VITAE

SHORT ARTICLE
Published 29 September 2025
DOI: https://doi.org/10.17533/udea.vitae.v32n2a359587

Effect of tuber starch type on the sensory texture profile of traditional Colombian baked products

Efecto del tipo de almidón de tubérculo en el perfil de textura sensorial de productos horneados tradicionales de Colombia

Ana Ruby Correa[a*], Diana Dix Sotelo[b], Aycardo Emilio Robayo[c], Marta Cecilia Quicazán[d]

JOURNAL VITAE
School of Pharmaceutical and Food Sciences
ISSN 0121-4004 | ISSNe 2145-2660
University of Antioquia
Medellin, Colombia

Afilliations

[a] IA. Universidad de la Amazonía. Colombia. MSc. Universidad Nacional de Colombia. Colombia. Docente. Universitaria Agustiniana. Colombia. ana.corream@uniagustiniana.edu.co.

[b] IA. Fundación Universitaria Agraria de Colombia. Colombia. Esp. Nutrición. Universidad Nacional de Colombia. Colombia. Docente. Universitaria Agustiniana. Colombia. diana.dix@uniagustiniana.edu.co

[c] AH. Universitaria Agustiniana. Colombia. Esp. Pedagogia. Universitaria Agustiniana.Colombia. Docente. Universitaria Agustiniana. aycardo.robayo@uniagustiniana.edu.co

[d] IQ, Universidad Nacional de Colombia. Colombia. PhD. Ingeniería química. Universidad Nacional de Colombia. Colombia. Docente Asociado. ICTA. Colombia. mcquicazand@unal.edu.co

****Corresponding***
Ana Ruby Correa
ana.corream@uniagustiniana.edu.co

Received: 21 January 2025
Accepted: 15 September 2025
Published: 29 September 2025

How to cite: Correa Mosquera, A. R., Dix Sotelo, D. I., Robayo Rodríguez, A. E., & Quicazan Sierra, M. C. (2025). Effect of tuber starch type on the sensory texture profile of traditional Colombian baked products. *Vitae*, *32*(3). DOI: https://doi.org/10.17533/udea.vitae.v32n2a359587

ABSTRACT

Background: This study evaluated the effect of replacing traditional cassava and maize starches with starches from arracacha, yam, and malanga on the sensory texture profile, instrumental texture parameters (TPA), color, and microstructure of four Colombian baked products: pandebono, pandeyuca, dusty cookies, and panderos. **Objective:** The aim was to determine how these alternative starches modified texture attributes and product appearance while maintaining acceptable sensory quality through adjustments in formulation and processing. A trained panel evaluated hardness, adhesiveness, fracturability, springiness, cohesiveness, gumminess, and chewiness; color was measured using the CIELAB system; texture was analyzed instrumentally; and microstructure was studied by scanning electron microscopy (SEM). **Results:** arracacha starch increased cohesiveness, adhesiveness, and chewiness in pandebonos and panderos, yam starch produced higher hardness and changes in gumminess and cohesiveness in pandeyuca, and malanga starch yielded softer and less brittle textures in dusty cookies, consistent with its lower gelatinization temperature. SEM analyses confirmed variations in starch granule distribution and size that explained the observed differences in texture. **Conclusions:** incorporation of Andean tuber starches makes it possible to diversify traditional recipes, expand the range of naturally gluten-free products, and add value to Colombian gastronomy.

Keywords: Texture Profile Analysis, sensory evaluation, Colombian baked products, starch substitution, gluten-free formulations, Andean tubers.

RESUMEN

Antecedentes: Este estudio evaluó el efecto de reemplazar los almidones tradicionales de yuca y maíz por almidones de arracacha, ñame y malanga en el perfil de textura sensorial, parámetros de textura instrumental (TPA), color y microestructura de cuatro productos horneados colombianos: pandebono, pandeyuca, galletas polvorientas y panderos. **Objetivo:** determinar cómo estos almidones alternativos modificaron los atributos de textura y la apariencia del producto, manteniendo al mismo tiempo una calidad sensorial aceptable mediante ajustes en la formulación y el procesamiento. Un panel entrenado evaluó la dureza, adhesividad, fracturabilidad, elasticidad, cohesividad, gomosidad y masticabilidad; el color se midió utilizando el sistema CIELAB; la textura se analizó instrumentalmente; y la microestructura se estudió mediante microscopía electrónica de barrido (SEM). **Resultados:** El almidón de arracacha incrementó la cohesión, la adhesividad y la masticabilidad en pandebonos y panderos; el almidón de ñame produjo mayor dureza y cambios en la gomosidad y la cohesión en pandeyuca; y el almidón de malanga produjo texturas más suaves y menos quebradizas en galletas polvorientas, en consonancia con su menor temperatura de gelatinización. Los análisis de SEM confirmaron variaciones en la distribución y el tamaño de los gránulos de almidón, lo que explicó las diferencias observadas en la textura. **Conclusiones**: La incorporación de almidones de tubérculos andinos permite diversificar recetas tradicionales, ampliar la gama de productos naturalmente libres de gluten y agregar valor a la gastronomía colombiana.

Palabras claves: Análisis de perfil de textura, evaluación sensorial, productos horneados colombianos, sustitución de almidón, tubérculos andinos.

INTRODUCTION

The main components of starch are amylose and amylopectin. These polymers are very different in their structural form; amylose has a linear structure, whereas amylopectin is branched (1). In the formulation of food products, starch is an ingredient with great advantages due to its physical, chemical, and functional properties, such as water absorption and retention capacity, solubility, gelatinization, and adhesiveness, when it is subjected to high temperatures and easy modification to optimize its functional properties (2). Starches are used in the elaboration of gluten-free baked products because of their versatility. The masses of starches expand when they are subjected to heat; this condition allows starches to mimic the texture characteristics generated by gluten in food. Foods made with starch are a good alternative for the consumption of gluten-susceptible people (3).

In Colombia, some traditional baked products are made from doughs of flour or cereal starches (rice, corn) or tubers (cassava, banana) and include fresh cheeses ('campesino' cheese, curd) and spun pasta cheeses (quesillo, double cream cheese and/or mozzarella cheese), as in the case of pandebonos, pan de yuca, rice bread, almojabanas, cheese bread, fritters, and chambray empanadas (which is a pandebono filled with guava sauce). Additionally, there is a wide variety of traditional biscuit products in which starches are protagonists (4). This is the case for panderos, a traditional cookie from the Department of Valle, which is made with cassava starch, butter, sugar, and egg and is characterized by its dusty, dry, and brittle texture (4), and dusty cookies, made with wheat flour, corn starch, margarine, and milk (5).

During the baking process, the doughs experience structural, sensory, and physicochemical changes that influence the final presentation of the product. Equally, the formation and expansion of dough structures occur because of the production of carbon dioxide and water vapor (6). Carbon dioxide is released during the fermentation process carried out by yeasts produced by baking powder. In contrast, steam production occurs when the dough is heated and the water present in the dough is vaporized. When gases are made, they are trapped in elastic networks formed by gluten and egg proteins and/or plastic networks formed by doughs of starch and egg.

During the cooking process, the starches absorb moisture and form gels, while the proteins coagulate or solidify, after which they melt, and the product's cortex is formed. The crusts in baked products appear when the water evaporates from the surface and dries. The golden color in some cortices is due to the heat that caramelizes the simple sugars present in the dough (6).

The texture is a complex property and includes many different attributes, which can be classified into three groups: geometric, mechanical, and compositional. Texture measurements can be made using instruments or sensory tests. Texture profile analysis is one of the most important methods and consists of cycles of two complete compressions with approximately 10 s between cycles. The samples are compressed at 25% of their original height, with a diameter of 75 mm with a cylindrical probe, and finally, the texture attributes are calculated: hardness, adhesiveness, cohesion, springiness, and chewiness (7).

Therefore, the sensory perception of texture is very important, as it is related to consumers' purchasing intentions. Sensorial analysis is less objective than instrumental methods and presents difficulties in obtaining and collecting data. However, they are essential for understanding the perceptions and acceptance of consumers. Panel training decreases variability in the results of sensory food evaluation. For this reason, training methodologies have been established for evaluating the texture profiles of foods (8,9).

The texture of food is perceived mainly by the sense of contact with the hands and mouth during the chewing process. Mechanical properties, such as hardness, adhesiveness, cohesiveness, and rubberiness, are measured by touching the hands, lips, tongue, and jaw. The geometric attributes and sensations related to humidity (granular, sandy, oily, dry, wet, etc.) are perceived in the skin of the hands, lips or tongue (10). In this context, this study aimed to evaluate the effects of starches from different tubers on the sensory texture profile of traditional baked products from Colombia.

MATERIALS AND METHODS

Starch extraction

The extraction of yam, malanga, and arracacha starch was carried out via the methodology of Meñano (11), and commercial cassava sweet starch was used as a control. The tubers were acquired from the market of Bogotá D.C. Corabastos S.A. They were washed, peeled, cut into small cubes, and then crushed in an industrial blender (Vitamix) at 30 rpm for 5 min. The grout was filtered through a fine 80 μm mesh opening sieve and placed to stand for 4 h. Then, the supernatant liquid was removed, and the sedimented starch was dehydrated at 50 °C for 12 h. Finally, the starch was ground, sieved, and stored until it was used.

Baked Colombian products

Four types of typical baked Colombian products were made: pandebono, pandeyuca, dusty cookies, and panderos.

Pandebono: Pandebono is a traditional baked muffin from the Department of *Valle del Cauca* made mainly with cassava starch and fresh cheese. Table 1 shows the list of ingredients used to bake traditional pandebono and the recipe variations with arracacha, yam, and malanga starches.

Table 1. Traditional recipe and recipe variations of pandebono with arracacha, yam, and malanga starches

Ingredients	g for ingredients for 100 g products			
	Traditional recipe (Cassava starch)	Arracacha starch	Yam starch	Malanga starch
Starches*	31.8	26.3	26.3	26.9
Corn starch	11.8	9.8	9.8	10.0
Farmer Cheese	45.5	37.6	37.6	38.5
Egg	10.9	12.8	12.8	13.1
Milk	0.0	13.5	13.5	11.5

*Ingredient that was varied in each formulation

For the preparation, all the ingredients (by type of starch) were placed in a blender and mixed until a homogeneous *dough* was obtained. The mixture was extracted and kneaded until a smooth product was obtained. The samples were divided into portions of approximately 20 g each, and pellets were formed. The samples were subsequently organized on a tray and baked at 210 °C for 15 min until they were larger and browned (4). Afterwards, they were allowed to cool, packed, and stored in polypropylene bags at 4 °C.

Pandeyuca: Pan de yuca is a typical baked snack of the Department of Huila made mainly with fresh cheese and cassava starch. Table 2 lists the ingredients used to bake the product according to the traditional recipe and the different variations with the arracacha, yam, and malanga starches.

Table 2. Traditional recipe and recipe variations of pan de yuca with arracacha, yam, and malanga starches.

Ingredients	g for ingredients for 100 g products			
	Traditional recipe (maize starch)	Arracacha starch	Yam starch	Malanga starch
Farmer Cheese	53.0	50.8	51.7	51.7
Starch*	26.8	25.7	26.2	26.2
Egg	12.8	12.2	12.5	12.5
Milk	6.4	10.4	8.7	8.7
Baking powder	0.6	0.6	0.6	0.6
Sugar	0.3	0.3	0.3	0.3

*Ingredient that was varied in each formulation

For the preparation of the pan de yuca (different mixtures were made for each type of starch), all the ingredients were mixed in a blender until a smooth product was obtained. The mixture was extracted, kneaded and allowed to stand for 10 min. The dough was cut into 20 g portions, and pieces with half-moon kneads were molded, placed on a tray and baked at 170 °C for 15 min. The doughs were allowed to cool, packed and stored in polypropylene bags at 4 °C.

Dusty cookies: These are typical of the cundiboyacense region and are made mainly with cornstarch, sugar, and margarine. Table 3 lists the ingredients used for the preparation of traditional "dusts" and the variations of the recipe with arracacha, yam, and malanga starches.

Table 3. Traditional recipe and recipe variations of dusty cookies with arracacha, yam, and malanga starches.

Ingredients	g for ingredients for 100 g products			
	Traditional reci-pe (maize starch)	Arra-cacha starch	Yam starch	Malanga starch
Starch*	-	14.4	14.4	14.4
Cornstarch	48.0	33.6	33.6	33.6
Wheat flour	4.8	4.8	4.8	4.8
Sugar	17.2	17.2	17.2	17.2
Margarine	17.2	17.2	17.2	17.2
Egg	7.2	7.2	7.2	7.2
Milk	4.6	4.6	4.6	4.6
Fennel essence	0.9	0.9	0.9	0.9

*Ingredient that varied in each formulation.

For the preparation, all ingredients (one mixture for each type of starch) were kneaded, the dough was allowed to stand for 10 min, and finally, pieces of the dough (approximately 15 g) were taken, and cylinders were formed by hand and flattened with fingertips. The product was organized on a tray and baked at 170 °C for 15 min. The products were allowed to cool, packed, and stored in polypropylene bags at 19 °C.

Panderos: These are cookies characterized mainly by their dusty and soft texture. They are traditionally made with cassava starch in the Department of Huila. Table 4 contains the list of ingredients used to bake traditional panderos and variations of the recipe with arracacha, yam, and malanga starches.

Table 4. Traditional recipe and recipe variations of panderos with arracacha, yam, and malanga starches.

Ingredients	g for ingredients for 100 g products			
	Traditional recipe (Cassava)	Arracacha starch	Yam starch	Malanga starch
Starch	39.4	39.4	39.4	39.4
Cornstarch	13.1	13.1	13.1	13.1
Sugar	15.8	15.8	15.8	15.8
Butter	15.8	15.8	15.8	15.8
Egg	10.5	10.5	10.5	10.5
Milk	3.8	3.8	3.8	3.8
Baking powder	1.1	1.1	1.1	1.1
Fennel essence	0.5	0.5	0.5	0.5

*Ingredient that was varied in each formulation

For the preparation, all the ingredients were kneaded manually (a mixture for each type of starch), the dough was allowed to stand for 10 min, and finally, pieces of the dough of approximately 15 g were taken, pellets formed by hand, and flattened with fingertips. The product was placed on a tray and baked at 170 °C for 15 min. The dough was allowed to cool, packed, and stored in polypropylene bags at room temperature (19 °C).

Recruitment of panels

A total of 25 people between 28 and 42 years of age were recruited from Agustiniana University in Bogotá D.C., Colombia, including teachers and support staff from the gastronomy program. None of the participants had previously received training in sensory food analysis. The group consisted of 14 women and 11 men.

All interested candidates completed a screening form designed to gather information on health conditions and lifestyle factors that could interfere with sensory analysis. The form included questions on visual, olfactory, or gustatory disorders; work schedules and availability to attend training sessions; motivation and interest in joining the panel; prior training in sensory analysis; frequency of food consumption; intake of coffee, alcoholic beverages, and spicy foods; as well as any other conditions that might affect sensory perception.

After this initial screening, candidates completed tests for the identification of basic tastes (sweet, acid, bitter, salty, and umami), recognition of main colors (yellow, red, blue, green, and purple), and common odors (pepper, cumin, cloves, cinnamon, detergent, alcohol, ground coffee, chocolate, and tea). Additionally, ordering tasks were conducted to evaluate the ability to rank basic tastes (sweet, salty, bitter, and sour by intensity). Participants who obtained a score above 80% in these tests were selected to continue, resulting in 15 sensory judges, following the procedure described by Vivas & Sangronis (12).

Inclusion criteria were: (i) self-reported normal taste and smell conditions based on the screening form; (ii) availability to attend all training and evaluation sessions; and (iii) absence of allergies to the products used. Exclusion criteria included: (i) medical conditions or treatments that could interfere with sensory perception; (ii) regular use of medications affecting taste or smell; (iii) respiratory infections during the study; and (iv) absence from more than two training sessions.

The researchers did not consider it necessary to submit the sensory evaluation to an ethics committee for approval, as the study involved only non-invasive food tests that posed no risk to the participants. Nevertheless, all panelists voluntarily signed an informed consent form before participating, and data management was conducted in accordance with the data protection regulations established by Colombian law and the policies of the hosting university, as well as the training provided for the panel in sensory evaluation of texture.

The training was carried out over four consecutive weeks, with daily sessions from Monday to Friday, each lasting approximately 60 to 90 minutes, for a total of 20 sessions. The program followed the guidelines of the Colombian Technical Standard NTC 4489 (8) and included both theoretical discussions and practical demonstrations of the techniques used to evaluate texture attributes.

During the process, panelists were introduced to the definitions and evaluation procedures for mechanical attributes (hardness, adhesiveness, cohesiveness, chewiness, gumminess, springiness, and fracturability), geometric attributes (size, shape, and particle orientation), and attributes related to moisture and fat perception. The reference samples used for calibration were selected according to the recommendations of NTC 4489, and the complete list of products, preparation details, portion sizes, and serving conditions is presented in Table 5.

To ensure reliability, panelists repeatedly evaluated the reference samples under controlled conditions, recording attribute intensities according to the agreed descriptive scales. At the end of the training period, duplicate evaluations of selected samples were performed to assess intra-assessor repeatability. At the same time, inter-assessor agreement was verified using two-way ANOVA and simple discrimination tests. These procedures confirmed that the panel achieved an acceptable level of repeatability and consensus in evaluating texture attributes, ensuring that the group was calibrated correctly to assess the experimental baked products.

Table 5. List of foods used in each of the texture attribute scales

Product	Brand, type of preparation	Manufacturer	Sample size	Temperature
		Hardness		
Cream cheese	Colanta	Fresh, soft	5 g Teaspoon	7°C a 13 °C
Egg White	Hard, cooked 5 min		1,25 cm cube	Room
Frankfurtes	JBO	Medium, not cooked and without skin	1,25 cm slice	10°C - 18°C
Cheese	Paipa Cheese Camporeal	Craft and semihard	1,25 cm cube	7°C a 13 °C
Olives	JBO	Boneless olives	Half Unity	Room
Peanuts	La Especial	Peanuts with light sodium salt	3 nuts	Room
Carrots	uncooked, fresh		1,25 cm slice	Room
Hard candy	Super coco	Natural coconut turron	Unity	Room
		Adhesiveness		
Hydrogenated vegetable oil	Rama		1,25 cm cube	Room
Masa de biscocho	Biscuit dough	55% flour paste	5 g Teaspoon	Room
Cheese cream	Colanta	Fresh, soft	5 g Teaspoon	7°C a 13 °C
Marshmallow topping		Flavored jelly and glucose syrup	5 g Teaspoon	7°C a 13 °C
Peanut butter		Soft	5 g Teaspoon	Room
		Chewiness		
Rye bread			1,25 cm cube	Room
Frankfurters	JBO	Medium, not cooked, and without skin	1,25 cm slice	10°C - 18°C
Chewing Gum	Clichet`s		Unity	Room
Steak		With onion	1,25 cm cube	60 °C
Chewing Gum	Adams			
Peannut	La Especial	Peanuts with light sodium salt	3 nuts	Room
Melcocha		Craft	1,25 cm cube	Room
		Gumminess		
40% flour paste	Haz de oro		1 tablespoon	Room
45% flour paste	Haz de oro		1 tablespoon	Room
50% flour paste	Haz de oro		1 tablespoon	Room
55% flour paste	Haz de oro		1 tablespoon	Room
60% flour paste	Haz de oro		1 tablespoon	Room

Product	Brand, type of preparation	Manufacturer	Sample size	Temperature
		Fracturability		
Corn muffins	Ramo	Colaziones	Unity	Room
Angel fritters	JBO	Laminated	Unity	Room
Cookies	Ducales	Laminated	Unity	Room
Toasted	Guadalupe		Unity	Room
Hazelnuts cookies	Tosh	Rounded	Unity	Room
Ginger cookies	Grajales		Unity	Room
Turrons	Super coco	Natural coconut turron	Unity	Room
		Springiness		
Cream cheese	Colanta	Fresh, soft	5 g Teaspoon	7°C a 13 °C
Frankfurt Sausage	JBO	Medium, not cooked and without skin	1,25 cm slice	10°C - 18°C
Mashmellows	Millows		3 cm Unity	Room
Jelly	Frutiño	Craft made	1,25 cm cube	7°C a 13 °C
		Cohesiveness		
Corn bread	Ramo			
Cheese	Queso Paipa Camporeal	Craft and semihard	1,25 cm cube	7°C a 13 °C
Sandwich White bread	Guadalupe		1,25 cm cube	Room
Cookies	Ducales	Laminated	Unity	Room
Driedfruits		Raisins	Twounities	Room
Chewablefruit		Chilean grapes	Unity	Room
Candy		Milkcandy	1,25 cm cube	Room
Chewgum	Adam`s			

Source: NTC 4489 (8)

Fifteen trained panelists evaluated each sample, and each texture attribute (hardness, cohesion, viscosity, springiness, and adhesiveness) was rated on an 8-point scale, where 1 corresponded to low intensity and 8 to high intensity. At the beginning of each session, all the members of the panel received written instructions including the definitions of each attribute (Table 6), the operational procedures for their evaluation, and the way the assessment should be performed in the mouth. After reading the instructions, participants were allowed to demonstrate the evaluation of each attribute. To ensure consistency and accurate understanding, the instructions and definitions were made available throughout all training sessions and formal assessments.

Table 6. Texture attribute definitions

Attributes of texture	Sensory definition
Hardness	Force required to obtain a deformation or penetration of a product.
Adhesiveness	The force required to remove material that adheres to the mouth or a substrate.
Chewiness	Corresponds to the time or number of chews required to masticate a solid product until it is ready to swallow.
Gumminess	It is related to the effort required to disintegrate the product until it is ready to swallow.
Fracturability	Force is required to break a product into crumbs or pieces.
Springiness	It is related to the speed of recovery of a deforming force and the degree to which a deformed material returns to its non-deformed condition after removing the deformation force.
Cohesiveness	It is related to the degree to which a substance can deform before breaking.

Source: NTC 4489 (8)

COLOR ANALYSIS

Baked products were evaluated for color via the Hunter LAB color scale, CIELAB L* a* b, where L* indicates luminosity, a* indicates chromaticity on the green (–) and red (+) axes, and b* indicates chromaticity on the blue (–) and yellow (+) axes. For this purpose, a colorimeter, MiniScan Spectro colorimeter Hunter-Lab, model MS/B, with diffuse geometry, was used. Each value represents an average value of three repeated determinations. In addition, the total color difference (ΔE) was calculated according to the CIELAB formula (Equation 1), taking the traditional formulation of each product as the control.

$$\Delta E = \sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]} \quad \text{Equation 1.}$$

Microstructure analysis

A small amount of the baked product (less than 10 mg) was mounted on an SEM holder and metallized by coating with a layer of gold. The samples were examined with an FEI Quanta 200 scanning electron microscope (Hillsboro, USA), which was bombarded with a beam of electrons at an acceleration voltage between 15 kV in the vacuum chamber where the samples were placed and a working distance (WD) of 11.9 mm. Different images were taken at magnitudes of 500X and an amplitude of 100 µm (13).

Analysis of texture

A texture analysis profile (TPA) was carried out for the pandebono and cassava bread samples, in which hardness, fracturability, cohesiveness, adhesiveness, springiness, chewiness, and gumminess were determined via a texture analyzer TA-XT2i Texture Analyzer (Stable Micro Systems Ltd.). The samples were compressed to 50% of their original height with a 75 mm probe, with a force of 0.049 N and a speed of 4 mm/s. The hardness and fracturability of powdery cookie samples were determined via a TA-XT2i texture analyzer (Stable Micro Systems Ltd.). The samples were compressed with a force of 50 g, depth of 15 mm, and speed of 3 mm/s according to Vivas & Sangronis (12).

Statistical analysis

Statistical analyses were conducted using ANOVA to evaluate the effect of starch type on color and texture parameters. Before the study, data were tested for normality (Shapiro–Wilk test) and homogeneity of variances (Levene's test). When assumptions were met, ANOVA was applied, followed by Tukey's test to identify differences between means. The significance level was set at $\alpha = 0.05$. All analyses were performed using Minitab 1.8 software. Additionally, correlation analyses (Pearson) and a Principal Component Analysis (PCA) were conducted to explore the relationships among sensory attributes, instrumental texture parameters, and color values.

RESULTS

Baked Colombian products

The appearance of the baked Colombian products that the panelists evaluated is shown in Figure 1. Each participant ate one unit of each product for the sensory evaluation of the texture profile. The appearance and presentation of each product approached the products of the original recipe.

Figure 1. I: pandebono, II: pandeyuca, III: dusty cookies, IV: panderos, A: traditional recipe, B: yam starch, C: Malanga starch, and D: arracacha starch.

Bulk product sensory texture profile

The responses of each of the texture attributes evaluated by the panelists in the cooked Colombian goods were recorded, and the weighted average was reported.

Pandebono: The type of starch significantly changed the springiness, cohesiveness and chewiness of the pandebono (Table 7). Arracacha starch presented the greatest difference. This may be because arracacha starches have a lower amylopectin content (69.88%) than the amylopectin content of corn starch (72.4%) (14), and this condition increases water retention in starch granules, increasing springiness and cohesiveness. Pandebonos are characterized by being a non-fracturable bread with medium rubberiness, hardness, and adhesiveness; having an airy orientation structure; and having a perception of dry food without lipid sensations in the mouth. These texture properties were not affected by the type of starch used in its preparation. It could become an opportunity for different regions of Colombia to offer traditional baked products in their local markets, using the starches of the tubers grown in each area as raw material.

Table 7. Sensory texture profile of pandebono made with different starches

Attributes of texture	Starches			
	Cassava	Arracacha	Yam	Malanga
Hardness	4.5±1.6[a]	4.1±1.3[a]	4.1±1.3[a]	4.4±1.3[a]
Fracturability	2.5±1.3[a]	2.9±1.0[a]	2.8±1.0[a]	3.7±1.6[b]
Adhesiveness	1.7±1.5[a]	2.7±1.5[b]	3.2±0.7[c]	2.9±0.7[b]
Springiness	2.6±0.7[a]	2.0±1.3[a]	2.0±0.7[a]	2.2±0.7[a]
Cohesiveness	3.1±1.0[a]	3.4±1.3[a]	4.8±0.7[b]	4.5±1.6[b]
Gumminess	2.7±1.3[a]	3.4±1.3[b]	3.5±1.3[b]	2.9±1.6[a]
Chewiness	2.5±0.7[a]	3.0±1.3[a]	2.9±0.7[a]	3.2±0.7[a]

Values correspond to sensory scores obtained on an 8-point intensity scale, where 1 indicates low intensity and 8 indicates high intensity. The data are expressed as the means ± standard deviations (n=15). Values with different letters in the same row indicate significant differences.

Pandeyuca: Reported that yam starch caused significant variations in the texture profile of breads that are traditionally made with cassava. Breads made with yam starch presented greater hardness, lower rubberiness, springiness, and cohesiveness (Table 8) and significantly changed color (Figure 1-IIB). The color change may be due to the oxidation of the yam pieces during the starch extraction process (15). The changes in the texture profile could be due to the high content of starch amylose in yam (24.08%) (16) compared with the content of amylose in cassava starch (17.0%) (17). The high content of amylose in yam starch causes the gelling temperature of yam starch (84.2 °C) to be much higher than the temperature of cassava starch (64 °C) (16), and water retention is greater in yam starch. Therefore, adjusting the baking temperature and increasing the moisture content of the pandeyuca when they are made with yam starch are necessary.

Table 8. Sensory texture profile of pandeyuca made with different starches

Attributes of texture	Starches			
	Maize	Arracacha	Yam	Malanga
Hardness	3.4±1.0[a]	4.4±1.6[b]	4.0±1.6[b]	4.5±1.3[b]
Fracturability	3.1±1.3[a]	2.5±1.3[b]	3.5±0.7[a]	3.9±1.9[a]
Adhesiveness	3.6±2.0[a]	1.4±0.7[b]	3.6±1.4[a]	3.6±1.4[a]
Springiness	1.6±1.0[a]	1.7±1.0[a]	1.9±1.3[a]	1.7±1.0[a]
Cohesiveness	6.5±1.0[a]	4.5±1.3[b]	6.4±1.6[a]	6.5±1.0[a]
Gumminess	3.9±1.3[a]	2.2±1.0[b]	3.8±1.0[a]	3.7±1.0[a]
Chewiness	3.4±1.3[a]	2.6±1.0[b]	4.0±1.0[c]	3.3±1.0[a]

Values correspond to sensory scores obtained on an 8-point intensity scale, where 1 indicates low intensity and 8 indicates high intensity. The data are expressed as the means ± standard deviations (n=15). Values with different letters in the same row indicate significant differences.

Dusty cookies: Dusty cookies made with arracacha starch presented greater changes in their sensory texture profile than traditional dusty cookies made with cornstarch. The dust samples with arracacha presented greater hardness because the cookies were very compact; therefore, they were much more brittle than overflowing, as expected (Table 9). Both the cookies of arracachas and those of yam presented a crack in their structure, as shown in Figure 1, due to the low moisture that they could have presented during the elaboration process. The changes in the texture of the dusty starches were influenced by the greater water absorption capacity of the arracacha and yam starches (16). The rheological and functional behavior of malanga starch, especially its low gelation temperature (54 °C), gives this product the possibility of being included in preparations with lower baking temperatures (18).

Table 9. Sensory texture profile of dusty cookies made with different starches

Attributes of texture	Starches			
	Maize	Arracacha	Yam	Malanga
Hardness	2.4±1.3[a]	2.5±1.3[a]	2.4±1.0[a]	5.3±1.0[b]
Fracturability	2.4±0.7[a]	1.7±1.3[b]	1.7±1.2[b]	5.6±1.3[c]
Adhesiveness	1.1±0.7[a]	1.1±0.7[a]	1.1±0.7[a]	1.2±0.7[a]
Springiness	2.5±0.7[a]	2.8±0.7[a]	2.2±1.0[a]	2.0±0.7[a]
Cohesiveness	2.2±1.0[a]	2.1±1.0[a]	2.2±1.3[a]	5.5±1.0[b]
Gumminess	1.1±0.7[a]	1.1±0.7[a]	1.1±0.7[a]	1.2±0.7[a]
Chewiness	2.1±0.7[a]	1.9±1.3[a]	1.9±0.7[a]	3.1±1.3[b]

Values correspond to sensory scores obtained on an 8-point intensity scale, where 1 indicates low intensity and 8 indicates high intensity. The data are expressed as the means ± standard deviations (n = 15). Values with different letters in the same row indicate significant differences.

Panderos: Panderos made with arracacha starch presented the greatest changes in the sensory texture profile. These compounds exhibited greater cohesiveness, adhesiveness, and fracturability, as well as the lowest chewable value, as shown in Table 10. This occurred because, compared with cassava starch, arracacha starch has a lower gelation temperature and a high-water absorption capacity (19). Therefore, the process of making panderos with arracacha starch requires more moisture.

Table 10. Sensory texture profile of panderos made with different starches

Attributes of texture	Starches			
	Cassava	Arracacha	Yam	Malanga
Hardness	4.6±1.3[a]	4.7±1.3[a]	4.4±1.6[a]	4.6±1.0[a]
Fracturability	2.6±0.7[a]	2.6±1.6[a]	2.3±1.3[a]	2.3±1.0[a]
Adhesiveness	1.6±0.0[a]	1.8±0.7[a]	1.8±0.7[a]	1.5±0.7[a]
Springiness	2.4±1.3[a]	1.8±1.3[b]	2.1±1.0[a]	2.0±1.0[a]
Cohesiveness	2.6±1.3[a]	2.4±1.0[a]	2.7±0.7[a]	2.6±0.7[a]
Gumminess	2.3±1.3[a]	2.6±0.7[a]	2.7±0.7[a]	2.3±1.0[a]
Chewiness	1.7±1.0[a]	2.0±0.7[b]	2.4±1.0[b]	2.1±1.0[b]

Values correspond to sensory scores obtained on an 8-point intensity scale, where 1 indicates low intensity and 8 indicates high intensity. The data are expressed as the means ± standard deviations (n=15). Values with different letters in the same row indicate significant differences.

Texture profile analysis (TPA)

Pandebono: Products made with arracacha starch and yam starch were the hardest, stickiest, and most fracturable, while those made with cassava and malanga starch were slightly softer and more cohesive. Although no significant differences were observed in the TPA, the moisture retention capacity of each starch can influence the texture measurements of the products. Pandebonos are Colombian pastries where the fluffy, firm, and soft textures appreciated sensorially are generated by the moisture from the fresh cheeses used in their preparation, as shown in Table 11.

Table 11. Texture parameters according to TPA for Pandebono

Attributes of texture	Starches			
	Maize	Arracacha	Yam	Malanga
Hardness (N)	4907±421[a]	14149±2820[b]	17352±4530[b]	4609±1331[a]
Fracturability (N)	3149±883[a]	4005±423[a]	4107±0.0[a]	2525±543[b]
Adhesiveness (g)	-0.761±0.0[a]	-1.39±0.25[b]	-0.98±0.58[a]	-0.576±0.74[a]
Springiness	0.84±0.09[a]	0.74±0.03[a]	0.80±0.08[a]	0.77±0.06[a]
Cohesiveness	0.56±0.06[a]	0.44±0.08[a]	0.51±0.10[a]	0.52±0.05[a]
Gumminess (N)	2763±542[a]	6268±354[b]	9097±4001[c]	2379±659[a]
Chewiness (N)	2334±710[a]	4632±498[a]	7423±3946[a]	1831±918[a]

The data are expressed as the means ± standard deviations (n=3). Values with different letters in the same row indicate significant differences.

Pandeyuca: The texture analysis of bread made with cassava, arracacha, yam, and malanga starches reveals significant variations that influence product acceptance (Table 12). Malanga bread is the hardest and most gummy, indicating a dense structure, while arracacha bread presents a softer and lighter texture, possibly more appealing to consumers. In terms of fracturability, cassava and malanga bread show good breaking capacity, in contrast to the homogeneity of arracacha and yam. Adhesiveness is low across all samples, although yam bread is the stickiest, which may affect the consumption experience. Regarding springiness, yam bread stands out for its recovery ability, suggesting a fluffy texture.

The cohesiveness of arracacha bread is notable, favoring crumb formation. The gumminess of malanga bread, which requires more chewing effort, contrasts with the softness of arracacha, making it easier to consume. These differences not only affect perceptions of freshness and quality but are also crucial for market positioning, making it essential for producers to understand these variations to develop products that meet consumer preferences.

The texture profile of cassava bread is fundamental to its acceptance and popularity, mainly due to the unique properties of cassava starch, which include its gelatinization capacity and elastic texture. According to Hernández (17), cassava starch has a high gelatinization index and notable moisture retention capacity, resulting in a soft and fluffy crumb, ideal for this type of product. This behavior contrasts with other starches, such as corn, which, as indicated in the study by Dhital (14), can produce a denser and less airy texture in baked goods, negatively affecting the quality of cassava bread.

Replacing cassava starch with alternative starches, such as arracacha or malanga, could have significant implications. For example, arracacha starch tends to generate a gumminess, as detailed in the research by Vera (3), which could result in a bread that is less light and fluffy, altering the traditional sensory experience that consumers expect. Similarly, while malanga starch presents interesting functional properties, it may affect the cohesiveness and springiness of the crumb, potentially making the bread less appealing to those who value the soft and fluffy texture of the original cassava bread.

Moreover, any change in the texture profile could have cultural repercussions. Cassava bread is not just food; it is a symbol of the culinary identity of many regions in Colombia. Texture is a crucial factor in food perception, and as noted by Meilgarrd (10), consumer acceptance is strongly influenced by textural characteristics. Therefore, a change in the traditional texture could be viewed as an alteration of a gastronomic legacy, leading to resistance from consumers.

Table 12. Texture parameters according to TPA for Pandeyuca

Attributes of texture	Starches			
	Cassava	Arracacha	Yam	Malanga
Hardness (N)	12127±52ª	8334±286ᵇ	15385±1463ª	24939±1305ᶜ
Fracturability (N)	7892±0ª	0.0±0.ᵇ	0.0±0ᵇ	9402±0ª
Adhesiveness (g)	-1.25±1.07ª	-0.78±0.19ª	-5.07±0.59ᵇ	-1.97±2.42ª
Springiness	0.52±0.04ª	0.55±0.31ª	0.68±0.18ª	0.61±0.39ª
Cohesiveness	0.38±0.29ª	0.50±0.22ª	0.38±0.09ª	0.42±0.24ª
Gumminess (N)	5086±4609ª	4610±2933ª	6459±686ª	11978±1149ᵇ
Chewiness (N)	2734±2694ª	2543±244ª	4978±579ᵇ	9512±1163ᶜ

The data are expressed as the means ± standard deviations (n=3). Values with different letters in the same row indicate significant differences.

The texture evaluation results of dusty cookies and panderos, made with various starches, show notable differences in hardness and fracturability. Yam cookies exhibit the highest hardness and fracturability, followed by those made from maize and arracacha, while malanga cookies are the softest and least brittle. On the other hand, panderos made with arracacha starch are the hardest, showing similar performance to the cookies, whereas those made with cassava and yam are softer. These texture differences are crucial for consumer acceptance, as crunchy cookies may be preferred in certain contexts, while the softness of panderos can offer a more comforting experience. In the context of Colombian gastronomy, these products are fundamental not only for their cultural value but also for the opportunities they present to utilize starches from local tubers, such as cassava, yam, and arracacha. Promoting the use of these ingredients not only helps preserve culinary traditions but can also stimulate the local economy by diversifying the food supply and encouraging the consumption of indigenous products, thereby strengthening the country's gastronomic identity.

Table 13. Texture parameters according to TPA for dusty cookies and panderos

Products	Starches	Hardness (N)	Fracturability (N)
Dusty cookies	Maize	3373±453ª	9.71±0.28ª
	Arracacha	2919±231ª	9.43±1.2ª
	Yam	5193±610ᵇ	17.24±3.85ᵇ
	Malanga	2444±305ª	8.66±0.38ª
Panderos	Cassava	1404±518ᶜ	8.61±0.03ª
	Arracacha	3224±0ª	9.03±0.0ª
	Yam	1574±608ᶜ	8.65±0.54ª
	Malanga	3168±105ª	10.77±0.02ª

The data are expressed as the means ± standard deviations (n=3). Values with different letters in the same column indicate significant differences.

Color

In Table 14, the results of color and texture parameters in the preparation of Colombian amasijos such as pandebono, pandeyuca, dusty cookies, and panderos reveal significant differences when using starches from arracacha, yam, and malanga compared to traditional recipes. For pandebono, the luminosity (L*) remains relatively constant between the traditional recipe and that of arracacha. Still, it increases with the use of yam and malanga starch, producing a variation clearly perceptible to consumers. The a* value shows a marked decrease with these starches, reflecting a reduction in red hues. In contrast, the b* value remains stable, with subtle shifts in the yellow tone that may nonetheless affect visual perception (20). In general, ΔE values above 3 are considered perceptible to the human eye, and values above 5 are regarded as clearly noticeable. Several starch substitutions in this study exceeded these thresholds, confirming that the observed color differences are not only statistically significant but also visually relevant to consumers.

Table 14. Color parameters according to CIELAB

Parameters		Traditional recipe	Arracacha starch	Yam starch	Malanga starch
Pandebono	L*	66.88±0.72ª	67.39±0.08ª	76.61±0.53ᵇ	76.23±0.08ᵇ
	a*	9.88±0.16ª	9.77±0.08ª	5.81±0.11ᵇ	5.73±0.08ᵇ
	b*	29.59±0.06ª	29.55±0.08ª	30.05±0.37ª	29.78±0.08ª
	ΔE	1.02±0.26ª	0.52±0.09ᶜ	10.56±1.23ᵇ	10.23±1.52ᵇ
Pandeyuca	L*	69.60±0.12ª	69.22±0.18ª	56.50±3.61ᵇ	65.94±0.69ª
	a*	9.07±0.01ª	6.99±0.02ᵇ	12.32±2.73ᶜ	11.19±0.33ᶜ
	b*	32.63±0.11ª	27.26±0.08ᵇ	34.97±3.19ª	34.84±0.66ª
	ΔE	0.12±0.00ª	5.78±0.07ᵇ	14.16±2.19ᶜ	4.77±0.98ᵇ
Dusty cookies	L*	75.38±1.39ª	74.54±0.08ª	69.59±1.05ᵇ	71.78±0.88ᵇ
	a*	3.91±1.14ª	4.17±0.08ª	5.21±0.71ª	4.78±1.06ª
	b*	29.09±1.41ª	29.61±0.08ª	28.98±0.70ª	28.86±1.98ª
	ΔE	1.85±0.80ª	1.02±0.06ª	5.98±1.19ᵇ	4.12±1.0ᵇ
Panderos	L*	72.08±1.08ª	69.93±1.37ª	69.39±1.24ª	52.70±1.91ᵇ
	a*	7.02±0.56ª	9.46±0.57ᵇ	10.02±0.98ᵇ	16.47±0.47ᶜ
	b*	32.11±0.70ª	34.05±0.10ª	34.14±0.12ª	33.28±0.50ª
	ΔE	1.08±0.48ª	3.89±0.99ᵇ	4.51±0.65ᵇ	21.60±1.94ᶜ

The data are expressed as the means ± standard deviations (n=3). Values with different letters in the same row indicate significant differences.

In pandeyuca, arracacha starch significantly reduces luminosity compared to the traditional version, potentially resulting in a less visually appealing product. Yam starch generates the most pronounced differences, associated with both lower luminosity and greater redness, while malanga starch enhances the yellow tone. These variations highlight how the type of starch modifies the characteristic visual attributes of pandeyuca.

Dusty cookies present moderate but consistent variations. Luminosity is higher with arracacha starch compared to yam starch. Although the a* values are similar across all samples, the color differences are still perceptible, even if subtle. The b* value remains within similar ranges, indicating that the yellow coloration is large (21).

In the case of panderos, the color analysis shows clear differences. Luminosity is considerably lower in those made with malanga starch, resulting in a darker appearance that is easily recognizable by consumers. The a* value is higher in samples with arracacha and yam starch, indicating a redder hue that could be appealing. In contrast, malanga starch produced a darker shade often associated with more intense baking (22).

Overall, the results demonstrate that starch type produces color differences that are not only statistically significant but also perceptible to consumers. The analysis of color parameters provides a deeper understanding of how the choice of starch impacts both the texture and appearance of the final product, with direct implications for market acceptance. Previous studies have shown that color and texture are determinants in consumer perception, where luminosity and hue influence expectations of quality and freshness in amasijos (14).

Analysis microstructure

The scanning electron microscopy (SEM) images of starch granules in different amasijos reveal significant variations in granule structure depending on the type of product and starch used (Figure 11).

In image I, corresponding to pandebono, a uniform distribution of starch granules is observed, suggesting good gelatinization and cohesion in the mixture. These characteristics contribute to its airy and light texture. This structure aligns with previous studies indicating that well-gelatinized starch facilitates the formation of a more aerated crumb (14).

Image II, representing cassava bread, shows larger and less homogeneous starch granules. This may be related to the nature of cassava starch, which tends to form a denser and more compact texture due to its ability to retain moisture, resulting in a moister crumb (12).

In image III, corresponding to dusty cookies, the starch granules are smaller and less defined, indicating that the starch has disintegrated more during the mixing and cooking process. This characteristic may be responsible for the crispy and light texture of the cookies, as documented in previous research highlighting the effect of granule fragmentation on the final texture of baked products (21).

Finally, in image IV, which represents panderos, larger and more heterogeneous starch granules are noted. This suggests a less efficient interaction between the components of the dough, potentially resulting in a denser and less airy crumb. Previous studies indicate that the texture and homogeneity of the dough directly influence bread quality, where a less uniform structure may negatively affect consumer acceptance (22).

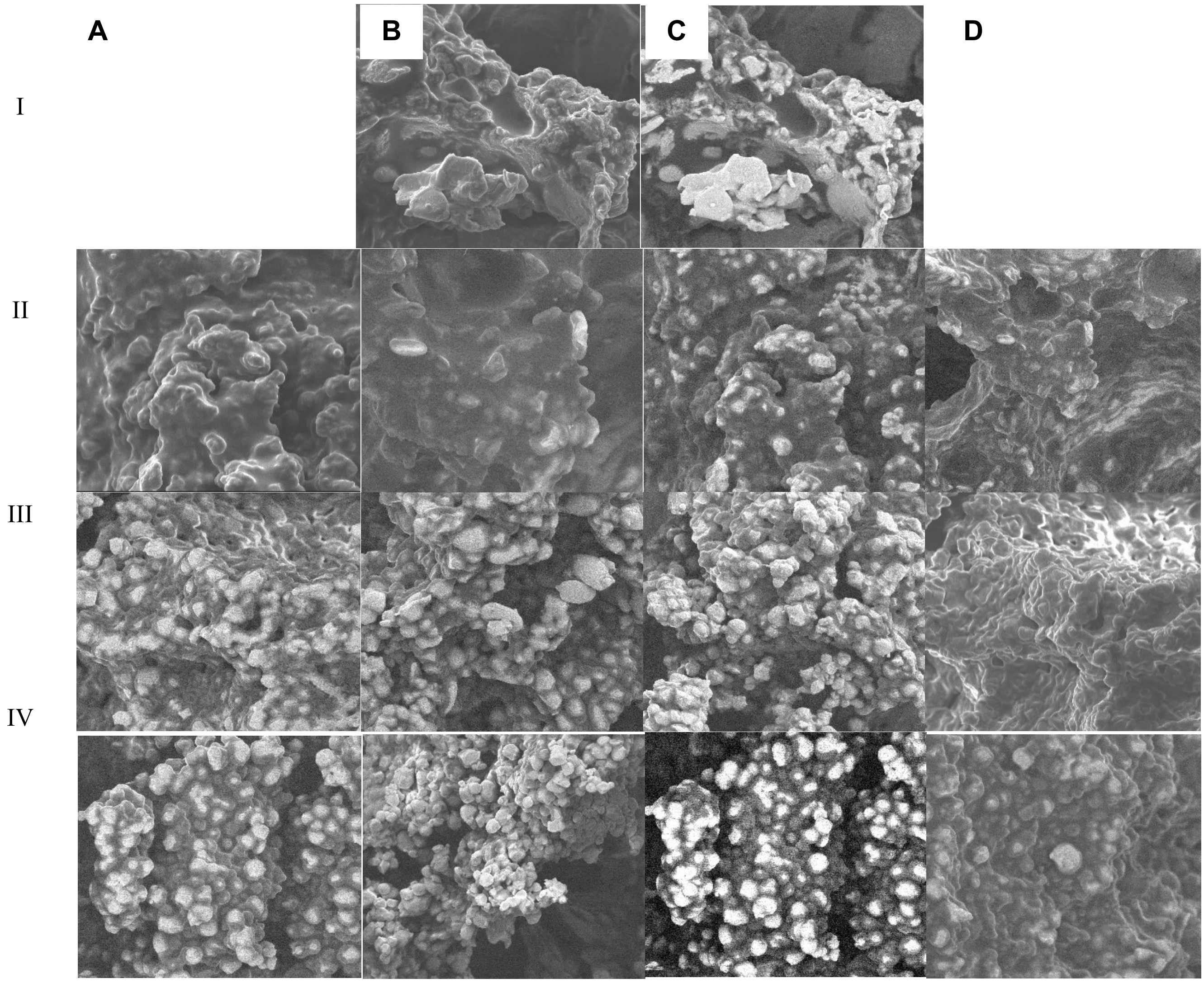

Figure 2. Scanning electron microscopy images of starch granules (100 µm). I: pandebono, II: pandeyuca, III: dusty cookies, IV: panderos, A: traditional recipe, B: yam starch, C: Malaga starch, and D: arracacha starch

Correlation and multivariate analysis

Principal Component Analysis (PCA) was applied to integrate sensory, instrumental texture (TPA), and color data (figure III). The first two principal components explained 80.8% of the total variance (PC1 = 60.3%, PC2 = 20.5%). Importantly, sensory hardness and instrumental hardness were aligned in PC1, confirming the consistency between panel perception and instrumental measurements. Likewise, PC2 separated the samples mainly according to color parameters, indicating that visual attributes provided an additional dimension for product differentiation. PC1 was mainly associated with texture attributes, both sensory and instrumental, while PC2 was strongly related to color parameters. This analysis revealed clear separation among products according to starch type, particularly distinguishing yam and malanga samples due to their higher luminosity and ΔE values, and arracacha samples due to lower cohesiveness and distinct color attributes.

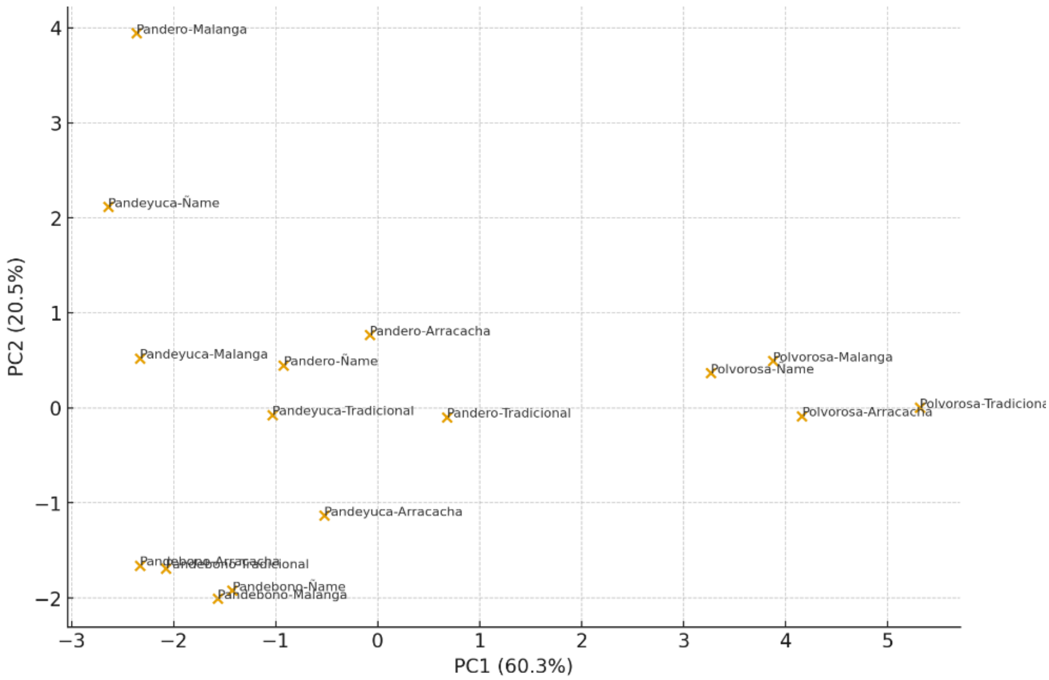

Figure 3. Multivariate analysis (PCA) integrating sensory, TPA, and color data for Colombian tuber-based baked products.

DISCUSSIONS

Starches are polysaccharides that play a crucial role in the structure and texture of baked products. According to Dhital (14), the interaction between starch and other components during cooking determines the formation of the structural network that supports the product's texture. In the case of pandebono, the cassava or corn starch used provides a base that, when gelatinized during baking, contributes to the bread's fluffiness and lightness.

Moreover, the choice of starch type directly affects the final texture. Starches from different sources exhibit variations in water retention, gelatinization, and retrogradation, which are essential for achieving the desired texture. Research has shown that cassava starch, frequently used in pandebono, produces a softer and moister texture compared to other starches (1).

Cheese, another fundamental ingredient in pandebono, not only adds flavor but also plays a significant role in the product's texture. The incorporation of fresh cheeses, such as costeño or white cheese, into the pandebono dough contributes to a creamy texture and the formation of air bubbles, enriching the final product's fluffiness. In addition to starch properties, the interaction with fresh cheeses also contributes to the texture profile of products such as pandebono. As noted by Sañudo (7), the texture of cheeses is influenced by biochemical and structural changes, which may explain some of the differences observed when these ingredients are incorporated into baked products. Due to their fat and protein content, cheeses also affect the formation of the crust and the color of pandebono. This results in a sensory experience that encompasses not only texture but also visual appeal and aroma, elements that are vital for consumer perception.

The use of starches in the preparation of Colombian amasijos is essential not only for preserving culinary traditions but also for innovating recipes that maintain the country's cultural identity. The diversity of ingredients, such as starches from tubers like cassava, arracacha, yam, and malanga, adds unique flavor and texture characteristics. Studies have shown that these starches present distinct capacities for gelatinization, moisture retention, and gel formation, which directly influences the texture of baked products. For instance, cassava starch provides a fluffier crumb, while arracacha starch may result in a denser texture (23). Additionally, texture and flavor are determinants in consumer acceptance; it has been shown that dusty cookies and panderos made with starches that balance hardness and softness are better received (22).

Differences in texture between products are attributed to the structure of the starch granules and their behavior during cooking. Cassava starch granules tend to absorb more water and expand, creating a soft texture, while those from arracacha and malanga may result in a denser crumb (17). The color of the products is also influenced by the type of starch used; cassava starch typically imparts a lighter and more attractive color, while others, like yam starch, may contribute to yellower or more orange tones, which are crucial for consumer perception (21).

The physicochemical properties of starches, such as viscosity and gelatinization index, are determinants for texture and mouthfeel, as starches with a high gelatinization index tend to form firmer gels, affecting the cohesion of the final product (14). Understanding these differences enables the development of recipes that maximize the characteristics of starches, thereby ensuring product quality and market acceptance. Thus, research in this field not only contributes to gastronomic diversity but also stimulates the local economy by promoting the use of indigenous products, strengthening Colombia's culinary identity.

These relationships were further supported by PCA, which demonstrated that sensory and instrumental texture attributes were consistent, while color parameters contributed independently to product differentiation. This multivariate approach reinforces the conclusion that starch type has a simultaneous impact on both the sensory perception and the physicochemical properties of Colombian baked products. Some considerations should be taken into account when interpreting these results. The study was conducted under laboratory-scale production with three independent replicates per condition, and the sensory panel consisted of trained evaluators from gastronomy programs. While these conditions ensured control and consistency, they may not fully reflect the variability of industrial production or of consumer populations. In addition, the findings are limited to the starch types evaluated in this work, so extrapolation to other tuber starches or regions should be made with caution. Nevertheless, the study offers meaningful insights into how starch type affects the sensory, instrumental, and color attributes of Colombian baked products, establishing a foundation for future research in broader production contexts.

CONCLUSIONS

This study demonstrated that replacing traditional cassava and maize starches with starches from arracacha, yam, and malanga in Colombian baked products (pandebono, pandeyuca, dusty cookies, and panderos) generates significant changes in both sensory texture profiles and instrumental parameters such as TPA and color. The results showed that arracacha starch increased cohesiveness, adhesiveness, and chewiness in pandebonos and panderos, while also modifying springiness and requiring adjustments in dough moisture to achieve acceptable structures. Yam starch produced higher hardness and changes in gumminess and cohesiveness, particularly in pandeyuca, an effect associated with its higher amylose content and gelatinization temperature. Malanga starch, in turn, resulted in softer and less brittle textures in dusty cookies, consistent with its lower gelatinization temperature, which makes it suitable for products that require reduced baking temperatures.

Taken together, these findings indicate that the observed variations in textural attributes are primarily explained by differences in water absorption capacity and gelatinization temperatures among starches, confirming the correspondence between instrumental analyses and sensory perception. Therefore, modifications to traditional recipes are feasible, but they must be accompanied by process adjustments especially in dough moisture and baking conditions—to maintain desirable sensory qualities. Incorporating Andean tuber starches not only diversifies the range of naturally gluten-free products but also adds value to local crops, supporting Colombian culinary heritage and the sustainable use of biodiversity. It should also be acknowledged that the tests were conducted under laboratory conditions with a limited trained panel, which may restrict the generalization of results. Future studies should include larger consumer panels, additional tuber varieties, and pilot-scale trials to validate industrial applicability and strengthen the cultural and commercial impact of these formulations.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Vice Rectory of Research at Uniagustiniana for funding this study, as well as to the Institute of Food Science and Technology (ICTA) for their contribution to the TPA texture analyses and SEM analyses.

AUTHOR CONTRIBUTIONS

Ana Ruby Correa: Research, methodology, formal analysis, and writing. Diana Dix Sotelo: Conceptualization and training of the sensory analysis panel. Aycardo Robayo: Recipe standardization, product development, and formal analysis. Marta Quicazán: Conceptualization, supervision, and editing.

CONFLICTS OF INTEREST

The authors declare no conflict of interest regarding the publication of this paper, and all authors approve manuscript for publication.

REFERENCES

[1] Aguilar PV, Hernández D. Harinas y almidones de yuca, ñame, camote y ñampí: Propiedades funcionales y posibles aplicaciones en la industria alimentaria. Tecnol Marcha. 2017;25(1):37-45. Available from: https://dialnet.unirioja.es/servlet/articulo?codigo=4835676

[2] Ogunsona E, Ojogbo E, Mekonnen T. Advanced material applications of starch and its derivatives. Eur Polym J. 2018;108:570-81. Doi: https://doi.org/10.1016/j.eurpolymj.2018.09.039

[3] Vera NG, Espino Manzano SO, Hernández HM. Use of Oxalis tuberosa in gluten-free baked goods manufacture. In: Holban A, Grumezescu A, editors. Handbook of food bioengineering: Alternative and replacement foods. Cambridge: Elsevier; 2018. p. 167-75. Available from: https://doi.org/10.1016/B978-0-12-811446-9.00006-X

[4] Ordoñez C. Gran libro de la cocina colombiana [Internet]. Bogotá (DC): Ministerio de Cultura; 2012 [cited 2025 Sep 22]. Available from: https://www.mincultura.gov.co/Sitios/patrimonio/bibliotecas-de-cocinas/tomos/tomo09.pdf

[5] Unilever. Galletas polvorosas. Recetas Marca Maizena [Internet]. 2019 [cited 2025 Sep 22]. Available from: http://www.maizena.com.co/articulo/detalle/994996/galletas-polvorosa

[6] Gisslen W. Panadería y repostería para profesionales. México (DF): Editorial Limusa; 2014.

[7] Sañudo A, Lipan L, Cano M, Vélez R, Noguera L, Sánchez L. Texture. In: Yahia E, editor. Postharvest physiology and biochemistry of fruits and vegetables. Cambridge: Elsevier; 2019. p. 293-314. DOI: https://doi.org/10.1016/B978-0-12-813278-4.00014-2

[8] Icontec. Norma Técnica Colombiana NTC 4489. Análisis sensorial. Perfil de textura. Bogotá: Icontec; 1998. 24 p.

[9] Icontec. Norma Técnica Colombiana NTC 4934. Análisis sensorial. Metodología guía general para establecer un perfil sensorial. Bogotá: Icontec; 2001. 13 p.

[10] Meilgaard MC, Carr BT. Sensory evaluation techniques. 4th ed. Boca Raton: CRC Press; 2006. DOI: https://doi.org/10.1201/b16452

[11] Meñano Correa N, Ciarfella Pérez AT, Dorta Villegas AM. Evaluation of chemical and functional properties of native starch of congo yam (*Dioscorea bulbifera* L.) to predict its possible technological uses. Saber [Internet]. 2014 [cited 2025 Sep 22];26(2):182-8. Available from: http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S1315-01622014000200011

[12] Vivas O, Sangronis E. Perfil de textura instrumental y sensorial de pastas elaboradas con Cajanus cajan fermentada. Rev Fac Farm [Internet]. 2018 [cited 2025 Sep 22];60(1):31-6.

[13] Zhuang Y, Wang Y, Yang H. Characterizing digestibility of potato starch with cations by SEM, X-ray, LF-NMR, FTIR. Food Chem. 2023; 424:136396. DOI: https://doi.org/10.1016/j.foodchem.2023.136396

[14] Dhital S, Shrestha AK, Hasjim J, Gidley MJ. Physicochemical and structural properties of maize and potato starches as a function of granule size. J Agric Food Chem. 2011;59(18):10151-61. DOI: https://doi.org/10.1021/jf202293s

[15] Andrade R, Palacio J, Pacheco W, Betin R. Almacenamiento de trozos de ñame (*Dioscorea rotundata*) en atmósferas modificadas. Inf Tecnol. 2012;23(4):65-72. DOI: https://doi.org/10.4067/S0718-07642012000400008

[16] Salcedo J, García C, Salcedo D. Propiedades funcionales de almidones de ñame (*Dioscorea alata*). Biotecnol Sect Agropecu Agroind. 2018;16(2):99-107. DOI: https://doi.org/10.18684/bsaa(16)99-107

[17] Hernández M, Torruco-Uco JG, Chel-Guerrero L, Betancur-Ancona D. Caracterización fisicoquímica de almidones de tubérculos cultivados en Yucatán, México. Cienc Tecnol Aliment. 2008;28(3):718-26. DOI: https://doi.org/10.1590/S0101-20612008000300031

[18] Torres A, Montero P, Durán M. Propiedades fisicoquímicas, morfológicas y funcionales del almidón de malanga (*Colocasia esculenta*). Rev Lasallista Investig [Internet]. 2013 [cited 2025 Sep 22];10(2):52-6. Available from: https://www.redalyc.org/pdf/695/69529816007.pdf

[19] Alayo B. Caracterización fisicoquímica y reológicas del almidón de la arracacha (*Arracacia xanthorrhiza*) variedad amarilla procedente de la Provincia de San Ignacio - Departamento de Cajamarca. Innov Desarro [Internet]. 2015 [cited 2025 Sep 22];1(1):1-7. Available from: http://revistas.ucv.edu.pe/index.php/INNOVACION/article/view/887

[20] Rivera FA. Un patrimonio cultural en riesgo: Valoración y divulgación de los oficios de las cocinas tradicionales - amasijos en el municipio de Firavitoba-Boyacá [master's thesis]. Tunja: Universidad Pedagógica y Tecnológica de Colombia; 2022.

[21] Mora AC. Evaluación de la calidad de cocción y calidad sensorial de pasta elaborada a partir de mezclas de sémola de trigo y harina de quinua [master's thesis]. Medellín: Universidad Nacional de Colombia; 2012.

[22] Granito M, Valero Y, Zambrano R. Desarrollo de productos horneados a base de leguminosas fermentadas y cereales destinados a la merienda escolar. Arch Latinoam Nutr. 2010;60(1):85-92.

[23] Irigoytia K, Parodi MB, Espósito N, de Escalada Pla M, Genevois C. Sensory profile of gluten-free breads based on alternative commercial flours. Biol Life Sci Forum. 2023;26(124). DOI: https://doi.org/10.3390/Foods2023-15217