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Influence of Cooking Method on the *in Vitro* Digestibility of Starch from Sweet Potato Roots

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HIGHLIGHTS

- Sweet potato cooking promotes starch hydrolysis.
- Maltose will be formed from starch degradation during cooking.
- Cooking method affects the degree of starch hydrolysis.
- Microwave oven cooking resulted in limited starch hydrolysis.

Abstract: Sweet potatoes (SP) have gained attention in the media as foods recommended for healthy diets. When preparing the roots for consumption, however, cooking methods do alter their chemical, physical and nutritional properties. In order to assess the changes in carbohydrates of four SP accessions, after common cooking treatments (pressure cooker, convection oven and microwave oven), the contents of sugars and total starch, as well as the starch digestibility were evaluated. The pressure-cooked and convection oven-cooked samples showed high levels of both total reducing sugars (TRS) and soluble reducing sugars (SRS). Among the samples, white pulp sweet potatoes showed the highest starch contents. When cooked by microwave oven without adding water the roots had higher contents of resistant starch (RS). The results demonstrate deep transformations in the carbohydrate profile after cooking, with increase in maltose levels and consequent reduction in starch levels.

Keywords: *Ipomoea batatas*; microwave oven; resistant starch; maltose.

INTRODUCTION

Sweet potatoes (SP) have been valued as nutritional and healthy food options since a study that was carried out *in vivo* reported that the 'Beauregard' variety, when steam-cooked, oven-baked or microwave oven-cooked behaved as a moderate glycemic index (GI) food [1].

Starch is the main component of SP storage roots and its digestibility calls attention to the nutritional quality and healthy aspect of this tuber crop [2]. Studies upon *in vitro* digestibility of starch classify it as rapidly digestible (RDS), slowly digestible (SDS) and resistant starch (RS), depending on the extension of digestion as well as the time needed [3]. A diet including food with high amounts of RS as well as low GI starch associates with reduced risk of type 2 diabetes and cardiovascular diseases [4].

SP roots modify during thermal treatment, with important biochemical reactions that increase the contents of soluble sugars (SS), mostly maltose [5]. Previous studies on cooking of starchy roots showed that the enzymatic digestion of starch increases after its gelatinization and the RS level depends on the employed cooking method [6; 7]. In addition, the genetic variability, the field and post-harvest management, as well as the storage conditions can alter the physiology of the roots affecting the SS concentration [8; 9; 10; 11]. The alterations that take part by cooking SP roots can be checked with the *in vitro* starch digestibility analysis [4]. Various cooking methods modify the chemical composition of starch-rich sweet potato roots, rendering them more easily digestible [12].

In the present study the contents of SS as well as the starch digestibility (RDS, SDS and RS) after different cooking methods (pressurized cooking, convection oven-cooking and microwave oven-cooking) of four different sweet potatoes were analyzed.

MATERIAL AND METHODS

Four SP samples, two varieties (BRS *Rubissol* and BRS *Amélia*) and the other two bought in the local commerce (Ponta Grossa PR, Brazil), presenting different colors for peel and pulp were studied (Table 1). The two first are part of a project from the Agriculture Mechanization Laboratory from the State University of Ponta Grossa (LAMA/UEPG) and were cultivated in an agroecological approach (2018/2019 harvest) [13]. The vines were planted by December 23, 2018 and the roots were harvested on April 21, 2019 after 120 d cultivation.

Table 1. SP samples used in this study.

Identification	Accession	Peel color	Pulp color
SP 14	*Commercial 1*	White	white
SP 18	*BRS Rubissol*	Purple	white
SP 21	*BRS Amélia*	Rose	light orange
SP 22	*Commercial 2*	Purple	purple

The enzymes Pancreatin from porcine pancreas (E.C. 3.2.1.1, 8 × USP specifications, P7545), Amyloglucosidase from *Aspergillus niger* (E.C. 3.2.1.3, A7095, ≥ 260 IU /mL) and Invertase (E.C 3.2.1.26 ≥ 300 IU/mg) were from Sigma-Aldrich (St. Louis, USA); another Invertase (2000 SU) was from Novozymes (Araucaria, Brazil); Total Starch Enzymatic Kit K-TSTA (AA/ AMG) and D-Glucose Assay Kit (GOPOD Format) were both from Megazyme (Wicklow, Ireland); guar gum was from Sigma-Aldrich (St. Louis, USA). Commercial grade cassava starch was bought in the local market. All other reagents were of analytical grade.

Cure of the SP Roots

The roots were washed with tap water and sanitized with sodium hypochlorite solution (200 ppm). After that, the cure step was started in a BOD incubator (Tecnal, Piracicaba, Brazil), at 30 °C and 80 % relative humidity for 7 d [13; 14]. The analyses were made with five units (roots) for each accession, weighing between 70 and 220 g each. The peeled roots and cut into pieces (1 cm x 5 cm/French fries shape), and 30 g portions were stored refrigerated until analyzed.

Amylase Activity Testing

Amylase activity was tested after grating and processing the roots in a blender with phosphate buffer (pH 7.0, 0.1 mM) at 4°C [15; 16; 17; 18; 19]. A 20 g grated root was processed in a blender with the buffer in 1:2 (w/v) proportion. After that, the suspension was mechanically stirred (15 min at 750 rpm) at 4 °C; the soluble supernatant was recovered by centrifugation (3,000 × g / 10 min) and stored refrigerated until use.

Cassava starch was used as the substrate for testing the amylolytic activity. A 1 % (w/v) starch suspension (pH 6.0, 100 mM citrate-phosphate buffer) was gelatinized in a boiling water bath for 20 min. The hydrolysis was carried out after pipetting 0.5 mL of the gelatinized starch suspension into a centrifuge tube that was put in a 40 °C water bath and adding 0.5 mL of the above-mentioned solution containing enzymatic activity (40°C for 30 min). At the end of this period, the reaction was stopped by adding 1 mL of 0.1 mM NaOH. The reducing sugars (RS) were analyzed by the Somogyi-Nelson method, adapted to the microplate

reader. A calibration curve was built with maltose (2.92×10^{-1} to 5.84×10^{-1} mM) [20]. One unit of enzymatic activity was defined as the amount of extract able to produce 1 mmol of maltose per min under the described reaction conditions [18].

Cooking Methods

a) Pressurized cooking: small pieces (1 x 5 cm) of sweet potatoes (30 g) were put inside a domestic pressure cooker with 3: 1 (v / m) (water: root pieces) heated up to water boiling and then cooked for additional 2 min under pressure, making a 17 min total cooking time. After that the samples were drained and smashed with a fork forming a puree that was stored until analyzed.

b) Convection oven cooking: small pieces (1 x 5 cm) of sweet potatoes (30 g) were packed in aluminum foil and put inside a preheated domestic gas oven (200 °C for 20 min). After that the samples were smashed with a fork forming a puree that was stored until analyzed.

c) Microwave oven cooking: small pieces (1 x 5 cm) of sweet potatoes (30 g) were cooked inside proper plastic bags in the microwave oven (Electrolux, São Carlos, Brazil) at maximum power for 2 min. After that the samples were smashed with a fork forming a puree that was stored until analyzed.

d) SP flour: small pieces of roots (60 g) were dried in an electric air-circulating oven (Tecnal - TE 394/1, Piracicaba, Brazil) at 45 °C for 24 h. After that, the dried material was grinded in a rotor laboratory mill (Tec Mill TE-633, Tecnal, Piracicaba, Brazil); the produced flour was sieved (80 mesh) and stored in hermetic glass flasks until analyzed. This SP flour was considered a control (uncooked) for all the analyses.

Color

The color of the SP pulp before and after cooking processes was measured by using a portable colorimeter (Mini Scan EZ, Hunter Lab, Reston VA, EUA). The color parameters (L*, a* and b*) were read and the chrome value (C*) was calculated (Eq. 1); the color difference (ΔE) between uncooked (index 0) and after cooking (index 1) was calculated (Eq. 2) as well as the Hue angle (h°) (Eq. 3) [21; 22].

$$C^* = (a^*2 + b^*2)^{1/2} \quad (1)$$

$$\Delta E = ((L1^* - L0^*)^2 + (a1^* - a0^*)^2 + (b1^* - b0^*)^2)^{1/2} \quad (2)$$

$$H° = \tan^{-1}(b^*/a^*) \quad (3)$$

Moisture

The moisture of the uncooked and cooked roots was determined by drying in a laboratory oven at 45 °C for 6 h followed by additional drying at 105 °C until constant weight [22]. The absorbed or lost moisture was calculated from the difference of the respective contents [24; 9].

Extraction and Quantification of Soluble Sugars (SS)

SS were extracted both from the raw and cooked sweet potatoes as described in previous studies [23; 9; 24] with modifications. The moist puree was weighed (2 g) into 50 mL Falcon tubes. Ethanol (5 mL) at 80 % (v/v) was added, the tube was vortexed and then heated in a water bath at 80 °C for 15 min. An additional 5 mL ethanol (80 %, v/v) was pipetted, and the tube was vortexed; the suspension was centrifuged (3,000 × *g* for 15 min). The supernatant fraction was collected in a 25 mL-volumetric flask. This procedure was repeated once again with addition of 10 mL of ethanol 80 % (v/v), recovering the supernatant in the same way. At the end the volume of the supernatant containing SS was adjusted to 25 mL with deionized water. This extract was used for quantification of soluble reducing sugars (SRS) and glucose.

The amounts of SRS and total reducing sugars (TRS) were analyzed by the Somogyi-Nelson method [25], adapted to the microplate reader [20]. Calibration curves were built with glucose ($1.39\ 10^{-1}$ to $5.55\ 10^{-1}$ mM) and maltose ($2.92\ 10^{-1}$ to $5.84\ 10^{-1}$ mM) and reading was performed in a Biotek Epoch microplate reader (Agilent, Santa Clara, USA) at 510 nm. TRS were quantified after the hydrolysis by invertase (E.C 3.2.1.26, 20000 SU – Novozymes, Araucaria, Brazil). The results were expressed in percentage of sugar per gram of the sample (dry basis). The moisture of each cooking process was taken into consideration for the dry basis calculation.

Total Starch (TS)

TS contents of the dried sweet potatoes and of the cooked roots were analyzed in the pellet from the soluble sugar extraction process. The residues were hydrolyzed using the Megazyme enzymatic kit for total starch determination [29], following the AOAC method 996.11 [22] and glucose quantification was made with the GOD reagent at a microplate reader (510 nm). The results were expressed as the percentage of starch per gram of sample (dry basis). In the case of *in natura* SP, total starch content was expressed in a moist basis. The amount of starch that was converted to SS during the cooking methods was calculated by the Eq. 4 [25].

$$\% \text{ Starch} = [\% \text{ starch}_{(control)} - \% \text{ starch}_{(cooked)}] / \% \text{ starch}_{(control)} \quad (4)$$

In Vitro Digestibility of Starch

In vitro starch digestibility was assessed following Englyst and coauthors [29] method and Kingman and Englyst [6] procedure. A 1 g sample (moist basis) was mixed with guar gum, glass pearls, and pH 5.2 acetate buffer. After temperature stabilization, an enzymatic solution was added, and aliquots were collected at different time points (0, 20, and 120 minutes) for glucose analysis. Glucose quantification was done using the GOPOD reactant, and total glucose was determined based on the control sample (SP flour) results. The glucose values (G0, G20, G120 and TG) were considered for calculating the total starch (TS), rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) (Eq. 5 to 8).

$$TS = (TG) \times 0.9 \quad (5)$$

$$RDS = (G20 - G0) \times 0.9 \quad (6)$$

$$SDS = (G120 - G20) \times 0.9 \quad (7)$$

$$RS = (GT - G120) \times 0.9 \quad (8)$$

Statistical Analysis

The experiment used a completely randomized design with four SP accessions and three cooking treatments. SS extraction was done in duplicates, and colorimetric readings were performed in triplicates. Results were expressed as mean ± standard deviation. The interaction between SP accessions and cooking treatments was assessed using a factorial ANOVA with Tukey test applied for significant differences ($p < 0.05$). The statistical analysis was conducted using Action Stat-Pro software (Statcamp, Brazil, 2016).

RESULTS AND DISCUSSION

Color Analysis

This analysis evaluates SP pulp color behavior with different cooking methods. L*, a*, b*, C*, Hº and color difference (ΔE) values were obtained. The visual aspect of the sweet potatoes can be observed in Figure 1.

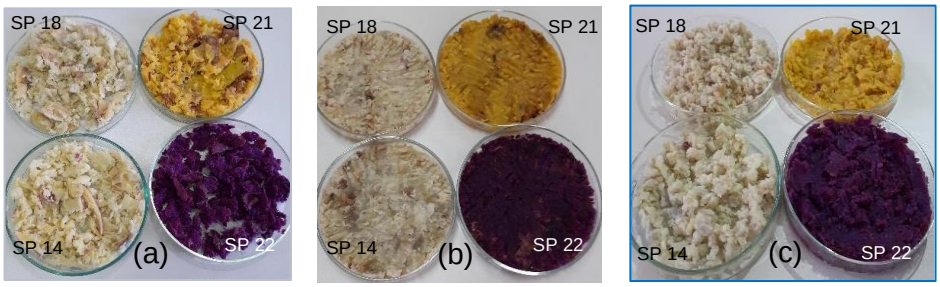

Figure 1. The visual appearance of cooked sweet potatoes: (a) pressure cooker, (b) convection oven, and (c) microwave oven.

Among the sweet potatoes, SP18 (uncooked) had the highest L* value (L* = 83.19), while SP22 (cooked in the microwave oven) had the lowest (L* = 1.44). This indicates that sweet potatoes with white pulp had the highest L* values, while colored sweet potatoes had the lowest L* values, both uncooked and cooked [8].

Cultivar SP14 (white peel and pulp) showed no difference in L* value between uncooked and cooked in a pressure cooker and convection oven. However, other samples' pulp colors differed when comparing raw

and cooked roots. For a* value, SP14 and SP18 (both white pulps) displayed a greenish color after cooking. SP18 showed no difference in this parameter when cooked in a microwave oven compared to its raw state. SP14, SP18, and SP21 exhibited elevated yellow color (b*) with a tendency to brown after cooking, unlike their raw counterparts. Hou and coauthors [8] also observed increased b* values in orange-flesh sweet potatoes due to non-enzymatic browning (Maillard reaction) during oven-cooking at high temperatures.

Initially, the purple-flesh SP22 sample showed a negative b* value, indicating a tendency towards a blue color. Surprisingly, after microwave oven cooking, the b* value changed to positive, unlike with other cooking methods. Lan Phan and coauthors [30] explain that purple-flesh sweet potatoes contain cyanidin and peonidin anthocyanins, responsible for red and blue colors, respectively. The change in the b* value suggests possible anthocyanin degradation during microwave cooking of SP22.

After cooking, chrome values increased for SP14 and SP21, irrespective of the cooking method. SP18 showed increased chrome value only with microwave-oven cooking, while SP22 exhibited this behavior with pressure cooker use. The hue angle (h°) for SP14 and SP22 shifted by 180° after cooking, with SP14 changing quadrants between cooked and uncooked samples. In SP22, this change was observed only with microwave cooking, in line with findings in purple-flesh SP [31].

After cooking, all sweet potatoes displayed a significant difference ($p < 0.05$) in color (ΔE). Previous studies by Tang and coauthors [12] examined color changes in SP flours based on different thermal treatments, considering temperatures and cooking periods. Additionally, Xu [32] investigated colored sweet potatoes cooked using various methods, attributing color changes to reduced levels of naturally occurring phenolic compounds, carotenoids, and anthocyanins.

Moisture

Table 2 shows moisture contents of cooked samples, with significant differences ($p < 0.05$). Uncooked roots' moisture content ranged from 50% to 71% for SP22 (purple flesh) and SP21 (orange flesh), respectively. Orange flesh sweet potatoes generally have the highest moisture content, as consistent with literature [33].

Table 2. Moisture contents of sweet potatoes (*in natura* and after thermal treatments).

Sample	Treatment	Moisture (%)	Δ M (%) *
SP14	*In natura* (roots)	60.87 ± 1.01 ^{g}	-
	Control (flour)	12.46 ± 0.3 ^{l}	79.52 ± 0.04 ^{c}
	Pressure-cooker	68.24 ± 0.74 ^{d}	-12.11 ± 1.22 ^{j}
	Convection oven	53.41 ± 0.40 ^{h}	12.25 ± 0.66 ^{f}
	Microwave oven	47.76 ± 0.81 ^{k}	21.54 ± 1.33 ^{e}
SP18	*In natura*	65.52 ± 0.11 ^{e}	-
	Control	11.38 ± 0.03 ^{lm}	82.64 ± 0.04 ^{ab}
	Pressure-cooker	72.32 ± 0.76 ^{c}	-10.38 ± 1.16 ^{j}
	Convection oven	63.88 ± 0.26 ^{ef}	2.50 ± 0.39 ^{h}
	Microwave oven	51.13 ± 0.30 ^{ij}	21.95 ± 0.46 ^{e}
SP21	*In natura*	71.28 ± 1.29 ^{c}	-
	Control	11.03 ± 0.02 ^{lm}	84.52 ± 0.02 ^{a}
	Pressure-cooker	74.86 ± 1.25 ^{b}	-5.02 ± 1.75 ^{i}
	Convection oven	49.97 ± 0.04 ^{jk}	29.90 ± 0.06 ^{d}
	Microwave oven	61.56 ± 0.59 ^{fg}	13.65 ± 0.83 ^{f}
SP22	*In natura*	51.35 ± 1.91 ^{ij}	-
	Control	9.47 ± 0.03 ^{m}	81.55 ± 0.05 ^{bc}
	Pressure-cooker	77.69 ± 0.60^{a}	-51.29 ± 1.17 ^{k}
	Convection oven	50.51 ± 0.58^{i}	1.64 ± 1.13 ^{h}
	Microwave oven	48.28 ± 0.35^{j}	5.98 ± 0.68 ^{g}

Note: * Negative value indicates water absorption during cooking. Small superscript letters in the same column indicate significant differences ($p \leq 0.05$) by the Tukey test.

The pressure cooker speeds up cooking but may extract soluble solids (sugar and color pigments) [34], leading to water absorption by the roots. Absorption levels varied from 5% to 51% (SP21 and SP22, respectively), corresponding to raw roots with the highest and lowest moisture contents.

Convection oven cooking resulted in water loss, ranging from 1.64% to 29.9% (SP22 and SP21, respectively), despite using aluminum foil wrapping. Previous studies on oven-cooked SP showed losses of 21.38% and 12% for orange and purple pulp varieties, respectively [23; 30]. This method involves indirect convection cooking through hot air contact with the food surface [8].

Microwave oven cooking heats food faster from the inside out [35]. In our study, small pieces of purple-flesh sweet potatoes (SP22) lost 6% of their weight, while no significant difference in moisture loss was observed for SP14 and SP18 during microwave cooking. Chen and coauthors [36] attributed water loss to mass transfer and moisture content during microwave cooking, reporting an 8% moisture loss in purple-fleshed sweet potatoes compared to fresh roots.

TRS, SRS and glucose percentages are expressed as reducing sugar and as glucose (m/m, dry basis) (Table 3).

Table 3. Sugar percentages of four SP accessions after thermal treatments: dried flour (control), pressure-cooked, convection oven-cooked, and microwave oven-cooked.

Sample	Treatment	TRS (%) *		SRS (%)		Glucose (%)	
SP14	Control	11.97 ± 0.60	j	2.86 ± 0.34	ef	0.59 ± 0.05	fg
	Pressure cooker	32.38 ± 5.00	bcde	18.85 ± 2.49	b	3.25 ± 0.58	bc
	Conventional oven	31.56 ± 3.37	cde	22.32 ± 1.78	a	1.78 ± 0.26	d
	Microwave oven	19.54 ± 5.45	ghi	4.09 ± 0.69	e	1.40 ± 0.17	de
SP18	Control	14.62 ± 1.20	ij	0.75 ± 0.06	f	0.18 ± 0.01	g
	Pressure cooker	38.96 ± 2.40	b	10.55 ± 1.65	cd	1.45 ± 0.45	de
	Conventional oven	25.74 ± 3.02	efgh	13.52 ± 1.82	c	0.90 ± 0.09	ef
	Microwave oven	25.95 ± 4.88	efg	2.72 ± 0.45	ef	0.60 ± 0.07	fg
SP21	Control	23.16 ± 0.52	fgh	11.97 ± 0.19	c	2.72 ± 0.25	c
	Pressure cooker	48.90 ± 4.15	a	23.53 ± 1.65	a	4.22 ± 0.56	a
	Conventional oven	30.33 ± 0.93	de	18.20 ± 0.44	b	1.53 ± 0.16	de
	Microwave oven	34.95 ± 4.96	bcd	11.94 ± 1.78	c	3.83 ± 0.64	ab
SP22	Control	19.08 ± 1.23	hi	4.18 ± 0.17	e	0.62 ± 0.07	fg
	Pressure cooker	37.86 ± 2.84	bc	17.36 ± 2.07	b	1.67 ± 0.22	d
	Conventional oven	20.28 ± 3.10	fghi	12.11 ± 2.29	c	1.30 ± 0.10	de
	Microwave oven	26.38 ± 1.29	ef	7.87 ± 1.84	d	1.91 ± 0.21	d

Note: Data shown as mean ± SD (n=6). Different superscript capital letters in the same column indicate statistical differences ($p \leq 0.05$) by the Tukey test. *Sum of glucose, sucrose and maltose

The sugar composition varied significantly among the four sweet potatoes studied, and it also changed after cooking the roots, in line with previous research [8;9;37; 25; 38]. SP21 (orange fleshed) had the highest sugar content in its raw state, and this remained true after pressure-cooking. In contrast, SP18 (white pulp and purple peel) had the lowest sugar content when cooked using a microwave oven. Overall, pressure-cooked sweet potatoes exhibited the highest sugar contents, while microwave cooking resulted in the lowest sugar values (SRS) for all samples, including SP21 and SP22 (orange pulp and purple pulp, respectively).

Wei and coauthors [26] reported varying sugar contents based on the flesh color of sweet potatoes, with orange-fleshed varieties having higher sugar levels than purple-fleshed ones. The literature documents the presence of sucrose, glucose, and fructose in raw sweet potato roots. Maltose, however, is typically reported only in cooked roots [9; 37; 39; 10; 25; 38]. According to Lai and coauthors [9], sucrose represents 49% to 92% of total sugars in raw roots, while after cooking, maltose constitutes 50% of the total sugars.

SP sticks quickly cooked in a microwave oven may leave raw starch partially uncooked [40]. In contrast, cooking whole sweet potato roots leads to more extensive starch hydrolysis with the formation of dextrins and maltose. The increase in maltose occurs in two steps [5; 41]: the first involves starch gelatinization and α-amylase activity, followed by the action of β-amylase at temperatures between 60 and 70 °C.

The moisture contents of the sweet potatoes in our study might have influenced the results, as starch gelatinization relies on sufficient water presence for completion [42]. The moisture level of the samples and starch hydrolysis are directly related to the sugars present in cooked sweet potatoes. Conversely, higher raw starch and greater water loss through evaporation lead to lower sugar contents in the cooked SP roots.

Pressure-cooking significantly increased sugar contents for all samples compared to their uncooked counterparts. Moisture content plays a crucial role in starch gelatinization. The slower cooking process with gradual temperature rise and cooking time might have contributed to higher starch hydrolysis levels [24;8; 37]. Both pressure-cooking and convection-oven cooking promoted the increase of SS ($p \leq 0.05$) in all samples, consistent with previous studies [8; 38].

In our study, glucose content increased in all samples compared to the raw roots, with the highest increase observed for SP18 when pressure cooked (+705%). However, no difference in glucose level was detected for SP22, similar to the findings reported by Chan and coauthors [25] for sweet potatoes. The sugar content after cooking generally depends on the sweet potato variety and the cooking method [43; 24].

Our results indicate that microwave cooking resulted in the lowest sugar levels, while pressure cooking led to the highest starch conversion (increase in maltose/soluble reducing sugar). Convection oven-cooking (40 - 50 min) also showed a high degree of starch conversion (high levels of TRS/SRS), consistent with a previous report [34].

Total Starch

Starch comprises the main portion of SP dry matter [43; 44; 45; 46], while protein content accounts for 2 - 5%. A significant portion of these root proteins consists of amylolytic enzymes (α- and β-amylases), with β-amylases making up about 5% of the soluble proteins in fresh SP roots [47; 18].

Table 4 presents the TS contents measured in the different accessions from our study, including uncooked in natura samples and those after cooking procedures. It also provides information on dry matter and the starch conversion to reducing sugars.

Table 4. Total starch (% m/m, dry basis), starch conversion to reducing sugars (% m/m) and dry matter (% m/m) for the four SP accessions and cooking methods.

Sample	Treatment	Dry matter (%)				Total starch (% db) *				Starch conversion (%)			
SP14	*In natura**	39.13	±	1.01	g	31.80	±	0.89	A		-		
	Control	87.54	±	0.21	b	81.27	±	2.27	a		-		
	Pressure cooking	31.76	±	0.74	j	41.91	±	0.87	e	48.42	±	1.07	bc
	Convection oven	46.59	±	0.40	f	47.64	±	2.39	cde	41.38	±	3.61	cde
	Microwave oven	52.24	±	0.81	c	54.90	±	1.55	c	32.45	±	1.90	e
SP18	*In natura**	34.48	±	0.11	i	28.00	±	0.85	B		-		
	Control	88.62	±	0.03	ab	81.19	±	2.46	a		-		
	Pressure cooking	27.68	±	0.76	k	50.71	±	2.77	cd	37.55	±	3.41	cde
	Convection oven	36.12	±	0.26	hi	65.54	±	0.98	b	19.27	±	1.21	f
	Microwave oven	48.87	±	0.30	de	44.55	±	3.57	de	45.13	±	4.40	cd
SP21	*In natura**	28.72	±	1.29	k	18.86	±	0.26	C		-		
	Control	88.97	±	0.20	ab	65.68	±	0.92	b		-		
	Pressure cooking	25.14	±	1.25	l	41.18	±	0.67	e	37.31	±	1.76	cde
	Convection oven	50.03	±	0.04	cd	45.26	±	4.31	de	31.10	±	6.57	ef
	Microwave oven	38.44	±	0.59	gh	44.79	±	1.81	de	31.81	±	2.76	e
SP22	*In natura**	48.65	±	1.91	de	34.08	±	0.28	A		-		
	Control	90.53	±	0.37	a	70.05	±	0.58	b		-		
	Pressure cooking	22.31	±	0.60	m	27.77	±	1.44	fc	60.36	±	2.06	Ab
	Convection oven	49.49	±	0.58	d	25.30	±	1.63	f	63.89	±	2.32	A
	Microwave oven	51.72	±	0.35	e	46.22	±	0.98	de	34.03	±	1.40	De

Note: *Total starch values of the *in natura* samples are shown in wet basis. Different superscript low letters in the same column indicate statistical difference ($p \leq 0,05$) by the Tukey test.

In Table 5 the results of amylase activity of SP extracts are shown. One unit of enzymatic activity (U) was defined as the capacity of the extract to hydrolyze a 1 % (m/m) cassava starch dispersion (pH 6.0) at 40 °C /30 min, with soluble reducing sugar formation. The soluble reducing sugar was measured as maltose equivalent (1 U means 1 mmol of maltose per min per g of SP, in wet basis).

Table 5. Amylase activity of *in natura* SP roots.

Sample	Amylase activity U (mmol/min)/g (wb)
SP14	3.68 ± 0.08b
SP18	3.02 ± 0.15b
SP21	2.90 ± 0.13b
SP22	10.00 ± 0.11a

Note: Different superscript low letters in the same column indicate statistical difference ($p < 0.05$) by the Tukey test; wb: wet basis

The total starch contents (wet basis) of the two commercial samples *in natura* were 18.8% and 34.1% for SP21 and SP22, respectively, representing 63.08% (SP21) and 68.29% (SP22) on a dry basis (SP flour). Therefore, on a dry weight basis, there was no significant difference between samples SP21 (orange flesh) and SP22 (purple flesh), as well as between samples SP14 and SP18 (white flesh). In China, SP varieties

have been reported to have total starch contents in the range of 53-63% (dry basis), while sweet potatoes cultivated in Turkey showed values from 49-65% for total starch (dry basis) [45; 44].

After cooking the roots, a decrease in total starch contents was observed. Sample SP22 *in natura*, after being cooked using a convection oven or a microwave oven, exhibited starch contents of 70.05% (db), 25.30% (db), and 46.22% (db), respectively, representing a reduction of roughly 30-60%. The decrease in starch contents after cooking sweet potatoes has been previously reported [44; 45; 48], and the time/temperature relationship influences the conversion degree. Starch conversion is favored by its gelatinization, promoted by the presence of water and the required temperature rise [44]. Hydrogen bonds relax, creating space for water/enzyme solution [7] particularly β-amylases, which catalyze the conversion of starch to maltose.

In our study, only pressure cooking involved the addition of water. The results demonstrated a decrease in starch contents ranging from 20% to 60%, and SRS increased from approximately twice (SP21) up to 1,400 times (SP18) for this thermal treatment. The highest amylase activity corresponded to the highest value of starch conversion (Tables 4 and 5). As a consequence, more starch presence led to higher amylolytic activity and, consequently, the formation of maltose during cooking.

SP22 had the highest amylase activity and exhibited the greatest starch degradation level among all the tested cooking methods, while the other three accessions did not show significant differences in amylase activity. Additionally, the decreases in TS content after cooking were lower for samples SP14, SP18, and SP21 compared to SP22.

The level of β-amylase was found to be dependent and influenced the starch degradation level [49] and sweetness of the cooked roots [25]. Sweet potatoes with low starch contents and low β-amylase levels hardly changed the starch percentage after steam-cooking and did not show detectable pulp texture changes.

The accessions in our study exhibited different behaviors regarding their rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) levels across various cooking methods (control/uncooked, pressure-cooked, convection-oven cooked, and microwave oven cooked) (Table 6).

Table 6. RDS, SDS and RS contents of SP roots after cooking by different methods.

Sample	Treatment	RDS (%)				SDS (%)				RS (%)			
SP14	Control	10.01	±	3.75	l	13.82	±	5.12	e	76.17	±	5.28	a
	Pressure cooking	51.64	±	10.66	bc	18.76	±	7.42	cde	29.59	±	3.76	ef
	Convection oven	45.39	±	2.10	cd	24.42	±	9.02	bc	30.20	±	8.26	ef
	Microwave oven	20.89	±	2.52	fgh	33.47	±	1.94	a	45.64	±	3.00	cd
SP18	Control	12.67	±	2.74	hi	15.31	±	2.68	de	72.03	±	2.08	a
	Pressure cooking	25.27	±	3.09	fg	19.77	±	4.02	bcde	54.96	±	3.71	bc
	Convection oven	60.61	±	7.69	ab	14.52	±	2.09	de	24.87	±	9.45	f
	Microwave oven	35.60	±	5.63	de	14.40	±	3.44	de	50.00	±	4.42	bc
SP21	Control	8.23	±	2.29	l	22.77	±	5.36	bcd	69.00	±	4.69	a
	Pressure cooking	36.21	±	3.58	de	16.44	±	2.80	cde	47.35	±	5.31	bc
	Convection oven	15.22	±	3.38	hi	27.49	±	2.24	ab	57.29	±	2.72	b
	Microwave oven	30.54	±	5.95	ef	33.47	±	1.73	a	35.99	±	5.93	de
SP22	Control	16.45	±	2.98	ghi	15.19	±	2.69	de	68.36	±	5.53	a
	Pressure cooking	58.09	±	4.20	ab	12.68	±	3.87	e	29.22	±	3.6.	ef
	Convection oven	64.16	±	5.02	A	13.37	±	1.93	e	22.47	±	4.14	f
	Microwave oven	30.54	±	5.95	abc	33.47	±	1.73	e	35.99	±	5.93	ef

Note: Different superscript low letters in the same column indicate statistical difference ($p \leq 0.05$) by the Tukey test.

The *in vitro* digestibility of starch showed significant differences among the different accessions. Our findings align with previous data [50]. SP flours (control) exhibited high levels of RS, ranging from 68.36% to 76.17% in samples SP22 and SP14, respectively. These results are consistent with a previous study [3], which reported RDS between 6% and 8%, SDS from 10% to 16%, and RS from 77% to 80% for SP flours from China analyzed without cooking.

In addition to the genetic effect, the cooking methods also influenced the variation of the digestibility profile. The highest RDS percentage was observed in SP22 after convection oven cooking. Conversely, the highest levels of SDS were found in SP14 and SP21 after microwave oven cooking. As for RS, the highest concentration was found in SP21 cooked in the convection oven. Our results have revealed opposite profiles for the same cooking treatment. Convection oven cooking promoted the highest level of RDS for SP22 (purple-fleshed), whereas it led to the highest RS percentage for SP21 (orange-fleshed). Microwave oven cooking was linked to higher SDS and RS percentages for all the accessions. Pressure cooking resulted in increased RS for SP18 and SP21, while convection oven cooking was associated with increased RS in SP21.

SP21 was the only variety with RS values higher than RDS and SDS in all cooking treatments. It is an orange-fleshed variety, similar to 'Beauregard,' the most popular variety of this color, which has been extensively studied for its glycemic index [1; 51; 11].

Despite the effects of cooking methods on SP accessions, RS was reduced in all cases compared to the uncooked control samples (SP flour). Xu and coauthors [38] reported a decrease in RS contents in freeze-dried flours of purple-fleshed sweet potatoes after being cooked by microwave oven and steam cooked.

Cui and Zhu [52] analyzed the amounts of RDS, SDS, and RS in SP flours and found significant differences between the studied varieties. Gelatinized starch from the cooked flours showed higher percentages of RDS and lower levels of SDS and RS. The cooking method has a profound influence on the RS content, as demonstrated in fried sweet potato chips [53].

The higher RDS in the cooked samples was associated with starch conversion, SRS, TRS, and color (ΔE). In other words, the increase in RDS depended on all parameters that promoted an increase in free glucose. On the other hand, RS levels were positively influenced by factors opposite to RDS, such as ΔM, dry matter, total starch, amylase activity, enzymatic efficiency, and L*. These parameters were related to the starch content of the roots.

CONCLUSION

The cooking methods had varying effects on sweet potatoes. Microwave oven-cooked samples showed the least differences in TRS and SRS levels compared to the control, indicating that this method resulted in the lowest changes in sugar composition. When the convection oven method was used, TRS content in SP22 did not differ from the control. Pressure cooking led to high levels of TRS and SRS. White-fleshed sweet potatoes had higher starch contents compared to colored pulp samples. SP22 exhibited the highest enzymatic activity, while the other accessions did not differ significantly. In terms of the *in vitro* digestibility of starch from the cooked sweet potato samples, significant differences were observed in the values of RDS, SDS, and RS for all cooking methods and accessions studied. Within this current study, we have illustrated that utilizing a microwave oven is the most effective approach for attaining reduced starch digestibility and increased resistant starch (RS) content.

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