and 28.51%, respectively).

In the protein content of the restructured products, there were no significant differences ($p > 0.05$); this is because the puree (very small variation in the formulations) and the sweet potato flour (fixed in the formulations) are the ingredients that provide protein (Table 1).

For the fiber of the restructured products, there were no significant differences ($p \geq 0.05$); this is since the contents of mash and sweet potato flour, which provide fiber in all the formulations, are the same (Table 1). The formulation with the highest protein content was F11 (4.48%) and that with the lowest was F1 (3.91%).

Concerning carbohydrates, there were no significant differences ($p \geq 0.05$), indicating that the alginate-calcium sulfate-PPTS variations influenced water retention, fat, and ash absorption and not the carbohydrate content of the formulations (Table 3). Formulation F6 had the highest value (21.21%), and F11 had the lowest.

The results of VCT were equal for all formulations ($p \geq 0.05$), showing that the highest value was F1 (370.50) and the lowest value was F10 (321.03).

The data on the colorimetric characteristics of the restructured products are shown in Table 5. The application of the gelation system to sweet potato restructured products generated significant differences ($p \leq 0.05$), in the variables L, a*, and b* in the formulations.

The lightness parameter (L), which is commonly used as a quality control measure for fried foods [20], presented significant differences between formulations ($p \leq 0.05$). Formulations F1, F6, and F11 presented the highest values of L, which did not differ significantly from one another ($p \geq 0.05$), and were therefore lighter in color than the other formulations. Formulation F7 stood out with the lowest L value and was thus darker than the other formulations.

For the parameter a* of the sweet potato fried restructured products, significant differences were evidenced ($p \leq 0.05$); formulations F1, F6, F10, and F11 stood out as having the highest values, which did not differ significantly between these four ($p \geq 0.05$). Formulation F7 recorded the lowest value for this parameter, which did not differ from that of F14 ($p \geq 0.05$). The range in a* was from 22.61 (F7) to 25.94 (F6).

For the parameter b*, differences between formulations were present ($p \leq 0.05$); F1 and F7 differed ($p \leq 0.05$) in this respect from the other formulations, while the b* values of F6, F10, F11, and F14 did not differ significantly from one another ($p \geq 0.05$). The formulation with the highest value was F1, and that with the lowest value was F7.

3.2.2. Instrumental texture and firmness analysis

The textural characteristics of the sweet potato fried restructured formulations, with the alginate-calcium sulfate-PPTS gelation system, are

Table 5. Color parameters of the most preferred sweet potato fried restructured.

Formulations	L	a*	b*
F1	39.99 ± 1.00a	24.50 ± 0.51a	40.25 ± 0.70a
F6	38.25 ± 044ab	25.94 ± 0.62a	34.60 ± 1.09b
F7	32.63 ± 051c	22.61 ± 0.53b	28.65 ± 1.18c
F10	37.85 ± 068b	24.43 ± 0.52a	34.43 ± 0.50b
F11	38.82 ± 077ab	23.87 ± 0.16ab	33.98 ± 0.78b
F14	37.03 ± 0.77b	22.74 ± 0.27b	35.95 ± 0.65b

* Different letters in the same column denote statistically significant differences ($p < 0.05$).

Table 6. Textural characteristics of the fried sweet potato restructured products.*

Formulations	Hardness (N)	Adhesiveness (N)	Gumminess (N)	Chewiness (Kg)	Elasticity
F1	2.63 ± 0.008a	-0.00030 ± 0.0001a	0.8858 ± 0.0019b	0.0559 ± 0.0015a	0.6153 ± 0.0136a
F6	2.63 ± 0.006a	-0.00026 ± 0.0001a	0.8899 ± 0.0013b	0.0564 ± 0.0011a	0.6107 ± 0.0891a
F7	2.47 ± 0.04b	-0.0067 ± 0.0002b	0.8627 ± 0.0044c	0.0505 ± 0.0002b	0.5563 ± 0.0097bc
F10	1.72 ± 0.03cd	-0.0164 ± 0.0001d	0.8341 ± 0.0041d	0.0474 ± 0.0003c	0.5283 ± 0.0008c
F11	1.78 ± 0.007c	-0.0202 ± 0.0001e	0.7818 ± 0.0015e	0.0426 ± 0.0001d	0.5400 ± 0.0067c
F14	1.69 ± 0.01d	-0.0131 ± 0.0012c	0.9224 ± 0.0002a	0.0558 ± 0.0004a	0.5843 ± 0.0024ab

*Average of three replicates ± standard deviation. Different letters in the same column denote significant statistical differences ($p \leq 0.05$).

Table 7. Results of the acceptance test by attributes and purchase intention of fried restructured products*.

Formulations	Smoothness	Crunchiness	Oily sensation	Sweet potato flavor	Purchase intention
F1	6.40 a	5.54 a	5.76 b	7.28 a	2.94 c
F6	6.36 a	6.40 a	6.64 a	7.36 a	3.24 c
F10	6.68 a	5.78 a	7.22 a	7.54 a	4.26 a
F11	6.82 a	5.92 a	6.74 a	7.34 a	4.08 ab
F14	6.46 a	6.32 a	6.50 ab	7.42 a	3.46 bc

* Different letters in the same column denote statistically significant differences ($p \leq 0.05$).

shown in Table 6, in which significant differences ($p \leq 0.05$) were evidenced in all five parameters.

For the results obtained with the application of alginate-calcium sulfate-PPTS, it is observed that they influence the instrumental hardness of the formulations. Formulations F1 and F6 are equal ($p > 0.05$) and differ from the others ($p < 0.05$), exhibited the highest hardness values (2.63 N); and F14 the lowest hardness (1.69 N), being statistically equal to F10 (1.72 N).

For the adhesiveness parameter, differences ($p \leq 0.05$) were observed between the formulations, with F1 and F2 having the highest values and F11 the lowest; however, these values are considered low, which is very important, since its magnitude indicates the effort to remove the food from the palate and is considered favorable and positive since this property is not desirable in fried products [21].

For gummosity, formulation F14 differs ($p \leq 0.05$) from the other formulations and presented the maximum value (0.9224 N), followed by F6 and F1 (0.8899 N and 0.8858 N respectively) which are equal to each other ($p > 0.05$).

Regarding chewiness (Table 6), formulations F1, F14, and F6 (equal to each other, $p > 0.05$) showed lower chewiness (0.0564, 0.0558, and 0.0564 kg, respectively).

For the elasticity attribute formulations F1 and F6 equal to each other ($p > 0.05$) with higher values and differ ($p \leq 0.05$) from F7, F10, and F11, but F14 is equal to F1, F6, and F7.

3.2.3. Sensory acceptance test

For the results of the acceptance test, no differences ($p \geq 0.05$) were observed between formulations for the attributes smoothness, crispiness, and sweet potato flavor, indicating that the means between samples were similar to the experimental error [22], while differences ($p \leq 0.05$) were observed in the attributes oily sensation and purchase intention (Table 7).

According to the acceptability index (%IA), the sensory attributes smoothness and sweet potato flavor presented values equal to and/or higher than 70%, whereas for crunchiness, formulations F6 and F14 stood out, and for oily sensation, F6, F10, F11, and F14 (Table 8). These values were similar to those found by De Paula et al. [23] for protein-restructured legumes.

4. Discussion

The moisture content values obtained in this study (Table 4) were lower than those found by Boari de Greissing [24] (restructured chicken 63.03%) and Vigo [3] (restructured alpaca with the inclusion of pecan 65.55%), thus indicating that the restructured products in the present research contained less water when compared with those in the literature. The variation found in ash content could be related to the addition of calcium and phosphorus in the gelling system (Table 1), which could have contributed to gel stability. The differences found in the fat absorption of the formulations were due to the variation of alginate-phosphorus-calcium concentrations, which, when the gel is forming, trap water in the matrix and prevent the entry of fat into the feed [6, 25, 26]. These contents are associated with the exchange between water and fat in the restructured products so that the moisture content varies concerning oil absorption during frying (Table 4).

When comparing sweet potato restructured with other products, for example, in potato chips, fat absorption varies from 35% to 40% [27], for green plantain slices it is 37.7% [28], in cassava chips with

Table 8. Acceptability index of sensory attributes of sweet potato restructured*.

Attributes	Formulations				
	F1	F6	F10	F11	F14
Softness	71.1	70.4	71.5	75.5	72.0
Crunchiness	61.5	71.1	64.2	65.8	70.0
Oily sensation	64.0	73.8	80.2	74.9	72.2
Sweet potato flavor	80.9	82.0	72.0	81.5	82.4

* *Values correspond to the percentages (%) of the acceptance index for the attributes evaluated, n = 50 consumers.

pre-treatments before frying it is less than 30% of oil absorption [29], which evidences the efficiency of the alginate-calcium sulfate-PPTS gelation system in reducing fat absorption in sweet potato restructured chips, since the contents were below those mentioned above [6, 30].

No significant variation was observed in protein content (Table 4), establishing that the protein contribution of the restructured products, offered by sweet potato puree and flour, could be proposed as an alternative source to complement protein requirements [23]. Regarding fiber content, like protein, it did not differ between treatments. Fiber is an important component of the diet because it helps to improve the functioning of the digestive system, decreases the level of cholesterol in the blood, has a favorable influence on the glycemic index, contributes to the prevention of colon cancer, and decreases constipation [31, 32]. This highlights the importance of calculating the VCT of food, as it indicates that caloric intake should be balanced with caloric expenditure [33].

According to Suaterna-Hurtado [34], the magnitude of the changes that occur during the frying process will depend on the conditions of the frying process, the type and amount of fat used, and the characteristics of the food to be fried.

The results for the parameter L (Table 5) were similar to those reported by Hernández [35] in fried tortilla chips with an edible coating (38.9) and to those of Alva et al. [36] in potato (*Solanum tuberosum*) flakes native to the single variety (25.3–42.2) and lower than those of De Paula [6] in fried restructured malanga (*Colocasia esculenta* L.) (40.00–63.77). The importance of the L value lies in the fact that an increase in this value indicates a lighter color, but a value approaching zero represents a dark color [37], which influences consumer preference, because color gives the first impression of a food and attracts the attention of consumers [38].

The color change in fried products is due to the presence of reducing sugars present in roots and tubers [39], which is generated by various reactions, such as caramelization, non-enzymatic reactions, and structural changes accelerated by high oil temperatures during frying, which negatively affects the color of the products [40].

The value of the parameter a* of the fried restructured sweet potato (Table 5) ranged from 22.61 (F7) to 25.94 (F6). These values are higher than those found by De Paula [6] for a fried restructured malanga (*Colocasia esculenta* L.) (9.40–18.61). The value of a* indicates the red/green hue; a color measurement in the direction of a* shows a shift toward a red color and for -a* from green [36]; therefore, the restructured product in this study presented a tendency toward a reddish color.

The b* parameter values obtained for the restructured product in the present study (Table 5) were similar to those found by De Paula [6] for fried restructured malanga (*Colocasia esculenta* L.) (27.92–39.57), Ravli et al. [41] for fried sweet potato slices (26.81–29.73), those of Su et al. [38] for microwave-fried potato chips (24.49–30.88), and those of Zhang et al. [42] for French fries (22.00–38.00) but higher than those of Hernández [35] for fried tortilla chips with an edible coating (19.7–21.9). The b* factor indicates yellow/blue tonality; a measurement of this parameter in the direction of +b* represents a yellow coloration of the product, while for -b* it is blue [36]. Thus it can be said that the restructured chips present a tendency toward a yellow color.

Low hardness values (Table 6) result in formulations with higher moisture contents (Table 4) because as the water in the products increases exponentially, the hardness of the feed decreases [43]. The formulations that presented the highest hardness values are those with the lowest water retention (Table 4) because as moisture content decreases, the magnitude of the strength increases [44].

The hardness values for the restructured products are lower than those found by Walter et al. [7] for fried sweet potato restructured products (3.3–22.7 N). This variation may be related to variations in formulations and measurement conditions of the method. However, the values found in the current investigation are similar to those reported by Tan and Mittal [45] for vacuum fried doughnuts (1.10–2.85 N) and to those of Miranda and Aguilera [46] for deep-fried potato slices (2.2–3.0 N). The addition of water retainers such as the alginate-calcium sulfate-PPTS system positively affects the restructured products as moisture influences the textural properties of the fried products [47].

Regarding adhesiveness, formulations F1 and F6 equal to each other ($p > 0.05$), but different ($p \leq 0.05$) from the rest of the formulations, were the ones that showed the highest adhesiveness (-0.00030 N and -0.00026 N, respectively); which is explained because they presented the lowest moisture contents (Table 4) [43]. In contrast, formulations F11 and F10 presented the highest values (-0.0202 N and -0.0164, respectively) which is because they were the formulations with the highest water retention (Table 4).

The adhesiveness of the restructured products is low and presents negative values, meaning that the texture of the formulations is not very sticky, which implies that when the restructured products are consumed, a minimum amount of work is required to remove the food adhered to the oral cavity [48].

The values of gumminess are lower than those reported by De Paula [6] with a range of 0.94 N–3.75 N for a fried restructured malanga (*Colocasia esculenta* L) and those of Walter et al. [7] for fried sweet potato restructured (1.0–4.8 N), however, low gumminess results indicate a minimum energy expenditure to disintegrate the restructured to be ingested [48].

The values of chewiness are lower than those reported by De Paula [6] for a fried restructured malanga *Colocasia esculenta* L.) (11.40–37.01 kg). The chewiness values of the restructured products are low, which is an advantage since less energy is required to chew the product and then ingest it [48].

The results obtained for elasticity (Table 6) show that the formulations with the lowest moisture content (Table 4) yielded higher elasticity values and vice versa [43]. It is generally observed from the results obtained from the instrumental texture profile analysis (TPA) of the sweet potato fried restructured products that hardness, gumminess, chewiness, and elasticity increased with decreasing moisture content, while adhesiveness increased with increasing moisture content. According to Rahman and Al-Farsi [43], two factors: the elastic nature (hardness, adhesiveness, gumminess, and chewiness) and the plastic nature (elasticity) can explain the instrumental attributes of the TPA of the sweet potato fried restructured.

According to the results of the acceptance test (Table 7), the smoothness of the formulations was located between the hedonic terms "I like it slightly" and "I like it moderately", and the F6 and F11 formulations obtained the highest and lowest values, respectively. For crunchiness, they were located between the hedonic terms "I am indifferent" and "I like it moderately", with F1 and F6 having the lowest and highest values, respectively. For oily sensation, differences ($p \leq 0.05$) between formulations were observed; formulations F6, F10, and F11 (equal to each other) differed from F1, and F14 was equal ($p \geq 0.05$) to F1, F6, F10, and F11. Formulations F6, F10, F11, and F14 were located between the hedonic terms "I like it slightly" to "I like it moderately" and F1 between the terms "I am indifferent" and "I like it slightly".

For the sweet potato flavor attribute (equal to each other, $p \geq 0.05$), they were located between the hedonic terms "I like it moderately" and "I like it very much". Flavor was the attribute that obtained the best qualification. This result is consistent with the formulations elaborated, since the same percentage of sweet potato flour was added, and the variations in the amount of puree were not very contrasting. F1 and F10 obtained the lowest and highest scores, respectively.

When the intention to purchase fried sweet potato restructured foods was evaluated, differences were observed ($p \leq 0.05$) between the formulations: F10 and F11; F11 and F14; and F1, F6, and F14 were equal to each other ($p \geq 0.05$). F1 presented the lowest value, located between the terms "I probably would not buy it" and "I have doubts if I would buy it", and F10 the highest value, located between the terms "I probably would buy it" and "Yes I would buy it". F1 was the lowest rated and F10 and F11 the highest. In this sense, formulations F10 and F11 were identified as those for which consumers had the highest purchase intention, which was related to considerable acceptance in terms of the attributes oily sensation and softness.

As for the value obtained for the AI of sweet potato restructured products (Table 8), according to Dutcosky [49], Monteiro [50], and Teixeira et al. [51], a product with a percentage equal to or greater than 70% is considered acceptable to consumers. Based on the above, the most accepted formulations were F6 and F14, since they were the only ones that obtained this value for all the attributes evaluated.

5. Conclusions

The preferred formulations of fried sweet potato restructured products were F1, F6, F10, F11, and F14. The alginate-calcium sulfate-PPTS gelation system made it possible to elaborate a stable sweet potato fried restructured product that was resistant to the frying process, since the control could not achieve the compaction of ingredients. The results of the physicochemical composition highlight the formulations F11, F10, F14, and F6 with higher moisture contents; F6 and F14 with higher ash contents, and F10, F11, F14, and F6 with lower fat contents. In relation to the color of the formulations, these were lighter (L), with F1, F6, F10, F11, and F14 standing out, with red (a*) and yellow (b*) colors prevailing. The formulations with the highest hardness (lower moisture content) and the highest adhesiveness (low tackiness) were F6 and F1. F14, F6, and F1 had low gumminess (minimum energy expenditure for disintegration) and low chewiness values (lower chewing energy). The formation of the gel was efficient at retaining water and preventing the restructured products from absorbing fat during frying. Formulations F6 and F14 had the highest acceptability index, and could be an alternative for industrial processing of sweet potato for possible commercialization.

Declarations

Author contribution statement

Claudia Denise De Paula: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Yenis Ibeth Pastrana-Puche: Conceived and designed the experiments; Wrote the paper.

Karen Margarita Viloria-Benítez, José Antonio Rubio-Arrieta: Performed the experiments; Wrote the paper.

Mónica Simanca-Sotelo, Beatriz Álvarez-Badel: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Yomar Avilez-Montes: Performed the experiments.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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