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Effect of thermal pretreatments and cooking characteristics on physicochemical, rheological, and sensorial properties of food products based on cassava (*Manihot esculenta* Crantz)

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Abstract

The aim of this work was to develop, characterize and standardize four food products using cassava: cassava cake, dessert, ice cream, and a milk drink, evaluating the effect of cooking on quality. The methodology included the food handling and processing of the cassava products and the performance of textural, rheological, nutritional, and sensory studies of the final products. The sensory panel favorably rated all foods. All of the products developed received high acceptability scores from the sensory panel. The apparent viscosity of the beverage increased over time, whereas the firmness of the ice cream bar and the firmness of the cassava cake did not significantly change during the observation period. The sensory analysis identified typical descriptors for each food. We concluded that cassava is a functional raw material, which combined with other additives, conserves their properties, and is ideal for preparing bakery products, flavored beverages, and ice cream.

Practical applications

In this study, four different food processing alternatives by cassava were performed by the community support of rural women from the village of Lebanon Township Andes, west of the Department of Antioquia in Colombia. Process lines were established for foods made from cassava, for its standardization and incorporation of processing of tubers in diet of the indigenous population of Colombia. Subsequent to this stage, the food obtained was evaluated physicochemical, nutritional, and sensory. It is important that research projects support the rural entrepreneurial units to strengthen the food security in the region as well as to improve the quality of life through the commercialization of new products. This research may contribute with strategy for the development and utilization of cassava and cassava products that can provide incentives for farmers, crop vendors and food processors to increase their incomes, and it can also provide food security for households producing and consuming this foods.

1 | INTRODUCTION

The nutritional quality of food is the main element considered by the consumer when choosing what to eat. The internationalization of many local cuisines has inspired researchers to focus their attention on investigating and standardizing the factors that determine the quality of food in terms of its flavor and health benefits. The cassava (*Manihot esculenta* Crantz) is the fourth most important raw material in the world after rice, wheat and corn and is consumed by 1,000 million people in the world (Charles, Chang, Ko, Sriroth, & Huang, 2005; FAO, 2000). It is an emerging crop in many rural regions, which is strengthening the food security in these locales. The roots and leaves are suitable for human consumption; the roots are rich in carbohydrates, and the leaves are rich in protein, vitamins, and minerals. The cassava is one of the most important sources for the commercial production of starch, along with the potato, maize, and wheat, and it is easily extractable (Gilhermne, 2004; Ospina & Ceballos, 2002). Cassava roots are commonly consumed cooked, fried, and roasted or are used to produce raw materials such as sugar and starch (Padonou, Mestres, & Nago, 2005). Cassava starch has an amylose/amylopectin ratio that provides the definitive characteristic functional properties of starches, the specific applications of which can utilized in product development. The cassava is widely used in various types of drinks and foods (Almeida, Rachid, & Schwan, 2007; Amoa-Awua & Jakobsen, 1995; Janick, 2013; Jisha, Padmaja, Moorthy, & Rajeshkumar, 2008), and the microorganisms present in a fermented drink based on cassava, rice, peanuts, and corn called *cauim* were analyzed (Almeida et al., 2007). The bakery industry has incorporated cassava starch into some products, such as bread and biscuits (Almeida et al., 2007; Janick, 2013; Jisha et al., 2008; Kimaryo, Massawe, Olasupo, & Holzapfel, 2000; Lertworasirikul, 2008; Mayyawadee & Schleining, 2010; Obadina, Oyewole, Sanni, Tomlins, & Westby, 2008; Padonou et al., 2009; Shittu, Aminu, & Abulude, 2009; Shittu, Dixon, Awonorin, Sanni, & Maziya-Dixon, 2008). Some desserts use cassava to prepare desserts, and the effects of its starch, carrageenan, and inulin on their rheological and sensorial properties have been studied (Costell & Tarrega, 2006; De Wijk, Kapper, Borsboom, & Prinz, 2009; Kaya & Tekin, 2001; Marek, Stanisław, Piotr, & Marek, 2007; Nindjina, Amania, & Sindic, 2011; Verbekena, Baela, Thas, & Dewettincka, 2006). The literature includes some textural, rheological, and sensorial studies of ice cream based on different raw materials (rice flour, green pulp of the coconut) containing low fat, dietary fiber or natural stabilizing ingredients, such as *salep* (Costell & Tarrega, 2006; De Wijk et al., 2009; Marek et al., 2007; Verbekena et al., 2006). Celiac disease occurs in genetically predisposed individuals, in which the ingestion of foods containing gluten damages the surface of the small intestinal mucosa, which leads to the inability to absorb nutrients (Soukoulis, Lebesi, & Tzia, 2009). The treatment of this condition is only dietary and involves the removal of the diet of cereals and products made from their flour (Soukoulis et al., 2009). While there have developed a number of commercial products for celiac patients, variety in the market is low. This tuber offers an interesting alternative food for this type of consumers, however there is little information on the nutritional characteristics of food products based on cassava. When a food system incorporates a food ingredient into it to enhance some quality attributes, other significant quality attributes may be compromised, additionally, whether heat-sensitive and/or nutritional compounds could be altered during processing is an important issue for consider. For these reasons, the aim of this study was to evaluate the effect of processing and cooking on quality of four types of cassava-based foods: cassava cake, a dessert, an ice cream bar, and a milk drink.

2 | MATERIALS AND METHODS

2.1 | Raw material

The cassava tubers were growth by the local farmer of the village of Libano Township Andes, west of the Department of Antioquia in Colombia (altitude of 1,360 m at 5°39′20″N and 75°52′49″W). Fifty kilograms of cassava were harvested, sorted, cleaned, and disinfected by dipping them in a sodium hypochlorite solution (5%, wt/wt). All of the chemicals used for the determination of the proximal composition (raw material and the foods developed) were of analytical grade. Deionized water was used to prepare all of the food products based on cassava. The other ingredients used on different cassava-based foods were the commonly used on bakery industry.

2.2 | Standardization of cassava-based food preparation

This research was conducted with the community support of country women from the village of Libano Township Andes. The typical recipes and formulations for each type of cassava-based food are present in Table 1. The basic stages of preparing all of the products based on cassava were weighing, washing, peeling, cutting, and cooking the cassava for 30 min. Samples of the mixture were placed in polyethylene packages and stored at −18 °C for 12 days. The different stages considered in the elaboration of cassava-based foods can be seen in Figure 1.

2.3 | Characterization and physicochemical analyses

2.3.1 | Rheological and textural analysis

The rheological analysis of the milk drink based on cassava was conducted using a Brookfield DV-I viscometer with a number 3 spindle (range 1.5–60 rpm). The samples were stored at 6 ± 0.5 °C and analyzed every 6 hr on days 1, 3, 7, and 9. A product's textural properties are of fundamental importance to its acceptability (Amoa-Awua & Jakobsen, 1995). Whether this is the “mouth feel” of food, the flow properties of creams and pastes or the tackiness of adhesives, textural analysis provides accurate product information. Textural analysis involved measuring the maximal force (N) required to penetrate the cassava-based ice cream and the cassava cake. A Stable Micro system

TABLE 1 Formulations of the foods derived from cassava (g/unit of food prepared)

Raw material (g)	Cassava cake	Dessert	Flavored beverage	Ice cream bar
Cassava	1,000	150	60	125
Sugar	230	200	75	55
Coconut	180	–	–	40
Butter	200	–	–	–
Coastal cheese	250	–	–	–
Egg (60 g/unit)	240	–	–	–
Baking powder	15	–	–	–
Vanilla (drops)	4	–	3	3
Water	–	400	300	500
Milk powder	–	150	65	125
Cinnamon	–	5	–	–
Coffee	–	10	–	–
Total (g)	2,115	1,525	503	848

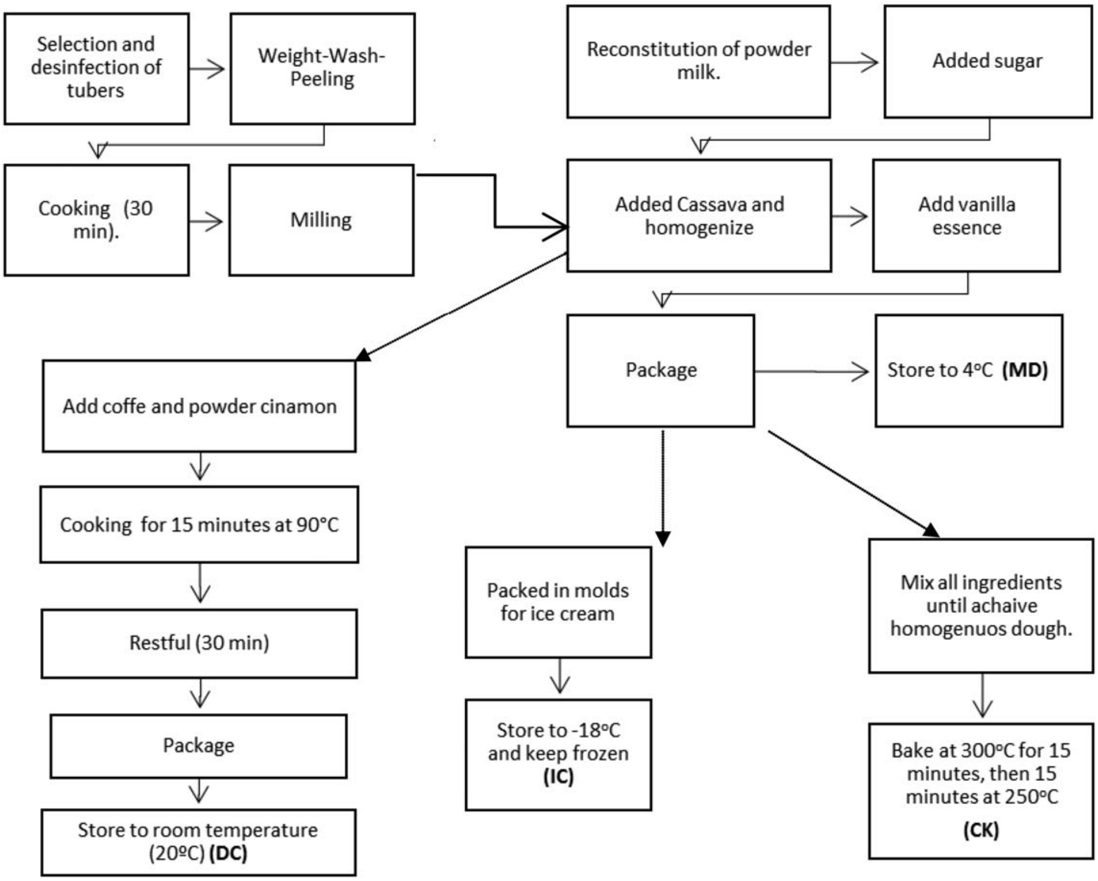

FIGURE 1 Preparation processes for cassava cake (CK), the dessert (DC), the ice cream (IC), and the milk drink (MD) based on cassava (*Manihot esculenta* Crantz)

TA-XT2 texture analyzer was used for this evaluation, using eight replicates for each measurement. The maximal force required to penetrate 8 mm into the foods was measured with a cylindrical piece 2 mm in diameter. Table 2 shows the distances and penetration rates used to evaluate the ice cream bars and cassava cake. The evaluations of the ice cream were performed in duplicate at days 1, 4, 6, 9, and 12; in the case of the cassava cake, segments of $4 \times 4 \times 3$ cm^3 were evaluated at days 1, 3, 5, and 10.

2.4 | Chemical analysis

2.4.1 | Proximate composition

All of the analyses of samples of each food developed were made by rules of AOAC and in triplicate (Kailasapathy & Sellepan, 1998). The results for the ash, total dietary fiber, and crude protein contents were expressed as g/100 g on an oil-free dry basis, whereas the moisture content results were expressed as g/100 g on a wet basis. Public Health Laboratories of the Universidad of Antioquia performed the physicochemical analyses.

TABLE 2 Details of textural analysis according to the type of food

Food sample	Distance (mm)	Speed test (mm/s)		
		Before	During	After
Ice cream bar	8	3	5	3
Cassava cake	8	3	4	3

2.5 | Sensorial analysis

A sensorial analytical method of multidimensional approximation was performed employing a panel of seven trained judges who spent two sessions developing a description of cassava-based foods and then

TABLE 3 Physicochemical parameters of raw material and cooked cassava

Parameter	Fresh cassava[a]	Fresh cassava[b]	Cooked cassava[a]
Moisture	59.76 ± 0.376	61.8	69.39 ± 1.347
Ash-Minerals	0.89 ± 0.052	0.90	0.66 ± 0.059
Fat	0.09 ± 0.018	0.10	0.04 ± 0.006
Nitrogen	0.06 ± 0.002	–	0.00 ± 0.000
Protein (N x 6.25)	0.39 ± 0.022	0.80	0.00 ± 0.000
Carbohydrates	38.85 ± 1.123	36.40	29.91 ± 1.013
Calories/100g portion.	157.84 ± 0.959	150.00	119.97 ± 0.942

[a]For each parameter, each value is the average of four replicates for each type of product derived from cassava.
[b]Reference values of the FAO for cassava *Manihot dulcis* Pax.

FIGURE 2 Fresh cassava boiled

performed the sensorial characterization of each cassava-based product and described the appearance, color, flavor, and textural attributes and the overall acceptability. Each attribute was evaluated using a nine-point hedonic scale (nine points was excellent; one point was extremely poor).

2.6 | Statistical analysis

The statistical analysis used was a completely randomized design with four replicates of four units of each of the formulated foods evaluated. The results were expressed as the mean value ± *SD*, the data were analyzed using a one-way analysis of variance, and the statistical significance was determined using the LSD test for quality assessment. The data were analyzed using STATGRAPHICS Centurion XVI v. 16.0.07 software.

3 | RESULTS AND DISCUSSION

3.1 | Physicochemical compositional analysis of the raw material and the food products developed

The proximate composition, essential mineral contents, and total dietary fiber contents of the raw material used in this research are shown in Table 3. The moisture content, ash, fat, nitrogen, protein, carbohydrates, and calories per serving are similar to those reported by the FAO, except in the case of the protein content (0.39 ± 0.022). The type of cassava species and the location of their growth could explain these differences. Preview research on sweet cassava[5,26] obtained values of 65–69.8, 1.25–2.62, and 0.29–0.56% for the moisture, protein, and fat contents, respectively. In cooked cassava, the moisture content was higher than that of raw material, reaching values of 69.39 ± 1.35 (59.76 ± 0.38), with an increase of approximately 13%, which could be due to water absorption by the starch granules that were gelatinized during cooking (Mayyawadee & Schleining (2010); Janick, (2013). Cooking reduced the carbohydrate content of cassava from 38.85 to 29.91%, and the same trend was observed in the calories per serving, with the value reduced from 157.84 to 119.97. The appearance of fresh boiled cassava can be shown in Figure 2. The appeareance of foods made from cassava are shown in Figures 3–6. Table 4 shows the results obtained for a product named "enyucado," which is called cassava cake here. This product had lower moisture content than raw cassava due to the baking process. The dramatically increased fat content (to 11.23%) was due to incorporating cheese and buttermilk in this product. In addition, the protein content increased from 0.39% in raw cassava to 3.63% in the cake, which was due to the ingredients that allowed the formation of the cassava cake. In general, the number of calories per serving was higher than that of cooked cassava, for example, increasing from 119.97 to 297.72. Previously, the effect of the baking time on moisture content of "enyucado" was studied (Garzón, 2003; Marcotte, Baik, & Castaigne, 2000), and its moisture content was from 14.4 to 27.2% (lower than that observed in this study). The FAO (2012a, 2012b) reported a physicochemical analysis of pancakes (similar to cassava cake) with values close to those obtained in our study (moisture content of 29.7%, protein content of 19.30%, ash content of 5.30, fat content of 1%, carbohydrate content of 44.7%, and energy content of 374 kcal). In the dessert (Figure 4), an interesting result was the increase in the protein content due to the incorporation of milk and the increase in the carbohydrate content due to the

FIGURE 3 Cassava cake

FIGURE 4 Dessert

FIGURE 6 Ice cream bar

inclusion of sugar; thus, it expected to have the high caloric content of approximately 185 calories per serving. The results for the milk drink based on cassava (Figure 5) should be similar to those for the dessert because the main difference between them was the storage condition. However, differences between them were found, mainly in the moisture and carbohydrate contents. The moisture content of the drink milk was increased from 52.7 to 66.07%, and the carbohydrate content of the drink milk was lower than that of the dessert; therefore, the number of calories per serving was lower than that of the dessert. In the case of the cassava ice cream bar (Figure 6), some studies reported the physicochemical properties of such foods formulated using alternative raw materials (Cueto & Pérez, 2010; Cueto, Pérez, Borneo, & Ribotta, 2011; FAO 2012b; Igutti, Pereira, Livia, Silva, & Ribeiro, 2011), with different fat contents, proteins, and ash contents ranged from 3.82 to 3.91, 4.14 to 8.55, and 0.88 to 0.96, respectively. FAO (2012a; 2012b) and Igutti et al. (2011) reported for cassava ice cream moisture content of 62.8%, protein content of 5%, fat content of 12%, ash content of 0.1%, and carbohydrate content of 20.10%, with an energy content of 208 kcal. The present results on carbohydrate content of the ice cream were similar than reported by FAO, and the fat and protein contents were lower contents.

FIGURE 5 Flavorage beverage

3.2 | Rheological analysis

Figure 7a shows the change in the apparent viscosity of the cassava-based milk drink that occurred during 9 days of storage. Viscosity significantly increased over time, from 4,405 cP on the first day to 12,446 cP on the last day, which was due to the gelatinized starch holding water and forming a weakly stable gel. In general, there is evidence that the gel produced by cassava starch is more viscous but is fewer firms (Cueto et al., 2011; FAO, 2012b). Some authors reported values of 0.26–0.48 Pa s for a yogurt drink (Adhikari, González, & Sancho-Madriz, 2011), while others authors evaluated the effect of the ultrahigh temperature (UHT) process on different milk formulations, reporting values of 3.26–20 mPa s according to the carrageen and sugar contents (Deeth, Sangeeta, Thom, & Olena, 2010). The values observed in this study are higher than those previously mentioned, mainly due to the starch content, which was not reported in the other studies. Figure 7b shows the rheological behavior of the cassava-based milk drink, demonstrating that this fluid behaves similarly to a Herschel–Bulkley fluid.

3.3 | Textural analysis

During the first 4 days of storage at −18 °C, the maximal force required to penetrate the cassava ice cream increased (Figure 8). This situation could be due that the molecular organization was becoming more homogeneous, but then, this values began to decrease, which meant that the molecular organization was becoming more homogeneous, but then, this values began to decrease, most likely due to destabilization of the structure of stabilizing agent included in the ice cream formulation. The hardness of ice cream based on soy was studied previously (Kailasapathy & Sellepan, 1998) and reported force values that ranged between 2.28 and 7.29 N. Preview reports had studied the effect of a low-fat content on ice cream and obtained results with force values between 58.9 and 79.9 N (Aime, Arntfield, Malcolmson, & Ryland, 2001). The variability in the data is clearly due to the use

TABLE 4 Results of the physicochemical analysis of each product developed

Parameter/portion (g)	Cassava cake	Dessert	Milk drink	Ice cream
Moisture	37.98 ± 1.506	52.70 ± 1.479	66.07 ± 0.116	74.43 ± 0.246
Ash-minerals	1.62 ± 0.023	1.10 ± 0.011	0.81 ± 0.009	0.60 ± 0.008
Fat	11.23 ± 1.071	0.05 ± 0.014	0.19 ± 0.017	0.81 ± 0.091
Nitrogen	0.58 ± 0.113	0.62 ± 0.305	0.53 ± 0.422	0.31 ± 0.376
Total protein ($N \times 6.25$)	3.63 ± 0.109	3.85 ± 0.296	3.31 ± 0.414	1.93 ± 0.366
Carbohydrates	45.54 ± 0.083	42.29 ± 0.075	29.62 ± 0.063	22.23 ± 0.051
Calories	297.72 ± 0.073	185.02 ± 0.065	133.40 ± 0.054	103.92 ± 0.049

For each parameter, each value is the average of four replicates for each type of product derived from cassava. Source: Public Health Laboratory, Antioquia University.

of different raw materials. In the case of the cassava cake, the firmness did not significantly change during the first 10 days of storage. Subsequently, the firmness values increased (Figure 8), which was due to the retrogradation phenomenon of starch that is typical of bakery products based on flours rich in this compound. The firmness for the first 10 days was close to 1.50 N, but after 10 days, the value increased to 3.27 N, indicating a remarkably harder product. Similar results were obtained on a cake formulated with turmeric, with firmness values that ranged from 1.69 to 3.02 N; on cakes based on rice (Seo, Park, & Sook, 2010), with values ranged from 0.68 to 2.56 N. Incorporating different hydrocolloids modified firmness of a cake formulated without eggs and obtained values that varied from 6.86 to 13.73 N (Indrani, Ashwini, & Jyotsna, 2009). These results are similar to those obtained in our study during the first 5 days of storage.

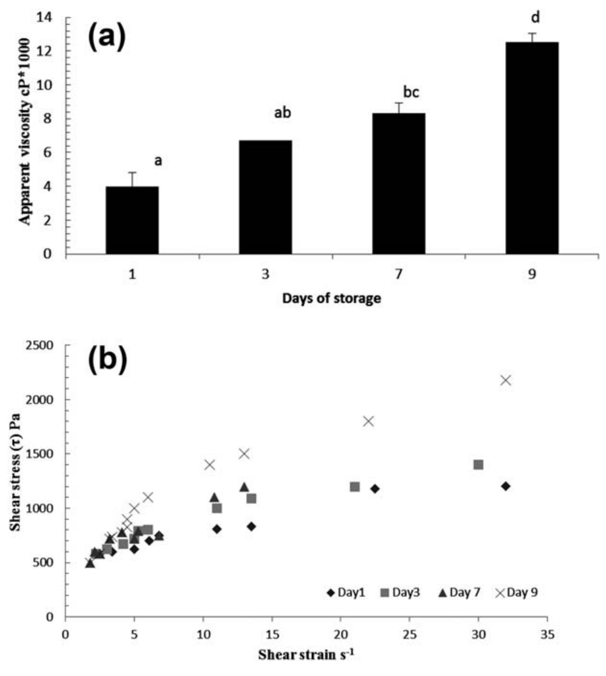

FIGURE 7 Aparent viscosity and rheological behavior of cassava-based milk drink based on cassava at 1, 3, 7, and 9 days of storage at 4 °C

3.4 | Sensorial analysis

The values for 10 descriptors of the appearance, flavor, and digital texture of the four food products developed were determined (Figure 9). The appearance of the cassava cake was mainly characterized by two descriptors, *fatty* and the *presence of a hard*, *irregular*, and *dry surface*, with scores of 6 and 4, respectively. This result indicated a product with a crunchy crust. The main descriptors of the milk drink were *bright*, *the presence of bubbles*, and *viscous*, with a score of 7 given for each descriptor. Three descriptors of the dessert, *bright*, *the presence of brown particles*, and *wet* were readily apparent; however, it was not considered *pasty*, which was advantageous because it could be easily eaten, sliding past the tongue, and easily swallowed. Only one descriptor of the ice cream received a high score, which was *hardness*, with a score of 6. The flavor descriptors are consistent with the raw materials used to prepare the cassava-based foods, as can see in Figure 10. The main flavor descriptors for the cassava cake were *sweet*, with a score of 8, *fermented*, and *coconut flavored*, with scores of 7, and *cheese*, *vanilla*, *cassava*, and *musty flavored*, with lower scores (6). These descriptors are commonly used for bakery products, which are pleasant from a sensorial point of view. The milk drink was characterized mainly by three descriptors that received scores of 7, which were sweet, milky, and vanilla flavored, whereas scores of 5 were obtained for the descriptors cooked and acidic. The dessert was described mainly as milky, with a score of 8, and other

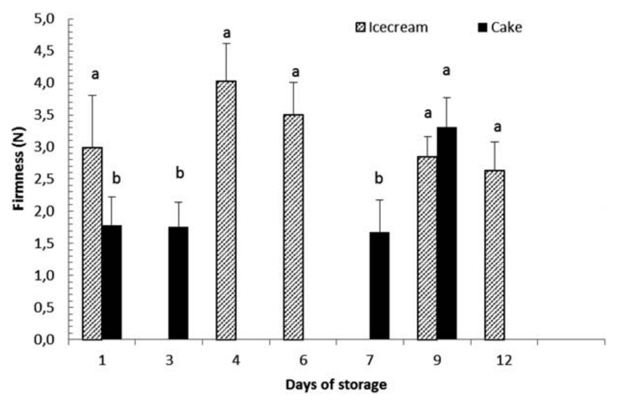

FIGURE 8 Effect of the storage time on the maximal firmness (N) of ice cream (18 °C) and cassava cake. Same letters for each food are not statistically different

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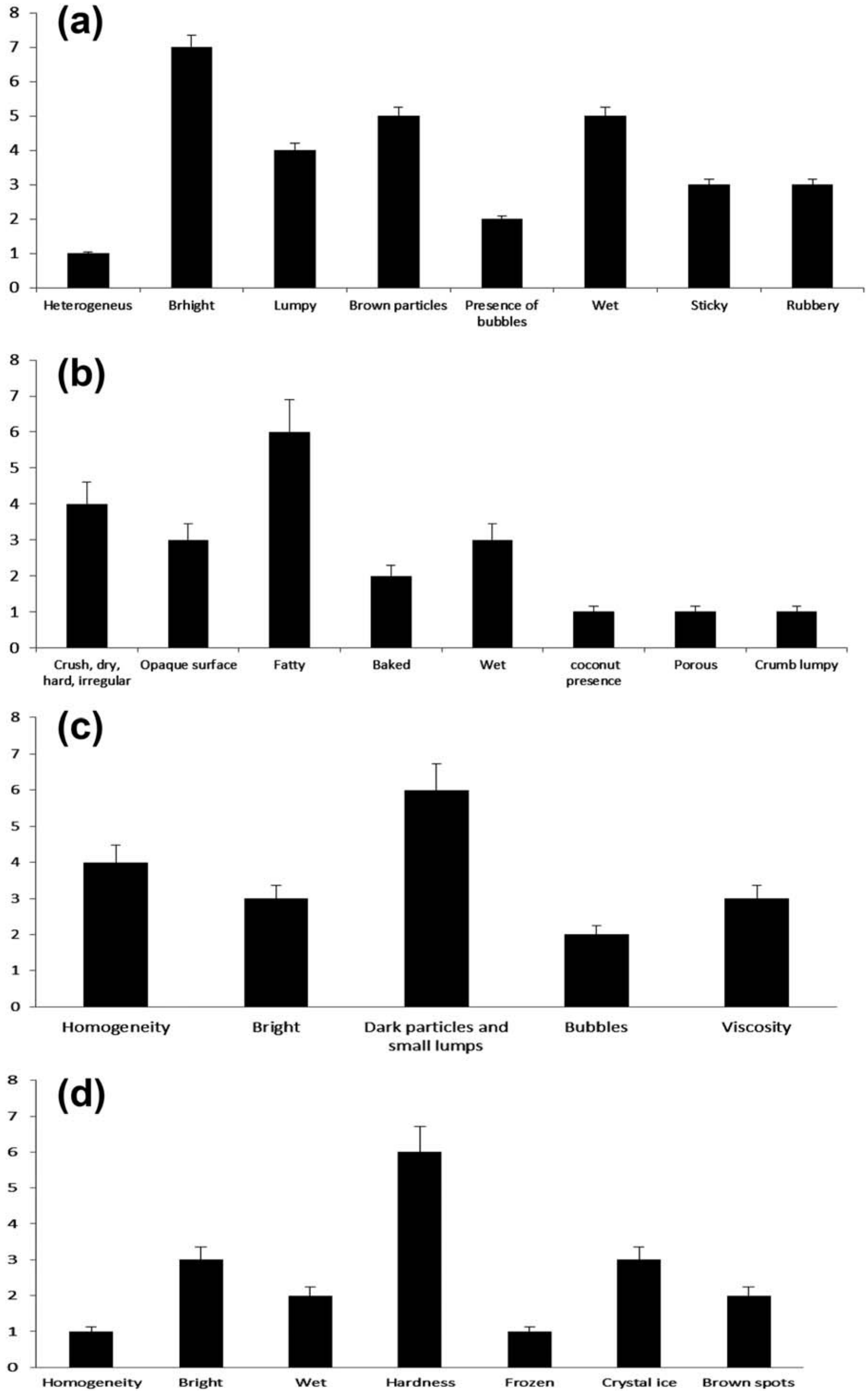

FIGURE 9 Descriptors for the appearance of the dessert (a), cassava cake (b), milk drink (c), and ice cream (d)

two descriptors, sweet and smoked, were scored as 7. This result is congruent, considering that the main ingredients after cassava were milk and sugar. The smoked flavor was due to the heating process, which induces the Maillard reaction that allows the formation of this type of flavor. The ice cream was described as sweet and milky, with flavors of cinnamon and cereal, receiving scores that ranged between 7 and 6. As seen here, cassava is almost unflavored. For this reason, the other ingredients figure strongly in the evaluations, which is advantageous because it is possible to incorporate all of the nutritional aspects of cassava without it interfering with the flavors.

4 | CONCLUSIONS

The results obtained in this study for the viscosity and the textural and sensorial attributes of different foods based on cassava are consistent with those reported by other authors, which indicated that their characteristics and behavior were typical for these types of products. The nutritional quality of the various formulations was enriched compared to similar products without cassava. Based on the consumer acceptability testing using the multidimensional approximation method, the formulated foods were acceptable products, delivering an alternative crop

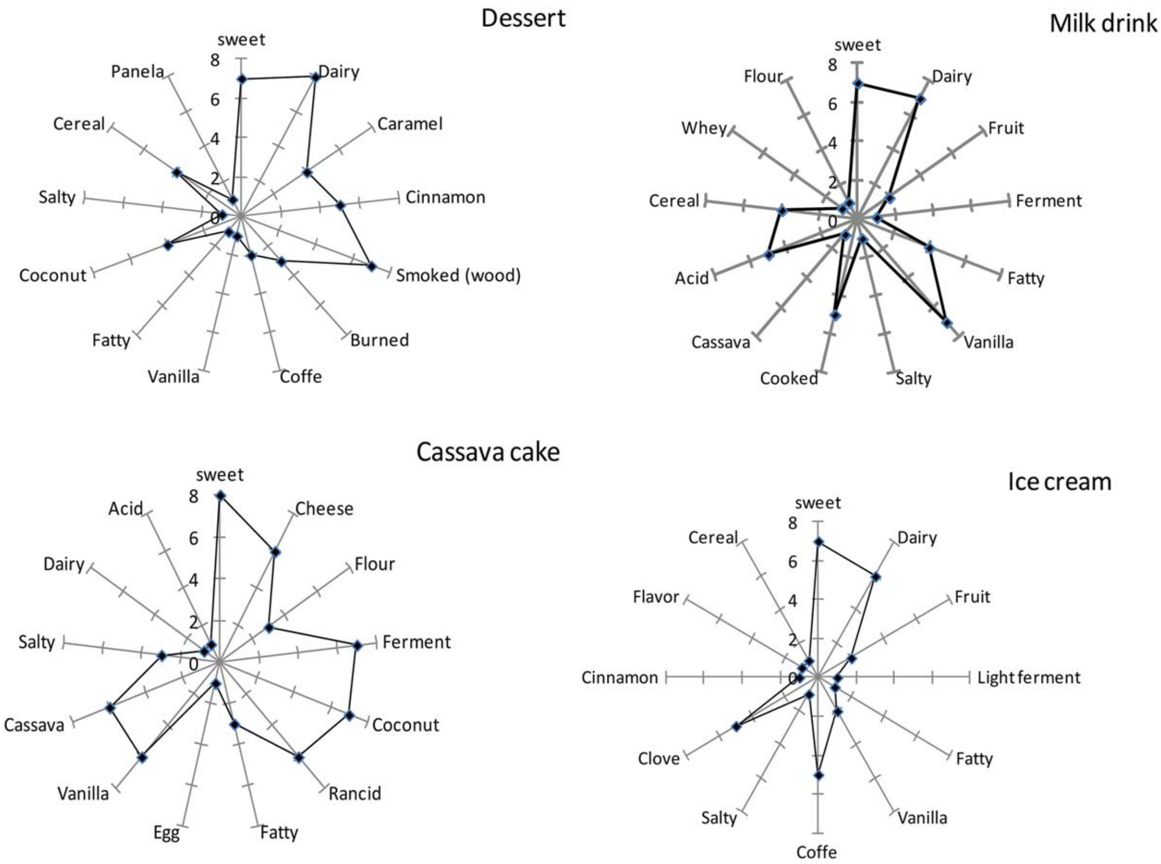

FIGURE 10 Sensory analysis of the food products developed using cassava. The flavor descriptors for the dessert, cassava cake, milk drink and ice cream

revaluation highlighting the properties of cassava and suggesting alternative value-added products of this crop. It was concluded that combining cassava with other raw materials, such as cheese, powdered milk, and flavoring, among other ingredients, following good manufacturing practices would allow the development of new products with significant nutritional value.

The novelty of this research lies in how cassava, as a fundamental food of the diet of the most vulnerable populations of developing countries, is susceptible to be transformed into a value added food, thus achieving greater diversification and better nutrition way of cassava consumption. In contrast, the present research shows a great contribution from the product standardization point of view. In addition, the product was made with raw materials of easy access for the communities in vulnerable situation, then the product can be developed within their own communities. The research is also a contribution due to the proximal characterization of cassava, both fresh and cooked and each of the products developed. Furthermore, the products were rheological and sensorially characterized. Finally, the research contributes into solving safety aspects in small communities.

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