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Effect of low-temperature storage time on rejected green banana for flour production

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Efecto del tiempo de almacenamiento a baja temperatura en banano verde de rechazo para la producción de harina

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ABSTRACT

Banana (*Musa* sp.) crops have one of the greatest economic impacts in Colombia, with an estimated production of 2.2 million tons in 2019. The aim of this study was to evaluate the effect of three anti-browning solutions: S1 (citric acid), S2 (citric acid + ascorbic acid), and S3 (citric acid + ascorbic acid + sodium metabisulfite) on the color, moisture, aw, pH, and acidity characteristics of flour from rejected green bananas. No significant differences were found ($P>0.05$). The values of a* and b* in all samples were in the grey zone. L* and WI presented values close to 50, which could be defined as a flour in a medium range of clarity. The citric acid anti-browning solution was selected based on criteria such as cost and availability. The second part of the study assessed the effect of the storage time (1, 3, 5, 7, 9 and 11 days) at 7 °C on the color and texture of fresh bananas; and pH, instrumental, and sensory color of banana flour. There were differences noticeable for the human eye in the color (ΔE) of the peel from day 3 compared to day 1; while in the pulp, these changes were observed from day 7. Statistically significant differences in instrumental and sensory color properties of banana flour were observed after day 7 ($P<0.05$). The maximum storage time at 7 °C of fresh green bananas to produce banana flour should not exceed 7 days because color may be affected.

Keywords:
Banana flour
Chilling injury
Enzymatic browning
Musa cavendish

RESUMEN

El banano (*Musa* sp.) es uno de los cultivos de mayor impacto económico en Colombia, se estima que para el 2019 se produjeron 2,2 millones de toneladas. El objetivo de este estudio fue evaluar el efecto de tres soluciones antipardeantes S1 (ácido cítrico), S2 (ácido cítrico + ácido ascórbico) y S3 (ácido cítrico + ácido ascórbico + metabisulfito de sodio) en las características de color, humedad, aw, pH, y la acidez de la harina de banana verde de rechazo. No se presentaron diferencias significativas ($P>0,05$). Los valores de a* y b* de todas las muestras se ubicaron en la zona gris. L* y WI presentaron valores cercanos a 50, lo que podría definirse como una harina en un rango medio de claridad. La solución antipardeante con ácido cítrico fue seleccionada basándose en criterios como el costo y la facilidad de acceso. La segunda parte del estudio consistió en evaluar el efecto del tiempo (1, 3, 5, 7, 9 y 11 días) de almacenamiento a 7 °C de los bananos frescos sobre las propiedades de color y textura en la fruta, el pH; además del color instrumental y sensorial de la harina de banano. Se observaron diferencias evidentes para el ojo humano en el color (ΔE) de la cáscara a partir del día 3 con respecto al día 1; mientras que, en la pulpa estos cambios tan evidentes se observaron a partir del día 7. Las diferencias estadísticamente significativas de propiedades de color instrumental y sensorial en la harina de banano se observaron después del día 7 ($P<0,05$). El tiempo máximo de almacenamiento a 7 °C de los bananos verdes en fresco para la producción de harina de banano no debe ser superior a los 7 días porque se puede afectar su color.

Palabras clave:
Harina de banano
Daño por frío
Pardeamiento enzimático
Musa cavendish

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Bananas are one of the most consumed fruits in the world. In Colombia, this crop has one of the greatest impacts on the economy and is one of the most exported agricultural products, along with coffee and flowers (Minagricultura 2022). It is estimated that 2.2 million tons were produced in 2019, a figure that placed the country as the ninth largest producer in the world and the fifth largest exporter of this fruit after Ecuador, the Philippines, Guatemala, and Costa Rica, thus supplying one tenth of the export market (Andersen et al. 2020; Minagricultura 2020). According to the Ministry of Agriculture and Rural Development (MADR), the departments of Antioquia, Magdalena, and La Guajira are the main producers of banana, and 86% of their production is exported (Minagricultura 2020). Andersen et al. (2020) estimate that 1.75 million tons were exported, and it generated approximately 155,000 direct and indirect jobs.

The cavendish variety is one of the most produced and marketed in the world. It is also an important product of international trade (Kuan et al. 2015; Padhi and Dwivedi 2022). In nutritional terms, bananas stand out as a source of minerals, vitamins, carbohydrates, flavonoids, phenolic compounds, among others (Singh et al. 2018). However, this fruit is climacteric, thus perishable, and prone to post-harvest loss (Odetayo et al. 2022). Different investigations have been developed to mitigate these losses, so that green bananas can be used, specifically rejected ones, i.e., those that do not meet the standards of international markets such as variety, number, and size of fingers per bunch, color, appearance, diameter, packaging, and phytosanitary conditions (Sartori and Menegalli 2016; Stanley 2017).

One way to delay the biochemical processes of biological material—like the production of ethylene in climacteric fruits—is storage at low temperatures, although it can damage the structure of the plant material, which is known as chilling injury (Tian et al. 2022). In the case of bananas, the physiological damage occurs below 12 °C and worsens as the temperature decreases. Among the undesirable effects, color changes in the shell (discoloration and brown spots) caused by polyphenol oxidase (PPO)—an enzyme responsible for browning—and an impediment in the normal maturation process have been reported (Tian et al. 2022). Moreover, other possible damages during storage due to mechanical and low moisture effects should be considered (Kader 2022).

Different by-products have been developed from rejected bananas to give them an added value, e.g., syrup, precooked products, dried banana, flour, and powder obtained by different technologies for food and pharmaceutical applications (Singh et al. 2018). Furthermore, green banana flour has gained greater interest due to its functional properties. However, some unfavorable reactions such as enzymatic browning occur during the flour production process. It is a biochemical reaction that occurs naturally in foods and affects especially fruits because the color of their pulp becomes dark. This leads to unwanted quality, sensory, and nutritional defects in the final product (Anyasi et al. 2017). The PPO enzyme, responsible for that reaction, acts on the phenolic compounds and oxidizes them to quinones. Subsequently, the latter are polymerized to form a relatively insoluble brown pigment known as melanin (Moon et al. 2020). Precisely, one of the challenges faced by the banana processing industry is to avoid the enzymatic browning that affects the pulp once the shell is removed (Anyasi et al. 2015).

Currently, there are various methods to control, reduce, or inhibit enzymatic browning. The most used physical methods are oxygen reduction and modified atmospheres, coating films, and inactivation of enzymes by heating, e.g., blanching (Dávila et al. 2016). Chemical methods have specialized in the use of substances that, according to their active ingredient, focus on the inhibition of the enzyme, oxygen, or formed products: acidulants reduce the pH of the food, therefore, the enzymatic action; sulfites delay the rate of melanin formation, thus reducing quinones to diphenols; antioxidants react with oxygen to prevent the oxidation of phenolic compounds; and chelating agents form complexes with the copper oxide present in PPO (Moon et al. 2020; Yupangui Tenesaca 2016).

The advantages of physical methods to avoid enzymatic browning are the homogenization of food treatment and the possibility of modulating process conditions. Some disadvantages are alteration of the consistency of the treated product, sometimes giving a cooked flavor, generating losses of nutrients, and resulting in a decreased weight of the product. Moreover, the effectiveness of chemical methods depends on environmental factors such as pH, water activity (aw), temperature, light, and composition of the atmosphere, and are limited by the presence of the cuticle. The advantages of these methods are quickly and effectively inhibiting enzymatic browning, they can be applied to a variety of fruits, are often readily available and relatively inexpensive compared to other methods, and do not cause noticeable changes in the taste, aroma, or texture of fruits when used in suitable concentrations. Despite these advantages, it is important to note that the use of chemical inhibitors should be regulated to ensure food safety and minimize any potential adverse effects (Moon et al. 2020).

Ascorbic acid and citric acid are among the most common agents to inhibit enzymatic browning, alone or in combination. They are Generally Recognized as Safe (GRAS), and their use is less restricted (Anyasi et al. 2015; Wang et al. 2014). It has also been determined that the use of sulphites prevents banana pulp from browning and enables obtaining a clearer flour with greater acceptability by the consumer (Salazar et al. 2022). However, their use is more limited due to their toxicity (Ojeda et al. 2020). The aim of this study was to evaluate the influence of pretreatments with anti-browning solutions based on ascorbic acid, citric acid, and sodium metabisulfite, and the storage time of rejected green banana fruits at 7 °C on the color, firmness, moisture, aw, pH, acidity, and sensory color of banana flour.

MATERIALS AND METHODS

Location

The plant material used to produce the flour was rejected green banana (*Musa cavendish*) from the department of Magdalena (Colombia), municipalities of Aracataca, Ciénaga, and Zona Bananera, specifically from the Gran Vía area (Latitude 10° 50'47.336"N, Longitude 74° 8' 30.477"W) and Santa Rosalía (Latitude 10° 49'45.672" N, Longitude 74° 7' 26.297"W). Their maturity stages were 1 and 2 (green) (Kader 2022).

Preparation of plant material

The bunches were harvested between 10 and 12 weeks, taking into account the harvest age criteria for banana exports. Bunches older than 12 weeks cannot be exported because by the time this product reaches the destination country, they will be more ripe than normal and could even have black spots (Alonso-Ugaglia et al. 2022). Furthermore, rejected bananas are not suitable for export due to the high-quality standards required by importers. The most outstanding characteristics of rejected bananas are low weight, presence of spots, physical damage and scars higher than 1%, fruit length less than 22 cm, and fruit diameter less than 3.5 cm (Vásquez-Castillo et al. 2019). The cutting process was carried out with the help of tapes placed during the taping process. When the order to cut a certain color of tape was given at first, only 25% is cut; the following week, 50%; and the last week, the remaining 25% (Alonso-Ugaglia et al. 2022).

Food-grade detergent and organic acid-based disinfectant (1% Acid-tech solution) were used for cleaning and disinfection. The following substances were used for pretreatment with anti-browning solutions: citric acid and ascorbic acid powder (Bell Chem, Medellín, Colombia), sodium metabisulfite powder (Químicos JM, Medellín, Colombia), reactive-grade phenolphthalein (Chemi, Milán, Italy), and sodium hydroxide (NaOH) pearls (Panreac, Darmstadt, Germany).

Rejected green banana fruits were transported from Santa Marta to Medellín by air at room temperature, packed in cardboard boxes, and properly arranged inside the box to be processed at Universidad Nacional de Colombia. The transportation time of the raw material was less than 12 h. Upon arrival, they were washed and disinfected. Subsequently, they were stored at 7 °C to delay the ripening process until they were used in flour preparation. During the pre-climacteric period, mature green fruit has a low basal respiration rate and ethylene production is almost undetectable. This period is also called "Green Life" (GL). The high sensitivity of the banana fruit to the duration and intensity of low temperatures could provoke chilling injury. The suitable storage GL is 35 days at 13 °C (Brat et al. 2020). However, this study was intended to evaluate the lowest temperature possible to verify its effect on the quality traits of banana flour; it was set at 7 °C. Studies have been carried out previously storing banana fruit at 7 and 9 °C (Chen et al. 2022; Othman et al. 2021).

Preparation of immersion solutions (Pretreatment)

For banana pre-treatment, anti-browning solutions (S1, S2, and S3) were prepared using citric acid, ascorbic acid, and sodium metabisulfite, as specified in Table 1. The methodology employed to prepare them was taken from Cortés et al. (2013). Each experimental unit consisted of 288 g of 5 mm-thick slices of green banana, which were immersed for 10 min in 1 L of anti-browning solution (S1, S2, and S3).

Obtaining green banana flour

The rejected green banana was processed 3 days after the banana was harvested. Bananas were manually peeled and then chopped into 5 mm-thick slices, using manual mandolins. The slices were immediately immersed in the anti-browning solution for 10 min. Subsequently, they were dried at 55 °C for 15 h in a forced convection oven (Memmert 750, Germany) and then ground in a blade mill (IKA MF 10 Basic, USA) to obtain the flour, which was packed in No. 12 metalized pet resealable bags (Alico, Colombia). They were stored at room temperature in a cool, dry place for further analysis.

Table 1. Anti-browning solutions.

Immersion solution	S1	S2	S3
Citric acid	50 mg 100 g^{-1} sample	50 mg 100 g^{-1} sample	50 mg 100 g^{-1} sample
Ascorbic acid		90 mg 100 g^{-1} sample	90 mg 100 g^{-1} sample
Sodium metabisulfite			500 ppm of the solution

Physicochemical characterization of green banana flour

The color was determined by instrumental measurement with a colorimeter (Chroma Meter CR-400/410, Japan) using the CIELAB color scale with the parameters L* (brightness), a* (red/green), and b* (yellow/blue) (Vélez-Uribe et al. 2023). Measurements were made in triplicate using Illuminant D65. The chromaticity parameters (C), hue angle (°H), and whiteness index (WI) were calculated. The pH was measured following the methodology described by AOAC 943.02 (AOAC 1997); titratable acidity (Padhi and Dwivedi 2022) with some modifications; water activity (aw) by modified AOAC 978.18 (AOAC 1997), moisture by AOAC 925.10 (AOAC 1997). The properties of the banana flours used in these treatments were compared to commercial banana flour (Harina de Cambur verde, Artesanos fit, Trujillo, Venezuela).

Evaluation of storage

The rejected green bananas' storage was evaluated on days 1, 3, 5, 7, 9 and 11. Color and firmness tests were carried out on both the shell and the pulp of the fresh fruits. In addition to the flour obtained, the color and pH parameters were evaluated under the aforementioned methodologies. Mechanical characterization was performed using the firmness test (Sanaeifar et al. 2016). It was determined in triplicate on a texture analyzer (Stable Micro System, TA-Xt2i) at three points. A firmness test was performed on bananas' shells and pulp. The firmness of the samples was determined by a one-way penetration test, using a 2 mm diameter stainless steel cylindrical shaft and a load cell 50 kg_f. The operating parameters for the firmness test were pre-test speed, 2 mm s^{-1}; test speed, 2 mm s^{-1}; post-test speed, 2 mm s^{-1}; and penetration distance, 20 mm. The color sensory analysis was carried out by a triangular test for sensory differentiation according to ISO 10399:2017 (ISO - International Standards Organization 2017) to a group of 40 selected panelists. They were presented with three samples—two from the same treatment and one different—and asked to identify the sample that had a different color among the three samples.

Statistical analysis

The effect of the anti-browning solution (S1, S2, and S3) on the physicochemical and color properties of processed banana flour, and the effect of storage time of the rejected green bananas (days 1, 3, 5, 7, 9, and 11) on the flour produced from it were analyzed by one-way factorial design. Means were assessed by a Tukey multiple comparison test with a significance level α=0.05 using the R statistical software (R Core Team 2022).

RESULTS AND DISCUSSION

Anti-browning solution

The effect of anti-browning solutions on physicochemical properties and CIELAB color coordinates (L*, a*, and b*) are shown in Table 2. The physicochemical and color properties of banana flour were not affected by pretreatment with S1, S2, and S3 solutions. The parameters in the chromatic plane a* and b* of all samples are in the grey zone. L* is a parameter associated with the clarity of the sample; in general, the results obtained in this research show values close to 50, which could be defined as a flour in a medium range of clarity. The WI is a parameter derived from the combination of luminosity and yellow/blue (b*) in a single term (Pathare et al. 2013). Therefore, when obtaining low values of L* and b*, the WI was not high. However, when comparing these results with a commercial flour, more relevant differences are observed in parameters such as L* and WI, which are lower.

Table 2. Effect of the anti-browning solution on color parameters and physicochemical properties of banana flour.

Solution	Variable				
	L*	a*	b*	C	°H
S1	44.77±0.18ᵃ	1.56±0.34ᵃ	8.69±0.21ᵃ	8.83±0.26ᵃ	79.86±1.92ᵃ
S2	45.60±0.80ᵃ	1.50±0.21ᵃ	9.26±0.50ᵃ	9.38±0.46ᵃ	80.78±1.75ᵃ
S3	49.50±2.99ᵃ	0.94±0.43ᵃ	9.51±0.29ᵃ	9.56±0.24ᵃ	84.30±2.73ᵃ
Commercial flour	36.85±2.40	1.46±0.14	7.70±0.17	7.84±0.19	79.30±0.87
	Variable				
Solution	**WI**	**Moisture %**	a_w	**pH**	**Acidity****
S1	44.07±0.14ᵃ	6.29±1.12ᵃ	0.166±0.045ᵃ	5.4±0.0ᵃ	0.16±0.05ᵃ
S2	44.80±0.72ᵃ	6.24±1.14ᵃ	0.168±0.037ᵃ	5.3±0.0ᵃ	0.20±0.00ᵃ
S3	48.60±2.98ᵃ	6.26±1.07ᵃ	0.175±0.035ᵃ	5.2±0.1ᵃ	0.20±0.00ᵃ
Commercial flour	36.36±2.37	10.56±0.15	0.459±0.06	5.9±0.0	0.13±0.03

The means of pretreatments with a common letter in a column do not differ significantly at a significance level α=0.05, according to Tukey's DSH test. **Acidity expressed as malic acid.

The moisture content and water activity (aw) properties in powdered products are critical, as they can affect other physical and chemical properties of food. In addition, they are key for shelf life and stability (Savlak et al. 2016). The moisture content found in green banana flours from Magdalena is within the percentages allowed in NTC 2799 (moisture<10%) (ICONTEC 2020). The results obtained are higher than those reported by Khoozani et al. (2019), who showed a moisture content in dried banana flour of 5.09, 4.56, and 4.46% at temperatures of 50, 80, and, 110 °C, respectively, and aw values of 0.25, 0.34, and 0.39 for the same temperatures—higher than those obtained in this experiment. Campuzano et al. (2018) evaluated the moisture content in cavendish banana flour (*Musa acuminata* AAA) from Ecuador at maturation stage one and obtained a higher moisture value of 10.88±0.17 g 100 g^{-1}. Meanwhile, Savlak et al. (2016) evaluated moisture, aw, and pH in "Dwarf cavendish" green banana flour (*Musa* spp. AAA) from Turkey and reported a moisture value of 9.07±0.35%, aw of 0.42±0.02, and pH of 5.66±0.01—higher than those presented in this study and similar to those of commercial flour. Solutions with only organic acids (S1 and S2) in some cases tend to be slightly more acidic because of the nature of the substances employed in the pretreatment; however, no statistically significant differences are reported between samples. The literature reports data that tend towards neutrality with pH=6.12 and 0.11% for acidity (Padhi and Dwivedi 2022).

As there were no significant differences among the anti-browning solutions to produce banana flour in the proposed design, the solution was selected considering other criteria such as the most used anti-browning agent, its adverse effects on health, and costs. Although all the agents used are considered GRAS, a positive effect of anti-browning agents has been observed when obtaining banana flours, e.g., citric acid used at different concentrations (Chang et al. 2022; Savlak et al. 2016). In addition, Sarpong et al. (2018) report the positive effect of citric acid on the inhibition of enzymes such as polyphenol oxidase. Ascorbic acid, in addition to inhibiting polyphenol oxidase, can repress the yield of o-quinones in diphenols (Homaida et al. 2017). Ali et al. (2015) also observed that a lower concentration of ascorbic acid acted as an inhibitor of enzymes, but a higher concentration only reduced the formation of quinones.

Sulfur dioxides or their salts, such as sodium metabisulfite, have also been applied due to their positive effect as anti-browning agents when obtaining banana flours (Padhi and Dwivedi 2022; Salazar et al. 2022). Although sodium metabisulfite has been widely used in the food industry due to its ability to prevent enzymatic and non-enzymatic browning and microbial growth, and as a bleaching agent that helps preserve flavor, texture, and color in food, it is regulated by INVIMA (maximum 1,500 mg kg^{-1}) in Colombia and there are some doubts about the use of sulphites in food products due to possible health effects (Ojeda et al. 2020).

Citric acid was selected as the best anti-browning agent considering that approximately 15,000, 1,500, and 204 t of citric acid, ascorbic acid, and sulfites were imported in 2021, which indicates increased availability of the first one, and their import costs were approximately 1.29, 641, and 2.13 USD kg^{-1}, respectively (MinCIT 2022); citric acid having the lower import cost.

Storage time

Once the anti-browning solution (S1) was selected, the fruit's storage time at low temperatures to obtain flour was evaluated using the color and firmness parameters of fresh green banana with the peel and in the pulp. Results are shown in Table 3. There are no significant changes in the peel firmness during storage with an average value of 13 to 14.5 N. Moreover, an increase in the pulp firmness was observed on the 3rd day of storage, and then it remained with values close to 6 N. The texture changes in the pulp can be due to several factors like the contributions of starch hydrolysis, the enzymatic disruption of the cell wall structure, the water migration from the banana peel to the pulp, fruit mechanical damage, fruit physiological problems, or poor post-harvest handling (Sinanoglou et al. 2023).

The hue angle or tone (°H) in vegetables expresses the color variation, which takes 0° for red, 90° for yellow, and 180° for green. Although this parameter gradually changes over time from green to yellow in bananas (Jaiswal et al. 2014), in this experiment, it remained green due to the low storage temperature that delayed ethylene production (Facundo et al. 2015). Values close to 90° in the pulp

Table 3. Effect of fresh banana storage time on color and firmness parameters.

Parameter	Part of the banana	DAY					
		1	3	5	7	9	11
L*	Peel	54.01±1.92^{a}	53.62±1.83^{a}	54.08±3.61^{a}	53.22±1.71^{a}	54.00±4.73^{a}	55.48±3.51^{a}
	Pulp	83.31±1.15^{b}	82.91±0.83^{b}	84.54±1.38^{b}	88.21±1.37^{a}	86.91±1.40^{a}	87.96±1.41^{a}
a*	Peel	-15.99±0.88^{c}	-17.1±0.75^{c}	-9.25±2.75^{a}	-11.94±1.25^{b}	-11.93±2.01^{b}	-13.32±0.92^{b}
	Pulp	-1.21±0.17^{ab}	-1.21±0.12^{ab}	-1.05±0.25^{a}	-1.24±0.12^{ab}	-1.54±0.29^{c}	-1.36±0.21^{bc}
b*	Peel	30.07±1.54^{b}	34.31±1.29^{a}	29.64±1.76^{b}	30.46±1.69^{b}	30.30±3.35^{b}	33.24±1.20^{a}
	Pulp	19.56±1.09^{bc}	18.17±0.92^{c}	19.79±1.10^{bc}	19.54±1.93^{bc}	22.13±1.23^{a}	20.97±0.95^{ab}
C	Peel	34.06±1.64^{bc}	38.33±1.45^{a}	31.12±2.43^{c}	32.73±1.94^{bc}	32.58±3.76^{c}	35.81±1.39^{ab}
	Pulp	19.59±1.08^{bc}	18.21±0.92^{c}	19.82±1.10^{bc}	19.58±1.93^{bc}	22.18±1.22^{a}	21.02±0.95^{ab}
°H	Peel	118.01±1.11^{a}	116.49±0.52^{a}	107.07±4.09^{c}	111.37±1.45^{b}	111.42±1.80^{b}	111.82±0.96^{b}
	Pulp	93.56±0.64^{ab}	93.81±0.50^{ab}	93.05±0.77^{b}	93.67±0.44^{ab}	94.00±0.80^{a}	93.70±0.57^{ab}
WI	Peel	42.73±1.32^{a}	39.81±1.75^{b}	44.41±2.19^{a}	42.86±0.57^{a}	43.38±2.21^{a}	42.83±3.08^{a}
	Pulp	74.24±1.13^{b}	75.02±1.00^{ab}	74.85±1.53^{b}	77.14±2.30^{a}	74.22±1.40^{b}	75.76±1.46^{ab}
ΔE	Peel	-	4.40	6.75	4.15	4.06	4.40
	Pulp	-	1.45	1.26	4.90	4.44	4.86
Firmness (N)	Peel	14.32±1.34^{a}	13.07±1.31^{a}	14.57±3.01^{a}	13.47±2.22^{a}	13.26±2.40^{a}	13.65±1.55^{a}
	Pulp	5.22±0.40^{b}	6.28±0.52^{a}	5.66±0.97^{ab}	5.51±0.44^{ab}	5.79±0.45^{ab}	5.90±0.60^{ab}

The means of properties with a common letter in a row do not differ significantly at a significance level α=0.05, according to Tukey's DSH test. Parameter ΔE was calculated based on day 1.

show a tendency to yellow. According to the ΔE in the banana peel, it was observed that the color difference on days 3, 5, 7, 9, and 11 is obvious to the human eye. Moreover, in banana pulp, the color difference in days 3 and 5 is smaller and could be appreciated by the human eye depending on the tone with respect to day 1. From day 7 of storage, changes in color with respect to day 1 are easily perceived by the human eye (Goswami et al. 2015).

Facundo et al. (2015) studied the influence of low-temperature storage on skin color and carotenoid content in two banana cultivars (cv. Prata and cv. Nanicao). They found that bananas stored at temperatures of 10 and 13 °C did not show changes in color and it was maintained until 15 days. Figure 1 shows that the color in the banana peel remained green during the 11 days of storage, although at day 5 some brown colorations began to appear. These results are similar to those reported by Wang et al. (2021), who observed some brown spots from day 4 of storage at 7 °C that may be associated with cold damage. It affects the parameters L*, C, and °H. During the 11 days, it was also found that the luminosity (L*) of the banana peel did not present significant differences, while significant changes were observed in the pulp ($P<0.05$) from day 7. The color changes of the banana pulp could be attributed to increases in the moisture content and oxygen penetration to the pulp during the storage period. Moreover, the redness (a*) fluctuations of the banana pulp could be associated with a differentiation of the total carotenoid-content during ripening and the brown spots on the peel (Sinanoglou et al. 2023).

Figure 1. Evolution of bananas in cold storage over time.

The effect of the storage time (1, 3, 5, 7, 9, and 11 day) on the fresh banana fruit to produce banana flour is shown in Table 4. In products such as flour, color is one of the sensory attributes that impacts the evaluation and acquisition of food for both the consumer and the food industries. Thus, whiter flour improves acceptance and interest, since when incorporated as an ingredient in products, it will cause few changes in the final color. When the yellow component (b*) or the green component (a*) predominates on the values of the coordinates a* and b*,

Table 4. Parameters of pH and color of banana flour.

Day	Parameter							
	pH	L*	a*	b*	C	°H	WI	ΔE'
1	5.57±0.01^{e}	52.46±1.48^{c}	1.45±0.06^{cd}	8.52±0.42^{b}	8.65±0.42^{b}	80.32±0.13^{cd}	51.68±1.38^{c}	-
3	5.68±0.0^{a}	52.97±0.88^{c}	1.58±0.05^{bc}	8.83±0.21^{b}	8.97±0.21^{b}	79.87±0.14^{d}	52.12±0.82^{c}	0.60
5	5.64±0.00^{bc}	51.83±1.26^{c}	1.48±0.02^{bc}	8.89±0.22^{b}	9.01±0.22^{b}	80.52±0.12^{c}	50.99±1.20^{c}	0.73
7	5.63±0.01^{cd}	53.53±1.12^{c}	1.36±0.04^{d}	9.42±0.20^{ab}	9.51±0.20^{ab}	81.78±0.14^{a}	52.57±1.05^{c}	1.40
9	5.62±0.01^{d}	64.69±2.70^{a}	1.62±0.08^{b}	10.37±0.60^{a}	10.49±0.61^{a}	81.12±0.08^{b}	63.14±2.42^{a}	12.37
11	5.65±0.01^{b}	59.11±2.64^{b}	1.94±0.03^{a}	9.35±0.34^{b}	9.55±0.34^{ab}	78.27±0.34^{e}	58.00±2.50^{b}	6.72

The means of pretreatments with a common letter in a column do not differ significantly at a significance level α=0.05, according to Tukey's DSH test. Parameter ΔE' was calculated based on day 1.

flour with tendencies to a darker or lighter yellow color is obtained (Bezerra et al. 2013).

The L* and WI values showed no statistically significant differences (P>0.05) until day 7 of storage with respect to day 1. However, although they are slightly higher than those found in the first part of this experiment, in the chromatic plane, the samples continue to be in the gray area with medium luminosity and whiteness. Lower L* values can be attributed to the oven drying process (Savlak et al. 2016). Additionally, the browning process is known to occur due to the presence of four components: oxygen, oxidizing enzyme (polyphenol oxidase), a metal ion (copper), and a suitable substrate (phenolic substrate) (Moon et al. 2020). Consequently, it would not be possible to attribute browning in flour only to the action of polyphenol oxidase. Regarding the color differences with respect to day 1, it is observed that the flours processed on days 3 and 5 are classified as non-perceptible ($\Delta E'<1$). On day 7 the changes are minor and could be perceived by the human eye depending on the tone of the sample on day 1 ($1<\Delta E'<3$). From day 9 of storage, there would be obvious changes for the human eye ($\Delta E'>3$) (Goswami et al. 2015).

Sensory color

Sensory analysis encompasses a set of techniques for correct judgment of human responses to food and tracks the potential bias effects of fraud, brand identity, and quality that influence consumer perception. Since it is a measurement science, it seeks—like other instrumental techniques—the accuracy, sensitivity, and prevention of false-positive results (Drake et al. 2023). Consumers generally evaluate the quality of a product based on its appearance and color; then, through this additional evaluation of color by instrumental methods, it intended to find out if a group of 40 panelists could determine the color differences between banana flours made on days 3, 5, 7, 9, and 11 with respect to day 1. Therefore, a triangular test was carried out in which a series of correct choices, beyond what is expected, is considered evidence of a discernible difference between samples (Mihafu et al. 2020). The results obtained for each day are presented in Table 5. The data were taken from a binomial statistical table, which establishes that when more than 19 panelists out of 40 respond correctly, the samples present statistically significant differences (P<0.05) (International Standards Organization- ISO 2017). The sensory panel of the triangular test showed a significant difference (P<0.05) between the banana flour made on days 9 and 11 of storage and that made on day 1, with a total of 20 and 24 correct answers, respectively. The color results of the flour at the sensory level confirmed what was obtained at the instrumental level, i.e., the color differences are more obvious for the human eye from day 9 of fresh green banana storage.

Table 5. Sensory color.

Day	Correct answers	*P*
3	10	0.9034
5	14	0.4703
7	9	0.9517
9	20	0.0214
11	24	0.0005

CONCLUSIONS

The contribution of this research indicates the anti-browning solutions used in this study do not have a significant effect on the color, moisture, aw, pH, and acidity of banana flour. Therefore, it is beneficial for the industry to select them appropriately based on their availability and cost. The use of citric acid is recommended as an anti-browning solution to produce banana flour due to its wide application in this field, low cost compared to the other two solutions evaluated, availability in the local market, and it is generally recognized as safe. Furthermore, this research corroborates the findings of other previous studies that have employed these chemical agents, obtaining similar results in line with the standards established by the corresponding regulations. Moreover, it is crucial to have knowledge of the maximum storage time of the fruit in the food industrial field to ensure flour production that does not exhibit alterations in terms of taste, color, or poor texture, while avoiding the loss of essential nutrients. These factors can directly impact production costs and process profitability. According to the literature, the suitable storage temperature for green bananas should be close to 13 °C; however, they were stored at 7 °C to evaluate a limited storage temperature for this climacteric fruit. The maximum storage time of rejected fresh green banana fruits at 7 °C to produce banana flour should not exceed 7 days because their color may be affected. It is suggested that future research delve further into the combination of physical treatments along with the use of anti-browning agents, or even the use of natural extracts as alternatives to these chemical agents. Furthermore, the effect of pretreatment with citric acid should be evaluated in pasting, thermal, and techno-functional properties of banana flour. Thus, innovative approaches can be identified to optimize the quality and preservation of banana flour, and both the industry and consumers could profit from it.

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