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RESEARCH ARTICLE

Physicochemical and nutritional traits of sweet potato (*Ipomoea batatas* (L.) Lam) landraces grown in traditional farming systems

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ABSTRACT

In response to global concerns over food scarcity, the sweet potato (*Ipomoea batatas* (L.) Lam) has emerged as a promising alternative due to its rich composition of carbohydrates (starch), protein, fiber, vitamins, and minerals. This study aims to assess the physicochemical characteristics and nutritional content of different sweet potato landraces cultivated in Yucatan, Mexico. The study involved the evaluation of eight landraces of sweet potato cultivated in traditional farming systems, assessing both physicochemical and proximate composition variables, and determining the starch yield, starch color, protein content, swelling degree, and starch solubility index. The sweet potato landraces showed values ranging from acidic to slightly neutral pH (6-6.4). The yellow sweet potato II, purple sweet potato, and pink sweet potato landraces displayed high levels of total soluble solids with a range of 12.5 to 14.33 °Brix. Significant differences were observed in both peel and root pulp coloration. The pink, yellow, purple I, mamey, yellow II, and purple sweet potato landraces, presented elevated percentages of carbohydrates (85.0% to 89.0%), fats (1.1% to 1.5%), protein (3.5% to 5.1%), fiber (4.0% to 5.0%), and ash (3.5% to 4.0%). The mamey sweet potato and pink sweet potato landraces showed higher starch yields. Swelling power and starch solubility index peaked at a temperature of 90 °C. These results highlight the significance of sweet potato landraces cultivated in Yucatan as a valuable genetic resource with nutritional potential, which can be included in the diet of people, genetic improvement and species conservation programs.

Key words: Nutritional traits, plant genetic resources, starch, sweet potato, ethnobotanics.

INTRODUCTION

Researchers have recognized the sweet potato (*Ipomoea batatas* (L.) Lam) as a globally significant crop in terms of both food and economic importance (Hossain, 2019; Nguyen et al., 2021; Sapakhova et al., 2023). The sweet potato belongs to the Convolvulaceae family, and using molecular markers its center of origin and highest diversity has been established in Central America (Zhang et al., 2000). The cultivation of sweet potato is extensive in tropical and subtropical regions worldwide (Loebenstein, 2009; Chandrasekara and Kumar, 2016). In Mexico is one of the oldest crops cultivated, and there are landraces of sweet potatoes about which little is known (Torres et al., 2019). In the southeastern region of Mexico, specifically on the Yucatan Peninsula, the sweet potato landraces are primarily grown under a traditional farming system known as “milpa” and serve as a substitute for potatoes. In the Yucatan state, researchers have reported eight different landraces of sweet potatoes showing differences in skin color, pulp color, root size, and

cultivation cycle (Terán et al., 1998). Globally, some studies suggest that the unique characteristics of sweet potato varieties confer specific nutritional and functional properties (Hossain, 2019; Nguyen et al., 2021). Studies have reported that orange and purple-fleshed sweet potatoes contain high levels of anthocyanins and carotenoids, while yellow-fleshed or lighter-colored sweet potatoes tend to have lower carotenoid content (Kim et al., 2011; Hossain, 2019; Pilon et al., 2021). According to Hossain (2019), purple sweet potato varieties contain starch, fiber, carotenoids, polyphenols, and proteins that can be utilized as raw materials for the development of food and industrial products. However, studies on the physicochemical and nutritional characteristics of sweet potato landraces cultivated in Yucatan are lacking. Furthermore, their properties and benefits are unknown to those who cultivate them, highlighting the need to determine their nutritional value and nutritive properties. The objective of this study was to evaluate the physicochemical and nutritional characteristics of eight sweet potato landraces cultivated in the Yucatan, Mexico.

MATERIALS AND METHODS

Collection of plant material

Eight sweet potato (*Ipomoea batatas* (L.) Lam) landraces collected from three Mayan areas of Yucatan state (Xocén, Xiulub and Mérida) (Table 1, Figure 1) were studied. For Xocén and Xiulub Mayan areas, sweet potato landraces were directly collected from the farmers' fields (within their traditional agricultural systems named "Milpa"), while for Merida Mayan area one landrace was collected from the municipal market. Fifteen roots in physiological maturity were collected from each landrace and labeled for subsequent analysis. For the assessment of physicochemical variables, roots were disinfected with ionized silver (Ag^{+1}; 0.35%) and for the proximate composition analysis, roots were dried in an air oven (FE-134ADU, Felisa, Jalisco, Mexico) at 50 °C for 24 h, ground and sieved through five different sieves to homogenize them, 300 150, 75, 45 and 38 µm) (RETSCH N° 50, 100, 200, 325 and 400 respectively). Finally, samples were stored under refrigeration (-80 °C) until use.

Table 1. Sites and origin of collection for eight sweet potato landraces grown in traditional farming systems in Yucatan, Mexico. *Traditional farming systems named Milpa.

Sweet potato landraces	Maya name	Collecting site	Collection origin
White	Sak iis	Xocén, Yucatan	Milpa*
Yellow	X ka'an iis	Xocén, Yucatan	Milpa
Purple	Xmóorado iis	Xocén, Yucatan	Milpa
Purple I	Xmóorado iis II	Xocén, Yucatan	Milpa
Mamey	X chakal ja'as iis	Xocén, Yucatan	Milpa
Yellow II	X ka'an iis-Xiulub	Xiulub, Yucatan	Milpa
Purple II	Xmóorado	Mérida, Yucatan	Local market
Pink	Xiulub purple	Xiulub, Yucatan	Milpa

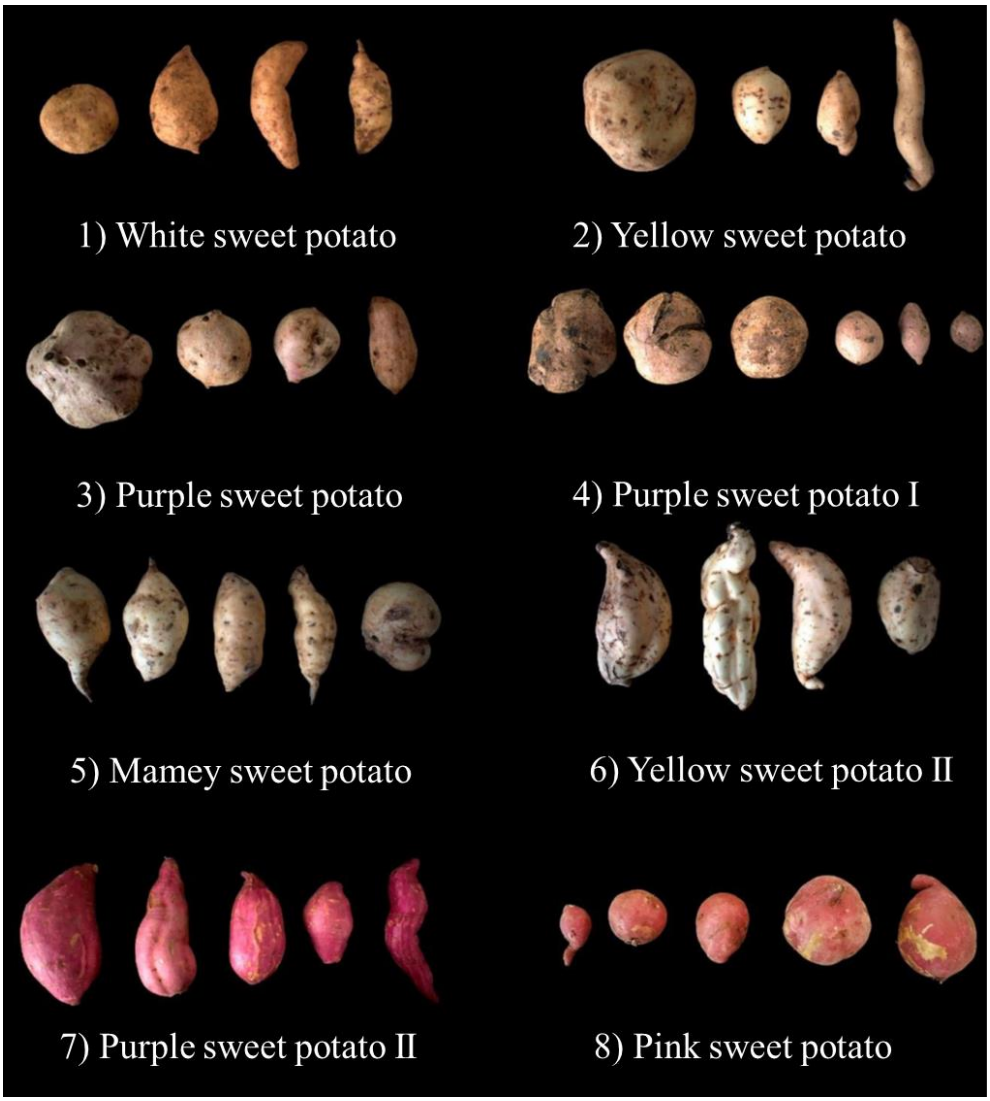

Figure 1. Sweet potato landraces collected in Yucatan, Mexico. 1) White sweet potato (maya name: sak iis); 2) Yellow sweet potato (maya name: xk'an iis); 3) Purple sweet potato (maya name: Xmóorado iis); 4) Purple sweet potato I (maya name: Xmóorado iis II); 5) Mamey sweet potato (maya name: Xchakal ja'as iis); 6) Yellow sweet potato II (maya name: X ka'an iis-Xiulub); 7) Purple sweet potato II (maya name: Xmóorado); 8) Pink sweet potato (maya name: Xiulub purple).

Physicochemical analysis

The physicochemical evaluations were conducted on fresh roots in accordance with the standard procedures by AOAC (2010). The pH was determined according to Mexican codex NMX-317-S-1987. Forty grams of sample from each landrace were weighed, 30 mL distilled water were added, and the mixture was processed in a blender. Afterwards, solids were separated through a cloth mesh and centrifuged the liquid at 4700 rpm for 30 min at 4 °C (Sorvall ST 8R, Thermo Scientific, Waltham, Massachusetts, USA). The pH of the supernatant was measured using a pH meter (pH 700 benchtop meter, Oakton, Vermon Hills, Illinois, USA). This analysis was performed by triplicate. To evaluate total soluble solids content (TSS, °Brix) and total titratable acidity (TTA, equivalent to g lactic acid L^{-1}), fresh samples were grated using a conventional grater, and solids were separated using a cloth mesh. The TSS were measured with a digital refractometer (Abbe NAR-1T liquid refractometer, ATAGO, Tokyo, Japan). The TTA value was measured according to Mexican codex NMX-F-102-S-1978. The maturity index was calculated based on the following formula: Maturity index = TSS/TTA.

To assess the sodium chloride content (NaCl), 1:10 dilutions of the samples were prepared, and NaCl content was measured using a digital refractometer (HI96821 digital refractometer for sodium chloride; Hanna Instruments, Smithfield, Rhode Island, USA) following the supplier's instructions. The evaluations of TSS, TTA and NaCl content were performed by duplicate. The color evaluation was conducted in triplicate using a colorimeter (ColorMeter Pro D/8-SCI; CHNSpec Technology, Zhejiang, China) and recorded Lab* data. Here, L* represents luminosity (L* = 0 for black and L* = 100 for white), a* indicates the position between red (+) and green (-), and b* indicates the position between yellow (+) and blue (-). Delta E (ΔE) represents the color difference, which can be defined as the Euclidean distance (Tang et al., 2015), hue and chroma values were obtained based on Waramboi et al. (2011) and Medina-Torres et al. (2021).

The hardness variable (maximum force texture) was evaluated in triplicate using a universal testing machine (EZ-SX Shimadzu Corporation, Kyoto, Japan) on all fresh roots. Hardness quantification was performed on a force *versus* needle displacement graph using texture analysis software (Trapezium X, V1.4.0, 2013; Shimadzu Corporation) with a 3-point bending test (1 cm opening), downward compression polarity, and a displacement speed and limit of 1.0 cm min^{-1}.

Proximate composition analysis

Proximate composition analysis was determined using the official methods as described by AOAC (2005) and included moisture content, ash, crude protein, fat, crude fiber, and total carbohydrate contents. Moisture and ash content were assessed in fresh samples (roots) and dry samples (sweet potato flour), while other analyses were conducted on the dry sample (sweet potato flour). Briefly, moisture content was measured after drying 2 g sample in an air oven (FE-134ADU) at 50 °C for 12 h. Ash was determined after incineration of the sample in a muffle furnace (FE-363, Felisa) at 525 °C for 3 h. The determination of proteins was carried out using the Kjeldahl-Gunning method, employing a Kjeldahl DKL 12 series digester coupled to a UDK 129 distillation unit (VELP Scientifica, Usmate, Italy) following the user manual and the AOAC (1997). For this, 1 g sample was weighed, and two catalyst tablets (K_2SO_4, 23,10%; Na_2SO_4, 69,30%; $CuSO_4$, 1,80%; TiO_2, 2,80%) and 13 mL sulfuric acid were added to the sample. Sample digestion was conducted at 420 °C in 60 min. The analyses were performed in duplicate, and the N percentage was calculated using the formula described by AOAC (2005). The protein content was calculated using a conversion factor of 6.25. Determinations of crude fiber and fat contents were performed in duplicate, using the standard methods as described by AOAC (2005). Finally, the total carbohydrates were calculated by difference.

Starch extraction

The starch extraction was carried out based on the procedure described by Kim et al. (2020) with some modifications. Forty grams of sweet potato flour were weighed, mixed with distilled water, and kept under constant stirring for 30 min. Subsequently, the sample was sieved through meshes of 300, 150, 75, 45, and 38 µm and centrifuged at 4700 rpm for 15 min (Sorvall ST 8R), with three washes using distilled water. Sodium hydroxide at 0.2% was added, and the pH was adjusted to 10, allowing it to settle for 4 h to remove pigments and proteins. After additional washing and overnight settling, the mixture was centrifuged and decanted. The sediment was dried at 50 °C for approximately 2 d, and the starch yield was calculated based on Vithu et al. (2020).

Color evaluation in starch

The color of the starch was measured using a colorimeter (MiniScan EZ 4500L portable spectrophotometer, HunterLab, Reston, Virginia, USA). Three samples of the starch were taken, placed in a Petri dish, and the values of L* (luminosity), a* (+a* = red, -a* = green), and b* (+b* = yellow, -b* = blue) were recorded. The hue angle and chroma (C*) (intensity of the color) were calculated based on Estrada-León et al. (2016).

Protein determination by the Kjeldahl-Gunning method in starch

A Kjeldahl DKL 12 series digester coupled with a UDK 129 distillation unit (VELP Scientifica) was used following the user manual and the procedures outlined in AOAC (1997). The analyses were conducted in duplicate, and the N content, expressed as a percentage, was calculated using the formula described by AOAC (2005). The protein content was calculated using a conversion factor of 6.25.

Solubility and swelling power of sweet potato starch

Solubility and swelling power were determined according to the methodology of Estrada-León et al. (2016). For this, 1 g starch was added to 10 mL distilled water in a tube. Subsequently, it was heated at a constant temperature (60, 70, 80, and 90 °C, in an air oven (FE-134ADU) and stirred for 30 min. The mixture was allowed to cool, then centrifuged at 3000 g for 15 min. The supernatant was weighed, and 5 mL supernatant were taken and placed in an oven at 120 °C for 4 h and finally solubility and swelling power were calculated based on Estrada-León et al. (2016).

Statistical analysis of data

For the statistical analysis, InfoStat software version 2020e (Grupo InfoStat, FCA, Universidad Nacional de Córdoba. Córdoba, Argentina) was used. A one-way ANOVA was conducted to determine significant differences among the evaluated variables. Subsequently, for the variables that showed significant differences, a multiple comparison of means was performed using the LSD-Fisher analysis, with a significance level of $p \leq 0.05$.

RESULTS

Physicochemical traits

The variables of hardness, pH, total soluble solids (TSS), total titratable acidity (TTA), and maturity index showed significant differences among the evaluated landraces (Table 2). The purple sweet potato II and white sweet potato landraces presented the highest and lowest values of hardness (61.66 and 87.67 N, respectively). The pH for all landraces ranged from acidic to slightly neutral, with a range of 6.10 to 6.46. For TTA values the yellow sweet potato and purple sweet potato landraces showed the lowest and the highest values (0.31 to 0.70 g L^{-1}, respectively), and TSS ranged from 10.33 to 14.33 °Brix, with the yellow sweet potato II landrace obtaining the highest value, followed by purple sweet potato (14.33 and 13.17 °Brix, respectively). Regarding the maturity index, the yellow sweet potato and pink sweet potato landraces obtained the highest values (39.52% and 39.99%, respectively). For the color L*, a*, b*, ΔE, and Chroma values were significantly different among the sweet potato landraces (Table 3). The skin color values of the mamey, yellow II, yellow, and white sweet potato landraces obtained higher values for L* and b*. The b* values ranged from +7 to +38 in the skin and from -3 to +34 in the pulp. Regarding Chroma values, a range of 20 to 39 was found for the skin and 9 to 35 for the pulp, respectively. While the values for Hue in the skin and pulp ranged from 0.25 to 13 and from -0.25 to 7, respectively (Table 3).

Table 2. Physicochemical variables of sweet potato landraces cultivated in Yucatán, Mexico. Different letters in the same column indicate significant differences. Mean ± SD (standard deviation). LSD $p < 0.05$.

Sweet potato landraces	Hardness	pH	Total titratable acidity	Total soluble solids	Maturity index
	N		g lactic acid L^{-1}	°Brix	%
Purple II	87.67 ± 5.90^{a}	6.10 ± 0.01^{f}	0.62 ± 0.00^{ab}	10.33 ± 0.58^{a}	16.78 ± 0.94^{a}
Pink	86.20 ± 6.90^{a}	6.25 ± 0.02^{d}	0.37 ± 0.07^{bc}	12.50 ± 0.00^{bc}	39.99 ± 9.51^{cd}
Mamey	75.48 ± 4.90^{ab}	6.12 ± 0.02^{e}	0.51 ± 0.25^{ab}	11.50 ± 0.00^{ab}	25.54 ± 9.68^{abc}
Yellow II	82.94 ± 7.90^{a}	6.46 ± 0.02^{a}	0.41 ± 0.04^{abc}	14.33 ± 0.29^{d}	35.06 ± 2.46^{bcd}
Yellow	75.48 ± 4.90^{a}	6.33 ± 0.02^{c}	0.31 ± 0.00^{c}	12.17 ± 0.29^{bc}	39.52 ± 0.94^{d}
White	61.66 ± 6.0^{b}	6.34 ± 0.02^{c}	0.45 ± 0.07^{abc}	10.50 ± 0.87^{a}	23.46 ± 1.95^{abc}
Purple	82.01 ± 6.0^{a}	6.41 ± 0.004^{b}	0.70 ± 0.07^{a}	13.17 ± 0.58^{cd}	18.95 ± 1.17^{a}
Purple I	76.64 ± 2.90^{ab}	6.35 ± 0.00^{c}	0.66 ± 0.04^{ab}	12.17 ± 0.29^{bc}	23.05 ± 4.62^{ab}

Table 3. Color values of the skin and pulp of the root in eight sweet potato landraces cultivated in Yucatán, Mexico. Different letters in the same column indicate significant differences. Mean ± SD (standard deviation). LSD $p < 0.05$. L*: luminosity; +a*: red; -a*: green; +b*: yellow; -b*: blue; Hue angle and Chroma: intensity of the color.

Sweet potato landraces	Skin color						
	L*	a*	b*	ΔE	°Hue	Chroma	Color
Purple II	30.70 ± 0.00^{e}	29.60 ± 0.00^{a}	7.10 ± 0.00^{c}	2.59	0.25 ± 0.10^{a}	28.65 ± 3.74^{bcd}	
Pink	35.50 ± 0.35^{de}	27.60 ± 4.16^{a}	15.07 ± 1.79^{b}	7.86	0.54 ± 0.06^{a}	36.33 ± 4.11^{ab}	
Mamey	67.73 ± 0.29^{ab}	9.93 ± 0.12^{b}	36.53 ± 1.44^{a}	2.56	0.51 ± 0.41^{a}	37.91 ± 1.32^{a}	
Yellow II	60.80 ± 0.17^{bc}	13.37 ± 3.18^{b}	37.27 ± 2.48^{a}	6.99	0.55 ± 0.17^{a}	36.61 ± 1.23^{ab}	
Yellow	69.67 ± 2.14^{a}	8.77 ± 2.14^{b}	38.90 ± 0.35^{a}	5.27	0.15 ± 0.72^{a}	39.34 ± 0.90^{a}	
White	63.23 ± 0.58^{ab}	10.37 ± 0.23^{b}	37.43 ± 0.46^{a}	1.34	4.84 ± 13.79^{a}	26.77± 9.98^{cd}	
Purple	51.53 ± 6.81^{c}	10.60 ± 0.87^{b}	17.70 ± 1.21^{b}	12.08	0.49 ± 0.22^{a}	33.57 ± 3.22^{abc}	
Purple I	43.20 ± 0.35^{d}	13.23 ± 0.81^{b}	15.73 ± 2.83^{b}	5.13	13.96 ± 21.11^{a}	20.54 ± 1.82^{d}	
	Pulp color						
	L*	a*	b*	ΔE	°Hue	Chroma	Color
Purple II	67.00 ± 1.27^{a}	6.75 ± 1.48^{c}	34.75 ± 0.92^{a}	2.31	1.28 ± 1.45^{a}	35.37 ± 0.45^{a}	
Pink	46.25 ± 2.76^{c}	-1.15 ± 0.35^{bc}	18.65 ± 1.48^{b}	12.3	0.49 ± 0.33^{ab}	9.74 ± 0.90^{d}	
Mamey	63.75 ± 8.56^{a}	5.25 ± 0.21^{c}	32.10 ± 2.12^{a}	5.27	7.15 ± 1.27^{a}	32.66 ± 1.47^{a}	
Yellow II	37.35 ± 1.48^{c}	9.35 ± 2.19^{bc}	19.55 ± 0.49^{b}	9.30	-2.21 ± 1.53^{ab}	22.42 ± 1.58^{b}	
Yellow	45.40 ± 0.14^{b}	7.10 ± 1.13^{c}	19.20 ± 1.98^{b}	3.81	-0.59 ± 0.26^{ab}	21.03 ± 1.86^{b}	
White	63.50 ± 1.56^{a}	-1.45 ± 0.49^{d}	10.15 ± 0.07^{c}	0.55	-0.46 ± 0.17^{ab}	21.01 ± 1.83^{b}	
Purple	12.65 ± 3.04^{d}	19.60 ± 2.69^{a}	-9.25 ± 1.20^{e}	6.16	-5.35 ± 8.54^{b}	21.12 ± 4.36^{b}	
Purple I	13.25 ± 1.06^{d}	13.15 ± 3.75^{b}	-3.25 ± 2.33^{d}	1.97	-0.25 ± 0.09^{ab}	14.12 ± 3.11^{c}	

Proximate composition

All evaluated proximate composition variables showed significant differences among the studied landraces (Table 4). For fresh roots on a dry basis (determinations performed on fresh samples), the moisture variable recorded values between 65.70% and 76.49%, while ash values ranged from 0.74% to 1.95%. The yellow sweet potato landrace obtained the highest values in both variables with 76.49% moisture and 1.95% ash. Regarding the moisture and ash variables determined in sweet potato flour (dry sample), the landrace with the highest moisture value was white sweet potato (5.79%), followed by mamey sweet potato (5.65%) and purple sweet potato II (5.49%). For ash, the highest values were recorded for the purple sweet potato II, white sweet potato and yellow sweet potato landraces.

Table 4. Moisture and ash determinations in fresh sweet potato and sweet potato flour of eight sweet potato landraces cultivated in Yucatan, Mexico. Different letters in the same column indicate significant differences between varieties. Mean ± SD (standard deviation). LSD $p < 0.05$. $^{N/D}$Determinations were not obtained for the landrace.

Sweet potato landraces	Fresh sweet potato (roots) (dry basis)		Sweet potato flour (dry basis)					
	Moisture	Ash	Moisture	Ash	Crude fiber	Proteins	Fat	Total carbohydrates
	%	%	%	%	%	%	%	%
Purple II	73.50 ± 0.15^{b}	1.27 ± 0.03^{abc}	5.49 ± 0.46^{ab}	4.24 ± 0.06^{a}	5.08 ± 0.52^{a}	3.93 ± 0.00^{c}	1.16 ± 0.04^{bc}	85.18 ± 0.43^{e}
Pink	65.70 ± 0.57^{e}	1.10 ± 0.07^{bc}	4.59 ± 0.34^{c}	3.15 ± 0.12^{d}	3.61 ± 0.27^{c}	3.53 ± 0.00^{e}	1.54 ± 0.13^{a}	87.18 ± 0.35^{c}
Mamey	71.32 ± 0.16^{c}	1.22 ± 0.15^{bc}	5.65 ± 0.15^{a}	3.19 ± 0.01^{d}	4.30 ± 0.11^{b}	4.97 ± 0.00^{b}	1.11 ± 0.16^{bc}	85.07 ± 0.00^{e}
Yellow II	75.87 ± 0.08^{a}	1.52 ± 0.10^{ab}	5.44 ± 0.15^{ab}	3.59 ± 0.02^{c}	4.23 ± 0.07^{bc}	5.16 ± 0.01^{a}	1.39 ± 0.01^{ab}	84.42 ± 0.16^{f}
White	69.94 ± 0.03^{d}	1.48 ± 0.05^{ab}	5.79 ± 0.50^{a}	4.14 ± 0.04^{a}	4.08 ± 0.20^{bc}	3.57 ± 0.01^{e}	0.97 ± 0.12^{cd}	85.53 ± 0.32^{e}
Yellow	76.49 ± 0.22^{a}	0.74 ± 0.05^{c}	4.94 ± 0.17^{bc}	2.95 ± 0.06^{e}	4.47 ± 0.23^{ab}	2.75 ± 0.12^{g}	0.80 ± 0.10^{de}	88.55 ± 0.11^{b}
Purple	71.21 ± 1.14^{c}	1.95 ± 0.74^{a}	5.32 ± 0.04^{ab}	3.86 ± 0.12^{b}	4.33 ± 0.01^{b}	3.20 ± 0.00^{f}	1.13 ± 0.03^{bc}	86.48 ± 0.11^{d}
Purple I	$^{N/D}$	$^{N/D}$	2.98 ± 0.06^{d}	3.21 ± 2.3^{d}	4.17 ± 0.35^{bc}	3.81 ± 0.01^{d}	0.62 ± 0.23^{e}	89.37 ± 0.15^{a}

The crude fiber content ranged from 3.61% to 5.08%, with the purple II and yellow sweet potato landraces obtaining the highest percentage of crude fiber. The protein percentage ranged from 2.75% to 5.16%. The yellow II and mamey sweet potato landraces obtained the highest protein percentages (5.16% and 4.97%, respectively). The variable fat content varied from 0.62% to 1.54%, with the purple sweet potato I landrace presenting the lowest fat percentage, while the pink sweet potato landrace obtained the highest fat percentage. The percentage of total carbohydrates ranged from 84.42% to 89.37%. The purple sweet potato I landrace had the highest total carbohydrate value, while the yellow sweet potato II landrace obtained the lowest values (Table 4).

Starch yield, protein content, and color in sweet potato starch

The starch yield (starch content) and percentage of residual protein in the starch showed significant differences among the landraces (Table 5). For the starch yield, a range of 21.48% to 34.26% was found. The landraces mamey and pink sweet potato exhibited the best starch yields. The percentage of residual protein obtained in the starch of the evaluated sweet potato varieties ranged from 0.55% to 1.05%. The mamey sweet potato landrace had the highest percentage of residual protein, while the white sweet potato landrace had the lowest percentage of residual protein. Regarding the starch color variable, the starches from the different studied landraces showed significant differences in color (Table 5). They had luminosity (L*) values ranging from 80.37 to 89.07, from 0.73 to 1.75 for a*, and from 9.42 to 13.90 for b* (Table 5). Three landraces exhibited the highest luminosity values (purple sweet potato, yellow sweet potato II, and yellow sweet potato) with lighter shades.

Starch solubility and swelling power

The starch solubility values obtained (Table 6) tend to be higher as the temperature increases; however, significant differences in solubility values among sweet potato landraces were only observed when the starch was heated to 60, 70 and 90 °C. For swelling power, a similar pattern is observed to that seen with solubility values because swelling values tend to increase as the heating temperature rises, and significant differences were only observed at temperatures of 60 and 70 °C.

Table 5. Starch yield, residual protein, and color pattern in starches from eight sweet potato landraces cultivated in Yucatan, Mexico. Different letters in the same column indicate significant differences between varieties. Mean ± SD (standard deviation) LSD $p < 0.05$.

Sweet potato landraces	Starch yield	Residual protein	Starch color					
			L*	a*	b*	Color	°Hue	Chroma
	%	%						
Purple II	22.04 ± 1.20^{d}	0.60 ± 0.07^{c}	89.07 ± 2.34^{a}	0.75 ± 0.05^{e}	9.42 ± 0.68^{f}		-0.09 ± 6.68^{a}	9.45 ± 0.68^{f}
Pink	31.51 ± 0.53^{ab}	0.59 ± 0.06^{c}	84.38 ± 1.73^{c}	0.73 ± 0.08^{e}	11.05 ± 0.23^{d}		0.01 ± 0.33^{a}	11.07 ±0.23^{de}
Mamey	34.46 ± 4.89^{a}	1.05 ± 0.12^{a}	84.27 ± 0.74^{c}	1.25 ± 0.10^{c}	12.62 ± 0.29^{b}		0.16 ± 1.21^{a}	12.68 ± 0.30^{b}
Yellow II	23.47 ± 0.22^{cd}	0.80 ± 0.01^{b}	86.47 ± 1.86^{b}	1.42 ± 0.15^{b}	11.65 ± 0.19^{c}		-1.31 ± 1.54^{a}	11.74 ± 0.18^{c}
Yellow	28.45 ± 0.72^{bc}	0.56 ± 0.01^{c}	86.90 ± 0.41^{b}	0.98 ± 0.08^{d}	10.65 ± 0.10^{e}		1.43 ± 2.41^{a}	10.70 ± 0.10^{e}
White	28.53 ± 1.92^{bc}	0.55 ± 3.7E-03^{c}	83.80 ± 0.71^{c}	1.30 ± 0.09^{c}	11.30 ± 0.33^{cd}		-1.37 ± 1.60^{a}	11.37 ± 0.34^{cd}
Purple I	21.48 ± 1.90^{d}	0.57 ± 0.12^{c}	80.37 ± 1.59^{d}	1.75 ± 0.10^{a}	13.90 ± 0.17^{a}		7.91 ± 20.41^{a}	14.01 ± 0.17^{a}

Table 6. Starch solubility and swelling power of sweet potato landraces at different temperature ranges. Different letters in the same column indicate significant differences between landraces. Mean ± SD (standard deviation). LSD $p < 0.05$.

Sweet potato	Solubility index (%)				Swelling power (%)			
landraces	60 °C	70 °C	80 °C	90 °C	60 °C	70 °C	80 °C	90 °C
Purple II	0.16 ± 0.03^{b}	0.32 ± 0.10^{b}	0.60 ± 0.38^{a}	0.89 ± 0.26^{ab}	2.10 ± 0.19^{b}	4.07 ± 0.63^{a}	3.45 ± 1.41^{a}	13.64 ± 1.46^{a}
Pink	0.33 ± 0.12^{ab}	0.42 ± 0.13^{ab}	0.41 ± 0.16^{a}	0.17 ± 0.15^{b}	2.49 ± 0.10^{a}	2.79 ± 0.08^{b}	3.49 ± 1.04^{a}	10.32 ± 0.96^{a}
Mamey	0.57 ± 0.11^{a}	0.57 ± 0.15^{a}	0.84 ± 0.05^{a}	1.00 ± 0.76^{ab}	2.46 ± 0.02^{a}	2.76 ± 0.29^{b}	3.32 ± 0.07^{a}	12.34 ± 2.42^{a}
Yellow II	0.44 ± 0.11^{ab}	0.51 ± 0.03^{ab}	1.87 ± 1.81^{a}	2.10 ± 0.89^{a}	2.11 ± 0.07^{b}	2.73 ± 0.79^{b}	2.58 ± 0.32^{a}	15.42 ± 0.58^{a}
Yellow	0.27 ± 0.24^{ab}	0.49 ± 0.06^{ab}	0.30 ± 0.10^{a}	0.89 ± 0.82^{ab}	2.34 ± 0.04^{ab}	2.65 ± 0.51^{b}	3.05 ± 0.06^{a}	12.08 ± 1.91^{a}
White	0.37 ± 0.21^{ab}	0.39 ± 0.13^{ab}	0.36 ± 0.08^{a}	1.22 ± 1.04^{ab}	2.34 ± 0.06^{ab}	2.74 ± 0.01^{b}	2.67 ± 0.13^{a}	13.29 ± 4.37^{a}
Purple	0.17 ± 0.04^{b}	0.51 ± 0.01^{ab}	0.28 ± 0.07^{a}	0.46 ± 0.18^{b}	2.16 ± 0.24^{b}	2.66 ± 0.26^{b}	2.79 ± 0.09^{a}	10.54 ± 1.46^{a}

DISCUSSION

Physicochemical traits

The results of the physicochemical characteristics obtained in this study are similar to those reported by Sugri et al. (2019), who found significant differences in pH, total titratable acidity (TTA), and total soluble solids (TSS) in sweet potato varieties from Ghana. Regarding the TSS values obtained in this study, they are higher than those reported by Pilon et al. (2021) and similar to those reported by Vizzotto et al. (2017) in sweet potato genotypes from Brazil. The content of TSS is an important characteristic for fruits in general and for sweet potato varieties because it can contribute to consumer acceptance (De Oliveira et al., 2019). However, the amount of sugar in a specific sample will depend on the variety, its characteristics, and the conditions in which the crop was grown. On the other hand, the pH results obtained in this study are similar to those reported by Techeira et al. (2014). The observed pH values in the evaluated sweet potato landraces (6.0 to 6.4) indicate that the roots of the sweet potato landraces are in a good state of maturation and suitable storage conditions. Sweet

potato landraces with pH below 6.0, specifically between 4.7 and 5.5, are more likely to have enzymes that break down the roots and change how they are stored, which is an important factor in how they are handled and how long they last (Feltran et al., 2004).

Regarding the variable TTA, the values in this study are lower than those reported by De Oliveira et al. (2019). The TTA levels indicate the concentration of organic acids present in foods, and their concentration mainly depends on the proteins and salts present in the sample. However, it is desirable to obtain low TTA values as they improve the taste and odor of foods, directly influencing the acceptance of food products (De Oliveira et al., 2019). The TTA levels observed in the studied sweet potato landraces can be considered low (0.3 to 0.7 g L^{-1}), a factor that has allowed these landraces to remain popular among consumers. The hardness results obtained in this study were higher than those reported by Utomo and Rahman (2015), who observed significant differences among the different sweet potato cultivars they evaluated. Regarding the color of the sweet potato skin and flesh, variability was observed in the Lab*, ΔE, °Hue, and Chroma values of all the studied landraces. In general, the colors observed in the flesh were lighter compared to the colors observed in the sweet potato skin, with some exceptions. Aina et al. (2012) and Tang et al. (2015) reported similar findings, stating that the color of sweet potato flesh is lighter than the color of the skin. Among the exceptions observed in the color of the sweet potato skin and flesh, mamey, yellow II, yellow, and white sweet potato landraces stand out, as they are the only landraces that presented lighter colors in the skin. The observed differences in color of the flesh and skin in the studied landraces primarily result from the presence of various pigments, including β-carotene in yellow or orange varieties, anthocyanins in red or purple varieties, and flavonoids in yellow varieties, these pigments contribute to the unique properties and characteristics of each variety, which can be exploited (Van Hal, 2000; Tang et al., 2015).

Proximate composition

The moisture and ash results obtained from fresh roots align with those of Yoon et al. (2018), who, in evaluating 10 sweet potato varieties, obtained moisture values ranging from 62.22% to 77.13%. Utomo and Rahman (2015) reported moisture values similar to those obtained in this study. Kim et al. (2011) reported similar moisture and ash results in sweet potato flour, evaluating eight Korean sweet potato varieties. Ahmed et al. (2010) reported similar values for the ash variable but found different values for moisture content. According to Van Hal (2000), the variation in moisture content in sweet potato flour can be attributed to factors such as drying method, drying time, drying period, and sample storage conditions. The moisture content of sweet potato flour is one of the most critical quality characteristics that is affected by the storage time of the sweet potato roots, as a higher moisture content tends to accelerate the deterioration of sweet potato flour (Acevedo et al., 2018).

The results of crude fiber, proteins, fats, and total carbohydrates obtained in this study are higher than those reported in other studies (Ahmed et al., 2010; Kim et al., 2011; Acevedo et al., 2018). However, Acevedo et al. (2018) reported a higher protein content (10.25%) in the varieties that they evaluated compared to the protein content of the sweet potato landraces of this study. In our results, the percentage of total carbohydrates present in sweet potato flour was high (ranging from 84.16% to 94.8%). However, the protein content obtained in this work is lower than those reported in other studies. Due to its contribution to daily protein intake, sweet potato is considered a good protein source, especially in countries where access to animal protein consumption is limited. Moreover, sweet potato flour is primarily composed of sporamins, which are abundant in essential amino acids, making it a valuable source of high-quality protein (Acevedo et al., 2018; Mu and Singh, 2019). In general, the composition and nutritional value of sweet potato flour depend largely on the chemical composition of the roots, which can be influenced by harvest time, management, and crop development conditions (Van Hal, 2000).

Starch yield, protein content, and color in sweet potato starch

The starch yield obtained in the studied sweet potato landraces is higher than that reported by Vithu et al. (2020), who evaluated starch yield in a sweet potato variety using different washing methods. Starch content is an agronomically important characteristic for sweet potato and can vary due to genetic and environmental factors; however, genotype has the most significant influence on starch content (Lu et al., 2015). Zhang et al. (2017) observed that water content and root development significantly affect the starch content of sweet

potatoes. On the other hand, the protein content in the starch of the evaluated sweet potato landraces was similar to that reported by Xu et al. (2018), but higher than that reported by Vithu et al. (2020) in different sweet potato varieties. Vithu et al. (2020) notes that starches with protein percentages below 0.3% can be considered high-quality starches. The starch extraction method used, crop age, and environmental conditions in which the crop was grown can account for the differences in protein percentages observed in sweet potato starch in this study and the aforementioned studies.

Starch color is an important characteristic, especially for its acceptance in the industry, and it is generally preferable for it to be white, therefore, the industry seeks starches with higher luminosity values. In this regard, three sweet potato landraces showed the highest luminosity values (purple sweet potato II, yellow sweet potato II, and yellow sweet potato) with lighter shades. Abegunde et al. (2013) recorded similar luminosity values in 11 sweet potato cultivars as observed in this study. However, other authors report luminosity values higher than those obtained in this study (Xu et al., 2018; Vithu et al., 2020). The extraction method used can influence starch coloration, and the number of washing stages during the extraction process and the solutions used for starch extraction are two critical factors in the final result.

Starch solubility and swelling power

The swelling capacity of starch granules is measured by the swelling power at a specific temperature, indicating the starch's water retention capacity after being heated, cooled, and centrifuged. On the other hand, solubility reflects the degree of dissolution during the starch swelling process, and both hydration and swelling indicate the magnitude of interaction between starch chains (Zhang et al., 2018). Compared to other studies, the studied sweet potato starches exhibit low values for both solubility index and swelling power. For instance, Abegunde et al. (2013), evaluating starches at a temperature of 90 °C, obtained swelling power and solubility values similar to those reported in this study. Another study by Xu et al. (2018), evaluating three sweet potato varieties at a temperature of 95 °C, yield, swelling and solubility values higher than those reported in this study. These variations in recorded values are primarily attributed to starch granule forces and the relationships between amylose and amylopectin, which constitute starch and tend to increase with the proportion of amylopectin and swelling power. On the other hand, these differences can also be attributed to the temperature difference used in each study.

CONCLUSIONS

The sweet potato landraces collected in the Yucatan state showed significant differences across the analyzed characteristics. Regarding physicochemical attributes, the sweet potato landraces exhibited a pH range from acidic to slightly neutral. Notably, three landraces (yellow sweet potato II, pink sweet potato, and yellow sweet potato) achieved the highest values for total soluble solids. This suggests a potential for better acceptance and preference due to their sweet taste. Significant variations were observed in color, both in the skin and flesh of the roots. Sweet potato landraces with lighter colors had high L* and b* values, while those with darker hues exhibited higher a* values in the root skin. Purple-fleshed landraces obtained negative b* values.

Six sweet potato landraces (pink, yellow, purple I, mamey, yellow II, and purple II) recorded the highest percentages in carbohydrates, fats, protein, fiber, and ash. Additionally, two landraces (mamey and pink sweet potato) demonstrated higher starch yield percentages. Overall, high luminosity values (L*) were observed, with purple II, yellow II and yellow sweet potato landraces displaying lighter shades compared to others. Swelling power and solubility index were higher at a temperature of 90 °C, among the sweet potato landraces. These results highlight the significance of sweet potato landraces cultivated in Yucatan as a valuable genetic resource, which can be included in the diet of people, genetic improvement and species conservation programs.

Author contribution

Conceptualization: R.H.A.N., N.P., H.H. Methodology: N.P., J.C.C.B., H.H. Formal analysis: H.H., N.P., J.C.C.B. Investigation: R.H.A.N., H.H., J.M.J. Resources: N.P., R.H.A.N. Writing-original draft: R.H.A.N., N.P., H.H., J.P.F., H.H. Writing-review & editing: R.H.A.N., H.H., J.P.F. All co-authors reviewed the final version and approved the manuscript before submission.

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