Transdisciplinary Science

| December 2024 | Volume 1 Number 2 | pp. 167-185

Development of food enriched with carotenoids from *arazá* as a strategy for valorizing Amazonian fruits

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Currently, the growing demand for products that contribute to health coincides with an upward trend towards the valorization of various Amazonian fruits, such as arazá *(Eugenia stipitata),* recognized for its high content of bioactive compounds. In this context, the present research focuses on highlighting the carotenoid content of arazá to incorporate them into the formulation of a functional muffin. The study addressed the integral physicochemical characterization of the fruit and the evaluation of two water removal technologies (lyophilization and refractive window drying) and the state of ripeness (ripe and overripe) to identify the conditions that would allow the greatest conservation of carotenoid compounds. Subsequently, muffins were formulated with different percentages of incorporation of arazá powder (0-0.75%, w/w), the characteristics of the arazá powder and the attributes of the arazá powder were studied. Properties of texture, rheology, color, and a sensory panel were developed and the bioaccessibility of the carotenoid compounds was analyzed through an *in vitro digestion process*, the packaging was designed and the theoretical proximal analysis of the formulation preferred by the sensory panel was carried out. The results revealed that the powder obtained from freeze-dried overripe fruits exhibited the highest concentration of carotenoids (497.55 (6.53) µg β-Carotene/g). About the muffins, it was observed that the increase in the proportion of the arazá powder content in the formulation produced an increase in the viscosity, firmness, consistency, and cohesiveness of the dough and a decrease in the elasticity of the muffin. Additionally, the sensory analysis indicated a clear preference for the formulation with 0.75% w/w of arazá powder, highlighting it as an excellent source of vitamin A according to *Resolution 810 of 2021* of the Ministry of Health and Social Protection of Colombia. Finally, *in vitro,* digestion of the winning muffin reported 109.39 µg of bioaccessible β-carotenes in the muffin. In conclusion, freeze-dried arazá powder was found to be an ingredient with nutritional and acceptance properties for the development of functional products.

Keywords: Enriched food, Carotenoids from arazá, Valuation strategy, Amazonian fruits.

DOI: 10.5281/zenodo.15880320

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1. INTRODUCTION

The Covid-19 pandemic has focused consumers' attention on their physical and mental well-being, leading to a greater appreciation for regular physical activity and the adoption of practices aimed at improving health. In 2023, a study by *Euromonitor International* found that 42% of consumers in Colombia reported having the habit of consuming health supplements or vitamins and 61% of them reported that they incorporated physical activity as an integral part of their daily routine [1]. In addition, 45% of consumers are actively looking for foods that offer additional health benefits and nutritional properties, and 74% of them expressed their willingness to pay a premium for products that provide such characteristics [1]. This change in the lifestyle of Colombians is also related to the main causes of death in the country.

According to the National Administrative Department of Statistics DANE in 2022 the main cause of mortality was acute myocardial infarction (ischemic heart disease), without further specification, with a total of 44,703 deaths recorded. This condition represented 17.1% and 18% of total deaths in men and women, respectively [2]. For this reason, a trend and demand for functional foods were generated, making them a potential strategy in the prevention of chronic diseases since they provide a specific benefit at a biological level in addition to their natural contribution of nutrients. Within the category of functional foods, there are those rich in antioxidants, which play a fundamental role in preventing or interrupting the physiological chain reactions that generate free radicals, which are neutralized by antioxidants by donating hydrogens. Among the most investigated antioxidant substances are phenolic compounds, phytosterols, terpenes or isoprenoids, and indoles [3].

Within the group of terpenes or isoprenoids are the carotenoids, which are *tetraterpenes made up of multiple units of isoprene with a substituted and unsaturated cyclohexane ring at each of their ends.* [3]There are two types of carotenoids: carotenes that do not contain oxygen in their terminal rings and xanthophylls that do. These natural fat-soluble pigments are deep yellow, orange, and red and are synthesized by plants, algae, and photosynthetic bacteria. The ingestion of carotenoids has been linked to the prevention and/or reduction of risk and incidence of some cardiovascular diseases, age-related degenerative diseases, and some types of cancer. In addition, previous research has shown that carotenoids increase resistance to oxidation of low-density lipoproteins and reduce DNA damage [4].

On the other hand, Amazonian fruits currently constitute a new productive chain with great potential for Colombian fruit growing and its cultivation represents an opportunity for regional strengthening and the construction of social fabric in this region of the country. The arazá *(Eugenia stipitata*) is a plant belonging to the *Myertaceae family*. Its fruit is shaped like a flattened spherical berry that measures 3 to 5 cm long and 4 to 7 cm in diameter with a delicate shell 1 mm thick that represents approximately 10% of the total weight of the fruit. [5]. The arazá contains 6 to 15 seeds and its average weight is between 150 to 200 grams. [4]. Regarding its organoleptic properties, it is highlighted that its fruit has an intense yellow color, good juiciness, and high acidity. The arazá is characterized by its adaptation to poor and acidic soils. In the country, it is cultivated mainly in the departments of Caquetá, Putumayo, Boyacá, and Amazonas [6].

The nutritional contribution of 100 g of dehydrated arazá pulp is 6.0% to 10.9% protein, 70% to 80.6% carbohydrates, 0.5% to 3.8% fat, 0.5% ash and 5.5% to 6.5% fiber. [7]. The carotenoid profile present in arazá is mainly composed of lutein (489 ± 115 µg / 100 g), β -cryptoxanthin (221 ± 72 µg / 100 g), β-carotene (53 ± 14 µg / 100 g) and zeaxanthin (28 ± 5 µg / 100 g) [4]. The carotenoids containing a ring of Unsubstituted β- ionine such as β-cryptoxanthin and β-carotene can be converted into vitamin A, which has biological effects such as *promoting growth, cell differentiation, and immune function.* [4]On the other hand, previous studies have established that *dietary intake of zeaxanthin and lutein has a statistically significant inverse relationship with the risk of macular degeneration, the main cause of irreversible blindness in the elderly.* [4]; In addition, zeaxanthin has been associated with reduced risk of cataracts and improved cognitive function in the geriatric population [4].

In response to current trends and consumer interest in healthier snacks with bioactive potential, there is a need to offer options that meet the demand for healthy and high-nutritional quality foods. This is especially important given that today's pace of life leaves little time for the preparation of healthy meals. For the

reasons mentioned above, the development of a muffin-type food enriched with carotenoids contained in arazá powder is of interest. To meet this objective, as much water as possible present in the raw material must first be removed. At this stage, conventional drying methods such as convection drying are ruled out due to their ability to adversely affect the organoleptic and nutritional characteristics of the product.

Therefore, it is proposed to evaluate two alternative methods: freeze-drying and refractive window drying, which stand out for their ability to reduce quality losses at the physicochemical and nutritional level of the food. [8]. Freeze-drying involves removing the water content of the fruit through a freezing process followed by the sublimation process at reduced pressures; while refractive window drying consists of transferring energy through a transparent plastic film using conduction and radiation. [8]. Therefore, considering the limited scientific literature that addresses the effect of water removal methods on the properties of arazá, a research opportunity is identified.

Finally, due to the absence of supporting tissue such as collenchyma and sclerenchyma, arazá is very susceptible to mechanical damage during the post-harvest period. [5]. This factor, in combination with its high moisture content, around 90%, contributes to the increase in the respiratory rate which directly leads to its high perishability. [5]. Therefore, there is a need to provide added value to this fruit, particularly when it is in the advanced stages of ripening and over-ripening, at which time its organoleptic characteristics do not meet consumer expectations. Thus, this study aimed to evaluate the effect of the type of water removal technology (lyophilization and refractive window drying) and the ripening state of the fruit on the carotenoid content in arazá powder, to choose the optimal treatment conditions of the raw material for the development of a muffin that is an excellent or good source of vitamin A according to *Resolution 810 of 2021* and that presents organoleptic characteristics and nutritional properties attractive to the consumer.

2. METHOD

2.1 Materials

10 kg of ripe arazá and 10 kg of overripe arazá were purchased in the city of Leticia, Amazonas. The input used for the disinfection of the fruit was acetic acid (5%, Suquin SAS). For the extraction of carotenoids, acetone C_3H_6O (Panreac, 99.5% v/v) was used. The ingredients used in the muffin formulation were wheat flour (Haz de Oros, Bogotá), eggs (Santa Ana, Bogotá), sugar (Manuelita, Bogotá), inulin (Bene, Bogotá), sunflower oil (Premier, Bogotá), whole milk (Alquería, Bogotá), vanilla essence (Levapan, Bogotá), instant dry yeast (Instant success, Bogotá) and sodium bicarbonate (Frescampo, Bogotá). During the sensory panel, salt crackers (Saltín Noel, Bogotá) and mineral water (Cristal, Bogotá) were used to cleanse the palate of each panelist. For *in vitro* digestion, the following reagents were used: ammonium carbonate, hydrochloric acid, pepsin and pancreatin from PanReac (ITW Reagents, Darmstadt, Germany), sodium chloride, calcium chloride and sodium hydroxide from Merck (Merck, St. Louis Missouri, USA), magnesium chloride 6-hydrate from JT Baker (Fisher Scientific Madrid, Spain), potassium chloride from Supelco (Merck, St. Louis Missouri, USA), potassium dihydrogen phosphate from Sharlau (Scharlab, Barcelona, Spain), sodium bicarbonate from Chemi (Bogotá, Colombia), and alpha-amylase from ChemCruz.

2.2 Sample preparation

To process the fruit, it was first classified according to its state of ripeness, which was determined using the color scale of the Amazonian Institute of Scientific Research SINCHI, which establishes that the fruit is ripe when 100% of its surface is yellow, while overripe fruit has a dark yellow or orange tone. Subsequently, it was washed and disinfected with a 5% acetic acid solution and filtered water. The fruit was cut into 4 parts and blended for 120 s at 18,000 rpm using the blender (Vitamix, The Quiet One, United States). The resulting paste (liquefied peel, pulp, and seeds) was placed in bags and subjected to a vacuum packing process (MSA, MSA 400M, Colombia) for 30 s at a temperature of 80. These bags were wrapped in aluminum foil and stored at -18°C in the freezer (True, T-49F-HC, United States) until their respective analysis. Additionally, 2 units of arazá of each state of ripeness were reserved to carry out the physicochemical characterization of the peel, pulp, and seeds. To obtain the peel, the fruit was peeled with the thinnest thickness possible, exposing the pulp, and the seeds were manually removed from this pulp.

2.3 Characterization of the arazá

2.3.1 Humidity

The moisture content of the peel, pulp, and seeds of the previously washed and disinfected fresh fruit, and the ripe and overripe arazá paste were analyzed using a thermobalance (Precisa, Series 330 XM, Switzerland). The weight of each sample was 2 g. This process was carried out in duplicate for each stage of ripening of the fruit.

2.3.2 Water activity (a_w)

The water activity of the peel, pulp, and seeds of the previously washed and disinfected fresh fruit, and the ripe and overripe arazá paste was determined using the water activity meter (Rotonic, HP23-AW-ASET, Switzerland). The cuvettes were filled with each sample up to 60% of their capacity. This process was carried out in duplicate for each stage of ripening of the fruit.

2.3.3 pH

The pH of the peel and pulp of previously washed and disinfected fresh fruit and the ripe and overripe arazá paste was determined at a temperature of 14°C using a multiparameter (Mettler Toledo, SevenMulti, Switzerland). This process was carried out in duplicate for each stage of fruit ripening.

2.3.4 Total soluble solids

The total soluble solids content of the peel and pulp of the previously washed and disinfected fresh fruit and the ripe and overripe arazá paste were determined using a digital refractometer (Atago, PAL-BX/ RI, Japan) to measure the brix degrees of each sample. This process was performed in duplicate for each ripening stage of the fruit.

2.3.5 Colorimetry

The color of the peel, pulp, and seeds of the previously washed and disinfected fresh fruit, and the ripe and overripe arazá paste was determined using the Commission system Internationale de l'Eclairage (CIELab) using the solids colorimeter (Konica Minolta, CR-20, Japan) with a visual angle of 8º and illuminant D65. This system defines the coordinates L*, a*, and b* to describe the color. In L*, the lightness of the color is measured, the coordinate a* represents the deviation towards red/green, and the coordinate b* describes the deviation towards yellow/blue. [9].

2.4 Experimental design for the water removal process and the ripening state of arazá

Was proposed to evaluate the water removal method (lyophilization and refractive window drying) and the effect of the fruit ripening state (ripe and overripe) on the carotenoid content of the samples. This design was carried out through the Minitab ® statistical tool (version 18.1) with a significance level of 5% in the ANOVA variance analysis, the best ANOVA was determined and the Tukey test was performed. Additionally, the assumptions of normality, independence, and constant variance were checked using the Anderson-Darling test, analysis of the Residual vs. Observation Order graph (it is randomly distributed), and the Barlett test respectively. The mean and standard deviation for the response variable were reported in the results.

2.4.1 Freeze-drying

The freeze-drying process was carried out in the freeze-dryer (Labconco, FreeZone 6 Liter Benchtop, United States). For this, 1kg of ripe arazá paste and 1kg of overripe arazá paste were thawed at room temperature. Then, the sample was divided into 5 trays that were frozen at -80ºC for 24h in the ultra-freezer (New Brunswick, Innova U101, Germany). After this time, the trays were taken to the freeze-dryer that operated at -80.6ºC and 0.065 mbar for 48h until reaching a humidity of less than 10%. The process was carried out in duplicate for each stage of ripening of the arazá.

2.4.2 Drying by refractive window

This process was carried out in the refractive window drying equipment (JM, Colombia). First, 1kg of ripe arazá paste and 1kg of overripe arazá paste were defrosted at room temperature; then, they were placed on the equipment tray with a thickness of 5 mm and left to dry at 75ºC for 1 hour and 15 minutes until obtaining a humidity of less than 10%. The process was carried out in duplicate for each stage of ripening of the arazá.

2.4.3 Particle size standardization

The ripe and overripe arazá previously dried by each technology previously presented was subjected to a size reduction process in the knife mill (Fritsch, Pulverisette 11, Germany) operating at 3000 rpm for 55 seconds followed by 8000 rpm for 7 s. Then, the electric sieve (Pinzuar, G081301, Colombia) was used for 30 s until a particle size was less than 75 µm. These samples were packed in bags and subjected to a vacuum packing process (MSA, MSA 400M, Colombia) for 30 s at a temperature of 80°C; subsequently, they were covered in aluminum foil and left in the desiccator until further analysis.

2.5 Extraction and quantification of carotenoids

The carotenoids present in the arazá samples were extracted by the conventional method following the methodology proposed by [10]. Firstly, 1 g of arazá powder from the different treatments evaluated was weighed and placed in 50 mL falcon tubes previously wrapped in aluminum foil and then 10 mL of cold acetone (99.5% v/v) was added [10]. The samples were then homogenized using a dispermat homogenizer (Vma-Getzmann Gmbh, Dispermat LC Dissolver (Germany) using a 10 mm light disk at 10000 rpm for 5 min [10]. The tubes were then placed in a refrigerated centrifuge (Thermo Fisher Scientific, MA, CL30R, USA) at 4300 rpm for 8 min at 0°C.

The extracted material was then filtered through grade 389 filter paper (Boeco, Germany), and the supernatant was collected in 10 mL volumetric flasks. The sediment was re-extracted using the conditions described above and the same process was continued until the sediment was translucent. Finally, the flasks were filled with acetone, and the absorbance at 454 nm was measured using a UV-VIS spectrophotometer (Thermo Scientific, Genesys 20, USA) [10]. The carotenoid content was estimated in µg of β-carotene per gram of sample using the calibration curve of standard β-carotene dissolved in acetone at 454 nm (y = 0.0245x + 0.043Cuadrado= 0.9932) [11].

2.6 Muffin formulation

According to the results obtained in the extraction and quantification of carotenoids, the water removal technology and the ripening state of the fruit with the highest carotenoid content were chosen for the muffin formulation. The formulation described in Table 1 was established through a study of the ingredients used in similar products available in the main supermarkets in Bogotá and taking into account Resolution *810 of 2021* of the Ministry of Health and Social Protection of Colombia. [12]To be within the permitted range of nutrients such as sugars, saturated fats, and trans fats to avoid warning labels on the product. In addition, it was determined that to ensure that the muffin is an excellent source or a good source of vitamin A, 0.5 g and 0.25 g of arazá powder respectively should be added to the formulation. On the other hand, a muffin with the inclusion of 0.75 g of arazá powder was evaluated.

Table 1. Composition of the control muffin and the one with the inclusion of arazá

Ingredients	Control	M1	M2	M3
	% w/w	% w/w	% w/w	% w/w
Arazá powder	0	0.25	0.5	0.75
Wheat flour	28	27.75	27.5	27.25
Eggs	22.6	22.6	22.6	22.6
Sugar	7.8	7.8	7.8	7.8
Inulin	9.9	9.9	9.9	9.9
Oil	20	20	20	20
Milk	10	10	10	10

Vanilla essence	1	1	1	1
Yeast	0.2	0.2	0.2	0.2
Baking soda	0.5	0.5	0.5	0.5
	100	100	100	100

To prepare the muffins, first beat the eggs with the sugar and inulin in the mixer (Dynasty, DM-10, Taiwan) at maximum speed for 1 min. Then, the wheat flour, arazá powder, baking powder, and baking soda were added to the mixture, and little by little the oil, milk, and vanilla essence were added.

These ingredients were left to mix for 5 min at maximum speed. Finally, the resulting dough was transferred to a muffin-lined mold with 1 cm diameter liners and placed in the convection oven (Memmert, UF110, Germany) for 13 min at 180ºC.

2.7 Properties of muffin

2.7.1 Texture

The texture of the muffin dough was studied in terms of firmness, consistency, and cohesiveness using a tetrameter (Stable Micro Systems, TA.HDplusC, UK). A 40mm DISC RIG geometry, a 5kgf load cell, a test speed of 1mm/s, and a penetration distance of 15mm [13]Were used.

To determine the firmness and elasticity of the muffin, the same equipment was used with a 36mm AACC cylindrical probe, a 5kgf load cell, a test speed of 1mm/s, and a penetration distance of 8mm. [13].

2.7.2 Rheology

The behavior of the muffin doughs was analyzed using the rotational rheometer (TA Instruments, AR-G2, PAIS) with a concentric conical cylinder geometry of 997616, a gap of 1000 µm at 20ºC [13]. The doughs were studied with a shear rate range between 1 and 100 s^{-1} [13] And the viscosity of each mass was reported at a shear rate of 50 s^{-1}. Additionally, linear fits were made to the logarithmic curves of the viscosity as a function of the shear rate to determine the flow index (n) and the consistency index (k) using the power law (Equation 1).

$$\mu = k * \gamma^{n-1} \qquad (1)$$

Where $\mu$is viscosity [Pa s], $k$consistencyndex [Pa s^{n} gamma sstearate [s^{-1}] and $n$now rate

2.7.3 Color

The color of the baked muffins was analyzed using a solids colorimeter (Konica Minolta, CR-20, Japan) with a visual angle of 8º and illuminant D65 in the same way as with the Arazá powders. Equation 2 was used to determine the overall color difference concerning the control sample.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \qquad (2)$$

2.8 Sensory panel

Sensory evaluation provides a basis for analyzing the acceptance of muffins and the preferences of their properties among the different variations, which is very useful in making decisions related to the formulation and marketing of the product. For these reasons, a sensory panel was conducted with 50 people who study and work at the Universidad de los Andes to find out their perception of the flavor, consistency, aroma, appearance, sponginess, bitterness, and color of the control muffin and the three formulations that include arazá powder. The participants were classified by age range, gender, the frequency with which they consume muffins, desired characteristics of this type of product, and whether they knew the properties of arazá and its health benefits.

The protocol was previously reviewed and approved by the Ethics Committee of the Faculty of Engineering of the Universidad de los Andes (approval No. 642) and each participant was informed about the ingredients and allergens contained in the muffins. Each panelist received a package with four muffins, one of which was the control and the remaining three were muffins with different percentages of arazá powder.

The coding of the samples consisted of a variation of three numbers (570: control, 139: 0.25% arazá powder, 292: 0.5% arazá powder, and 846: 0.75% arazá powder). Before each tasting of the samples, a random order of evaluation was established for each participant, and between each tasting the panelists had to rinse their mouths with water and salty crackers to cleanse their palate.

The survey for the panelists was divided into two parts. The first part aimed to rate the general acceptability of each muffin in terms of taste, consistency, aroma, appearance, and color using a hedonic scale from 1 to 9 (where: 1 = *I dislike it very much*, 5 = *I neither like it nor dislike it* and 9 = *I like it very much*). In the second part, they were asked about the bitterness and fluffiness of the muffins using a Just-About-Right (JAR) scale from 1 to 5 (where: 1 = *very slightly bitter / very slightly fluffy*, 3 = *just right* and 5 = *very bitter / very fluffy*).

Finally, the panelists were given a choice between the four muffins and which one they preferred and were asked the price they would be willing to pay for a 65g muffin. The data presented above were recorded in an online survey.

2.9 Statistical analysis

The results obtained from texture, rheology, and hedonic scale questions of the sensory panel were analyzed in the statistical tool Minitab ® (version 18.1) with a significance level of 5% in the one-way ANOVA variance analysis, the Tukey test was performed to compare the different formulations (0%, 0.25%, 0.50%, 0.75% of arazá powder). Additionally, the assumptions of normality, independence, and constant variance were checked using the Anderson-Darling test, analysis of the Residual vs. Observation Order graph (it is randomly distributed), and Barlett test respectively. The results were reported with their respective mean and standard deviation in the tables in the results section.

Furthermore, the JAR scale attributes of the sensory panel were analyzed in Excel ® using the penalty analysis method (mean drop, Equation 3) to determine whether the attribute rankings were below or above the ideal point.

$$\text{Penalización} = \text{OA}_{\text{J}} - \text{OA}_{\text{NJ}} \qquad (3)$$

Where OA_J represents the mean of the overall acceptability of the JAR subgroup panelists, and OA_{NJ} represents the mean of the overall acceptability of one of the non-JAR subgroups [14].

2.10 In vitro digestion, extraction, and quantification of carotenoids from the winning muffin

The in vitro digestion model attempts to mimic *in vivo physiological conditions* through the simulation of digestive processes to determine and analyze the bioaccessibility of carotenoids from arazá powder. The implementation of this model followed the methodology of Minekus et al. [15], which includes the generation of simulated salivary fluids (SSF), simulated gastric fluids SGF, and simulated intestinal fluids SIF. The pH values were adjusted to 6.5, 2.5, and 7 for salivary, gastric, and intestinal fluids, respectively. Subsequently, after the conclusion of the [16].*In vitro* digestion process, the extraction and quantification process of carotenoids present in the winning muffin was carried out, following the methodology detailed in section 2.5 of this document.

2.11 Theoretical proximal analysis and packaging development

A theoretical proximal analysis was performed on the muffin with the highest score in the sensory panel. This analysis took into consideration the formulation and caloric content of each ingredient in the muffin. With the data previously found, the nutritional label was created, a name was assigned to the product and packaging was designed by applying color psychology to food.

3. RESULTS AND DISCUSSION

This section analyses the data obtained from the characterization of arazá in its discriminated form (peel, pulp, and seeds) and paste, taking into account its two states of ripeness (ripe and overripe). In addition, the results of the extraction and quantification of carotenoids are presented to select the drying method and the state of ripeness of the fruit for the formulation of the muffins. Additionally, the texture, rheology, and colorimetry properties of the dough and the muffins developed are shown. Finally, the results of the sensory panel that allowed the best muffin to be chosen are presented, which was subjected to an *in vitro digestion process* to evaluate the bioaccessibility of the carotenoid compounds.

3.1 Characterization of the arazá

Table 2 presents the results obtained from each of the physicochemical properties analyzed for the peel, pulp, seeds, and paste of arazá in the ripe (M) and overripe (SM) states.

Table 2. Properties of ripe and overripe *arazá* paste

Properties	Peel		Pulp		Seeds		Paste	
	M	YE	M	YE	M	YE	M	YE
Humidity (%)	79.7 (0.4)	77.0 (0.9)	91.2 (0.7)	88.9 (0.4)	13.2 (1.0)	13.7 (1.4)	77.7 (1,3)	74, 9 (1,1)
Water activity (a_w)	0.82 (0.013)	0.87 (0.006)	0.95 (0.002)	0.91 (0.004)	0.33 (0.87)	0.39 (1.01)	0.94 (0.006)	0.96 (0.007)
pH	2.98 (0.02)	3.06 (0.05)	2.61 (0.01)	2.93 (0.06)	-	-	2.75 (0.002)	2.96 (0.006)
Soluble solids (ºbx)	3.3 (0.07)	3.6 (0.1)	4.2 (0.1)	5.0 (0.3)	-	-	6.6 (0.07)	7.9 (0.07)
L*	80.5 (1.5)	76.4 (1,1)	75.4 (2.5)	63.3 (1.4)	51.8 (1,3)	57.1 (1.0)	78.3 (1.9)	70.9 (1.6)
to*	16.2 (1.0)	23.8 (1.4)	1.0 (2,2)	5.0 (1.9)	7.3 (1,3)	10.9 (1.4)	5.2 (1.7)	7.2 (23)
b*	79.4 (1.6)	77.5 (1,3)	53.1 (0.7)	55.1 (1,1)	23.8 (0.9)	24.8 (1,1)	65.8 (1.6)	62.1 (1.8)

*Values in parentheses refer to standard deviations

3.1.1 Humidity

Humidity refers to the water content present in foods, which influences their quality, flavor, and durability. The arazá is a fruit that contains approximately 90% moisture in its ripe pulp. [17], where most of the fruit is water, which explains its characteristic juiciness and texture. This data is corroborated with those obtained experimentally in Table 2. The high moisture content contributes to the increase in the respiratory rate, which is directly related to the high perishability of the fruit [5]. As for the seeds, a moisture content of 13% is observed, a figure that is similar to the moisture of guava (*Psidium guajava*), which is approximately 11% [18]. These relatively low percentages are attributable to factors such as its ability to withstand adverse conditions and prolong its useful life.

Compared to the peel, the result, regardless of its state of ripeness, is similar to the peel/skin of the Tommy Atkins mango with a value of 70% [19]. On the other hand, there is currently no data in the literature about the moisture content of the arazá paste; however, the data discriminated coincide with the same fruit or similar fruits.

3.1.2 Water activity (a_w)

Water activity, expressed as a value between 0 and 1, becomes a key factor in estimating the shelf life of arazá [20]. A lower value of aw indicates a less favorable environment for the growth of bacteria and fungi, while a higher value suggests the opposite. The results detailed in Table 2 show values close to $_1$ in the paste, pulp, and peel of arazá, indicating a relevant availability of water for the growth of microorganisms and, therefore, the deterioration of the fruit. These results are compared with guava (*Psidium guajava)*, a fruit similar to arazá, where the w_{values} range between 0.97 and 0.99 during the first 7 days after harvesting. [21].

Regarding the seeds, their a_w is remarkably low compared to the other parts of the fruit, and this is related to the low moisture content they present.

3.1.3 pH

pH is a measure that indicates the concentration of hydrogen ions in a food [22], which shows its level of acidity or alkalinity. pH plays an important role in controlling the activity of microorganisms in food because in very acidic pH it is difficult for bacteria, fungi, and yeasts to grow and reproduce [23]. The results reported in Table 2 show the acidic nature of the fruit in its different states of ripening. These values are related to those obtained by [17], who states that the pH of the fruit depends on its state of ripening and is generally found in a range of 2.6 to 3.4 [17]. Although [17] performed tests only for the pulp, it can be seen that the pH of the paste obtained in both states of ripening does not deviate from the reported values.

3.1.4 Total soluble solids

Total soluble solids TSS are indicators of the approximate sugar content in fruits and are used as markers of quality and ripeness. Arazá, being a climacteric fruit, continues its ripening process after being harvested, in the same way, the sugar content also increases and the acid content decreases. [24]. Table 2 shows that the soluble solids content of the arazá paste and the parts of the fruit in the overripe state (3.6°bx – 7.9°bx) is higher compared to the ripe state (3.3°bx – 6.6°bx).

3.1.5 Colorimetry

It is important to know the color of fresh fruit to determine quality, ripeness, and consumer perception. Table 2 presents the data obtained through colorimetry of the fruit divided into peel, pulp, and seeds, and the arazá paste. It can be observed that, according to the L* coordinate, the peel decreases its brightness when its ripening state changes from ripe to overripe; a similar behavior occurs with the pulp and paste. On the contrary, the seeds increase their brightness. As for the* coordinate, the values in all parts of the fruit and the paste increase from the ripe to the overripe state, implying that as the fruit ripens, its reddish tones increase. Finally, about the b* coordinate, both the peel and the arazá paste show a decrease in yellow tones as it progresses in its ripening, while, in the pulp and seeds, these tones increase.

3.2 Extraction and quantification of carotenoids and statistical analysis

Table 3 shows the average carotenoid content (TCC) in µg β-Carotene/g in arazá powder, according to the water removal technology: freeze-drying (LIO) and refractive window drying (SVR) for each fruit ripening state: ripe (M) and overripe (SM). The analysis of variance (ANOVA) was performed with the two factors, their respective interaction, and the error term, and the Tukey test was applied. The results reveal that the dehydration method by freeze-drying exhibits higher levels of total carotenoid content (TCC) in contrast to drying through the refractive window.

Table 3. Results of the experimental design for the water removal process and the ripening state of the arazá

Run	Water removal technology	State of maturation	TCC (µg β-Carotene/g)
1	MESS	M	266.9 ^{BC} (4.3)
2	MESS	YE	497.6 ^{A} (6.5)
3	SVR	M	189.8 ^{C} (21.0)
4	SVR	YE	352.2 ^{B} (44.1)

For the same column, means that do not share the same letter are statistically significantly different according to the Tukey test ($p<0.05$). Values in parentheses refer to standard deviations.

This trend is also confirmed in a study carried out with cape gooseberry *(Physalis peruviana* L.*) pulp* where the refractive window drying method and freeze-drying were compared concerning carotenoid changes. It was found that the samples dehydrated by freeze-drying showed the lowest decrease in total carotenoid content, followed by those subjected to refractive window drying. This loss of carotenoids is mainly attributed to exposure to oxygen and high temperatures compared to freeze-drying [25]. In addition, it was

associated with oxidative processes induced by the activity of polyphenol oxidase and lipoxygenase, as documented in previous research on the freeze-drying of mango and papaya. [26].

Regarding the state of ripeness, it is evident that overripe fruit has higher amounts of carotenoids both in the freeze-drying process and in refractive window drying. This pattern was also observed in a previous study carried out with guava (*Psidium guajava*), where the carotenoid content was evaluated during the fruit ripening process, from the green, ripe to over-ripe state, indicating that the latter stage reached the highest carotenoid content. [27]. This behavior is attributed to the progressive accumulation of β-carotene throughout each stage of the ripening process, a phenomenon that is also observed in other fruits, such as mango. [28]and lycopene in tomato [29]. Taking into account the factors of each combination, it is seen that there are no significant differences between the LIO-M and SVR -SM combinations, and between LIO-M and SVR -M. However, the best treatment to obtain a higher carotenoid content was the one called LIO-SM.

3.3 Properties of muffin

3.3.1 Texture

The texture characteristics of doughs play an important role as they provide key information about their behavior during various handling stages such as kneading and molding. The results of the texture tests for the muffin dough and the final texture of the muffins are detailed in Table 4. As for the firmness, defined as the maximum force during the first deformation cycle, it can be concluded with 95% confidence that as the amount of freeze-dried arazá powder in the formulation increases, the firmness also increases.

In this sense, the control formulation and the formulation with 0.75% powder exhibit the lowest and highest firmness, respectively; which may be because a higher incorporation of arazá powder contributes to a higher incorporation of fiber in the muffin. This is in agreement with previous research such as that carried out by Harastani et al. [30]This indicates an increase in the firmness of muffins with the incorporation of dietary fibers due to their high-water retention capacity.

Table 4. Dough texture and baked product results

	Muffin dough			Muffins	
Lyophilized powder	Firmness (g)	Consistency (gs)	Cohesiveness (g)	Firmness (g)	Elasticity (%)
0%	91.0 ^{C} (2.5)	1213.8 ^{C} (13.2)	-86.2 ^{A} (3,3)	210.4 ^{C} (0.8)	60.7 ^{A} (0.4)
0.25%	97.0 ^{BC} (2.5)	1231.6 ^{C} (27.4)	-92.2 ^{A} (2.0)	219.7 ^{C} (8.8)	60.5 ^{A} (1.0)
0.5%	112.6 ^{B} (5,6)	1406.7 ^{B} (28.9)	-110.5 ^{B} (6.2)	238.6 ^{B} (3.5)	59.0 ^{A} (1.6)
0.75%	146.7 ^{A} (9.3)	1814.8 ^{A} (82.1)	-143.0 ^{C} (3.0)	322.1 ^{A} (8.0)	52.0 ^{B} (0.4)

For the same column, means that do not share the same letter are statistically significantly different according to the Tukey test ($p<0.05$). Values in parentheses refer to standard deviations.

As for consistency, it can be stated with 95% confidence that this increases significantly as the proportion of freeze-dried arazá powder increases. In this context, the control dough and the one with 0.75% powder present the lowest and highest consistency, respectively. This pattern coincides with previous studies such as those carried out by Vidaurre Ruiz. [31], who reported an increase in the consistency of bread doughs by incorporating Andean grain flours rich in fiber, which resulted in more compact doughs.

On the other hand, cohesiveness, which refers to the internal force needed to form the structure of the food [32], also shows a trend. With 95% confidence, it can be concluded that cohesiveness increases as the proportion of freeze-dried arazá powder in the formulation increases. Thus, the control doughs and those formulated with 0.75% powder present the lowest and highest cohesiveness, respectively. This behavior corresponds to what was found in previous research such as that carried out by Aydogfu et al. [33]Where higher cohesiveness values were reported when increasing the lemon fiber content in bread dough

formulations, because the wheat flour could not absorb enough water to develop, thus generating a rigid structure.

Regarding elasticity, which represents the sample's ability to return to its original state when the external force is removed, [32] It is concluded with 95% confidence that elasticity decreases as the proportion of freeze-dried arazá powder increases. This is attributed to the high-water retention capacity of dietary fiber, which reduces the amount of free water available to facilitate the movement of the muffin particles. This result is consistent with previous studies, such as that of Aydogfu et al [33].

3.3.2 Rheology

Rheological properties allow a quantitative relationship to be established between the deformation and stress of an object subjected to the action of an external force. [34]. The analysis of properties such as viscosity, flow index, and consistency index are very useful in industrial applications, processing, sensory evaluation, and quality control. [35]. The viscosity of the doughs in the four muffin formulations as a function of shear rate can be observed in Figure 1. This figure shows that the doughs exhibit the behavior of a pseudoplastic fluid since its viscosity decreases as the applied shear rate increases [35].

In Table 5, the statistical analysis performed is presented, where it can be concluded with 95% confidence that the viscosity at 50 s^{-1} of the formulations containing 0.25%, 0.50%, and 0.75% lyophilized arazá powder is not statistically different from the control formulation. However, a slight increase in this parameter is observed as the proportion of lyophilized arazá powder in the formulation increases. Previous studies such as those carried out by L. Meena et al. [36]Suggests that this increase in viscosity is attributed to the soluble dietary fiber content of freeze-dried arazá powder. This fiber, due to its physicochemical properties, binds with the water present in the other ingredients of the formulation, causing an increase in the viscosity of the dough. Additional justification can be found in research conducted by Alvine Sandrine et al.[37] Where they conclude that the inclusion of dietary fiber in baked products results in an increase in the specific gravity and viscosity of the dough by obstructing the incorporation of air during the mixing process.

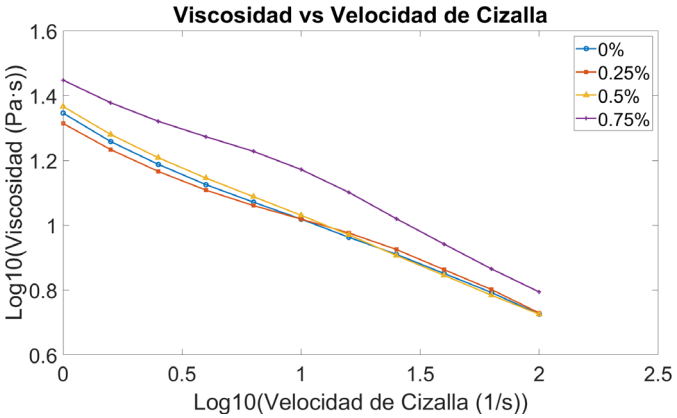


Figure 1. Flow behavior of the masses of the 4 muffin formulations

On the other hand, the values of the flow index (n) and the consistency index (k) are also detailed in Table 5, highlighting that the consistency index, which relates the shear stress with the deformation rate, increases as the proportion of lyophilized arazá powder in the formulation increases. This behavior corresponds to the variation in viscosity since both concepts are analogous. In addition, it is confirmed that all formulations exhibit a non-Newtonian pseudoplastic fluid behavior since n < 1 [38], indicating a shear-thinning tendency [36]. Finally, it is important to highlight that all coefficients of determination R^2were greater than 0.90 in all formulations, which indicates that the model has a good fit.

Table 5. Results of flow indexes, consistency index andR^2

Lyophilized powder	n	K (Pa ·s)	R^2	Viscosity 50 s^{-1}
0%	0.70	3.64	0.99	6.2 ^{A}(0.3)
0.25%	0.73	3.74	0.99	6.3 ^{A}(0.2)

0.50%	0.69	3.84	0.99	6.9 [A] (0.6)
0.75%	0.68	4.34	0.99	7.4 [A] (1.3)

For the same column, means that do not share the same letter are statistically significantly different according to the Tukey test ($p<0.05$). Values in parentheses refer to standard deviations.

3.3.3 Colorimetry

A colour analysis was carried out to evaluate the variations in the CIELAB scale parameters (see Table 6) of the different formulations. Figure 2 clearly shows that, as the number of arazá increases, the color of the muffin experiences a slight change to red/orange tones.



Figure 2. Muffins after baking. From left to right: control, 0.25%, 0.5%, and 0.75% arazá powder

The brightness coordinate (L*) experienced a change with the addition of arazá powder, as the muffin's brightness decreased, going from a lighter color to a darker color (Table 6). This pattern is also reflected in the b* coordinate, indicating a decrease in yellow tones. In contrast, the* coordinate shows that the muffins acquired reddish tones with increasing arazá content. Additionally, when calculating the total color difference (ΔE *), the claim that, with increasing the amount of arazá powder in the formulation, the muffin experiences a color change was confirmed.

Table 6. CIELAB coordinates for the different muffin formulations

Sample	L*	to*	b*	ΔE *
0%	85.6	3.4	40.9	-
0.25%	76.2	4.5	33.1	12.3
0.5%	72.2	5.3	31.4	16.5
0.25%	63.9	6.8	29.4	24.9

As previously mentioned, arazá is a fruit rich in carotenoids, especially lutein. [4]. This compound is highly susceptible to degradation at high temperatures, as well as light and pH. Since the muffin's baking temperature was 180ºC, a carotenoid degradation process occurred since, according to Manupa [39], these degrade above 60ºC, causing the muffins to change color.

3.4 Sensory panel

The results of the sensory panel were classified in terms of gender, age, and frequency with which participants consume muffins. Regarding gender, more men participated (56%) than women (44%). The age range with the highest participation in the sensory panel was 18 to 22 years (68%), followed by the range between 23 and 27 years (24%), between 28 to 32 years (4%) and older than 32 years (4%). Regarding the frequency with which they consume muffins, most people consume them several times a month (52%), followed by several times a week (24%) and people who never consume them (24%). As for the preferred characteristics in a muffin, 50% indicated that they like it to be free of artificial coloring, 48% without added sugar seals, 46% without saturated fat seals, 46% without artificial preservatives, 44% free of trans fat seals and 30% without sweeteners seals.

Panelists were also asked about their familiarity with the properties of arazá and the health benefits associated with its consumption. 84% of participants were not familiar with the properties of arazá while the remaining 16% were. Subsequently, information was provided on the benefits of arazá, and they were asked if they would be willing to consume a product enriched with arazá powder. 90% responded yes and

the remaining 10% expressed a possible willingness. Additionally, they were asked why they would or would not be willing to consume a product with arazá powder to which they responded: *Because vitamin A is often not given the adequate intake and is essential for the proper functioning of the body*, *Because of its beneficial properties for health and because value or interest is being given to raw materials that have not been researched* and *Since vitamin A is important for the body, I also like to buy products enriched with vitamins and various micro and macronutrients*.

Table 7 presents the results of the sensory panel attributes evaluated using the hedonic scale. First, no significant differences were observed in the attributes of appearance, flavor, consistency, and overall acceptability among the four muffin formulations. According to the scores obtained, it can be seen that the formulation with 0.25% arazá had the lowest values in most of the attributes. In contrast, the muffin with 0.75% arazá powder stood out in the attributes of flavor and overall acceptability. It is interesting to note that, concerning flavor, the increase in the amount of arazá powder gave it sweeter notes, thus contributing to the success of the formulation with the highest arazá content in that attribute.

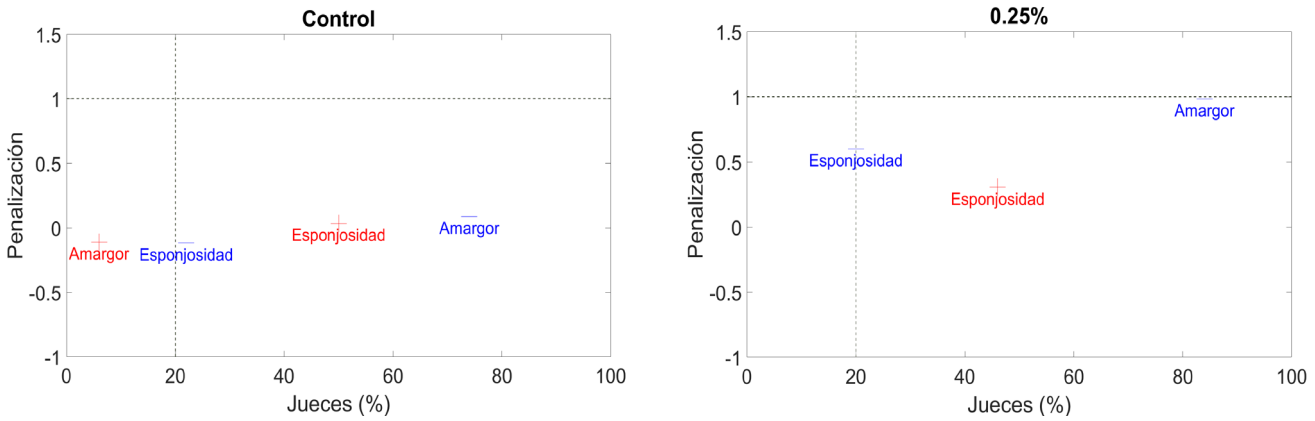
Additionally, the control muffin led in appearance, color, and consistency, while the 0.5% formulation stood out in the aroma attribute. Paying closer attention to the overall acceptability attribute, it is observed that the formulation with 0.75% arazá powder was the most accepted by the sensory panel. Although it did not achieve the best score in color due to the increase in arazá powder, which affected the brightness and generated darker tones, the value obtained in this attribute is very close to the highest, which also occurs in consistency. It is relevant to highlight that, in general, the scores obtained in the sensory panel are high (greater than 6), indicating that the muffins were liked.

Table 7. Sensory panel results of muffins

Lyophilized powder	Appearance	Flavor	Color	Consistency	Scent	Overall acceptability
0%	7.6 ^{A}(1.2)	6.6 ^{A}(1.8)	7.7 ^{A}(1.4)	7.3 ^{A}(1.2)	7.6 ^{A}(1.7)	7.2 ^{A}(1.3)
0.25%	6.9 ^{A}(1.9)	6.8 ^{A}(1.6)	6.0 ^{B}(1.9)	7.1 ^{A}(1.5)	6.8 ^{B}(1.7)	6.8 ^{A}(1.3)
0.50%	7.6 ^{A}(1.4)	6.9 ^{A}(1.8)	7.4 ^{A}(1.3)	7.3 ^{A}(1.4)	7.6 ^{A}(1.3)	7.0 ^{A}(1.5)
0.75%	7.5 ^{A}(1.3)	7.0 ^{A}(1.6)	7.1 ^{A}(1.4)	7.2 ^{A}(1.7)	7.5 ^{AB}(1.3)	7.3 ^{A}(1.2)

For the same column, means that do not share the same letter are statistically significantly different according to the Tukey test ($p<0.05$). Values in parentheses refer to standard deviations.

Figure 3 The JAR scale shows the effect of the fluffiness and bitterness of each muffin on the overall acceptance of the product. The attributes are considered not to have a significant effect on the overall acceptance of the product when: the penalty is less than 1 and the percentage of judges is less than 20% [14]. According to this criterion, it is observed that the bitterness was classified as *too high* in the formulations with 0%, 0.5%, and 0.75% of arazá powder but did not have a penalty in the acceptability of the product. Similarly, the fluffiness was classified as *too low* in the formulation with 0.5% and did not generate a penalty either. On the contrary, for the 0%, 0.5%, and 0.75% formulations the fluffiness was evaluated as *too high* and the bitterness as *too low* by a percentage of judges greater than 20%; however, the penalty in the acceptability of the product was low.



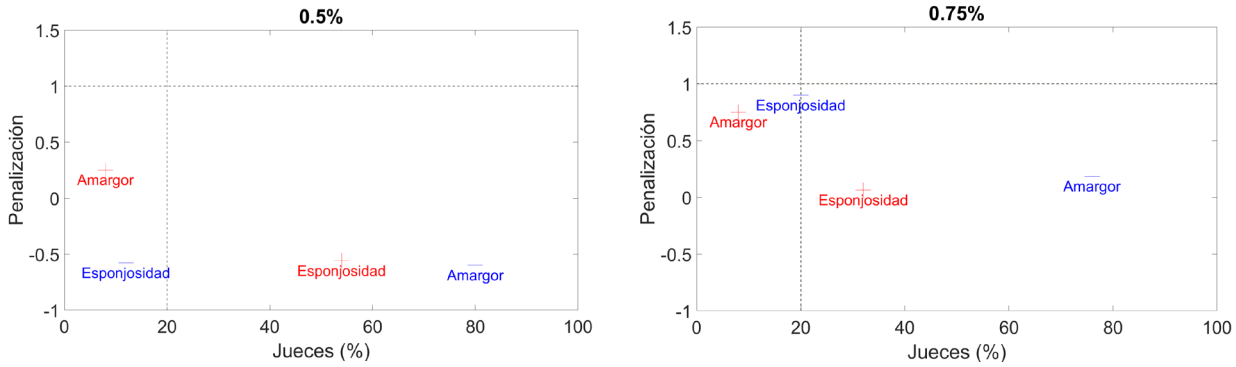


Figure 3. JAR scale penalties. Control (A), 0.25% arazá powder (B), 0.5% arazá powder (C), and 0.75% arazá powder (D). Too high (+), too low (-)

Thus, although consumers perceived that these two attributes did not reach optimal levels, their actual values did not significantly affect the overall acceptability of the product. Finally, it is important to be cautious about *too low bitterness in the muffins with 0.25% and too low* fluffiness in the muffins with 0.25% and 0.75% arazá powder.

The decrease in fluffiness is attributed to the fact that the fiber of the added arazá powder absorbs water from the muffin, resulting in a lower volume of the product. This can be related to the results of rheology and texture where it is observed that the value reported for viscosity increases as the amount of freeze-dried powder increases in each of the samples, while elasticity shows an inverse behavior. Although the attributes did not affect the acceptability of the overall product, it is important to note that they are within the penalty limits.

Similarly, the panelists were asked which muffin was their favorite. The most popular formulation was the one containing 0.75 % arazá powder (36%), followed equally by the muffin with 0.5% arazá powder and the control (28% each) and, finally, the muffin with 0.25% arazá powder (22%). It is worth noting that 10% liked all the muffins, while 2% did not like any muffins.

Considering the experience of the sensory panel and the benefits associated with arazá, the panelists were asked about their willingness to buy the muffin of their choice and what their reasons would be. The results revealed that 92% would be willing to buy it, while the remaining 8% would choose not to. Some of the reasons reported were: *Because in addition to being nutritious and providing benefits, it is delicious and is not high in any of the seals*, *It has good flavor, the presentation or appearance is pleasant, and the benefits mentioned sound interesting, as well as supporting the development of a region like the Amazon,* and *Because I feel that it is a good balance between a widely consumed food and healthy elements that are so in demand today*. The results of the evaluations carried out using the hedonic scale and the JAR scale in the sensory panel indicated that the *winning muffin* was the one with 0.75% arazá powder.

In the last phase, participants were asked about the price they would be willing to pay for a 65g muffin. The results indicated that 48% preferred the option between $2,000 and COP 3,000, 30% indicated they were willing to pay more than COP 3,000, and 22% opted for the $1,000 to COP 2,000 range. Considering the current market context in Colombia (2023), it is observed that the Ramo brand offers a 60g blueberry muffin at COP 4,000 and a 50g Ramito at COP 2,000. Likewise, the Vitad brand sells a 50g healthy muffin at COP 4,000. About this data and the associated production cost taking into account only the price of raw materials (approximately COP 1,400), it is concluded that the price range preferred by participants is within expectations. That is, although the panel's response is slightly below current offers, it remains in line with the cost of production of the product.

3.5 In vitro digestion, extraction, and quantification of carotenoids from the winning muffin

The highly unsaturated structure characteristic of carotenoids is not only the key to their beneficial effects but also the cause of their particular instability [40]. Among the main factors linked to the degradation of

these bioactive compounds are oxygen, light, temperature, pH, metal ions, peroxide, and enzymes [41]. This degradation not only decreases the nutritional value of the pigments but also causes discoloration and a reduction in the quality of their organoleptic properties.

Initially, the muffin with 0.75% lyophilized arazá powder addition contained approximately 373.16 µg of β-carotene. However, previous research by Tsiaka et al. [42]Shows that carotenoid degradation becomes significant at temperatures above 55°C and since the baking process is carried out at 180°C for 13 min, it is imperative to determine how many of these compounds are bioaccessible at the end of intestinal digestion, to estimate the amount that could be effectively used by the consumer's body. The results of the extraction and quantification of the supernatant resulting from *in vitro digestion revealed that approximately 109.39 µg of* bioaccessible β-carotenes remain, representing a loss of about 70.79% mainly due to exposure to light, oxygen, and high temperature. This finding is in line with previous studies such as those by [40], who reported losses of 72.6% of the β-carotenoids present in a bread roll after a baking process at 240°C for 14 min. Given the significant magnitude of the degradation, microencapsulation of the carotenoids is suggested in future research. This approach involves coating the bioactive compound with a protective barrier to increase its bioaccessibility and protect it from such external factors.

3.6 Theoretical proximal analysis and packaging development

The muffin formulation with 0.75% lyophilized arazá powder was identified as a potential product. The detailed nutritional information of this product is shown in Table 8. The muffin serving size was set at 65g after reviewing the average servings of similar products on the market. In terms of nutritional content per serving, the product provides 202.4kcal, with a contribution of 13.50g of total fat (2.53g of saturated fat), 15.64g of carbohydrates (7.89g of sugar, and 5.47g of fiber), 4.58g of protein and 242.56µg of vitamin A.

Table 8. Nutritional information of muffin with 0.75% freeze-dried *arazá* powder

Información nutricional		
Tamaño de porción: 65g		
Número de porciones por envase: 1		
Calorías (kcal)	Por 100g	Por porción
	311.3	**202.4**
Grasa total	20.77g	13.50g
Grasa poliinsaturada	7.99g	5.19g
Grasa saturada	**3.90g**	**2.53g**
Grasa trans	**53.83mg**	**34.99mg**
Carbohidratos totales	24.04g	15.64g
Fibra dietaria	8.42g	5.47g
Azúcares totales	12.13g	7.89g
Azúcares añadidos	**9.96g**	**6.47g**
Proteína	7.05g	4.58g
Sodio	**8.86mg**	**5.76mg**
Vitamina A	373.16µg	242.56µg
Vitamina D	5.64µg	3.66µg
Hierro	2.12mg	1.38mg
Calcio	27.76mg	18.04mg
Zinc	0.39mg	0.25mg

To comply with the labeling guidelines and nutritional requirements, the provisions of *Resolution 810 of 2021* of the Ministry of Health and Social Protection of Colombia were considered. By these requirements, the declaration of an *excellent source of fiber can be included on the product packaging* since the resolution establishes a minimum contribution of 6g of fiber per 100g of food, and the product provides 8.49g per 100g of this.

It is also possible to declare the product as *an excellent source of vitamin A* since the resolution establishes a contribution of 30% of the NRV - N (Reference Daily Values for Nutrients - Needs) for children over 4 years of age and adults, equivalent to 240 µg of vitamin A per 100g of food. In this case, the product contributes 242.56 µg of this micronutrient per 100g. Finally, the packaging can also include the declaration of a *good source of protein,* since the resolution establishes a contribution of 10% of the NRV - N for the same population, equivalent to 5g per 100g of food, and the product provides 7.05g of protein per 100g of this.

In the current market panorama, a product with a similar profile to the one developed is the Ramito cake, a muffin-shaped cake that is part of the portfolio of Productos Ramo SA, a Colombian food company specializing in bakery products. According to data from Euromonitor, by 2022, this company had a 27.128% market share in the baked goods category [43]. In terms of nutritional content per 100g, the Ramito product provides 399kcal, with a contribution of 14g of total fat (9.7g of saturated fat), 61g of carbohydrates (30g of sugar and 3g of fiber), 7.3g of protein and 52 µg of vitamin A.

In comparison, the product developed in this research provides approximately 3 times less sugar and half the saturated fat per 100g, while providing approximately three times the fiber and 7 times more vitamin A. In this way, the muffin with the addition of freeze-dried arazá powder stands out as a snack with a considerably healthier nutritional profile than products currently on the market.

On the other hand, for the design of the product packaging, color psychology was applied, thus opting for a palette of yellow tones. This choice is based on the perception that the yellow color stimulates appetite. [44]; in addition, previous studies such as those carried out by Álvarez Lara [44]Have identified that the use of this color generates a positive purchase response when applied in food product packaging. Likewise, yellow has an intrinsic connection with the ripening color of the arazá, which is the ingredient that adds value to the developed product. As for the name of the product, it was chosen to combine the words *Vitamin A* and *muffin*, resulting in *vitAmuffin*, a muffin with the incorporation of freeze-dried arazá powder which is an excellent source of vitamin A. The proposed design for the vitAmuffin packaging can be seen in Figure 4.



Figure 4. vitAmuffin packaging

4. CONCLUSIONS

The studies carried out in this research have revealed the great potential of arazá as an ingredient in the development of functional products. The application of freeze-drying technology and the choice of overripe fruit stand out as the combination that allows obtaining the highest carotenoid content, with a reported value of 4 97.55 (6.53) µg β-Carotene/g. Regarding the muffin formulations (0%, 0.25%, 0.5%, and 0.75% incorporation of arazá powder), it was found, with 95% confidence, that as the proportion of powder increased, the viscosity, firmness, consistency, and cohesiveness of the dough increased, mainly due to the high water retention capacity of the dietary fiber present in this ingredient. Simultaneously, the elasticity of the muffin decreased due to the restricted movement of the muffin particles, a result of the limited amount of free water in the medium.

On the other hand, in the sensory panel, a marked preference was identified for the formulation that incorporated 0.75% freeze-dried arazá powder, with an overall acceptability of 7.3 (1.2) out of 9 possible points. In addition, it was observed, with 95% confidence, that there were no statistically significant differences in aspects such as appearance, flavor, color, consistency, and aroma compared to the control formulation. Regarding attributes such as sponginess and bitterness, no significant effects on the overall acceptability of the product were observed in any formulation. The *in vitro digestion process* highlighted a degradation of 70.79% of this compound, which means that 109.39 µg of β-carotenes remained bioaccessible from the initial carotenoids in the muffin. Therefore, it is suggested for future research to

apply techniques such as microencapsulation of these compounds, possibly using polymeric biofilms, to protect them from factors such as temperature, oxygen, light, and pH, and thus improve their bioaccessibility.

The winning muffin stands out as an excellent source of vitamin A according to *Resolution 810 of 2021*. When compared with products on the market, it is evident that the product developed in this project contains 3 times less sugar and half the saturated fat, while providing approximately three times the fiber and 7 times more vitamin A. Consequently, vitAmuffin is a snack with a notable nutritional and acceptance potential, capable of partially replacing ingredients to contribute to the development of healthier products, thus promoting disease prevention. Finally, research on arazá as a functional ingredient is currently limited, which is why it is of great importance to continue conducting research on this topic in the country. This is crucial to developing high-value-added products, given the growing demand of consumers looking for alternatives in the market that favor their health and the great nutritional potential of Amazonian fruits available in Colombia.

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