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Characterization of the techno-functional properties of starch from Purple yam (*Dioscorea alata*), Hawthorn yam (*Dioscorea rotundata*) and Diamante 22-type yam

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Abstract
This study is aimed at evaluating the techno-functional properties of starches from several yam species (Purple yam, Hawthorn yam and Diamante 22-type yam). Analytical procedures were performed according to the methods described by different authors in order to calculate water-absorption index (WAI), water-solubility index (WSI), swelling power (SP) and syneresis. Likewise, descriptive statistics and experimental designs for interpretation of the results were also performed. The results showed that Hawthorn yam has the highest WAI (15.15 g gel/g sample, at 90°C). While WSI was similar for all species, SP is dependent on the temperature with values of 16.10 g gel/g sample (Purple yam and Hawthorn yam), and 11.25 g gel/g sample at 90°C (Diamante 22-type yam). All yam species underwent progressive reduction in syneresis, which suggests that these types of starches could be used to manufacture foods that require maintaining moisture levels.

Keywords: yam; starch; techno-functional properties

Caracterización de propiedades tecnofuncionales de almidones nativos de ñame Criollo (*Dioscorea alata*), Espino (*Dioscorea rotundata*) y Diamante 22

Resumen
Se estudiaron las propiedades tecnofuncionales de almidones extraídos de las especies de ñame Criollo, Espino y Diamante 22. Metodológicamente, se realizaron procedimientos analíticos siguiendo los métodos de distintos autores para calcular índice de absorción de agua (IAA), índice de solubilidad en agua (ISA), poder de hinchamiento (PH) y la sinéresis, seguido de estadística descriptiva y diseños experimentales para interpretación de los resultados. Se concluye que el ñame espino presentó el mayor IAA, 15,15 g gel/g muestra, a 90°C). El ISA fue similar para todas las especies. El PH se incrementa directamente en función de la temperatura, arrojando valores de 16,10 g gel/g muestra para las especies criollo y espino, en Diamante 22 el valor fue de 11,25 g gel/g muestra a 90°C. Todas las especies mostraron una disminución progresiva de la sinéresis, infiriendo que estos almidones podrían ser utilizados en la fabricación de alimentos que requieren mantener la humedad del producto.

Palabras clave: ñame; almidón; propiedades tecnofuncionales.

1. Introduction

Yam, a tuber belonging to the family Dioscoreaceae, is one of the most traditional products of the Caribbean region of Colombia. The department of Sucre is one of the largest producers of yam nationwide, however, yam is used primarily as a source of food and economic sustenance among the general population and small farmers. In addition, commercialization of yam is mostly at the national level and it also has low export rates. There is also a lack of investment

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Table 1.
Yam nutrition facts. Amount per 100 grams.

Compound	Amount*	Measurement unit
Water	69,6	Grams
Protein	1,53	Grams
Carbs	27,88	Grams
Sugar	0,5	Grams
Iron	0,54	Milligrams
Phosphorus	55	Milligrams
Sodium	9	Milligrams
Vitamin C	17,1	Milligrams
Vitamin A, IU	138	IU
Riboflavin	0,032	Milligrams
Vitamin B-6	0,293	Milligrams
Cholesterol	0	Milligrams
Calories	118	Kilocalories
Fat	0,17	Grams
Fiber	4,1	Grams
Calcium	17	Milligrams
Magnesium	21	Milligrams
Potassium	816	Milligrams
Zinc	0,24	Milligrams
Thiamin	0,112	Milligrams
Niacin	0,552	Milligrams
Vitamin A, RAE	7	Micrograms RAE
Vitamin E	0,35	Milligrams

Source: U.S. Department of Agriculture - USDA -. National Agricultural Library. Http://www.nal.usda.gov [7].

to modernize yam production and improve product quality [1]. Although a number of studies to improve yam production have been conducted, the lack of funding remains a major barrier [2,3].

Yam consumption has been widely addressed in a wide variety of studies. It has a number of nutrients including proteins, vitamins and minerals. It is also a good source of energy as well as low in cholesterol [4-6]. Table 1 shows that moisture content is one the predominant components of yam, therefore, the lack of transformation and processing processes will result in yam being susceptible to the mass transfer process as well as prone to bacterial attack. Likewise, yams are fairly high in carbohydrates, which makes this tuber a good source of energy for the human body. It is also rich in minerals such as potassium, phosphorus and magnesium, which are essential for good nervous system function and the production of growth-associated proteins thus promoting tissue repair and heart disease prevention.

In the Caribbean region of Colombia yam is used mainly to prepare traditional dishes such as sancocho (stew), mote de queso (yam soup), and sweets. Recent studies seek to provide information on the health benefits of yams such as the elimination of toxins. One of the most outstanding facts about yam relates to its high starch content, which makes it useful for preparing soups, cookies, breads, and noodles [1, 8,9]. For example, cassava flour is used to make baked goods such as pandebono (Colombian cheese bread) [10], therefore, this could help promote the production of yam starch in the department of Sucre in order to make foods such as the aforementioned products [11] and therefore encourage entry into the food industry.

All these aspects are addressed through the physicochemical characterization of native and/ or modified starches from root vegetables such as yams. So far, good results

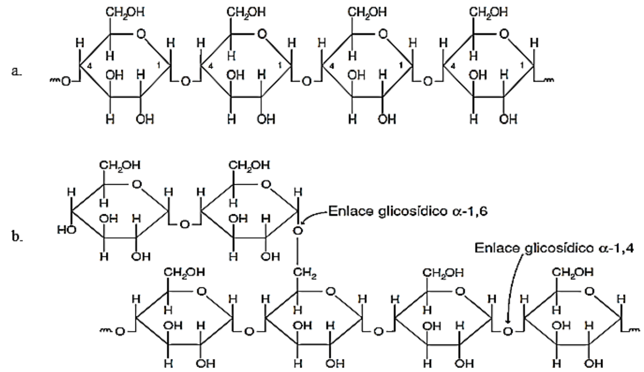

Figure 1. Structural segments of amylose (a) and amylopectin (b).
Source: The authors.

have been obtained in these areas, especially in terms of production of starches with improved stability, strength and mechanical properties [5,12-15]. Studies conducted in countries and regions that are not totally dependent on the farming and commercialization of specific products, and also have major research strengths, have made great progress in this regard.

On the other hand, because climatic conditions and soil characteristics vary from one country to another, any natural product is susceptible to changes in its metabolic composition as is the case of fungi [16] and plants [17], and therefore yams are not exempt from this phenomenon. It has also been shown that different starch contents can be found in both a single region and a single species. These starches are classified as type A, B, and C, depending on their content of amylose and amylopectin (Fig. 1) [18,19], which means that the physicochemical properties may vary, and therefore a number of applications can be obtained. These results provide a solid basis for the present study [18,19].

Considering the aforementioned, it is necessary to direct research towards the development of applications aimed at making new products and methods at the industry level, or otherwise, improve the existing resources, as contemplated in the Sucre department's strategic program for science, technology and innovation. [20].

It should also be emphasized that starches from certain tuber species have been used to make products such as soups, cookies, breads, beverages and noodles, which makes it possible the extraction of starch from yam in order to perform characterization and evaluate its potential use in food production. The purpose of this study was to characterize the techno-functional properties of starches from several yam species such as Purple yam, Hawthorn yam, and Diamante 22-type yam.

2. Materials and methods

This section describes the methodological aspects used in the experimental development of the project.

2.1. Starch extraction

For the extraction of the starch, a pilot scale continuous bubbling equipment was used located in the Unit Operations plant of the University of Sucre, which operates in environmental conditions with a 1/8 yam water solution ratio and whose basis is flotation due to the presence of air. The process consists of preliminary operations, adaptation of the raw material, operation of the equipment that lasts from 40 to 60 min and post-operation that consists of sedimentation, drying, which was carried out in a convective oven at 40ºC for 24 h, milling, sieving to 100 mesh and stored in hermetically sealed containers [21,22].

Once the starch was obtained, the yield with respect to the initial weight of the product (YIWP) was calculated, using eq. 1.

$$\text{YIWP} = \frac{(\text{Final weight of starch } (g))}{(\text{Initial weight of yam}(g))} \times 100 \quad (1)$$

In addition, the yield with respect to the weight of the pulp (YWP) fed to the bubbling equipment was calculated according to eq. 2.

$$\text{YWP} = \frac{(\text{Final weight of starch (g)})}{(\text{Weight of yam pulp (g)})} \times 100 \quad (2)$$

2.2. Determination of starch, amylose and amylopectin content

The following methodologies were used to obtain the main starch components of yam.

2.2.1. Starch

The starch content was determined by enzymatic hydrolysis following the [23] procedure. 42 ml of distilled water and 20 µL of alpha-amylase solution were added to 200 mg of sample. The mixture was then heated in a water bath to 80°C - 90 °C for 15 min with constant stirring. It was allowed to cool and the dextrinification of the starch was confirmed by a negative lugol test. Acetic acid was then added until a pH of 4.8 was obtained. Subsequently, 300 µL of amyloglucosidase solution was added and thermostated in a bath at 60°C for 30 min with constant agitation. The hydrolysed sample was cooled to room temperature and 2 drops of NaOH 2N solution were added to neutralize. The sample was taken to a volume of 125 ml by adding distilled water and the concentration of reducing sugars (RS) was determined using the [24] method. The percentage of starch was calculated according to the following eqs. 3-5.

$$\text{DNS} = \text{Concentration RS} \times 0.125 \quad (3)$$

Then

$$\text{Starch on wet basis} = \frac{(\%\ \text{DNS} \times 0.9 \times 100)}{(\text{Sample weight})} \quad (4)$$

And

$$\%\ \text{Starch on dry basis} = \frac{(\%\ \text{wet basis starch} \times 100)}{(100\text{-}\%\ \text{moisture starch})} \quad (5)$$

2.2.2. Amylose

The content of amylose in starch samples (100 mg) was calculated by a standardized colorimetric method based on the iodine-binding-spectrophotometry according to ISO 6647-1:2007 [25]. The calibration curve (Fig. 2) was calculated using Sigma Aldrich's amylose from potato (St. Louis, MO). Absorbance was measured at 630 nm using the Thermo Scientific™ Evolution 60S UV-Visible spectrophotometer. The content of amylose is calculated by subtracting the blank from the absorbance reading of the sample, then the intercept is subtracted and the corrected absorbance is divided by the slope.

2.2.3. Amylopectin

The content of amylopectin was calculated by difference of the amylose content using colorimetric method [26].

2.3. Water absorption index (WAI), water solubility index (WSI) and swelling power (PH)

This experiment is based on the method used by Salcedo [27]. A starch sample (1g) was deposited on a dry basis into a previously tared centrifuge tube. Then 25 ml of distilled water preheated to different temperatures (60°C, 70°C, 80ºC) was added. The suspension was placed in a water bath at the desired temperature for 30 min and mixed by stirring manually 10 min after the heating started. The suspension was centrifuged at 565 g for 15 min. Then, the supernatant (soluble starch) was extracted and the total volume (V) was determined. Next, a 10-ml supernatant sample was placed in a pre-weighed Petri dish and then oven dried at 70 °C for 16 h. The weights of the Petri dish containing the soluble material and the centrifuge tube containing insoluble starch (gel) were recorded. Water absorption index was determined by eq. 6.

$$\text{WAI} = \frac{\text{Gw}(\text{g})}{\text{Sw}(\text{g})} \quad (6)$$

Where *WAI* stands for water absorption index, *Gw* stands for gel weight expressed in grams, and *Sw* is the weight of the sample expressed in grams. Water-solubility index was calculated by eq. 7.

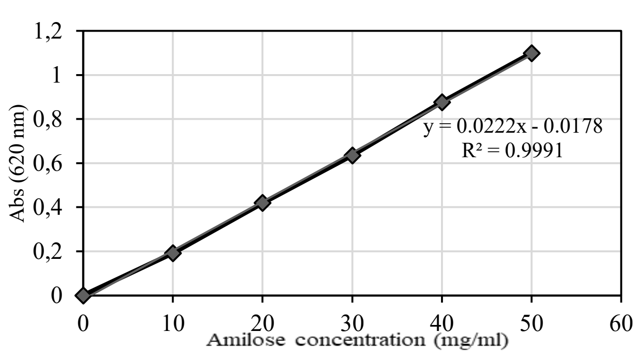

Figure 2. Standard curve of amylose.
Source: The authors.

$$\mathrm{WSI} = \frac{\frac{\mathrm{Swg}(\mathrm{g}) \times \mathrm{V}}{10}}{\mathrm{Sw}(\mathrm{g})} \tag{7}$$

Where *Swg* stands for soluble weight expressed in grams, *V* stands for the volume of the supernatant, and *Sw* is the weight of the sample expressed in grams. The swelling power was determined by eq. 8.

$$\mathrm{SP} = \frac{\mathrm{Gw}(\mathrm{g})}{\mathrm{Sw}(\mathrm{g}) - \mathrm{Swg}(\mathrm{g})} \tag{8}$$

Where *SP* stands for the swelling power, *Gw* stands for gel weight expressed in grams, *Sw* is the weight of the sample expressed in grams, and *Swg* is the soluble weight expressed in grams.

2.4. Water absorption capacity (WAC)

A 1g sample was deposited into a centrifuge tube, then 10 ml of distilled water was added and gently stirred to reach adequate homogenization. The suspension was centrifuged at 3500 rpm for 15 min after which the supernatant was extracted. Next, the centrifuge tube was turned upside down at an angle of 45°, allowed to stand for 30 min, and then weighed [28]. Mass gain is represented by the water absorption capacity of the sample as shown in the following eq.:

$$\mathrm{WAC} = \left(\frac{\mathrm{MH_2OR}(\mathrm{g})}{\mathrm{Mm}(\mathrm{g})} \right) \times 100 \tag{9}$$

Where *WAC* stands for the water absorption capacity of the sample, MH_2OR stands for the amount of water expressed in grams, and *Mm* is the sample mass expressed in grams.

2.5. Solubility

Solubility was estimated according to the method recommended by Eastman [29]. A 1g sample was weighed, and 100 ml of distilled water was added. The suspension underwent homogenization at 5000 rpm for 1 min and then centrifuged at 10000 rpm for 2 min until adequate solubilization of the sample was achieved. 25 ml of the suspension was placed into centrifuge tubes and then centrifuged at 3500 rpm for 15 min. Next, the supernatant was removed and 10-ml aliquot of this solution was transferred to a pre-weighed Petri dish. The sample was oven dried at 110 ºC for 4 h and then placed into the desiccator. Solubility percentage was calculated by difference using the eq. 10.

$$\%\mathrm{Sol} = \left(\frac{\mathrm{Wos}(\mathrm{g}) \times 10}{\mathrm{Sw}(\mathrm{g})} \right) \times 100 \tag{10}$$

Where, *%Sol* is the percentage of solubility, *Wos* stands for the weight of the solids in the supernatant, and *Sw* is the sample weight expressed in grams.

2.6. Freeze-thaw resistance

Starch suspensions (2% w/v) were heated at 90°C with constant stirring for 15 min. A 10-g gel sample was placed into polypropylene centrifuge tubes and then stored at -5 °C for 22 h. Then the frozen samples were placed in a water bath at 30°C for 90 min and centrifuged at 4000 rpm for 15 min. Next, the amount of water released (supernatant liquid) was calculated. The samples were frozen at -5 °C for 22 h after removal of the remaining supernatant. The procedure was repeated for five (5) cycles, and the amount of water released in each cycle was calculated [30]. Syneresis was calculated (according to the total mass of the sample) as the amount of liquid expelled by the gel sample after centrifugation, as follows:

$$\%\mathrm{S} = \left(\frac{\mathrm{LW}}{\mathrm{Sw}} \right) \times 100 \tag{11}$$

Where *%S* is the syneresis rate, *LW* is the weight of the liquid released, and *Sw* is the sample weight.

2.7. Statistical analysis

For the statistical analysis of the data, two experimental designs were designed. Initially for the analysis of the variables amylose content, amylopectin content, WAC and % solubility in cold medium (%S), an experiment was conducted under completely random arrangement (CRD), where the source of variation was the variety of yam samples, with three levels (Purple, Hawthorn and Diamante 22) in triplicate. The mathematical model used for this experiment was the one illustrated in eq. 12.

$$Y_{ij} = \mu + \tau_j + \varepsilon_{ij} \tag{12}$$

Where, Y_{ij} was the observation obtained is the i-ésima experimental unit of the j-ésimo treatment applied, μ is a common parameter all treatments corresponding to the general mean, τ_j is the j-ésimo treatment effect, ε_{ij} is the random error that is committed in the i-ésima experimental unit of the j-ésimo treatment. To establish the effect of independent variables on dependent variables, an analysis of variance was applied (p≤0.05). To compare the mean values, the Tukey multiple range test (p≤0.05) was used for those variables that showed significant differences according to the variation factor applied.

Similarly, for the statistical analysis of the variables WAI, WSI and SP, a factorial experiment was used under completely random arrangement using three replicas, due to the influence of two variation factors that were the variety of yam from which the samples were obtained with three levels (Purple, Hawthorn and Diamante 22) and the temperature with four levels (60°C, 70°C, 80°C and 90°C). The mathematical model described in eq. 13 was used.

$$Y_{ijk} = \mu + \alpha_j + \beta_k + (\alpha\beta)_{jk} + \varepsilon_{ijk} \tag{13}$$

Table 2.
Analysis of variance for YIPW and YWP variables.

YIPW					
Factor	**DF**	**SS**	**MS**	**FC**	**P-Value**
Variety	2	2.546	1.2728	1.659	0.267
Residuals	6	4.603	0.7671		
YWP					
Factor	**DF**	**SS**	**MS**	**FC**	**P-Value**
Variety	2	1.611	0.8055	1.296	0.341
Residuals	6	3.730	0.6216		

Source: The authors.

Where, Y_{ijk} was the variable answer in the i-ésima experimental unit, for j-ésimo variety factor level and k-ésimo temperature factor level, μ was the general average of the treatments, α_j Main effect of j-ésimo variety factor level, βk is the main effect of k-ésimo temperature factor level, $(\alpha\beta)_{jk}$ was the effect of the j-ésimo variety factor level, with the effect of the k-ésimo temperature factor level and finally, ε_{ijk} is the random error in the i-ésima experimental unit for the j-ésimo variety factor level and k-ésimo temperature factor level. Similarly, to establish the effect of the independent variables on the dependent variables, a variance analysis was applied ($p \leq 0.05$). To compare the mean values, Tukey multiple range test was used ($p \leq 0.05$).

Additionally, in order to verify the veracity of the results obtained, the assumptions of the models were checked, considering that the errors were random variables that followed a normal and independent distribution with mean zero ($\mu=0$) and variance σ2. In addition, variance σ2 was assumed to be constant, so the treatments were subject to the same conditions and the only variant of the experiment came from the study factors, so the observations were considered mutually independent. To verify these assumptions, the normality test was performed with the Shapiro-Wilk test, the Bartlett test for variance homogeneity and the Durbin-Watson test to verify the independence assumption ($p \leq 0.05$). The data obtained were processed using the statistical software R studio Version 1.1.447 - © 2009-2018 R Studio, Inc. Under GNU license

3. Results and discussion

3.1. Starch yield

Table 2 illustrates the results obtained for the analysis of variance performed for the YIPW and YWP of the yam starch samples. Where it is possible to observe that the p-values were higher than the previously configured level of significance, therefore, the starch varieties used do not represent a marked variation that represents significant differences for the YIPW and YWP variables.

In a complementary way and with the purpose of ratifying the results obtained in Table 2, The Table 3 presents the results obtained from the yield of starches extracted using continuous bubbling equipment, observing that there were no statistically significant differences ($p \geq 0.05$) between the species evaluated both for yield with respect to the initial weight of yam and for yield with respect to the pulp fed to the equipment used for extraction.

Table 3.
Starch yield.

Parameter	**Variety**		
	Hawthorn	**Diamante 22**	**Purple**
YIWP (%)	9.16±0.68^a	10.46±1.26^a	9.87±0.49^a
YWP (%)	11.36±0.30^a	12.35±1.09^a	11.59±0.77^a

Different letters in the same row denote statistically significant differences ($p \leq 0.05$), according to Tukey's test.
Source: The authors.

Table 4.
Analysis of variance for amylose and amylopectin variables.

Amilose					
Factor	**DF**	**SS**	**MS**	**FC**	**P-Value**
Variety	2	5.521	2.7605	11.17	0.00949
Residuals	6	1.483	0.2472		
Amylopectin					
Factor	**DF**	**SS**	**MS**	**FC**	**P-Value**
Variety	2	5.521	2.7605	11.17	0.00949
Residuals	6	1.483	0.2472		
Starch					
Factor	**DF**	**SS**	**MS**	**FC**	**P-Value**
Variety	2	0.0503	0.0251	0.055	0.947
Residuals	6	2.7417	0.4569		

Source: The authors.

Table 5.
Tukey Multiple Range Test Results ($p \leq 0.05$).

Groups	**Amilose (%)**	**Amylopectin (%)**	**Starch**
Purple	23.636$^{\mathbf{b}}$	76.363$^{\mathbf{a}}$	98.86±0.66^a
Hawthorn	24.851$^{\mathbf{ab}}$	75.148$^{\mathbf{ab}}$	98.70±0.55^a
Diamante 22	25.529$^{\mathbf{a}}$	74.470$^{\mathbf{b}}$	98.85±0.79^a

Different letters in the same row denote statistically significant differences ($p \leq 0.05$), according to Tukey's test.
Source: The authors.

The yields obtained in this work were higher than those found by [31], in native starch of yam of the congo species (7.44%) extracted manually, which evidences an improvement in the yield using the bubbling equipment, possibly due to a greater separation of the starch granule from the mucilage, gel-like colloidal system where the starch granule is often contained [21].

3.2. Amylose/amylopectin concentration

Table 4 illustrates the results obtained for the analysis of variance performed for the amylose and amylopectin content of the yam starch samples.

Specifically, the above results indicate at a significance level of 5% that the p-values obtained for the amylose and amylopectin content was lower than the significance level, therefore, there is sufficient statistical evidence to infer that the content of amylose and amylopectin in the yam starch samples is statistically different according to the varieties evaluated experimentally. To test the treatments that are marking the differences in Table 5, the results obtained for Tukey's multiple range test of the above variables are illustrated.

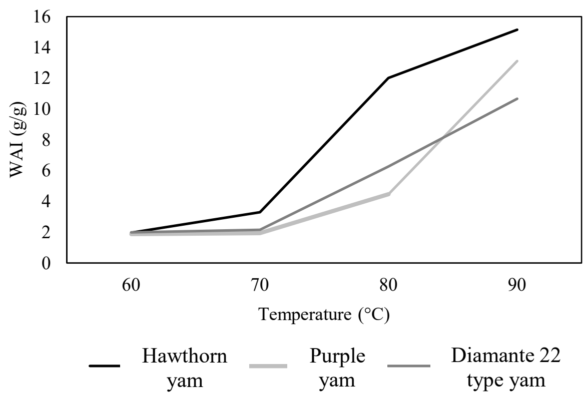

Figure 3. Variation of water absorption index (WAI) as temperature changes.
Source: The authors.

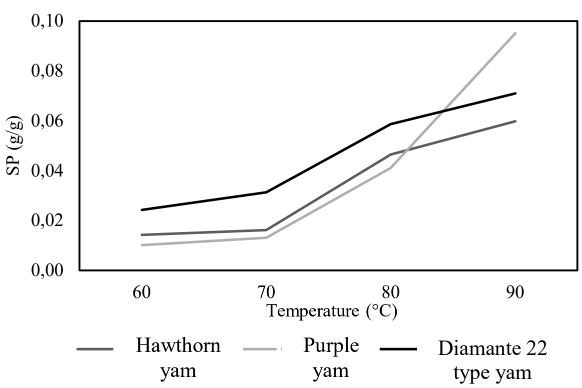

Figure 4. Variation of swelling power (SP) as temperature changes.
Source: The authors.

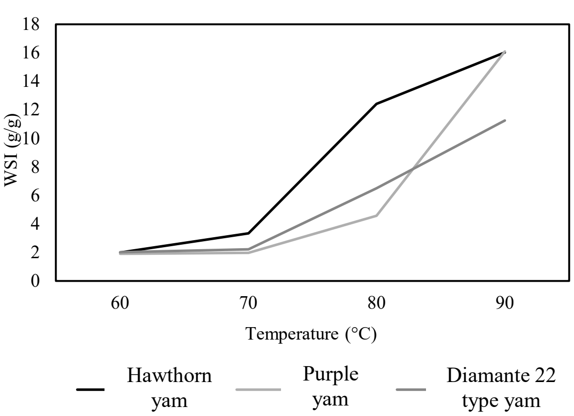

Figure 5. Variation of water-solubility index (WSI) as temperature changes.
Source: The authors.

The starches produced did not show significant differences ($p \geq 0.05$) between them with respect to starch content; however, the values obtained were high, indicating a high purity of the extracted starches. In addition, the values in this study were higher than those reported by [32] for native starch (94.67%) and modified starches (between 95.64 and 98.27%) of yams and were within the range reported by [33] for native and modified starches of yams (97.76 to 99.64%). Furthermore Table 4 shows that Diamante 22-type yam and Purple yam have the highest concentrations of amylose, while Hawthorn yam has the lowest amylose concentration, which means significant differences respect to the other species evaluated. On the other hand, higher amylopectin concentrations are present in Hawthorn yam, while Diamante 22-type yam has the lowest content of amylopectin. The reasons for these variations in the contents of amylose and amylopectin have been attributed to the variation in the vegetable source from which starch is extracted, demonstrating that for yams from the same region and even from the same species it is possible to find different contents of starch, which are classified into starches type A, B, C, which correspond to differences in the contents of amylose and amylopectin [18, 19]. The results obtained for amylose concentrations were within the range of those reported for *Dioscorea esculenta* and *Dioscorea alata* species (19.98% - 29.29%) [34], as well as those reported for native and modified corn starch (23.47 - 28.95%) [35]. Amylopectin concentrations are higher than those found in *Dioscorea bulbifera* (70.62%) [36].

3.3. Techno-functional properties

Figs. 3-6 show values for WAI, WSI and SP depending on the temperature and syneresis of the yam species.

Figs. 3 and 4, show the behavior of WAI and SP At temperatures lower than 70°C both Purple yam and Diamante 22-type yam species show resistance to swelling and absorption, which could be attributed to the high temperature associated with gelatinization [37]. Hawthorn yam exhibits the highest WAI (15.15 g gel/g sample) at a temperature of 90°C. On the other hand, Purple yam and hawthorn yam species have the same SP (16.10 g gel / g sample) at 90°C, while the SP value for Diamante 22-type yam was lower (11.25 g gel / g sample) under the same conditions, which can be attributed to high amylopectin concentrations present in yam species with higher SP values [37]. Similarly, the results

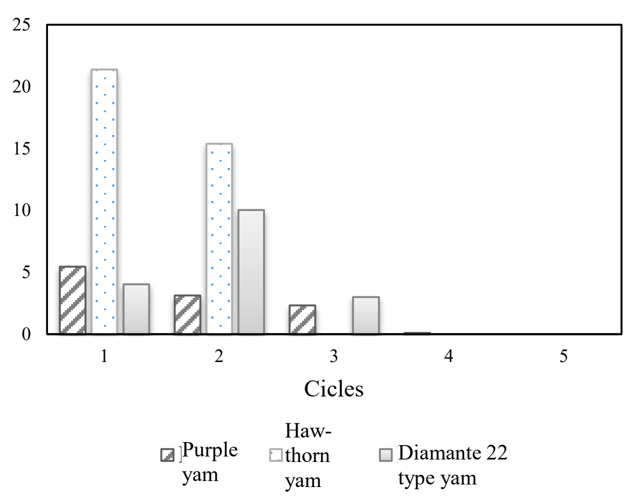

Figure 6. Variation of syneresis (freeze-thaw resistance).
Source: The authors.

Table 6.
Analysis of variance for the variables WAI, WSI and SP.

Factors	DF	SS	MS	FC	P-Value
WAI					
Variety	2	62.57	31.28	70.18	9.40e-11
Temp.	3	718.84	239.61	537.53	0.00e+00
Variety*Temp.	6	63.99	10.66	23.93	5.11e-09
Residuals	24	10.70	0.44		
Total	35	856.09			
WSI					
Variety	2	0.0093	0.004	1.73	0.1979
Temp.	3	0.0614	0.020	7.60	0.0009
Variety*Temp.	6	0.0444	0.007	2.75	0.0351
Residuals	24	0.0645	0.002		
Total	35	0.1797			
SP					
Variety	2	57.87	28.933	224.03	2.98e-16
Temp.	3	915.17	305.05	2362.1	0.0e+00
Variety*Temp.	6	92.19	15.365	118.98	1.20e-16
Residuals	24	3.10	3.10		
Total	35	1068.33			

Source: The authors.

indicate that the amylose content in the starch granule may strongly inhibit swelling [38]. In general, these properties vary directly with temperature increase.

Table 6 illustrates the results obtained for the analysis of variance performed for the variables WAI, WSI and SP.

Specifically, the previous results indicate at a significance level of 5% that the p-value obtained for WAI, WSI and SP was lower than the significance level, therefore, there is sufficient statistical evidence that mark a behavior with statistically significant differences between the starches of the species studied according to the varieties evaluated experimentally (WAI, WSI and SP). To check the treatments that are marking the differences, Table 7 illustrates the results obtained for the Tukey multiple range test of the mentioned variables.

Table 7.
Tukey multiple comparison test results.

Variable	Temperature (°C)	Variety: Purple	Hawthorn	Diamante 22
WAI (g/g)	60	$1.980^{c,A}$	$1.893^{c,A}$	$1.999^{c,A}$
	70	$3.288^{c,A}$	$1.932^{c,A}$	$2.147^{c,A}$
	80	$12.011^{b,A}$	$4.469^{b,C}$	$6.281^{b,B}$
	90	$15.153^{a,A}$	$13.118^{a,B}$	$10.661^{a,C}$
WSI (g/g)	60	$0.014^{a,A}$	$0.010^{b,A}$	$0.024^{a,A}$
	70	$0.016^{a,A}$	$0.013^{b,A}$	$0.031^{a,A}$
	80	$0.046^{a,A}$	$0.041^{b,A}$	$0.058^{a,A}$
	90	$0.060^{a,B}$	$0.227^{a,A}$	$0.070^{a,B}$
SP (g/g)	60	$1.993^{d,A}$	$1.901^{c,A}$	$2.019^{c,A}$
	70	$3.312^{c,A}$	$1.943^{c,B}$	$2.176^{c,B}$
	80	$12.415^{b,A}$	$4.560^{b,C}$	$6.494^{b,B}$
	90	$16.029^{a,A}$	$16.100^{a,A}$	$11.253^{a,B}$

Different lowercase letters indicate significant differences in temperatures within variety levels. Different capital letters indicate significant differences of variety within temperature levels (p≤0.05), according to Tukey's test.

Source: The authors.

For the WAI, a continuous increase was noted with the increase in temperature, behavior similar to that exposed by [38]. Similarly, there were significant differences between Hawthorn-Purple yam and Diamond 22- Purple yam species at temperatures of 60°C and 80°C, which is also shown in Fig. 3. Similarly, the statistical analysis showed significant differences in the SP behavior between the species with higher and lower values studied, as well as an increase in the same as the study temperature increased. As for WSI, the species showed a similar trend up to 80°C and significant differences were observed between them when reaching 90°C.

The solubility of the Hawthorn and Diamante 22 species evaluated at temperatures of 60°C, 70°C, 80°C and 90°C did not show statistically significant differences between them (with a significance level of 5%), however, the data obtained were lower than those reported for Dioscórea rotundata and cayenensis (2.77 and 2.29% respectively) [39]; yam starch Discorea bulbifera, Discorea Trifida and Discorea Esculenta [40]. The variety with the lowest solubility of the extracted starches was the Espino species, which could be associated with its lower amylose content [41]. On the other hand, the syneresis of the species was also observed; the highest values of 21.37% and 15.39% in the first two cycles are given for Hawthorn yam. Finally, a gradual decrease of the syneresis is also observed until the values become null, where a greater stability is observed for the species Hawthorn (Fig. 6).

Analyses were also performed for the characterization of native starches in terms of water absorption capacity (WAC) and solubility properties in cold water. Table 8 illustrates the results obtained for the analysis of variance performed for these variables and Table 9 presents the results of Tukey's multiple comparison test.

Since p-values lower than the 5% significance level were obtained, there is sufficient statistical evidence to affirm that there are significant differences between the response variables (WAC and Solubility) caused by the variety of yam starch samples evaluated. Therefore, the results of the comparison test are illustrated in Table 9 as stated above.

Table 8.
Analysis of variance for the variables of WAC and % Solubility on cool water.

Factor	DF	SS	MS	FC	Pr>Fc
CAA					
Variety	2	0.07796	0.03898	25.7	0.00114
Residuals	6	0.00910	0.00152		
% Solubility on cool water					
Variety	2	0.4822	0.24111	72.33	6.32e-05
Residuals	6	0.0200	0.00333		

Source: The authors.

Tabla 9.
Resultados de test de comparaciones múltiples de Tukey.

Groups	WAC	Solubility
Purple	1.069^{b}	0.333^{b}
Hawthorn	1.062^{b}	0.766^{a}
Diamante 22	1.263^{a}	0.866^{a}

Source: The authors.

Table 10.
P-values of the assumptions of the models obtained.

Test	Amilose	Amylopectin	WAC	% S
Shapiro-Wilk	0.195	0.196	0.076	0.098
Bartlett-Test	0.075	0.075	1.000	0.999
Durbin-Watson Test	0.296	0.096	0.540	0.114

Source: The authors.

Starches obtained from Purple and Hawthorn yam species showed no statistically significant differences with respect to WAC, and were within the range reported for native and modified yam starches from species such as *Dioscorea rotundata*, *Dioscorea alata*, *Dioscorea cayenensis* and *Dioscorea dumetorum* (0.63 – 1.04 g water/g starch) [38]. There were statistically significant differences in WAC values. Diamante 22-type yam exhibits the highest WAC values, a fact that could be related to the presence of different proportions of crystalline and amorphous regions within starch granules, since granules with amorphous, weakly-connected regions are expected to absorb more water [45].

Hawthorn yam starch has the lowest solubility values, which could be associated with lower amylose content [45]. Although no statistically significant differences were found between Purple yam and Diamante 22-type yam, the data obtained were lower than those reported for *Dioscorea rotundata* and *Dioscorea cayenensis* (2.77 and 2.29%, respectively) [46]. On the other hand, Purple yam exhibits the highest values with respect to syneresis (21.37% and 15.39%) in the first two cycles. Also, a gradual decrease in syneresis occurs as the values become null, where hawthorn-type yam presents greater stability (Fig. 6).

Regarding syneresis, significant differences were found in starch samples ($p \leq 0.05$), being Purple yam the species with the highest value, while Diamante 22-type yam has the lowest syneresis values. Although these starches presented the same content of amylose and amylopectin, the differences presented may be due to a greater reorganization of the amylose in the gel obtained from Hawthorn starch, losing the domain of the water molecules, which come out of the gel [47], as the technofunctional properties in starches depend not only on the relative proportion of amylose and amylopectin, but also on the chain length distribution and branching frequency of these two components, the molecular organization, granule shape and size [42]. However, the values found were lower in starches native to *Dioscorea alata* (67%), and *Dioscorea esculenta* (28.4%) [43].

To complete this analysis, Table 10 shows that the experimental designs developed comply with the model's assumptions regarding normality, homogeneity of variances and independence. Therefore, the reliability of the results obtained is valid due to the robust statistical support elaborated.

Indicating that the errors of the model follow a normal distribution, in the same way that the variances are homogeneous and that the errors are independent random variables.

4. Conclusions

The techno-functional characterization of yam species showed that purple yam starch has higher WAI values. This property makes it suitable for use in the production of bakery and pastry goods, and especially sausages, since it can be used as a stabilizer for this type of products due to its ability to bind and absorb the water released during protein denaturation occurring in the cooking process [44].

Starches from yam species evaluated showed reduced syneresis rate, which makes it suitable for use in the frozen food industry as they allow to maintain aspects such as flavor, texture and nutritional value [45].

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