Agriculture and Food

AIMS Agriculture and Food, 10(3): 698–715.
DOI: 10.3934/agrfood.2025035
Received: 22 May 2025
Revised: 27 July 2025
Accepted: 03 September 2025
Published: 24 September 2025

https://www.aimspress.com/journal/agriculture

Research article

Effect of processing on functional properties, physicochemical characteristics and in vitro starch digestibility of two sweet potato varieties

Christian Villegas[1,*], Elena Villacrés[2], María Quelal[2] and María Morales[1]

[1] Technical University of Cotopaxi, P.O. Box 050103, Latacunga, Ecuador
[2] Department of Nutrition and Quality National Institute of Agricultural Research Mejía, INIAP, P.O. Box 17 0518, Mejía, Ecuador

* **Correspondence:** Email: christian.villegas1185@utc.edu.ec; Tel: +593988237726.

Abstract: This study investigates the effect of different processing methods (boiling, baking, and frying) on the functional properties, physicochemical characteristics and in vitro starch digestibility of two sweet potato varieties: Guayaco morado and Toquecita. Thermal processing affected the rate of starch digestion, focusing on parameters, such as total digestible starch (TDS), rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS), from which the hydrolytic index was determined and allowed estimation of the glycemic index (pGI) to be derived from sweet potato intake. Each cooking technique has a unique impact on sweet potatoes. For example, boiling maximizes starch gelatinization (improving digestibility) but leaches water soluble nutrients, baking develops desirable flavors and retains carotenoids, although high temperatures can form acrylamide and frying increases resistant starch which reduces glycemic impact, it also leads to decreased starch solubility and creates crisp textures but introduces excess calories and potential heat contaminants. Among the varieties studied, Toquecita exhibited higher TDS (73.75 ± 0.18 g/100 g dw) and RDS (31.21 ± 0.10 g/100 g dw) in boiled samples, while fried samples showed a higher RS content (9.83 ± 0.03) compared to Guayaco morado. This difference reflects Toquecita's lower amylose content and water absorption index. Both varieties exhibited a lower glycemic index (pGI) in the raw state. However, among the processed samples, the fried Guayaco morado variety displayed a lower pGI (64.15 ± 0.89). These results emphasize the significant impact of cooking methods on the nutritional profile of sweet potato starch. The findings suggest that boiling and baking are processes for enhancing starch digestibility, while frying may diminish it. Overall, this study highlights the potential of sweet potatoes as a functional food ingredient, particularly for diets with a moderate glycemic index.

Keywords: sweet potato; starch digestibility; glycemic index; resistant starch; digestible starch; gelatinization

1. Introduction

The sweet potato (*Ipomoea batatas*) is a root vegetable that, within the group of roots and tubers, ranks third in global importance, preceded by the potato and cassava [1]. Sweet potato is a globally consumed tuber crop renowned for its moderate nutritional value, including its rich content of carbohydrates, vitamins, and dietary fiber. Beyond carbohydrates, sweet potatoes are rich in functional active ingredients that contribute to their nutraceutical properties.

These include dietary fiber (soluble and insoluble), which regulates digestion and moderates glycemic responses [2]; antioxidants such as β-carotene (provitamin A) in orange-fleshed varieties and anthocyanins (e.g., cyanidin and peonidin) in purple-fleshed types, which exhibit anti-inflammatory and free-radical-scavenging activities [3]; micronutrients, including vitamin C, B vitamins, potassium, and manganese, which support metabolic functions; phenolic compounds (e.g., chlorogenic acid) that influence starch digestibility and offer cardioprotective benefits [4]. These bioactive components interact with starch during processing, modulating its digestibility and nutritional impact. For instance, anthocyanins in purple-fleshed varieties (e.g., Guayaco morado) can inhibit digestive enzymes, while fiber forms matrices that slow starch hydrolysis[5].

Its adaptability to various climatic conditions and resistance to environmental stressors make it a viable crop for addressing food security challenges, particularly in the context of climate change [6][7]. The roots are particularly valued for their carbohydrate content, which constitutes 25–30% of its total composition, with 98% being easily digestible, making it a significant source of energy [8][9]. However, the digestibility of sweet potato starch, a key determinant of its nutritional value, can be significantly influenced by processing methods, such as boiling, baking, and frying. Understanding how these processes affect starch digestibility is crucial for optimizing the nutritional benefits of sweet potatoes, particularly in the development of functional foods with moderate glycemic index (pGI) properties.

Starch digestibility is a critical factor in human nutrition, as it directly impacts the rate at which glucose is released into the bloodstream, influencing postprandial glycemic responses [10]. The digestibility of starch is influenced by its structural composition, particularly the ratio of amylose to amylopectin [11]. Different starch fractions have been classified according to their digestibility in the small intestine, including rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) [12][13]. SDS and RS are not fully digested in the small intestine; they pass to be fermented in the colon. Many reviews have shown the positive health benefits of the SDS and RS [14]. The processing methods can also influence the composition and behavior of the starch. Thermal processing, such as boiling and baking, induces gelatinization, which disrupts the crystalline structure of starch granules, making them more accessible to digestive enzymes and thereby increasing digestibility [15]. Conversely, frying can lead to the formation of RS and other complex compounds that may reduce starch digestibility [16]. These changes in starch structure and digestibility have significant implications for human health, particularly for individuals managing diabetes or insulin resistance, as foods with lower pGI values are associated with slower glucose release and better glycemic control [17].

Management of carbohydrate quality and quantity in our daily foods is an effective way to slow

down the pandemic of diabetes around the world. The widely accepted method to categorize and rank carbohydrate quality and quantity in foods is represented by the concept of glycemic index (pGI) [18]. This value is an important factor determining the postprandial glycemic response of available carbohydrate in our daily foods. The pGI is used to classify dietary carbohydrates based on their impact on the blood glucose response after intake of starch or sugar rich meals. According to this definition, a diet with a lower pGI may result in slower rates of digestion and absorption, which may decrease the rapid rise in postprandial hyperglycemia and insulin concentration, as well as subsequently have an impact on the treatment of diabetes [19].The glycemic response of a food depends on factors such as its particle size, degree of processing, cooking method, starch structure and the number of food components (dietary fiber, protein, fat) present in it [20] .

Carbohydrate consumption has been continuously increasing during the last few decades, especially among developing countries from Latin America, Asia and Africa [18]. However, accumulating evidences have suggested that high consumption of carbohydrates is linked to the postprandial hyperglycemia and occurrence of type 2 diabetes [21]. Therefore, knowledge of starch digestibility on the nutritional characteristics of sweet potato and the current health benefits of RS and SDS, can help for reducing malnutrition linked to cardiometabolic diseases [22]. Consequently, this study determines functional properties, in vitro starch digestibility and the pGI of two sweet potato varieties as a helpful tool for nutritionists to make an appropriate healthy diet recommendation and as a basis for the development of foods with healthy properties.

2. Materials and methods

2.1. Materials

The Two varieties of sweet potato (Guayaco morado and Toquecita) were used in this study. The Guayaco morado variety comes from the National Germplasm Bank of INIAP, Ecuador. The shape of the tuberous root is long, irregular, or curved, with no surface defects; the skin thickness is medium (2–3 mm). The predominant skin color is pale purple with no secondary color. The predominant flesh color is pale purple, and the secondary color is white, which is distributed throughout most of the flesh. The Toquecita variety was introduced from the International Potato Center (CIP) in Peru, with the code CIP 440045 and under the collection number SPV55. The tuberous root has an elliptical shape and shows superficial horizontal constrictions. The predominant skin color is orange with medium intensity, and it does not show a secondary color. In the flesh, the predominant color is orange with medium intensity, while the secondary color is a more intense orange, distributed in thin rings near the skin [23].

2.2. Samples Preparation

The two sweet potato varieties underwent three heat treatments, cooking, baking, and frying. Subsequently, they were dried and ground to obtain a representative sample. For each technique, 2 kg of peeled roots were used. Cooking was carried out with distilled water at 91°C for 40 minutes, complete gelatinization of the starch will be facilitated and water absorption in the granules will be increased, increasing access to digestive enzymes. Baking was performed at 180 °C for 90 min in an oven (Teka Hydroclean, Innova, Quito), This dry heat process promotes the Maillard reactions and

caramelization. The evaporation of moisture concentrates the solids, while the controlled heat soak partially gelatinizes the starch with limited water availability. For the frying process, the sweet potato was sliced into 1 mm thick slices, which were fried in 13 L of edible maize oil (The Favorita, Ecuador) at 120 ℃ for 18 min, in a vacuum fryer (Ckstaf55-013, Innova, Quito) equipped with a centrifuge [24]. Obtaining a crispy texture to the sweet potato and increasing resistant starch. For analysis, the two raw varieties were sliced and lyophilized in a machine (LABCONCO, Kansas, USA) at −0.8 bar pressure, then ground in an equipment (Retsch, Haan, Germany) to obtain a particle size of 100 mm and stored at 4 ℃ in airtight glass containers.

2.3. Functional properties

2.3.1. Water Absorption Index (WAI), Water Solubility Index (WSI), and Swelling Power (SP)

WAI, WSI, and SP of the raw and processed sweet potato flours were determined by the method of Anderson et al. [25]

2.5 g of ground sample was placed in a centrifuge tube with 30 mL of distilled water at 30 ℃. The samples were incubated in a Sybron Thermolyne shaking bath (Dubuque, Lowa, USA) for 30 min, then shaken in a Damon/IEC division centrifuge (Needham Hts., MA, USA) for 5 min. The supernatant was separated, placed in Petri dishes and dried for 4 hours at 90 ℃. [26] The gel weight was recorded. The results were expressed as the average of 3 observations. WAI and WSI were calculated using the following formulas [26].

$$\text{WAI}\left(\frac{\text{g}}{\text{g}}\right) = (\text{gel weight}/(\text{sample weight}) \text{ x } 100 \quad (1)$$

$$\text{WSI}\,(\%) = (\text{Soluble weight}\,(\text{g}) \times \text{V} \times 10/\text{Sample weight}) \quad (2)$$

$$\text{SP}\left(\frac{\text{g}}{\text{g}}\right) = (\text{Gel weight}/(\text{Sample weight}\,(\text{g})\ \text{bs} - \text{Soluble weight}\,(\text{g})) \quad (3)$$

2.4. Physical-chemical analysis of the two varieties of sweet potato

2.4.1. Determination of moisture

The moisture content of each raw sweet potato variety was determined using the AOAC 925.09 [27]. The previously prepared samples (dried and ground sweet potato) were centrifuged and placed in an oven at 50 ℃ for 30 minutes [28].

2.4.2. Amylose and amylopectin

The sample extract was prepared by dissolving 1 gram of previously obtained sweet potato sample in 100 mL of a 6 M urea dimethyl sulfoxide (DMSO) solution, with continuous stirring at room temperature (22 ℃) for 24 hours; from this urea/DMSO stock solution, a 1 mL aliquot was accurately measured and transferred to a 100 mL volumetric flask. Approximately 95 mL of distilled water was then added, shaking the flask after each addition to ensure a homogeneous mixture. Then, 2 mL of I_2-KI solution (2 mg I_2, 20 mg KI/mL) was added. Finally, the contents of the flask were made up to 100 mL

with distilled water. The absorbance of the solution was measured at 635 nm, 15 minutes after adding the I_2-KI reagent. The spectrophotometer was calibrated with water in the reference cell, using a blank of UDMSO-I_2-KI solution in the sample cell [29].

2.4.3. Reducing sugars

The quantification of reducing sugars was executed utilizing the 3,5-dinitrosalicylic acid (DNS) method as delineated by Dias et al. [30], albeit with certain modifications. This technique fundamentally relies on the interaction between the reducing sugar and DNS, which man- ifests a yellow hue that is subsequently converted into a reddish compound, specifically 3-amino, 5-nitrosalicylic acid, through the oxidation of the monosaccharide reducing agent. An aliquot measuring 500 μL of the sample, comprising 5 g of maize flour that was homogenized in a blender with 20 mL of distilled water, was combined with 500 μL of the DNS reagent solution, which consists of 10 g of 3,5-dinitrosalicylic acid, 2 g of phenol,0.5 g of sodium sulfite, and 10 g of sodium hydroxide, all diluted to a final volume of 1 L in distilled water. The resultant mixture was subjected to heating at a temperature of 100 ℃ for a duration of 5 minutes, followed by transfer to an ice bath for an additional 5 minutes [30].

Subsequently, an aliquot of 4 mL of a potassium sodium tartrate solution at 40% w/v concentration was incorporated to stabilize the resulting color. The absorbance of the solution was assessed at a wavelength of 540 nm. For the purposes of quantification, a calibration curve utilizing glucose was constructed with concentrations ranging from 0.1 to 1.0 g L^{-1} (r2 = 0.9977) [30].

2.4.4. Degree gelatinization

A mass of (0.2 g) of the sample was meticulously measured within a 50 mL beaker, followed by the addition of 25 mL of distilled water and 0.1 g of α-amylase (≥ 5 units/mg solid), ensuring thorough homogenization of the mixture. Subsequently, the beaker was positioned in a constant temperature water bath maintained at 39 ℃ for a duration of 1.5 hours. The enzymatic activity of amylase was terminated by the introduction of 1 mL of mol/L hydrochloric acid, after which the resultant mixture was transferred to a 50 mL volumetric flask, calibrated to volume with distilled water, and subsequently subjected to filtration through filter paper. A control was established utilizing distilled water to which the enzyme solution was incorporated. Following this, 1 mL of the diluted sample solution was introduced into a test tube, combined with 1.5 mL of DNS solution and 1 mL of distilled water, and then subjected to heating in a boiling water bath for a period of 5 minutes, after which it was promptly cooled to ambient temperature using cold water. Thereafter, 21.5 mL of distilled water was added to each tube, followed by vigorous agitation of the mixture. The absorbance was quantified at 540 nm, and this procedure was repeated thrice to derive an average value. The degrees of gelatinization (DG) were computed utilizing the following formula [16]:

$$\alpha = (\mathrm{A} - \mathrm{B})/\mathrm{C} \times 100 \tag{4}$$

where α signifies the degree of gelatinization, A denotes the reducing sugar content subsequent to the precooking phase, B represents the reducing sugar content prior to the precooking phase, and C indicates the reducing sugar content following complete pasting.[16].

2.4.5. Total (TDF), Insoluble (IDF), and Soluble dietary fiber (SDF)

The dietary fiber, including TDF, IDF, and SDF was analyzed using Megazyme K-TDFR kit by a Fibertec System 1023 (Foss Electric, Copenhagen, Denmark) according to AOAC Method 991.43 [31]

2.4.6. Total starch (TS)

The Soluble compounds of flour were removed along with the initial rinsing water, so starch was determined from the free samples of water-soluble solids [32]. Thermostable α- amylase hydrolyses starch into soluble branched and unbranched maltodextrins. Resistant starch in the sample was pre-dissolved by stirring the sample with 2M KOH at approx. 40 °C, followed by neutralization with sodium acetate buffer and hydrolysis with α-amylase [33]. Amyloglucosidase (AMG) quantitatively hydrolyzed maltodextrins to D-glucose. It was oxidized to D-gluconate with the release of one mole of hydrogen peroxide (H_2O_2) which was quantitatively measured in a colorimetric reaction employing peroxidase and the production of a quinoneimine dye (AACC, Official Method 76-11) [24].

2.5. Digestibility analysis:

The Starch digestibility was evaluated using the enzymatic assay kit (Resistant Starch Assay Kit), the starch fractions were classified as RDS, SDS, and RS [27].

2.5.1. The glycemic index (pGI)

The was calculated based on the hydrolysis rate of starch over 180 minutes, using the methodology described by Goñi et al. [34] The formula used was:

$$pIG = 8.198 + 0.862\,HI \tag{5}$$

2.5.2. Total digestible starch (TDS) and RS

The measurement of RS was determined using an enzymatic assay kit (Resistant Starch Assay Kit), sweet potato flour samples were incubated with a mixture of pancreatic α-amylase and amyloglucosidase in maleate buffer, pH 6.0, at 37 *o*C for up to 4 h with continual stirring [27].

Aliquots of the reaction solution were removed at 20 min to measure RDS, at 120 min to measure SDS; (starch value at 120 min-starch value at 20 min), and at 240 min to measure TDS and RS. For RDS, SDS, and TDS, 1.0 mL aliquots were removed while the suspension was stirred and transferred to 20 mL of 50 mM acetic acid (to terminate the reaction) [35].

These solutions were mixed thoroughly and 0.1 mL aliquots were incubated with 0.1 mL of amyloglucosidase AMG (100 U/mL) to hydrolyze the remaining traces of maltose to glucose which was measured with glucose oxidase plus peroxidase, GOPOD reagent.

A nonlinear model was used to describe the kinetics of starch hydrolysis and the first order equation was as following:

$$C = \mathrm{C}\infty(1 - \mathrm{e} - \mathrm{kt}) \tag{6}$$

where C (%) is the concentration at t (min), C∞ (%) is the equilibrium concentration, K is the kinetic constant and t is the time.

2.6. Statistical analysis

The All analyses were performed in triplicate; the results are given as the mean ± standard deviation. The data were analyzed by applying one-way ANOVA, using the INFOSTAT statistical software package [36], to compare the means concerning sweet potato varieties and the effect of cooking techniques on functional properties, physical-chemical characteristics and in vitro starch digestibility. Tukey's multiple range test was applied to determine significant differences at the 5% level.

3. Results and discussion

3.1. Functional properties

The effects of different processing methods (boiled, baked and fried) and raw roots on the WAI, WSI, and SP of the two sweet potato varieties (Guayaco morado and Toquecita) are presented in Table1. Significant differences ($p < 0.05$) were observed in the functional properties of the two sweet potato varieties.

3.1.1. WAI

For the Guayaco morado variety, baking resulted in the highest WAI (4.31 ± 0.06 g/100 g dw). This method generates the greatest alteration of the starch crystalline structure, releasing amylose and amylopectin and forming gelatinous networks, which maximizes water-holding capacity, followed by boiling (3.57 ± 0.02 g/100 g dw). While frying reduced water absorption capacity (3.23 ± 0.07 g/100 g dw) due to rapid dehydration and crust formation, in addition to oil penetration competing with water, reducing WAI. In contrast, the Toquecita variety exhibited higher WAI values overall, with baking showing the most significant increase (5.94 ± 0.20 g/g). These findings suggest that baking modifies the starch structure, improving its water retention capacity, which could be due to the disruption of crystalline regions and the formation of a starch gel network, which is consistent with previous studies on starch gelatinization by Roa Acosta et al.[37]. A study by Chang et al. [38] showed that heat treatments such as baking and boiling significantly improve the water solubility index (WSI) of starches by promoting molecular interactions with water molecules.

3.1.2. WSI

The WSI was maximized when baking in Guayaco Morado (25.68 ± 0.79 g/100 g dw). The process breaks the integrity of the granules, releasing soluble amylose/amylopectin chains and dramatically increasing solubility. Frying obtained the lowest WSI (8.60 ± 0.06 g/100 g dw) as it limits water penetration. The thermally processed Toquecita variety showed no significant differences in WSI between treatments, although all processed samples exceeded the values for raw roots. Notably, the highest WSI in Toquecita was observed in fried roots (14.64 ± 0.03 g/100 g dw). These results indicate that thermal processing improves starch solubility by disrupting granule integrity, releasing amylose and amylopectin chains, and increasing water accessibility [39]. In contrast, raw starch

granules maintain a compact crystalline structure that limits water penetration, thereby reducing solubility. This allows correlation between starch molecular structure and rheological behavior, guiding the development of ingredients with predictable functionalities [39].

3.1.3. SP

SP of starch is a measure of its ability to absorb water, swell, and change its structure during cooking or heat treatment [40]. This parameter was higher in the baked (15.40 g/g dw) and fried (14.64 g/g dw) Toquecita variety, possibly due to the higher amylopectin content in this variety, a compound that is more soluble in water and allows greater absorption [40]. Another factor that could have influenced in this result, is the granule size, according to Wei et al.[41], large starch granules (27–30 μm) have higher viscosity, which suggests a greater water absorption capacity, while smaller particles (14–16 μm) show lower viscosity. These findings are consistent with previous studies, which have shown that thermal processing can significantly alter the physicochemical properties of starch [15][42]. A study carried out by Shi et al. [43] emphasized that thermal treatments like baking and frying enhance SP by disrupting hydrogen bonds within starch granules, allowing for greater water uptake.

Table 1. Starch functional properties of two varieties of raw and processed sweet potato.

Parameter	Varieties							
	Guayaco Morado				Toquecita			
	Raw	Boiled	Baked	Fried	Raw	Boiled	Baked	Fried
WAI	3.43 ± 0.02^{cd}	3.57 ± 0.02^{c}	4.31 ± 0.06^{b}	3.23 ± 0.07^{d}	3.55 ± 0.01^{cd}	3.64 ± 0.01^{c}	5.94 ± 0.20^{a}	3.56 ± 0.06^{c}
WSI	14.10 ± 0.01^{c}	17.09 ± 0.01^{b}	25.68 ± 0.79^{a}	8.60 ± 0.06^{e}	10.22 ± 0.01^{d}	13.41 ± 0.01^{c}	13.86 ± 0.14^{c}	14.64 ± 0.68^{c}
SP	4.01 ± 0.01^{bc}	4.31 ± 0.01^{bc}	5.40 ± 0.58^{b}	3.21 ± 0.52^{c}	3.95 ± 0.01^{bc}	4.20 ± 0.01^{bc}	15.40 ± 0.91^{a}	14.64 ± 0.68^{a}

Different letters in the same row indicate significant differences ($p \leq 0.05$). WAI= Water Absorption Index, WSI = Water Solubility Index, Swelling Power = SP. *WAI, WSI and SP data are expressed as g/100 g dw.

3.2. Physicochemical characteristics

The physicochemical characteristics of two sweet potato varieties, including moisture content, TS, amylose, amylopectin, reducing sugars, degree of gelatinization, soluble fiber (FS), and insoluble fiber (FI), are presented in Table 2. Significant differences ($p \leq 0.05$) were observed in the above-mentioned parameters of the two sweet potato varieties.

3.2.1. Moisture Content

The moisture content was significantly higher in boiled samples for both varieties, with values of 14.35 g/100 g for Guayaco morado and 15.30 g/100 g for Toquecita. These contents are attributed to water absorption during the boiling process. In contrast, the frying process resulted in the lowest moisture content, with values of 11.60 g/100 g for Guayaco morado and 12.26 g/100 g for Toquecita, due to water evaporation during frying.

These results are consistent with previous studies carried out by Shi et al [44] who reported that the moisture content in boiled potato samples increased by 15% compared to raw samples, while fried samples showed a 20% reduction in moisture content. These findings suggest that the cooking method

has a significant impact on water retention in foods.

3.2.2. TS

Both varieties experienced variation in TS content due to the effect of thermal processing. In Guayaco Morado, TS increased with the boiled and baked processes, but decreased with the frying process. In this regard, [45] indicates that partial starch decomposition can occur due to the effect of high processing temperature or the cooking time is too long. The degradation of starch during thermal processing is a well-documented phenomenon. A study by Chen et al. [45] found that TS in corn samples decreased by 10–15% after frying, which is consistent with our findings. Additionally, prolonged heat exposure during frying can cause the breakdown of starch chains, resulting in a reduction in TS content. In Toquecita variety, TS increased with the boiling, baking and frying processes, which could be attributed to its chemical composition. These results highlight the importance of considering the cooking method when evaluating the nutritional content of foods.

3.2.3. Amylose and Amylopectin

Amylose content decreased significantly in both varieties after thermal processing; in Guayaco Morado, amylose decreased from 29.53 g/100 g in raw samples to 12.83 g/100 g dw in boiled samples. Toquecita variety showed the lowest amylose content in boiled samples (5.61 g/100 g dw). Amylopectin content showed an inverse trend to amylose. In Guayaco morado, amylopectin increased from 70.40 g/100 g dw in raw samples to 87.15 ± 0.04 g/100 g in boiled samples. The Toquecita variety showed similar behavior, with the highest amylopectin content in boiled samples (94.35 g/100 g dw).

The reduction in amylose content during boiling is consistent with the findings of [46], who reported that starch gelatinization under moist heat conditions leads to the release of amylose from starch granules, resulting in a less compact structure. The increase in amylopectin content during thermal processing aligns with the results of [47], who demonstrated that starch granule disruption during gelatinization enhances the availability of amylopectin for analytical detection. These findings suggest that thermal processing significantly alters the amylose to amylopectin ratio, which can impact the functional properties of starch, such as viscosity, gel formation and the quality of processed food products.

3.2.4. Reducing Sugars

Reducing sugars increased significantly ($p \leq 0.05$) with thermal processing, particularly in boiled and baked samples. For Guayaco morado, reducing sugars increased from 1.35 g/100 g in raw samples to 43.25 g/100 g in boiled samples. The Toquecita variety showed similar trends, with the highest reducing sugar content in baked samples (36.20 g/100 g). This increase could be due to enzymatic activity and the thermal decomposition of starch, leading to a higher sugar content. These results align with the studies of [48], who reported that boiling and baking promote the breakdown of starch into reducing sugars, while frying reduces the content of these compounds, due to caramelization [49], as observed in Guayaco Morado, that showed a low content of reducing sugars in the fried samples.

3.2.5. Gelatinization Degree (GD)

GD was highest in boiled and baked samples, reaching 96.75 % in boiled Guayaco morado and 94.97 % in baked Toquecita. This confirms that water and heat are essential for starch gelatinization. In fried samples, GD was significantly lower (12.86 %) in Guayaco morado, likely due to reduced water availability during frying.

These results are supported by research from Majzoobi et al. [50] who demonstrated that gelatinization is highly dependent on water availability and heat, with boiling and baking providing optimal conditions for starch granule disruption. Conversely, frying limits gelatinization due to the lack of sufficient water, as noted by Dehghannya et al. [51], who reported 15 % decrease in the degree of gelatinization of fried potato starch.

3.2.6. Soluble and Insoluble Fiber

SDF decreased slightly with thermal processing; For Guayaco morado, SDF decreased from 3.03 g/100 g dw in raw samples to 2.44 g/100 g dw in baked samples. Similar behavior was shown by Toquecita variety with SDF 2.04 g/100 g dw. This reduction may be due to direct decomposition, dissolution in water or chemical alterations caused by the thermal processing of sweet potato. Heat can break down the structures of soluble fibers, such as hemicellulose and pectin's, which are sensitive to heat. These soluble fibers disintegrate or are transformed into simpler compounds under elevated temperatures, which reduces their amount in the final sweet potato [52].

IDF exhibited slight changes with the heat treatments, in Guayaco Morado IDF varied between 10.51 g/100 g dw in raw samples to 12.03 g/100 g dw in baked samples, while in Toquecita variety, FDI increased 22.59 % with respect to raw sweet potato, indicating that IDF may undergo variations in its structure and content depending on the type of heat treatment and specific conditions of moisture. In general, IDF tended to be more stable during heat processing. These results are consistent with studies by Li et al. [53], who found that SDF is more sensitive to heat, while IDF remains stable due to its structural integrity[54][52].

3.2.7. TDF

The TDF varied significantly ($p \leq 0.05$) between varieties and heat treatments. TDF in Guayaco Morado varied from 5 g/100 g dw in raw roots to 12 g/100 g dw in fried roots. TDF in Toquecita varied from 7.69 % in boiled roots to 23 % in fried roots. The change of TDF in roots depends on several factors, including both intrinsic characteristics of the sweet potato itself, growing and processing conditions. Some of the most relevant factors are cooking, boiling or frying. In this research, it was shown that heat affects the amount and composition of dietary fiber, especially soluble fiber. Heat processing may have affected the solubility of the fiber and the water holding capacity, which modified its content in the sweet potato. Likewise, the use of water in cooking extracted some soluble fiber, especially through the boiling technique. The high frying temperature applied to the Toquecita variety possibly solubilized dietary fiber and caused its decrease to 10 g/100 g dw.

3.3. Starch Digestibility and Glycemic Index

Starch digestibility and the pGI of the two sweet potato varieties, were evaluated under different thermal processes (boiled, baked, and fried). The results presented in Table 3, show significant differences ($p \leq 0.05$) in TDS, RDS, SDS, RS, and pGI.

Table 2. Physico-chemical characteristics of two varieties of raw and processed sweet potato*.

Parameter	Guayaco Morado				Toquecita			
	Raw	Boiled	Baked	Fried	Raw	Boiled	Baked	Fried
Moisture	11.30 ± 0.28^{e}	14.35 ± 0.07^{b}	13.30 ± 0.28^{c}	11.60 ± 0.14^{de}	11.80 ± 0.14^{de}	15.30 ± 0.14^{a}	14.45 ± 0.07^{b}	12.26 ± 0.08^{d}
Amylose	29.53 ± 0.08^{a}	12.83 ± 0.01^{e}	13.45 ± 0.06^{d}	14.40 ± 0.03^{c}	18.82 ± 0.02^{b}	5.61 ± 0.08^{h}	8.95 ± 0.03^{g}	9.89 ± 0.13^{f}
Amylopectin	70.40 ± 0.02^{h}	87.15 ± 0.04^{d}	86.49 ± 0.04^{e}	85.51 ± 0.11^{f}	81.11 ± 0.09^{g}	94.35 ± 0.01^{a}	91.02 ± 0.01^{b}	90.01 ± 0.02^{c}
Reducing sugars	1.35 ± 0.06^{h}	43.25 ± 0.01^{a}	32.48 ± 0.04^{c}	6.92 ± 0.05^{f}	1.82 ± 0.01^{g}	8.22 ± 0.04^{e}	36.20 ± 0.07^{b}	12.22 ± 0.05^{d}
Gelatinization degree	-	96.75 ± 0.05^{a}	$71,91 \pm 0.04^{c}$	$12.86 \pm 0,01^{f}$	-	17.73 ± 0.05^{e}	94.97 ± 0.05^{b}	28.78 ± 0.04^{d}
TS	72.58 ± 0.55^{b}	77.49 ± 0.58^{a}	77.17 ± 0.13^{a}	60.14 ± 0.44^{c}	45.95 ± 0.49^{d}	77.52 ± 0.00^{a}	71.92 ± 0.24^{b}	76.21 ± 0.05^{a}
SDF	3.03 ± 0.08^{a}	2.96 ± 0.01^{a}	2.44 ± 0.01^{bc}	2.33 ± 0.04^{c}	2.45 ± 0.01^{bc}	2.53 ± 0.03^{b}	2.12 ± 0.04^{d}	2.04 ± 0.02^{d}
IDF	10.51 ± 0.01^{g}	13.38 ± 0.10^{b}	12.03 ± 0.03^{d}	11.46 ± 0.01^{f}	11.86 ± 0.01^{e}	14.54 ± 0.05^{a}	13.48 ± 0.03^{b}	12.69 ± 0.01^{c}
TDF	13.54 ± 0.01^{e}	16.34 ± 0.01^{d}	14.47 ± 0.01^{b}	13.79 ± 0.01^{b}	$14.31.01^{a}$	17.07 ± 0.01^{a}	15.60 ± 0.01^{b}	14.73 ± 0.01^{c}

SDF = Soluble Dietary Fiber, IDF = Insoluble Dietary Fiber, Total Dietary Fiber = TDF. Different letters in the same row indicate significant differences ($p \leq 0.05$). Data are expressed as g/100 g dw. *Roots dehydrated and powdered.

3.3.1. pGI

pGI is a key indicator for assessing how quickly carbohydrates in a food are converted into glucose in the body. pGI in Guayaco Morado varied significantly depending of the thermal treatment applied, with the lowest value in fried roots (64.15) and the highest in boiled roots (76.77) (Table 1). About it, [55] during cooking (boiling, baking, etc.), heat and water break down the crystalline structure of starch, which facilitates its digestion and absorption in the intestine. Toquecita variety showed similar behavior, with the highest pGI (74.70) in baked roots and lowest value (73.57) in fried roots.

These results correlated with the lower SDG, sugar content, WAI, WSI and SP and higher amylopectin, conditions that predominate in fried sweet potatoes and are in line with previous studies by Nagy et al. [55] who indicate that frying reduces pGI due to the formation of more complex structures [56]. Indicate that chemical composition and heat treatment influence the pGI of food and they suggest choosing an appropriate cooking method such as boiling to modulate the pGI.

3.3.2. TDS

TDS is a key indicator of the fraction of carbohydrates that the body can assimilate. In Guayaco Morado and Toquecita TDS was higher in boiled samples (72.14 and 73.75 g/100 g dw). These results correlate ($r^2 = 0.91$) with the highest amylopectin content in the boiled roots and could be due to heating with water breaks the crystalline structure of starch, increasing its digestibility. In contrast, frying reduced TDS in both sweet potato varieties, possibly due to the combined effect of retro degradation,

lipid complexation, dehydration and fat barrier, which reduces digestible starch, despite the partial gelatinization of starch due to frying [56]. These results are consistent with the studies conducted by Wang et al. [57],where the analysis of corn starch subjected to dry heating showed higher digestibility levels due to the reduction in molecular weight, the particles have greater flexibility and deformability.

3.3.3. RDS

RDS refers to the fraction of starch that is rapidly broken down and absorbed in the gastrointestinal tract, which can have an impact on blood glucose levels. The highest RDS values (23.48 and 31.21 g/ 100 g dw) corresponded to the Guayaco Morado and Toquecita processed by cooking in water (boiled). This evidences the effect of cooking increasing starch digestibility, since heat alters its molecular structure, making it more accessible to digestive enzymes, [58]. Starch from fried roots showed lower values (18.72 and 27.62 g/100 g dw), which correlated with the lower degree of starch gelatinization and amylopectin content. These results are consistent with studies indicating that thermal treatments favor the breakdown of crystalline starch structures, increasing its digestibility, while frying reduces digestibility due to lower starch gelatinization and formation of lipid-starch complexes [59].

3.3.4. SDS

SDS is the starch fraction that is digested and absorbed at a slower rate in the gastrointestinal tract. This type of starch has a smaller and more gradual impact on blood glucose levels compared to RDS, [60]. The highest SDS values (36.14 and 39.92 g/100 g dw) were recorded in boiled Guayaco Morado and Toquecita. These results show that cooking at 91 °C can preserve the starch structure, which increases its resistance to digestion. Another factor that influenced this result was the higher content of soluble fiber in the boiled roots; this component is capable of forming gels that interfere with the action of digestive enzymes, favoring the slow release of glucose. The carotenoid of Toquecita may also have influenced starch digestion, by partially inhibiting the action of digestive enzymes, causing a slower release of glucose. These findings are consistent with studies showing that thermal treatments such as boiling and baking increase the proportion of SDS, while frying reduces it due to the formation of a physical barrier that reduces the rate of starch digestion, [61].

3.3.5. RS

RS is a fraction of starch that is not digested in the small intestine, but passes to the large intestine, where it can be fermented by intestinal bacteria. RS has several health benefits, such as improving intestinal health and regulating blood glucose levels,[5]. This parameter reached the highest value (6.63 g/100 g dw) in the baked Guayaco Morado and the fried roots of Toquecita (9.83 g/100 g dw). As mentioned above, in frying the proportion of non-gelatinized starch is higher, this is minimally digestible, which increases the RS content in fried sweet potato, underlining the correlation and potential to control starch digestibility through proper management of cooking methods to avoid the rapid increase in the glycemic index and the maintenance of postprandial glycemia. Another factor that influenced the RS values of the two sweet potato varieties was the dietary fiber in the baked and fried roots, because fiber can form a matrix around the starch that makes it more difficult to digest [62]. In the plantain study, Kim et al [5], observed that cooking methods that promote RS formation, such

as post-cooking cooling or certain thermal processes, significantly increased this type of starch, contributing to the beneficial effects on metabolic health and glucose regulation. These results reinforce the importance of careful preparation to enhance RS content and take advantage of its benefits, as shown by our observation of increased RS in sweet potato roots when baked or fried, where the lower degree of gelatinization and food structure favor resistance to digestion in the small intestine.

Table 3. Glycemic Index and starch digestibility of two varieties of raw and processed sweet potato.

Parameter	Varieties							
	Guayaco Morado				Toquecita			
	Raw	Boiled	Baked	Fried	Raw	Boiled	Baked	Fried
pGI	65.97 ± 0.49^{c}	76.77 ± 0.69^{a}	73.25 ± 0.48^{b}	64.15 ± 0.89^{c}	65.76 ± 0.66^{c}	73.96 ± 0.95^{b}	74.70 ± 0.04^{ab}	73.57 ± 0.42^{b}
TDS	65.11 ± 0.20^{f}	72.14 ± 0.22^{b}	70.54 ± 0.21^{c}	57.23 ± 0.23^{g}	43.40 ± 0.39^{h}	73.75 ± 0.18^{a}	67.43 ± 0.37^{d}	66.38 ± 0.08^{e}
RDS	13.12 ± 0.09^{g}	23.48 ± 0.07^{d}	21.43 ± 0.17^{e}	18.72 ± 0.28^{f}	8.55 ± 0.23^{h}	31.21 ± 0.10^{a}	29.41 ± 0.54^{b}	27.62 ± 0.36^{c}
SDS	26.18 ± 0.41^{e}	36.14 ± 0.01^{c}	34.67 ± 0.34^{d}	25.02 ± 0.25^{e}	21.82 ± 0.41^{f}	39.92 ± 0.25^{a}	37.70 ± 0.29^{b}	35.59 ± 0.52^{cd}
RS	7.46 ± 0.34^{b}	5.35 ± 0.36^{c}	6.63 ± 0.34^{b}	2.91 ± 0.21^{ef}	2.55 ± 0.10^{f}	3.77 ± 0.18^{de}	4.49 ± 0.12^{cd}	9.83 ± 0.03^{a}

Different letters in the same row indicate significant differences ($p \leq 0.05$). Data are expressed as g/100 g dw. pGI= Glycemic Index, TDS = Total Digestible Starch, RDS = Rapidly Digestible Starch, Slowly Digestible Starch = SDS, Resistant Starch = RS.

4. Conclusions

This study presents a comprehensive approach for the characterization of Guayaco Morado and Toquecita sweet potatoes under three thermal processing methods (cooking, baking, and frying), which had a significant and differentiated impact on the functional properties and starch digestibility of the two sweet potato varieties. These two varieties present improved functional characteristics, such as water absorption rate (TAA), water solubility index (WSI), and powder fluffiness (PP), which correlate with a higher degree of starch gelatinization and amylopectin content. These changes also resulted in an increase in TDS, RDS, and SDS, confirming that moist and dry heat cooking improves digestibility. However, cooking does not limit starch gelatinization or reduce digestible starch content, but rather significantly increases RS, particularly in the Toquecita variety, indicating potential benefits for glucose control and intestinal health. Toquecita, characterized by a low amylose content and a higher amylopectin content, showed greater swelling capacity, solubility, and starch digestibility in all treatments. From an industrial perspective, boiled and baked sweet potato flours may be suitable for formulating purees, baby foods, and instant products, while fried sweet potato, thanks to its RS content, can be used in foods that promote metabolic health.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Acknowledgments

The National Institute of Agricultural Research INIAP supported this work, and the authors would like to thank the National Legumes and Andian Grains Program, EESC for providing quinoa varieties

for the study and Technical University of Cotopaxi "Project harvest and post-harvest management of agricultural products and study of agricultural waste transformation processes" to facilities provided for the completion of this work. The authors wish to thank the Technical University of Cotopaxi for providing financial assistance.

Conflict of interest

All authors declare that they have no conflict of interest.

Author contributions

Christian Villegas: Conceptualization, Methodology, Investigation, Writing—Original Draft; Elena Villacrés: Supervision, Validation, Writing—Review & Editing; María Quelal: Supervision, Validation, Writing—Review & Editing; María Morales: Supervision, Writing—Review & Editing. All authors have read and agreed to the published version of the manuscript.

References

1. Cobeña Ruiz G, Cañarte Bermúdez E, Mendoza García A, et al. (2017) Manual técnico del cultivo de camote. INIAP EXP Portoviejo. Edited by E.I.E.E.P. Ecuador: Portoviejo, 1–89. http://repositorio.iniap.gob.ec/handle/41000/4789
2. Teow CC, Truong V, McFeeters RF, et al. (2007) Antioxidant activities, phenolic and β-carotene contents of sweet potato genotypes with varying flesh colours. *Food Chem* 103: 829–838. https://doi.org/10.1016/j.foodchem.2006.09.033
3. Xu J, Su X, Lim S, et al. (2015) Characterisation and stability of anthocyanins in purple-fleshed sweet potato P40. *Food Chem* 186: 90–96. https://doi.org/10.1016/j.foodchem.2014.08.123
4. Das S, Gazdag Z, Szente L, et al. (2019) Antioxidant and antimicrobial properties of randomly methylated β cyclodextrin—Captured essential oils. *Food Chem* 278: 305–313. https://doi.org/10.1016/j.foodchem.2018.11.047
5. Kim, HR, Hong JS, Ryu AR, et al. (2020) Combination of rice varieties and cooking methods resulting in a high content of resistant starch. *Cereal Chem* 97: 149–157. https://doi.org/https://doi.org/10.1002/cche.10221
6. Mert B, Demirkesen I (2016) Reducing saturated fat with oleogel/shortening blends in a baked product. *Food Chem* 199: 809–816. https://doi.org/10.1016/j.foodchem.2015.12.087
7. Dinu M, Soare R, Babeanu C, et al. (2018) Analysis of nutritional composition and antioxidant activity of sweet potato (Ipomoea batatas L.) leaf and petiole. *J Appl Bot Food Quality* 91: 120–125. https://doi.org/https://doi.org/10.5073/JABFQ.2018.091.017
8. Oyetayo FL, Akomolafe SF, Osesanmi TJ (2020) Effect of dietary inclusion of pumpkin (Cucurbita *pepo L*) seed on nephrotoxicity occasioned by cisplatin in experimental rats. *J Food Biochem* 44: 1–11. https://doi.org/10.1111/jfbc.13439
9. Samarakoon ERJ (2020) Impact of physical modifications on starch nutritional fractions: rapidly digestible starch, slowly digestible starch and resistant starch. *J Food Bioact* 12: 106–121. https://doi.org/10.31665/JFB.2020.12249

10. Zhu F (2017) Structures, properties, modifications, and uses of oat starch. *Food Chem* 229: 329–340. https://doi.org/10.1016/j.foodchem.2017.02.064
11. Kim HJ, Woo KS, Lee HU, et al. (2020) Physicochemical characteristics of starch in sweet potato cultivars grown in Korea. *Prev Nutr Food Sci* 25: 212–218. https://doi.org/10.3746/pnf.2020.25.2.212
12. Englyst HN, Veenstra J, Hudson GJ (1996) Measurement of rapidly available glucose (RAG) in plant foods: A potential *in vitro* predictor of the glycaemic response. *Br J Nutr* 75: 327–337. https://doi.org/https://doi.org/10.1079/BJN19960137
13. Mulla MZ, Annapure US, Bharadwaj VR, et al. (2017) A study on the kinetics of acrylamide formation in banana chips. *J Food Proc Preserv* 41: e12739. https://doi.org/10.1111/jfpp.12739
14. Bello-Perez LA, Flores-Silva PC, Agama-Acevedo E, et al. (2020) Starch digestibility: Past, present, and future. *J Sci Food Agric* 100: 5009–5016. https://doi.org/https://doi.org/10.1002/jsfa.8955
15. Wang X, Kristo E, LaPointe G (2019) The effect of apple pomace on the texture, rheology and microstructure of set type yogurt. *Food Hydrocolloids* 91: 83–91. https://doi.org/10.1016/j.foodhyd.2019.01.004
16. Liang J, Yu S, Li Z, et al. (2025) Effect of plasma manipulation on the developing quick-cooking and the hydration promotion of adzuki bean. *Int J Food Sci Technol* 60: vvae023. https://doi.org/10.1093/ijfood/vvae023
17. Abiche MG, Teferi MB, Olbamo SK (2019) Determination of glycemic index and glycemic loads of commonly consumed food items of cassava and sweet potato of Bench Maji Zone, South West Ethiopia 2017. *Int J Biochem Res Rev* 26: 1–12. https://doi.org/10.9734/ijbcrr/2019/v26i430104
18. Li C, Hu Y (2022) *In vitro* and animal models to predict the glycemic index value of carbohydrate-containing foods. *Trends Food Sci Technol* 120: 16–24. https://doi.org/https://doi.org/10.1016/j.tifs.2021.12.031
19. Ngo T, Van Kunyanee K, Luangsakul N (2023) Insights into recent updates on factors and technologies that modulate the glycemic index of rice and its products. *Foods* 12: 3659. https://doi.org/https://doi.org/10.3390/foods12193659
20. Lal MK, Singh B, Sharma S, et al. (2021) Glycemic index of starchy crops and factors affecting its digestibility: A review. *Trends Food Sci Technol* 111: 741–755. https://doi.org/10.1016/j.tifs.2021.02.067
21. Seah JYH, Koh WP, Yuan JM, et al. (2019) Rice intake and risk of type 2 diabetes: the Singapore Chinese Health Study. *Eur J Nutr* 58: 3349–3360. https://doi.org/https://doi.org/10.1007/s00394-018-1879-7
22. Cornejo F, Salazar R, Martínez-Espinosa R, et al. (2022) Evaluation of starch digestibility of Andean crops oriented to healthy diet recommendation. *Int J Food Prop* 25: 1146–1155. https://doi.org/https://doi.org/10.1080/10942912.2022.2074036
23. Eddie ZZ, Park CH, Gloria CR (2024) CAPÍTULO 6—VARIABILIDAD GENÉTICA DEL CAMOTE. In: Gloria C, Xavier OD, Luis DG, et al. (Eds.), Cultivo de camote en Ecuador, CIDEPRO., Portoviejo, Manabí, Ecuador: INIAP-KOPIA, 135: 83–104. Available from: http://repositorio.iniap.gob.ec/handle/41000/6307
24. Villacrés E, Manosalvas L, Simbaña K, et al. (2025) Effect of vacuum frying on changes in the quality attributes of three varieties of maize. *Int J Food Sci Technol* 60: vvae039. https://doi.org/https://doi.org/10.1093/ijfood/vvae039

25. Anderson RA, Conway HF, Peplinski AJ (1970) 'Gelatinization of corn grits by roll cooking, extrusion cooking and steaming. *Starch-Stärke* 22: 130–135. https://doi.org/https://doi.org/10.1002/star.19700220408
26. Calderón C, Quelal M, Villacrés E, et al. (2023) 'Impact of extrusion on the physicochemical parameters of two varieties of corn (*Zea mays*). *AIMS Agric Food* 8: 873–888. https://doi.org/10.3934/agrfood.2023046
27. Official Methods of Analysis of the AOAC (2005) *Association of Official Analytical Chemists (AOAC).* 18th ed. Washington DC, USA: A.O.A.C. Available from: https://www.scirp.org/reference/ReferencesPapers?ReferenceID=2033299.
28. Waidyarathna GRNN, Ekanayake S, Chandrasekara A (2021) Comparative analysis of nutrient composition and glycaemic indices of nine sweet potatoes (Ipomoea batatas) varieties. *Int J Biol Chem Sci* 15: 1410–1420. https://doi.org/10.4314/ijbcs.v15i4.9
29. Morrison WR, Laignelet B (1983) An improved colorimetric procedure for determining apparent and total amylose in cereal and other starches. *J Cereal Sci* 1: 9–20. https://doi.org/10.1016/S0733-5210(83)80004-6
30. Dias FFG, Bogusz S, Hantao LW, et al. (2017) Acrylamide mitigation in French fries using native l-asparaginase from Aspergillus oryzae CCT 3940. *LWT-Food Sci Technol* 76: 222–229. https://doi.org/https://doi.org/10.1016/j.lwt.2016.04.017
31. Sun X, Yu C, Fu M, et al. (2019) Extruded whole buckwheat noodles: Effects of processing variables on the degree of starch gelatinization, changes of nutritional components, cooking characteristics and *in vitro* starch digestibility. *Food Funct* 10: 6362–6373. https://doi.org/10.1039/C9FO01111K
32. Samotus B, Tuz J, Doerre E (2014) Evaluation of Blue Value in different plant materials as a tool for rapid starch determination. *Acta Soc Bot Pol* 62: 137–141. https://doi.org/https://doi.org/10.5586/asbp.1993.020
33. Jameel MR, Ansari Z, Al-Huqail AA, et al. (2022) CRISPR/Cas9-mediated genome editing of soluble starch synthesis enzyme in rice for low glycemic index. *Agronomy* 12: 2206. https://doi.org/https://doi.org/10.3390/agronomy12092206
34. Goñi I, Garcia-Alonso A, Saura-Calixto F (1997) A starch hydrolysis procedure to estimate glycemic index. *Nutr Res* 17: 427–437. https://doi.org/10.1016/S0271-5317(97)00010-9
35. Megazyme International Ireland (2024) *Resistant Starch Assay Kit*. Available from: https://www.megazyme.com/resistant-starch-assay-kit-rapid.
36. Di Rienzo JA, Casanoves F, Balzarini MG, et al. (2020) InfoStat, versión 2020. Córdoba-Argentina: Grupo InfoStat, FCA, Universidad Nacional de Córdoba. Available from: https://www.infostat.com.ar/index.php?mod=page&id=46.
37. Roa Acosta DF, Solanilla-Duque GS, Agudelo Laverde LM, et al. (2020) Structural and thermal properties of the amaranth starch granule obtained by high-impact wet milling. *Int J Food Eng* 16: 0024. https://doi.org/10.1515/ijfe-2020-0024
38. Chang Q, Zheng B, Zhang Y, et al. (2021) A comprehensive review of the factors influencing the formation of retrograded starch. *Int J Biological Macromol* 186: 163–173. https://doi.org/10.1016/j.ijbiomac.2021.07.050
39. Liu X, Huang S, Chao C, et al. (2022) Changes of starch during thermal processing of foods: Current status and future directions. *Trends Food Sci Technol* 119: 320–337. https://doi.org/10.1016/j.tifs.2021.12.011

40. Zhuang Y, Wang Y, Yang H (2024) Effects of cation valence on swelling power, solubility, pasting, gel strength characteristics of potato starch. *Food Chem* 434: 137510. https://doi.org/10.1016/j.foodchem.2023.137510
41. Zhao J, Chen Z, Jin Z, et al. (2015) Effects of granule size of cross-linked and hydroxypropylated sweet potato starches on their physicochemical properties. *J Agric Food Chem* 63: 4646–4654. https://doi.org/10.1021/jf506349w
42. Zhong Y, Zhu H, Liang W, et al. (2018) High-amylose starch as a new ingredient to balance nutrition and texture of food. *J Cereal Sci* 81: 8–14. https://doi.org/10.1016/j.jcs.2018.02.009
43. Allan MC, Marinos N, Johanningsmeier SD, et al. (2021) Relationships between isolated sweetpotato starch properties and textural attributes of sweetpotato French fries. *J Food Sci* 86: 1819–1834. https://doi.org/10.1111/1750-3841.15725
44. Shi M, Li D, Yan Y, et al. (2018) Effect of moisture content on structure and properties of fried potato starch. *Starch-Stärke* 70: 1800012. https://doi.org/10.1002/star.201800012
45. Chen L, Tian Y, Bai Y, et al. (2018) Effect of frying on the pasting and rheological properties of normal maize starch. *Food Hydrocolloids* 77: 85–95. https://doi.org/10.1016/j.foodhyd.2017.09.024
46. Yang Z, Hao H, Wu Y, et al. (2021) Influence of moisture and amylose on the physicochemical properties of rice starch during heat treatment. *Int J Biol Macromol* 168: 656–662. https://doi.org/10.1016/j.ijbiomac.2020.11.122
47. Beech D, Beech J, Gould J, et al. (2022) Effect of amylose/amylopectin ratio and extent of processing on the physical properties of expanded maize starches. *Int J Food Sci Technol* 57: 2298–2309. https://doi.org/10.1111/ijfs.15581
48. Wei S, Lu G, Cao H (2017) Effects of cooking methods on starch and sugar composition of sweetpotato storage roots. *PLOS ONE* 12: e0182604. https://doi.org/10.1371/journal.pone.0182604
49. Zhang R, Chen H, Chen Y, et al. (2023) Impact of different cooking methods on the flavor and chemical profile of yellow-fleshed table-stock sweetpotatoes (Ipomoea batatas L.). *Food Chem: X* 17: 100542. https://doi.org/10.1016/j.fochx.2022.100542
50. Majzoobi M, Farahnaky A (2021) Granular cold-water swelling starch; properties, preparation and applications, a review. *Food Hydrocolloids* 111: 106393. https://doi.org/10.1016/j.foodhyd.2020.106393
51. Dehghannya J, Ngadi M (2021) Recent advances in microstructure characterization of fried foods: Different frying techniques and process modeling. *Trends Food Sci Technol* 116: 786–801. https://doi.org/10.1016/j.tifs.2021.03.033
52. Qadir N, Wani IA (2022) In-vitro digestibility of rice starch and factors regulating its digestion process: A review. *Carbohydr Polym* 291: 119600. https://doi.org/10.1016/j.carbpol.2022.119600
53. Li X, Wang L, Tan B, et al. (2024) Effect of structural characteristics on the physicochemical properties and functional activities of dietary fiber: A review of structure-activity relationship. *Int J Biol Macromol* 269: 132214. https://doi.org/10.1016/j.ijbiomac.2024.132214
54. Ochoa-Martínez LA, Luna Solís HA, Bermúdez Quiñones G (2021) Almidón de camote: Modificaciones enzimáticas, físicas y químicas. *TECNOCIENCIA Chihuahua* 15: 221–233. https://doi.org/10.54167/tecnociencia.v15i3.854
55. Nagy R, Máthé E, Csapó J, et al. (2020) Modifying effects of physical processes on starch and dietary fiber content of foodstuffs. *Processes* 9: 17. https://doi.org/10.3390/pr9010017

56. Leite CEC, Souza BDKF, Manfio CE, et al. (2022) Sweet potato new varieties screening based on morphology, pulp color, proximal composition, and total dietary fiber content via factor analysis and principal component analysis. *Front Plant Sci* 13: 852709. https://doi.org/10.3389/fpls.2022.852709
57. Wang, Y. Chen L, Yang T, et al. (2021) A review of structural transformations and properties changes in starch during thermal processing of foods. *Food Hydrocolloids* 113: 106543. https://doi.org/10.1016/j.foodhyd.2020.106543
58. Chi C, Li X, Lu P, et al. (2019) Dry heating and annealing treatment synergistically modulate starch structure and digestibility. *Int J Biological Macromol* 137: 554–561. https://doi.org/https://doi.org/10.1016/j.ijbiomac.2019.06.137
59. Krishnan V, Mondal D, Thomas B, et al. (2021) Starch-lipid interaction alters the molecular structure and ultimate starch bioavailability: A comprehensive review. *Int J Biol Macromol* 182: 626–638. https://doi.org/https://doi.org/10.1016/j.ijbiomac.2021.04.030
60. Guo L, Tao H, Cui B, et al. (2019) The effects of sequential enzyme modifications on structural and physicochemical properties of sweet potato starch granules. *Food Chem* 277: 504–514. https://doi.org/10.1016/j.foodchem.2018.11.014
61. Vernaza MG, Chang YK (2017) Survival of resistant starch during the processing of atmospheric and vacuum fried instant noodles. *Food Sci Technol* 37: 425–431. https://doi.org/10.1590/1678-457x.17716
62. De Oliveira AF, Soares JM, da Silva EC, et al. (2019) Evaluation of the chemical, physical and nutritional composition and sensory acceptability of different sweet potato cultivars. *Semina: Ciências Agrárias* 40: 1127. https://doi.org/https://doi.org/10.5433/1679-0359.2019v40n3p1127

AIMS Press