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Vacuum impregnation: A methodology for the preparation of a ready-to-eat sweet potato enriched in polyphenols

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ABSTRACT

Vacuum impregnation (VI) is a widely used methodology to add various substances of interest to porous foods, thus acquiring enhanced nutritional and sensory properties depending on the functionality of the impregnation solution. The work reported here was thus aimed at the preparation of sweet potato containing the addition of polyphenols through vacuum impregnation and low-pressure cooking. A commercial solution of polyphenol extract (95% [v/v] proanthocyanidins) was used as an impregnation medium.

In the characterization of the vacuum-impregnated samples, the physicochemical parameters of pH, moisture, color, texture, and total polyphenol content were measured, the cooking behavior was evaluated, and sensory assessments were performed (preference tests and the CATA—check-all-that-apply—questionnaire). The result was a preparation of sweet potatoes that had been vacuum-impregnated with a subsequent increase of 473 % in the concentration of phenolic compounds compared to the control sample. The parameters such as color and texture remained stable. We conclude that VI enabled the preparation of a product providing some 220.0 mg of gallic-acid equivalents of polyphenols per 100 g (GAE/100 g) per serving, a value similar to those of vegetables rich in those compounds.

1. Introduction

The sweet potato (*Ipomoea batatas* (L.) Lam) is a tuber with high nutritional and culinary characteristics. In Argentina, the average consumption is between 3 and 4 kg per person per year, representing 90 % of the cultivated food (Martí, 2018). Distinguished medical organizations such as the American Cancer Society and the American Heart Association consider sweet potato a highly nutritious food with disease-prevention properties (North Carolina sweet potato Commission, 2003). This food provides approximately 84 Kcal in 100 g of product. The main carbohydrate is starch, while sugars (sucrose, glucose, and fructose)—though being the components providing the characteristic sweet taste—are found in low proportions. Although sweet potatoes do not have significant amounts of protein, that food does provide lysine, an amino acid of high biologic value (Martí, 2018), and contains 46.5 mg of gallic-acid equivalents (GAE) per 100 g of polyphenols. These phenolic compounds constitute some of the main secondary metabolites of vegetables and have various physiologic functions. Polyphenols have a chemical structure amenable to combination with free radicals, thus neutralizing reactive oxygen species, and to the chelation of metal ions, by that means exerting an antioxidant action. The consumption of these compounds is of nutritional benefit because of their contribution to the prevention of various diseases related to oxidative stress (Godos, Rapisarda, Marventano, Mistretta, & Grosso, 2017; Quinones, Miguel, & Aleixandre, 2012). Different studies have corroborated the beneficial effect on health of incorporating these types of compounds in the diet. Several authors agree that carrying out a diet rich in antioxidants with fruits, vegetables, and vegetable-derived foods is beneficial to health. Unfortunately, a lack of sufficient concrete data exists for the determination of a recommended daily requirement for antioxidant consumption providing an optimum benefit to health (Grosso et al., 2016; Tapsell, Dunning, Warensjo, Lyons Wall, & Dehlsen, 2014; Zamora et al., 2014).

Other studies have incorporated polyphenols into different foods by means of vacuum impregnation, though incorporating a somewhat different methodology and type of food from sweet potatoes, the objective of the present work (Moreira & Almohaimeed, 2018; Tappi et al., 2017).

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Vacuum impregnation (VI) is a methodology widely used to add physiologically active substances to porous foods for the development of functional commestibles. Structured foods such as fruits and vegetables have a large number of pores (intercellular spaces), which enable the impregnation of specific solutes selected to modify the composition and improve the quality of the products. The hydrodynamic mechanism of VI involves the exchange of internal gas and/or occluded liquid in the open pores with an external liquid phase promoted by pressure changes. This mechanism enables the incorporation of liquid into the pores during VI. The porosity, mechanical properties, size, and shape of the food matrix used affects the incorporation of the liquid during VI in porous foods (Ostos, Díaz, & Díaz, 2012). Vacuum impregnation is a tool used in the development of vegetable or fruit products that enables a modification of the original composition of the food without destroying the cellular structure (Fito et al., 2001a; Guillemin, Degraeve, Noël, & Saurel, 2008; Hironaka, Oda, & Koaze, 2014). This process is carried out at room temperature and can be done through different types of equipment. The VI experiments of the present work were done with the culinary module Gastrovac®, designed by the Polytechnic University of Valencia (Montes-Ortega, 2009).

In recent years food technology has focussed on investigating and developing innovative cooking, packaging, and conservation techniques that ensure the production of safe, easy-to-prepare and consumer-beneficial foods, with the sensory and nutritional characteristics sought by the consumers. Among those technologies is the technique of *sous vide*, which consists of subjecting raw (or partially cooked) foods vacuum-packed in bags or trays to a controlled cooking-pasteurization process, thus extending the shelf life of the products. This methodology significantly reduces the losses of water and volatile compounds normally occurring through evaporation during cooking and also produces food with better nutritional quality than otherwise produced by conventional methods as a result of the lower losses from oxidation or diffusion of nutrients, such as water-soluble vitamins (Iborra-Bernad, Tárrega, García-Segovia, & Martínez-Monzó, 2014). In general, a Roner® cooker, with a bath of regulation and digital reading of temperature and time, is used with constant water circulation. Despite the clear technologic, sensory, and nutritional advantages, no studies have been conducted to date on vacuum-impregnated vegetables cooked by *sous vide*.

The objective of this work was therefore to characterize a procedure for preparing a ready-to-eat sweet potato with the addition of polyphenols by vacuum impregnation.

2. Materials and methods

2.1. Raw material

Sweet potatoes (*Ipomoea batatas* (L.) Lam)—harvest of March 2019—were bought at the local market of cultivars from the city of Gualeguaychú. Tubers of 200–250 g were selected considering their freshness, firmness and absence of microbial or mechanical damage. The sweet potatoes were washed with tap water to remove the attached soil and then were dried with tissue paper, finally were peeled and cut into slices 3 mm thick and 50 mm in diameter and batons 5 cm long by 5 mm thick. The average weights for the experimental samples were 12.3 g for the slices and 15.7 g for the batons. The sweet potato samples were separated into two groups with regard to treatments: Non-treated (control) and vacuum impregnation (VI).

2.2. Impregnation solution

The polyphenol solution used was Vitisol® of the domestic company Nialtec S.A. This polyphenol extract contains 95 % oligomeric proanthocyanidins. The formulation of the 3.5 % VI solution was performed based on the study conducted by Rózek, Achaerandio, Güell, López, and Ferrando (2008).

2.3. Vacuum impregnation (VI) methodology

The VI experiments were performed with Gastrovac® vacuum-cooking culinary equipment, designed and patented by the Polytechnic University of Valencia, Spain and the restaurants La Sucursal (Valencia) and El Rodat (Javea). This equipment in professional use enables cooking and impregnation at low pressure. The cooker consists of an 8-L kettle with a lid of the aluminum alloy methacrylate connected to a vacuum pump that reaches a maximum vacuum value of -0.8 bars. The unit is equipped with a heat source that is regulated by a probe connected to a thermostat (Montes-Ortega, 2009).

The sweet potatoes were immersed in the VI solution in the equipment and subjected to vacuum for 10, 15, 20, 25, and 30 min at 20 °C, for each type of cut. In the restoration stage, the pressure was restored over the same time intervals as those of the VI—*i. e.*, 10, 15, 20, 25 and 30 min. The 11 slices of vegetables were cooked in 1 L of the solution so that all the samples were immersed in it.

2.4. Heat treatment

Three methods were used to cook the samples:

a) Steam: the samples were heated at 100 °C for 15 min in a steamer.
b) *Cook vide*: the samples were heated in the Gastrovac® under continuous vacuum (-0.8 bar) at 80 °C for 30 min. Inside the steamer, the samples were placed on a rack to avoid direct contact with the boiling liquid.
c) *Sous vide*: the samples were vacuum-packed inside polyamide-polyethylene bags of O_2 permeability from 25 to 30 cm^3/m^2 and water-vapor permeability 5 g/m^2 (Sealed Air Co, Argentina) and then sealed in a packaging machine (Vacuum Packing ICC, Barcelona, Spain). The samples were cooked in a bath with temperature and time regulation and constant water circulation (Roner Compact 80060/80080™, Barcelona, Spain) at 80 °C for 30 min.

The cooking temperatures were monitored with an HY93530N thermocouple (HANNA Instruments, Italy).

2.5. Physicochemical characterization

The determinations made in control raw sweet potato and in vacuum-impregnated raw sweet potato were the following: the pH with a pH meter with a combined Ag/AgCl electrode (Fischer Scientific Model Accumet AB250), soluble solids (°Bx) with table refractometer (A. KrussOptronic, Germany) according to the Association of Official Analytical Chemists (AOAC) 932.12, the moisture content after heating in an infrared drying oven (Radwag Mag. 50/WH, Poland) according to AOAC, 2005.003–84, water activity with a Rotronic Hygrolab C1 hygrometer, the acidity by volumetric methods, the apparent density by the ratio of the mass and volume occupied by the sample in a 30 ml graduated cylinder, and the density of the impregnating liquid with a pycnometer.

The texture was determined in control cooked sweet potato and sweet potato cooked by VI. The compression test was performed with the Instron 3342™ instrument (Massachusetts, USA). The values obtained for the maximum compression force were expressed in Newtons (N). The tests were carried out in quintuplicate, with a deformation of 30 % and at a test speed 0.5 mm/s. The firmness (strength) of the material was calculated from the relationship between the maximum force (N) and the maximum deformation (mm). The elastic modulus was calculated on the basis of the relationship between the maximum force (N) and the initial module $(\frac{mm}{mm})$

The color was determined on a Miniscan EZ colorimeter (Minolta) in the CIE L* a* b* color space. The variation was evaluated in the parameters L* (black 0, white 100), a* (red-green) and b* (yellow-blue).

The color parameters were determined from triplicate measurements in each sample. The color intensity C*ab (Equation (1)) and the color change ΔE (Equation (2)) were calculated, where L_0, a_0, and b_0 represent the readings of the samples not impregnated (CIE, 1971).

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

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)} \quad (2)$$

The total phenol content was determined by the Folin-Ciocalteu method, modified by Heimer, Vignolini, Dini, and Romani (2005). Samples of sweet potatoes of 16 g were processed in a blender with 50 ml of methanol (Sintorgan, Lot N°. 38931). The homogenates obtained were placed in a beaker and heated at 40 °C with continuous stirring (Barnstead Thermoline) for 15 min before centrifugation (Rolco Mod. 2036™ centrifuge) for 5 min at 11.200 g force and filtration. A 0.5-ml aliquot was added to a test tube together with 1 ml of Folin-Ciocalteau reagent (Biokar) and 10 ml of distilled water, left to stand for 2 min. Then, 4 ml of a 20 % (w/v) sodium carbonate solution (Merck, Argentina) was added, brought up to a final volume of 25 ml, and heated at 50 °C for 5 min in a thermostatic bath (Vicking Mod. Masson). The optical density was finally measured in a spectrophotometer (Jenway Mod. 6505 UV/VIS™) at 765 nm.

2.6. Sensory characterization

The check-all-that-apply (CATA) questionnaire consists of multiple questions in which the consumer can mark all the options that are considered appropriate for the sensory characterization of a product. The sensory characterization was carried out with 60 consumers (students, teachers, and administrative staff of the School of Bromatology). CATA sensory analysis requires a minimum of 50 consumers (Parente, Manzoni, & Ares, 2011). The consumer judges determined the acceptance of the 5 sweet potato samples (Table 1). A 9-point hedonic scale was used containing the categories "I dislike it a lot" (valued at 1 point) to "I like it very much" (valued at 9 points). In the CATA questionnaire, consumers indicated the attributes considered appropriate to describe the sensory characteristics of sweet potato. The terms were defined by using a previous focus group.

Consumer tests were carried out in a sensory laboratory that was designed in accordance with ISO 8589 (ISO, 1988). Evaluations were performed under artificial daylight type illumination, temperature control (between 22 °C and 24 °C) and air circulation. Data were collected in paper ballots, through self-administered questionnaires previously explained to each consumer.

Sensory characterization by applying the CATA questionnaire does not require a minimum or maximum number of samples, but correspondence analysis (CA) as a method of data analysis is best used with 5 or more samples (Williams, Carr, & Popper, 2011).

2.7. Statistical analysis

The data of the test results are expressed as the means ± the standard deviations as computed by the software SPSS (SPSS 19.0, United Kingdom Ltd.). The significance of differences between the means was determined by the analysis of variance ANOVA followed by the Tukey multiple-comparison test with a limit of significance at $p < 0.05$.

For the preference test, the table of significance was the one used by Anzaldúa Morales (1994) for testing the two samples of Roessler, Baker, and Amerine (1956). The difference in each of the attributes of the CATA questionnaire was evaluated by means of the Cochran Q test.

A correspondence analysis was used to obtain a two-dimensional representation of the relationship between the attributes for each of the identified groups. The results were statistically analyzed by means of the XLSTAT program for Windows, version 2018.7.5 (Addinsoft, 2020).

Table 1
Ingredient percentage composition of the five samples prepared for the CATA questionnaire.

Ingredients	Samples				
	1	2	3	4	5
Sweet potato	100	90	80	80	80
Provençal	…	10	20	…	…
Onion	…	…	…	20	…
Garlic	…	…	…	…	20

Provençal: a mixture of powdered garlic and parsley.
1: control sweet potato; 2: sweet potato vacuum-impregnated VI with polyphenols flavored with provençal (10 %); 3: sweet potato vacuum-impregnated with polyphenols flavored with provençal (20 %); 4: sweet potato vacuum-impregnated with polyphenols flavored with onion; and 5: sweet potato vacuum-impregnated with polyphenols flavored with garlic.

3. Results and discussion

3.1. Vacuum impregnation

VI in a porous food occurs by means of a hydrodynamic mechanism, consisting of the exchange of a previously occluded internal gas and/or liquid through the open pores by an external liquid phase promoted by a pressure gradient (Fito et al., 2001b; Hironaka et al., 2014). Therefore, this mechanism—which is responsible for the incorporation of liquid during VI in porous foods—is necessarily influenced by the porosity, mechanical properties, size, and shape of the food used. Consequently, the first step to determine is the appropriate form of the VI cut and the treatment time for the VI (Ostos et al., 2012).

Table 2 illustrates influence of the VI processing time and sample size on the final concentration of polyphenols. Slice and baton cuts increased the concentration of mg GAE/100 g of final product, although the slice cut required less time to reach a higher concentration of polyphenols compared to the baton cut. After analyzing these data and comparing the values with the control sample (control sweet potato) with 46.5 mg GAE/100 g of incorporated polyphenol, the most effective VI time was 25 min, in sliced sweet potato samples, at a significant difference ($p < 0.05$) with respect to the shorter times tested. Moreover, the 30-min treatment resulted in no significant difference ($p > 0.05$) from the 25-min treatment.

No studies were found for that same time of VI treatment for sweet potatoes, though the times used by Hironaka et al. (2014) for the VI of potatoes with vitamin C were similar. Other authors, however, had used shorter times for the VI—Degraeve, Noel, and Saurel (2008) for calcium-fortified apple cubes and Gras, Vidal, Betoret, Chiralt, and Fito (2003) for calcium-impregnated eggplant cylinders. Upon analyzing the results from these studies, it was possible to conclude that the sweet potato behaved in a similar way to potatoes—as such, requiring a longer VI time than other vegetables such as eggplant. This difference may be because the sweet potato is a less porous food and thus less permeable to water and to gas. These results confirm that, in general, every vegetable and every nutrient that is impregnated by this vacuum mechanism

Table 2
Influence of the cut of the sample and the VI time on the final polyphenol concentration (mg GAE/100 g product)*.

Time (min)	Slices of 3 mm (mg EAG/100)	Batons of 5 mm (mg EAG/100)
0 (control)	46.5 ± 4.20 [a]	46.5 ± 4.20 [a]
10	125.10 ± 0.10[a]	92.70 ± 0.04[a]
15	120.40 ± 0.90[b]	80.10 ± 0.61[a]
20	136.20 ± 0.40[c]	114.50 ± 0.16[b]
25	199.60 ± 0.80[d]	114.10 ± 0.40[b]
30	220.0 ± 0.30[d]	118.60 ± 0.30[c]

*Average value ± standard deviation of the results (n = 3). Samples with the same letter in the same column were not significantly different by the Tukey test ($p < 0.05$).

Table 3
Physicochemical parameters in the vacuum-impregnated dish: sweet potato with the addition of polyphenols.

Parameters	Control sweet potato	IV sweet potato
Moisture (%)	83.64 ± 0.56[a]	89.17 ± 1.12[b]
pH (sample)	5.76 ± 0.04[a]	6.27 ± 0.03[b]
Soluble solids (° Bx)	8.78 ± 0.42[a]	7.07 ± 0.05[a]
Acidity (g/l)	0.09 ± 0.02[a]	0.17 ± 0.02[a]
Water activity	0.98 ± 0.02[a]	0.99 ± 0.01[a]
Bulk density	1.07 ± 0.08[a]	1.09 ± 0.08[b]
Texture		
Initial modulus (mm/mm)	0.308 ± 0.02[a]	0.312 ± 0.01[a]
Hardness (N)	113.67 ± 8.42[a]	158.344 ± 22.08[b]
Maximum deformation (mm)	6.15 ± 0.67[a]	6.22 ± 0.19[a]
Firmness (N/mm)	18.48 ± 1.74[a]	25.4 ± 2.82[b]
Elastic modulus	368.59 ± 25.16[a]	506.50 ± 58.76[b]
Color		
L*	44.78 ± 2.06[a]	55.11 ± 1.78[b]
A*	23.65 ± 1.45[a]	33.62 ± 1.91[b]
B*	34.38 ± 2.34[a]	45.77 ± 2.62[b]
ΔE	13.03 ± 1.12[a]	28.92 ± 6.01[b]
C*ab	41.77 ± 1.12[a]	56.83 ± 1.22[b]

Average value and standard deviation of the results (n = 5). Samples with the same letter between the two columns were not significantly different by the Tukey test ($p < 0.05$).

Table 4
Influence of cooking on the concentration of polyphenols of vacuum-impregnated samples.

Samples	Gallic acid (mg %)
Impregnated raw (25 min)	220.00 ± 3.30[b]
Steam-impregnated	152.50 ± 6.00[c]
Sous-vide impregnated	189.20 ± 2.48[b]
Cook-vide impregnated	179.70 ± 3.02[b]

Average value ± standard deviation of the results (n = 5). Samples with the same letter were not significantly different by the Tukey test ($p < 0.05$).

requires a specific individual VI time.

Data analysis indicated that the impregnated sweet potato represents an increase in phenolic-compound concentration over the control sample of 473 %. Thus, this method could be considered as suitable for incorporating biologically active substances into vegetables, so as to facilitate the improvement of the nutritional quality by those supplements. Several authors have demonstrated the effectiveness of the VI process as a fortification methodology, resulting in an improvement in the quality of the final product—such as phenolic enriched mushroom by Yilmaz and Bastioglu (2020). In addition, this technology considered feasible for creating new product categories: calcio-fortified pineapple snack (Maeus De Lima et al., 2016), ascorbic acid enrichment of whole potato (Hironoka et al., 2014), and fortified apple snacks of calcium lactate (Assis et al., 2019).

3.2. Physicochemical characterization

Table 3 summarizes the differences in the physicochemical parameters between the vacuum-impregnated samples and the control.

The moisture content of the vacuum-impregnated samples was significantly higher ($p < 0.05$) than the controls as a result of the water absorption during the vacuum application The increase of moisture content was also observed by Mateus de Lima et al. 2016, in VI of calcium-fortified pineapple.

Furthermore, the pH of the samples was also higher after VI. The results obtained coincided with those reported by Xie and Zhao (2004) and Assis et al. (2019).

The texture—one of the most essential properties for the acceptability of food, especially for solid products—can be altered by incorporating external substances other than the basic plant structure. For this property, the vacuum-impregnated samples presented higher values in the elastic modulus than the nonimpregnated ones. A significant difference ($p < 0.05$) was found in the parameters of maximum force and firmness, with the highest values characterizing the impregnated samples.

Morgado and Castro-Montero (2007) suggested that in the case of hardness products, the elastic modulus should correlate with firmness since the sensory evaluation of this parameter is based on a flexion test. Cell turgidity, the integrity of cell walls (Iborra Bernard et al., 2014), water content and water stress (Meilgaard, Civille, & Carr, 2006) are important components of the firmness of plant materials. Higher moisture content can cause more plasticized cell wall component biopolymers, causing less fracture resistance in the textural and greater plasticity (relative strain %). The significant increase in the moisture content—in the impregnated sweet potatoes compared to the control samples—could cause a different gelatinization in the starch, forming granules with less swelling power with the consequent formation of firmer gels (Tupa Valencia, 2019). Thus, it would be interesting to carry out a DSC study to evaluate the behavior of sweet potato starch VI.

An exchange of the gas occluded in the cellular structure of the sweet potato by solutes contained in the liquid used in the VI through capillary action and the pressure gradients imposed in the system via the hydrodynamic mechanism. Several authors have reported similar textural changes: Park, Kodihalli, and Zhao (2005), working with apples impregnated with calcium, found lower values in the breaking force and fracture in impregnated samples than in their controls, while Occhino, Hernando, Llorca, Neri, and Pittia (2011) observed a significant change in the textural properties (*i. e.*, the cutting force and energy) of vacuum-impregnated zucchini from those parameters in non-impregnated zucchini.

The values obtained for the chromatic parameters L*, a*, and b*; the color intensity C*ab; and the color shift ΔE revealed significant differences between the control and the vacuum-impregnated samples (p <

Table 5
Frequency (n) with which the indicated terms of the CATA question were used by consumers to describe the five sweet potato samples and the results from Cochran's Q test for comparison between the samples.

Attributes	Samples				
	1	2	3	4	5
Fibrous*	12	19	21	19	19
Hard *	56	56	56	56	55
Firm*	56	55	56	56	56
Juicy*	56	56	56	56	55
Dry*	7	5	7	6	1
Oily	2	13	15	14	12
Pickled	4	10	26	21	23
Garlic flavor	4	8	30	2	30
Onion flavor	3	16	6	15	15
Sweet potato flavor	26	10	7	5	2
Aromatic*	5	14	12	12	15
Acid	0	6	19	10	10
Sweet	53	56	56	56	56
Bitter*	1	5	2	3	1
Excessive flavor	4	14	33	12	38
Poor flavor	21	15	0	17	3
Excessive odor	2	8	24	8	12
Poor odor	19	13	4	7	7
Excessive color*	24	17	21	18	13
Poor color*	2	3	4	6	7
Shiny	6	13	23	19	30
Opaque	23	18	10	8	4

*Indicates significant differences between the samples ($p < 0.05$) according to the Cochran Q test. 1: control sweet potato; 2: sweet potato vacuum-impregnated IV with polyphenols flavored with provençal (10 %); 3: sweet potato vacuum-impregnated with polyphenols flavored with provençal (20 %); 4: sweet potato vacuum-impregnated with polyphenols flavored with onion; and 5: sweet potato vacuum-impregnated with polyphenols flavored with garlic.

0.05). In all instances, the latter samples evidenced higher values than those of the controls. This enhancement can be attributed to the occupation of the intercellular spaces of the sweet potato matrix with the impregnation liquid; which filling, in turn, produces a change in the optical properties of the plant surface so as to increase the absorption of light, thus making the vacuum-impregnated samples appear darker (Cortés-Rodríguez, Herrera-Herrera, & Gil-González, 2016).

In addition, it was found that the color of the VI solution has impacts on the color of VI products due to the filling of the pores with the solution (Xie & Zhao, 2003). The change in product density during VI, especially in highly porous samples, affects color and texture (Xie & Zhao, 2004).

3.3. Heat treatment of sweet potato with the addition of polyphenols

Vacuum cooking compared to traditional cooking uses temperatures of less than 100 °C and does not require oxygen, allowing the preservation of sensory and nutritional food properties (Martínez-Monzó, Andrés, Torres, San Juán, & García-Segovia, 2004). Table 4 illustrates the effect of vacuum cooking compared to traditional cooking (steam cooking) on the concentration of polyphenols (in mg GAE/100 g of product) in the sweet-potato preparations.

When samples are submitted to a temperature for cooking, either in a vacuum or under atmospheric pressure, the concentration of polyphenols decreases. The vacuum-impregnated steam sample had the greatest loss of GAEs ($p < 0.05$) than the rest of the treatments, and especially with the vacuum-impregnated raw sample. In contrast, the polyphenol levels after the rest of the heat treatments—*i. e.*, in the samples cooked by *cook vide* and *sous vide*—were not significantly different from those in the raw vacuum-impregnated sample. This result coincides with the study carried out by Hironaka et al. (2014) in impregnated potatoes with vitamin C, where a greater loss occurred in traditional cooking than in vacuum cooking.

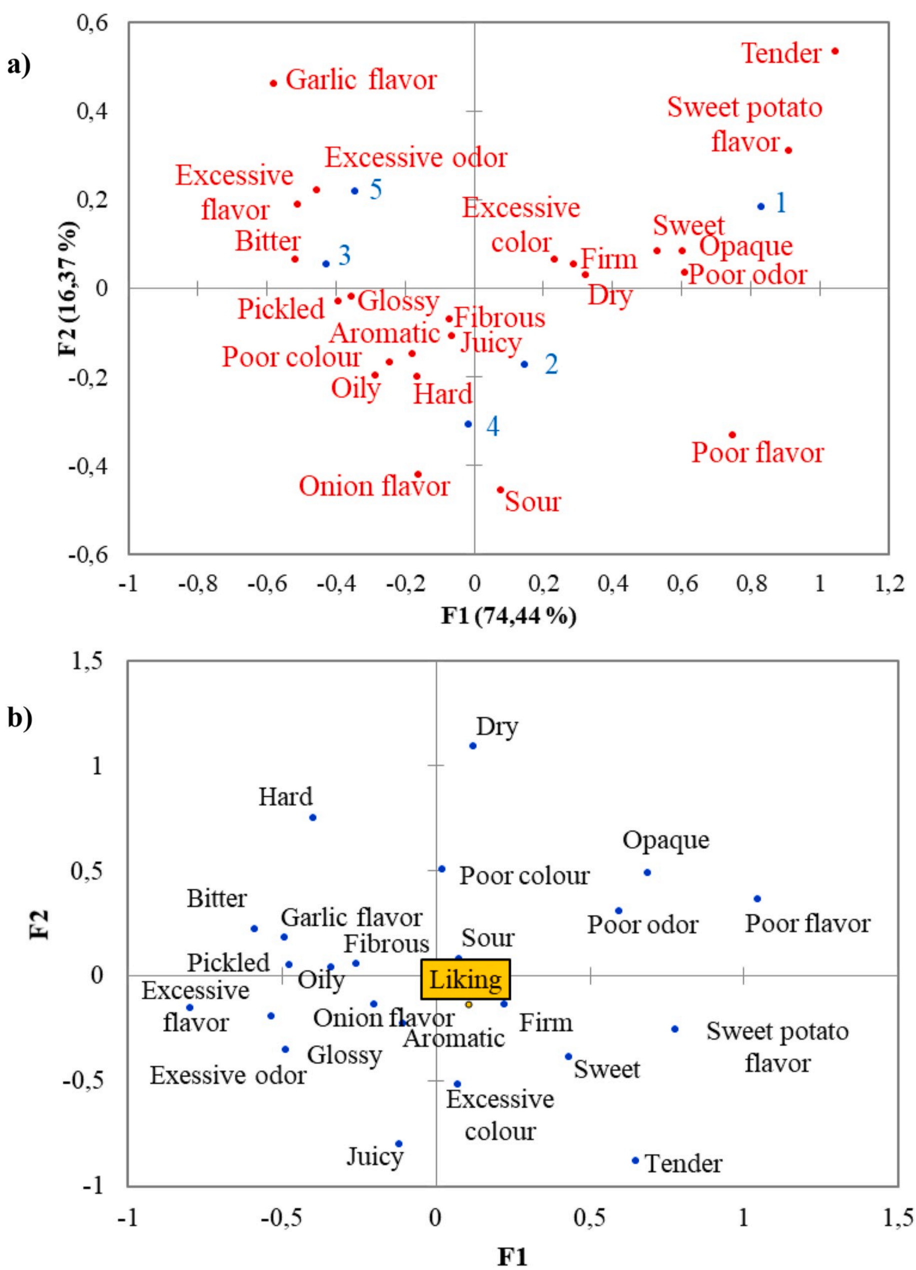

Fig. 1. Correspondence analysis map of sensory attributes for different sweet-potato preparations. Panel a: 1, control sweet potato; 2, sweet potato vacuum-impregnated VI with polyphenols flavored with provençal (10 %); 3, sweet potato vacuum-impregnated with polyphenols flavored with provençal (20 %); 4, sweet potato vacuum-impregnated with polyphenols flavored with onion; and 5 sweet-potato vacuum-impregnated with polyphenols flavored with garlic. Panel b: Representation of the sensory attributes related to liking or disliking.

3.4. Sensory characterization

The main objective at this stage of the work was to determine how consumers would characterize sweet potatoes polyphenol-enriched through VI. Fifty-six consumers evaluated the liking or disliking of samples of sweet potatoes prepared in that fashion, through the use of a scale of 9 points, grouped into the following categories: "I dislike it" (1–3), "I am indifferent about it" (4–6), and "I like it" (7–9). The sample with the highest score with respect to the options "I like" and "I am indifferent about it" was the control sample (sample 1; 49 %). The samples with the lowest score were the sweet potatoes that were vacuum-impregnated with polyphenols and flavored with onion (sample 4) along with the preparation that had been the flavored with garlic (sample 5; 19 %). In addition to the taste and odor, the attributes that consumers most often selected to describe the samples were: hard, firm, sweet, and juicy. According to the Cochran Q-test (Table 5), the samples of vacuum-impregnated sweet potatoes with polyphenols and with additional flavoring were not significantly different ($p > 0.05$) with respect to the following terms: soft, fibrous, hard, firm, juicy, dry, aromatic, bitter, intense color and little color.

Fig. 1 depicts the sensory map of the CATA questionnaire. The sensory map shows how consumers classified the samples according to the added flavoring. The five samples were separated into three groups in the first two dimensions of the projective mapping task. One group composed of samples 3 and 5, another one of samples 2 and 4, whereas sample 1 was located apart from the rest.

The group formed by samples 5 and 3 were characterized as being excessive odor and flavor; garlic flavor and bitter. Samples 4 and 2 were characterized as fibrous, juicy, hard, and onion flavor. Finally, sample 1, was the most accepted, and was characterized by sweet potato flavor, sweet, opaque, and poor odor.

The CATA questionnaire is thus useful for analyzing the sensory characterization of a food by consumers through facilitating a perception of the differences cited among the various attributes. Certain authors accordingly have performed a sensory characterization of different foods using the CATA questionnaire, but no studies have been found to date on that approach with vacuum-impregnated vegetables cooked by *sous vide*. For this reason, no direct comparison can be made with the present results at this time.

4. Conclusion

Vacuum impregnation for 25 min at 20 °C allowed to obtain sweet potato slices that provide 200.23 mg EAG/100 g—similar level to those of polyphenol-rich vegetables. This value represents an increase in phenolic-compound concentration over the control sample of 473 %.

The VI process is presented as an effective methodology for adding polyphenols that also preserves the physicochemical parameters of the sweet potato.

The *sous vide* cooking caused lower losses of polyphenols than otherwise resulted under normal atmospheric pressure. The sensory evaluation of sweet potatoes with the addition of polyphenols gained a wider acceptance in the samples possessing the characteristic taste of the vegetable. The perception of the main attributes that characterize this type of product could be ascertained through the CATA technique. The consumers described sweet potatoes prepared in that way as hard, firm, juicy, and sweet.

Thus, the vaccum impregnation with *sous vide* cooking processes could be considered as suitable for incorporating biologically active substances into vegetables, for the development of new products by the improvement of the nutritional quality.

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Declaration of competing interest

The authors declare that there are no known conflicts of interest associated with this publication.

CRediT authorship contribution statement

Rosa Ana Abalos: Methodology, Investigation. **Elisa Fernanda Naef:** Formal analysis, Investigation. **M. Victoria Aviles:** Investigation. **María Beatríz Gómez:** Writing - review & editing, Supervision.

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