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Variation of color with baking time in snacks made with pregelatinized cassava

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Abstract: Color is an importantaspect when formulating products, as the consumer will evaluate this aspect in the first instance. There is a growing interest in non-wheat producing regions to replace it with local sources of starches. However, the substitution of wheat flour affects characteristics such as texture, flavor, and color of the intermediate and final products. The objective of this work was to determine if the variation of the baking time allows reducing the color difference that the replacement of flour generates by dehydrated cassava puree (DCP). For that, four replacement levels were evaluated using the CIE-L * a * b * and CIE-L * C * H * methodology. The browning index and total color difference (ΔE) between samples with different replacement levels and between different stages of production were also evaluated. It was proved that the decrease in the baking time allowed the development of a similar coloring between snacks made with DCP and those made without substitution. Also, moisture values of less than 5% (dry basis) were obtained in the snacks. The browning index increased with the proportion of DCP in flour and doughs, but not in baked snacks. The pregelatinization of starches could be a mechanism to improve the quality of products with substitutions of wheat flour.

Practical Application: Color is a critical attribute of foods in consumer acceptance. The accelerated color development that pregelatinized cassava starch produces in the appearance of baked goods can be useful for food development. A quick color development can mean shorter exposure time to heat, which is important for some products with heat-sensitive components. Also, it is interesting to note that the cassava dehydrated puree is a gluten-free product.

KEYWORDS
Cassava, Cie-L * a * b *, pregelatinized starch, Substitution, Wheat flour

1 | INTRODUCTION

There is a growing interest in promoting the use of local sources of flour and starch for the partial replacement of wheat flour. This is important in countries and regions where wheat is an imported product that affects food security (Aristizábal & Sánchez, 2007; Chisenga et al., 2019). It would be useful for the industry to evaluate the potential of using cassava as a substitute for flours for the development of new products with high added value (Chang et al., 2001; Martinez-Flores et al., 2004; Salcedo Mendoza et al., 2017). However, the substitution of wheat flour affects the properties and the quality of doughs and final products. For example, the difference in the amylose/amylopectin ratio influences viscosity, gelatinization, and retrogradation that affect the texture of the final

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product. The absence of gluten and the acceptability of the final products among consumers in terms of sensory attributes are important issues to consider (Eduardo et al., 2013; Eriksson et al., 2014). Among these properties, color is a quality attribute that plays a critical role in food selection. Although there are many methodologies for the evaluation of this characteristic in foods, the one most used is the CIE L * a * b * color space due to its uniform color distribution and because its perception of color is closer to the human eye. One of the difficulties of this methodology is that the measures are not considered representative for most heterogeneous materials (Markovic et al., 2013). For example, in flours, the color is affected by the size of the particles, treatments applied, temperatures, time, and type of drying (Oladunmoye et al., 2010). Previously, research was carried out about the effects that the substitution of wheat flour produces by flours of different origins such as soy, quinoa, taro, rice-berry, Jerusalem artichoke, bagasse and cassava starch, cassava flour, mocaf (fermented cassava flour), and modified cassava starch. The authors of these studies found that the color in one or all its components (L *, a *, b *) is significantly modified (Aristizábal & Sánchez, 2007; Díaz et al., 2019; Fiorda et al., 2013; Kaushal & Sharma, 2014; Kusumaningrum et al., n.d.; Panduro Castañeda, 2015; Rodriguez-Sandoval et al., 2017; Sirichokworrakit et al., 2015). Dehydrated cassava puree (DCP) also creates a difference in the color of flours, doughs, and baked snacks. Investigating how to counteract the effects of the substitution of wheat flour in the color of intermediate and finished products is still a subject of investigation. Hence, the objective of this work was to determine if the variation of the baking time allows reducing the color difference generated by replacing flour with DCP.

2 | MATERIALS AND METHODS

2.1 | Materials

2.1.1 | Flours

Wheat flour type 0000 (Cake Flour) and DCP were used. Both were acquired from a local market (Argentina). The flour package declares 10 g of proteins, 70 g of carbohydrates, 1 g of fat, and 3 g of fiber per 100 g of flour. The DCP package declares 1.17 g of proteins, 88.33 g of carbohydrates, and 1.67 g of fiber per 100 g of DCP. The declared ingredients on the DCP packaging are cassava, sodium bisulfite (preservative), and glycerol monostearate (emulsifier).

In Figure 1, the flour (A), the DCP (D), and the blends (B and C) are shown. Sample B is made up of 50% wheat flour and 50% DCP, while sample C has 25% wheat flour and 75% of DCP. Sample A was used as the control sample. For samples B, C, and D, the proportions were chosen to maximize the quantity of DCP used.

FIGURE 1 Photograph of flour samples

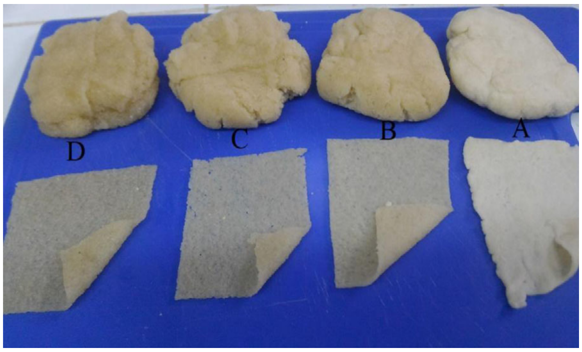

FIGURE 2 Photograph of the doughs and rolled doughs made

2.1.2 | Doughs

For sample A, 32% of water was used; for B, 34%; for C, 37.5%; and for D, 41%. Sample A did not contain DCP, and sample D did not contain wheat flour. Sample B had 50% wheat flour and DCP, while sample C had 14.5% wheat flour and 43% DCP. All the doughs contained the same amount of salt, sugar, and sunflower oil (0.2%, 0.3%, and 4.5% of the weight of the dough, respectively). First, the DCP, wheat flour, sugar, and salt were mixed. Then oil was added, followed by water. Finally, it was kneaded by hand for approximately 2–3 min. Figure 2 shows the resulting doughs.

2.1.3 | Snacks

The doughs were left to rest for 30 min in hermetically sealed containers. Then, they were laminated to a thickness of 2 mm, and the snacks were formed, employing a hexagonal cutting mold of 20 mm side. Four different temperatures were tested for baking: 190, 205, 220, and 235°C. The oven temperature was set through a digital controller with a thermocouple. When it was stable, a disposable aluminum tray with 15 samples was placed in it. First, the resulting color of the snacks was evaluated, with an identical baking time for all samples. Then, the color of the samples with DCP was evaluated, reducing their baking time. The standard used to determine the end of cooking was that the final moisture (dry basis) was less than 5%, and there were no signs of charring on the surface. Table 2 shows the bake times for each sample.

2.2 | Methods

2.2.1 | Determination of color

The values of the tristimulus color space (L *, a *, b *) of the Commission Internationale de l'Eclairage (CIE) were measured. Color coordinates were determined using a HunterLab brand colorimeter, Miniscan EZ model 4500L (Hunter Associates Laboratory, Reston, Virginia, USA). This is a colorimeter with a large area view 45° illumination and 0° viewing spectrophotometer that provides a 31.8 mm port size that has a 25 mm viewed area. The equipment was standardized using black and white standards. The determinations were made in triplicate.

The determination of the color coordinates for flours and doughs was carried out by placing the samples on a Petri dish so that they covered the entire surface, and were covered using a transparent "film" type paper in order to not damage the colorimeter. For the snacks, the same procedure was followed, but first, they were cut into small pieces to be able to distribute them in such a way that no gaps were found on the surface.

2.2.2 | Color parameters

From the color parameters L *, a *, and b *, the following parameters were determined:

Chroma (C *): Represents the distance from the axis of luminosity (L *), and begins in the center with a value of 0. It was determined from Equation (1):

$$C^{*} = \left(a^{*2} + b^{*2}\right)^{1/2}. \tag{1}$$

HUE (H *): It is defined as the pure state of the color. It is the sum of wavelengths that a surface can reflect. In the CIE L * C * H * system, it is represented as the pitch angle, and is expressed in degrees ranging from 0° (inclusive) to 360° (excluded). It was calculated from Equation (2):

$$H^{*} = tan^{-1}\left(\frac{b^{*}}{a^{*}}\right) \tag{2}$$

Total color difference (ΔE *): It is the sum of the differences that exist between parameters L *, a *, and b * of two samples (Equation 3).

$$\Delta E^{*} = [(L^{*} - L_{1}^{*})^{2} + (a^{*} - a_{1}^{*})^{2} + (b - b_{1}^{*})^{2}]^{1/2}. \tag{3}$$

Where L *, a *, and b * are the color parameters of each compared sample.

Browning index (BI): It was obtained by applying Equation (4):

$$\mathrm{BI} = [100(x - 0.31)]/017, \tag{4}$$

Where $x = \frac{a^{*}+1.75L^{*}}{(5.645L^{*}+a^{*}-3.012b^{*})}$

Where L *, a *, and b * are the color parameters of each compared sample.

2.2.3 | Granulometry

Granulometry was determined using the vibrating sieve ZONYTEST LR 2006 DIGITAL, equipped with meshes of 420, 250, 210, 177, and 119 µm. Each samplewas sieved for 15 min, then the fractions were weighed by an analytical grade balance.

2.2.4 | Snacks moisture

The moisture determination was carried out using the AACC (2000) method.

2.2.5 | Statistical analysis

The data were processed using ANOVA, with a significance level of 95%. Correlations were calculated using Pearson's product-moment test ($p < 0.05$). For that, the statistical package used was Statgraphics Centurion XVIII.

3 | RESULTS AND DISCUSSION

3.1 | Color of the flours

From the analysis of the data obtained for wheat flour, DCP, and the blends, it was observed that luminosity

TABLE 1 Parameters CIE-L * a * b *, CIE- L * C * H *, and browning index (BI) of flour and dough

		Mean particle size	L*	a*	b*	C*	H*	BI
Flours	A	169.9 ± 3.4^{a}	95.3 ± 0.5^{a}	0.6 ± 0.03^{d}	7.5 ± 0.22^{d}	7.6 ± 0.2^{d}	1.52 ± 0.004^{a}	8.54 ± 0.26^{d}
	B	244.4 ± 8.0^{b}	92.8 ± 1.6^{b}	1.1 ± 0.05^{b}	10.0 ± 0.09^{c}	10.0 ± 0.1^{c}	1.477 ± 0.003^{c}	11.98 ± 0.35^{c}
	C	282.2 ± 11.5^{c}	91.5 ± 0.6^{b}	1.2 ± 0.09^{a}	13.0 ± 0.47^{b}	13.0 ± 0.5^{b}	1.463 ± 0.004^{d}	15.92 ± 0.59^{b}
	D	322.1 ± 8.8^{d}	86.4 ± 1.7^{c}	0.9 ± 0.04^{c}	18.2 ± 1.60^{a}	18.2 ± 1.6^{a}	1.486 ± 0.005^{b}	23.93 ± 2.54^{a}
Doughs	A		85.8 ± 0.3^{a}	1.06 ± 0.06^{d}	15.76 ± 0.7^{a}	15.79 ± 0.7^{c}	1.50 ± 0.001^{a}	20.75 ± 1.10^{d}
	B		77.2 ± 0.9^{b}	2.22 ± 0.16^{c}	22.03 ± 0.5^{b}	22.14 ± 0.5^{b}	1.47 ± 0.01^{b}	34.99 ± 1.14^{c}
	C		75.1 ± 0.3^{c}	2.97 ± 0.28^{b}	24.11 ± 0.2^{c}	24.29 ± 0.2^{a}	1.45 ± 0.01^{c}	40.79 ± 0.56^{b}
	D		70.6 ± 0.7^{d}	3.27 ± 0.20^{a}	24.37 ± 0.5^{c}	24.59 ± 0.5^{a}	1.44 ± 0.01^{c}	44.77 ± 1.21^{a}

Note: Average values of three samples. Values after ± are standard deviations. There are no statistically significant differences between those levels that share the same superscript in the same column.

(L *) decreased with the increase of the proportion of puree. At the same time, this produced an increase in the red (a *) and yellow (b *) coloration. The results obtained are shown in Table 1. Similar results were observed with the substitution of wheat flour for quinoa or soybean flour in batters, where there was also a decrease in L *. However, in those studies, a* and b* parameters also decreased (Panduro Castañeda, 2015)

There were no significant differences in luminosity between samples B and C made with the blends of DCP and flour, although DCP is significantly less luminous than wheat flour.

Differences in the color parameters of the flours are generally due to contrasts in the current pigments. Those will depend on the botanical origin of the plant as well as the composition of the flour (Virginia Madrigal-Ambriz et al., 2018). In this sense, DCP obtained significantly higher values for L * and b* than those obtained from cassava flours of white and yellow varieties by Techeira et al. (2014). However, in DCP, the caramelization and Maillard reactions that occur during processing (drying of the mash) seem to provide a better explanation for the color of DCP than the presence of natural pigments.

BI, which indicates the purity of the brown color, increased with the percentage of DCP (Table 1). This is because component b * is the main factor that determines BI (Equation 4), and in DCP, it was found in a greater proportion.

In the CIE L * C * H * system, the Chroma (C *) color parameter values correspond to the degree of color saturation. Higher values of a * and b * correspond to higher Chroma values. The H * coordinate represents the true color, effective in showing the color appearance of food products (Dussán-Sarria et al., 2019). In this study, the value of C * increased with the increment in the proportion of DCP. This indicates that wheat flour is less chromatic, which means that it has a lower color saturation level than DCP. The value of H * in all samples was similar, although statistically different due to their small coefficients of variation. This represented a color located in the red-yellow quadrant, but close to the + a * (red) axis.

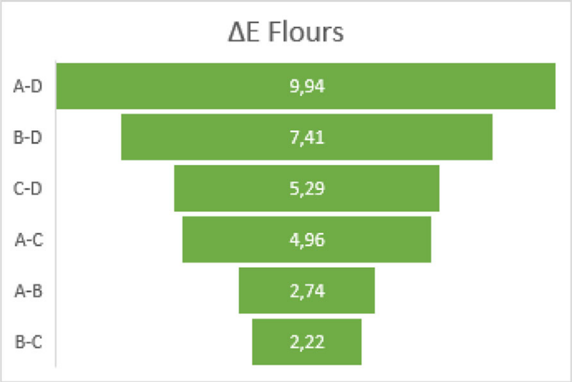

FIGURE 3 The total color difference between flour, DCP, and blends

The results found for total color difference (ΔE) can be seen in Figure 3. The most considerable difference in color was found between the wheat flour (A) and DCP (D) samples. However, the color variation between samples D and B was higher than that between B and A. Likewise, the difference between samples A and C was less than between samples C and D. This would indicate that the color composition, of the flour and DCP blends, is more influenced by the color of the flour than that of the DCP sample. While the addition of DCP to wheat flour also means color variation, this was found to be less.

The lowest ΔE values were found between samples A and B, and samples B and C. However, the difference between the samples can be perceived by the human eye not only by color, but also by the difference in the granulometry of both (Table 1 and Figure 1). Granulometry maintained a positive correlation with the proportion of DCP (0.991 $p < 0.05$).

FIGURE 4 Total color difference between the doughs obtained from flour, DCP, and blends and between the doughs and the flours

3.2 | Color of doughs

From the results of Table 1, it can be observed that the doughs kept the trend shown by the samples of flours in decreasing luminosity (L *) with the increase in the proportion of DCP, and in turn, it provided an increase in red (a *) and yellow (b *) coloration. The variation in parameters a * and b * showed a significant difference between samples A, B, C, and D, but samples C and D were homogeneous in the b * coordinate.

Variations in thecoloration between the samples of doughs and flours are associated with the addition of water and other ingredients since previously, it has been established that the amount of water in dough mainly influences the value of L* (Rajchasom, 2014) as a consequence of the hydration of the proteins and the swelling of the starch granules (Bot, 2008). However, in this work also the value of the b * parameter in sample A of doughs was double than that of the flour. This increase in the b * value of the dough compared with the flour also occurred in the other samples. Though, as the proportion of DCP increased, the difference between flour and dough decreased.

The values of a * (red) had an inverse behavior to that of b *. That is, the samples with more proportions of DCP showed a greater difference between a* of flour and a* of dough.

In the CIE-L * C * H * system, the angle indicated by the H * coordinate was kept for the doughs at similar values to those obtained for the flours, that is, close to the +a * axis.

The C * parameter increments with the “a * ” and “b *” values, reflecting the increase in color saturation with the increment in DCP proportion, though there was no significant difference from the 75% replacement of flour by DCP (sample C). The changes that occur in color saturation are linked to the incorporation of water in the system when the dough is produced (Solah et al., 2007; Ye et al., 2009). By incorporating water into the flours, a series of physicochemical transformations take place, such as the swelling of the starch granules, or the formation of the gluten network. These transformations and interactions between compounds generate changes in the absorption capacity of electromagnetic waves. This is how the variation in the proportion of different components of raw materials (starch, proteins, pigments, sugars, etc.) produce changes in the coloration of doughs (Oladunmoye et al., 2010). In this study, the elaboration of the dough produced a decrease in luminosity and an increase in saturation regarding the flours. That is, an increase in the reflection of the wavelengths corresponding to the colors yellow and red.

As can be seen in Figure 4, all the samples tested showed variation in total color (ΔE) among the flour samples and the doughs. A more noticeable color difference was found among the samples that included blends of wheat flour and DCP (samples B and C). The least variation between flour and dough was found in sample D.

The ΔE values among the doughs were higher than the ΔE values among the flours. Similar to the results found for flours (Figure 3), in the doughs, the most notable difference was between samples A and D. The smallest difference was found between B and C (Figure 4).

The ΔE found between doughs B and C with dough D (Figure 4) was lower than that found among their flours (Figure 3). This was also reflected in an increase in the difference between samples B and C with sample A. That is to say that, when the doughs were formed, the color of blends B and C pointed towards the color of dough D. This would indicate that the color of the doughs was more influenced by DCP than by wheat flour. In dough B, which maintained the same proportion of both flours, it could have been because the DCP starch completely gelatinized and produced a greater absorption of water, generating a greater swelling of the granules, compared with what was produced by the starch contained in the flour of wheat (Cazzaniga et al., 2021). Thus, a greater homogeneity in the color of the dough than that of the flour was observed. Logically, this behavior increases when the proportion of DCP

TABLE 2 CIE-L*a*b* and CIE-LCH parameters and browning index (BI) of baked snacks first under the same conditions of time/temperature and baked at different times

°C	Time (min)		*L**	a*	b*	C*	H*	BI	Final moisture % (dry basis)
190	**14**	**A**	69.7 ± 1.04^{a}	8.2 ± 0.6^{a}	24.8 ± 0.4^{ab}	26.15 ± 0.1^{ab}	1.25 ± 0.03^{b}	51.9 ± 1.0^{b}	
		B	33.2 ± 4.0^{b}	6.7 ± 0.7^{ab}	18.9 ± 2.7^{a}	20.08 ± 2.6^{b}	1.23 ± 0.04^{b}	91.5 ± 24.6^{a}	
		C	44.3 ± 7.6^{ab}	5.0 ± 1.4^{b}	31.00 ± 5.4^{b}	31.43 ± 5.4^{a}	1.41 ± 0.05^{a}	118.0 ± 2.7^{a}	
		D	43.6 ± 1.6^{b}	7.0 ± 0.8^{a}	31.2 ± 6.2^{b}	31.94 ± 6.2^{a}	1.35 ± 0.03^{a}	126.5 ± 31.3^{a}	
205	**9**	**A**	74.0 ± 0.9^{a}	5.3 ± 0.5^{a}	21.4 ± 0.6^{a}	22.1 ± 0.7^{b}	1.33 ± 0.02^{a}	38.9 ± 2.0^{b}	
		B	30.2 ± 1.7^{c}	9.6 ± 1.1^{b}	18.3 ± 4.5^{a}	20.7 ± 3.7^{b}	1.07 ± 0.1^{b}	112.5 ± 24.5^{b}	
		C	52.9 ± 2.9^{b}	8.4 ± 1.5^{b}	21.3 ± 0.3^{a}	22.9 ± 0.6^{b}	1.19 ± 0.06^{ab}	62.2 ± 4.4^{b}	
		D	20.1 ± 2.4^{d}	19.7 ± 1.5^{c}	21.6 ± 3.5^{a}	29.2 ± 3.5^{a}	0.83 ± 0.05^{c}	315 ± 112^{a}	
220	**9**	**A**	72.3 ± 0.9^{a}	6.5 ± 0.4^{c}	23.5 ± 0.9^{a}	24.4 ± 0.8^{a}	1.30 ± 0.02^{a}	45.2 ± 1.6^{c}	
		B	30.3 ± 2.8^{b}	14.4 ± 3.2^{b}	16.5 ± 3.7^{b}	22.2 ± 2.5^{ab}	0.85 ± 0.2^{b}	110.0 ± 13.6^{a}	
		C	26.5 ± 2.6^{bc}	18.6 ± 1.1^{a}	-4.1 ± 0.6^{d}	19.0 ± 1.1^{b}	-0.22 ± 0.03^{c}	29.5 ± 4.9^{c}	
		D	23.4 ± 2.6^{c}	11.0 ± 2.3^{b}	9.9 ± 3.2^{c}	14.9 ± 2.9^{c}	0.72 ± 0.2^{b}	87.6 ± 17.4^{b}	
235	**7**	**A**	69.4 ± 0.9^{a}	7.0 ± 0.5^{a}	23.9 ± 0.9^{a}	25.0 ± 0.9^{ab}	1.28 ± 0.02^{a}	49.07 ± 1.8^{c}	
		B	44.2 ± 4.8^{c}	9.4 ± 5.9^{a}	26.4 ± 4.7^{a}	28.6 ± 2.5^{a}	1.22 ± 0.25^{a}	102.3 ± 4.3^{a}	
		C	31.8 ± 1.4^{d}	8.1 ± 3.3^{a}	31.8 ± 8.1^{a}	8.5 ± 3.0^{c}	0.30 ± 0.17^{b}	24.8 ± 6.4^{b}	
		D	53.6 ± 4.2^{b}	6.3 ± 2.2^{a}	21.1 ± 5.7^{a}	22.3 ± 4.9^{b}	1.25 ± 0.17^{a}	57.7 ± 8.5^{b}	
190	**14**	**A**	69.7 ± 1.4^{a}	8.2 ± 0.6^{a}	24.8 ± 0.4^{a}	26.1 ± 0.1^{b}	1.25 ± 0.03^{c}	51.9 ± 1.0^{b}	2.1 ± 0.1^{d}
	9	**B**	68.0 ± 1.7^{a}	7.8 ± 0.6^{a}	25.0 ± 0.8^{a}	26.2 ± 0.9^{b}	1.27 ± 0.02^{bc}	53.5 ± 2.0^{b}	4.1 ± 0.1^{b}
	8	**C**	70.3 ± 1.4^{a}	7.0 ± 0.5^{a}	28.7 ± 1.1^{c}	29.5 ± 1.1^{a}	1.33 ± 0.02^{a}	58.7 ± 2.9^{a}	3.4 ± 0.2^{c}
	9	**D**	66.0 ± 2.7^{a}	7.4 ± 0.5^{a}	26.5 ± 0.4^{b}	27.5 ± 0.4^{b}	1.30 ± 0.02^{ab}	58.5 ± 2.9^{a}	4.0 ± 0.3^{ab}
205	**9**	**A**	74.0 ± 0.9^{a}	5.3 ± 0.5^{b}	21.4 ± 0.6^{b}	22.1 ± 0.7^{c}	1.33 ± 0.02^{b}	38.9 ± 2^{c}	3.4 ± 0.1^{d}
	6	**B**	72.3 ± 1.0^{ab}	6.9 ± 0.5^{a}	22.4 ± 0.3^{b}	23.5 ± 0.2^{bc}	1.27 ± 0.02^{c}	$43,5 \pm 0.8^{bc}$	3.6 ± 0.1^{c}
	5	**C**	69.9 ± 2.3^{ab}	4.8 ± 0.4^{b}	24.2 ± 1.2^{a}	24.7 ± 1.2^{ab}	1.37 ± 0.01^{a}	46.8 ± 4.7^{ab}	4.9 ± 0.1^{b}
	7	**D**	71.8 ± 1.0^{b}	6.2 ± 0.3^{a}	25.5 ± 0.9^{a}	26.2 ± 0.8^{a}	1.33 ± 0.02^{b}	49.4 ± 2.6^{a}	6.0 ± 0.1^{a}
220	**9**	**A**	72.3 ± 0.9^{ab}	6.5 ± 0.4^{b}	23.5 ± 0.9^{ab}	24.4 ± 0.8^{a}	1.30 ± 0.02^{b}	45.2 ± 1.6^{ab}	5.6 ± 0.03^{b}
	6	**B**	69.6 ± 0.8^{c}	8.5 ± 0.5^{a}	22.6 ± 2.7^{b}	24.2 ± 1.3^{a}	1.21 ± 0.02^{c}	47.6 ± 2.7^{a}	5.7 ± 0.1^{b}
	5	**C**	74.4 ± 2.4^{a}	4.1 ± 0.3^{c}	23.0 ± 0.9^{ab}	23.4 ± 0.9^{a}	1.39 ± 0.01^{a}	40.5 ± 3.4^{b}	6.5 ± 0.3^{a}
	7	**D**	71.2 ± 0.4^{cb}	3.9 ± 0.3^{c}	24.6 ± 1.1^{a}	24.9 ± 1.1^{a}	1.41 ± 0.01^{a}	45.6 ± 2.4^{a}	4.8 ± 0.1^{c}
235	**7**	**A**	69.4 ± 0.9^{ab}	7.0 ± 0.5^{a}	23.9 ± 0.9^{a}	25.0 ± 0.9^{a}	1.28 ± 0.02^{bc}	49.1 ± 1.8^{a}	7.1 ± 0.3^{a}
	5	**B**	71.5 ± 2^{ab}	6.8 ± 0.6^{a}	21.4 ± 0.6^{b}	22.4 ± 0.7^{bc}	1.26 ± 0.02^{c}	42.7 ± 2.6^{b}	4.9 ± 0.1^{b}
	4.5	**C**	72.4 ± 2.4^{a}	3.8 ± 0.2^{c}	21.3 ± 0.4^{b}	21.6 ± 0.4^{c}	1.39 ± 0.01^{a}	38.0 ± 0.7^{c}	6.5 ± 0.4^{a}
	6	**D**	68.7 ± 0.6^{b}	5.9 ± 0.4^{b}	23.3 ± 1.3^{a}	24.0 ± 1.2^{ab}	1.32 ± 0.03^{b}	46.9 ± 2.0^{a}	7.3 ± 0.3^{a}

Note: Average values of three samples. Values after ± are standard deviations. There are no statistically significant differences between those levels that share the same superscript in the same column.

grows. The difference that persists between dough samples B, C, and D may be due to other fractions of the composition, such as protein, fat, and fiber.

3.3 | Color of finished products

When the temperature reaches 60–70°C, the gluten coagulates, and the starch gelatinizes. This generates a deterioration in the plasticity of the walls of the dough while the formation of the definitive structure of the snack occurs. The surface of the piece then dries out and forms the crust of the snack (Bot, 2008). The baking process is subordinate to temperature and time. It irreversibly modifies the physicochemical and sensory properties of the dough, including color.

Table 2 showsthe values of the color parameters obtained for the baked snacks using the same time and temperature conditions that were recognized as satisfactory for the control sample (A).

All samples with DCP presented less luminosity than sample A at all temperatures. A correlation of −0.74 ($p < 0.05$) was found between luminosity (L *) and the rate

TABLE 3 Changes in the browning index (BI) according to the baking time

Sample	°C	Time (min)	BI	Difference IB snack-dough	Time	BI	Difference IB snacks-dough	Difference BI snack–snack
A	**190**	14	51.9 ± 1.0^{a}	31.15	14	51.9 ± 1.0^{a}	31.15	
	205	9	38.8 ± 2.0^{b}	18.05	9	38.8 ± 2.0^{b}	18.05	
	220	9	45.2 ± 1.6^{c}	24.45	9	45.2 ± 1.6^{c}	24.45	
	235	7	49.1 ± 1.8^{a}	28.35	7	49.1 ± 1.8^{a}	28.35	
B	**190**	14	91.52 ± 22.88^{a}	56.53	9	53.5 ± 2.0^{a}	18.51	-38.02
	205	9	112.5 ± 23.94^{a}	77.51	6	43.5 ± 0.8^{b}	8.51	-69.0
	220	9	110.03 ± 6.95^{a}	75.04	6	47.6 ± 4.3^{c}	12.61	-62.43
	235	7	102.35 ± 4.29^{a}	67.36	5	42.7 ± 2.6^{b}	7.71	-59.65
C	**190**	14	118.03 ± 1.42^{a}	77.24	8	58.7 ± 2.9^{a}	17.01	-59.33
	205	9	62.21 ± 3.03^{b}	21.42	5	46.8 ± 4.7^{b}	9.01	-15.41
	220	9	29.55 ± 0.61^{c}	−11.24	5	40.5 ± 3.4^{c}	-0.29	10.95
	235	7	24.83 ± 6.22^{c}	−15.96	4:30	38.0 ± 0.7^{c}	-2.79	13.17
D	**190**	14	126.52 ± 0.89^{a}	81.75	9	58.5 ± 2.9^{a}	13.73	-68.02
	205	9	314.93 ± 87.04^{b}	270.16	7	49.4 ± 2.6^{b}	4.63	-265.53
	220	9	87.57 ± 4.04^{a}	42.8	7	45.6 ± 2.4^{b}	0.83	-41.97
	235	7	57.71 ± 3.89^{a}	12.94	6	46.9 ± 2.0^{b}	2.13	-10.81

Note: Average values of three samples. Values after ± are standard deviations. There are no statistically significant differences between those levels that share the same superscript in the same column.

of DCP. Parameters a *, b *, C *, and H * showed significant correlations neither with the percentage of DCP, nor with temperature. Although BI did not keep a significant correlation with the rate of DCP, most of the samples with DCP showed higher values than those presented by sample A.

The variation of color that happens during baking is the consequence of caramelization and Maillard reactions; this occurs with different intensities in all doughs. The difference between the samples is because the proportion of sugars, starch, and proteins will rule this process under the same baking conditions.

The values obtained for the coordinates of L *, a *, and b *, with differentiated baking times, can also be seen in Table 2. The L * values of the snacks were smaller than those of the flour and dough, while the values of a * and b * were increased. In coordinates L * C * H *, this resulted in higher color saturation and a smaller angle, getting even closer to the +a * axis.

Final moisture values do not exceed 5% on a dry basis in most of the samples studied. The snacks were not perceived as more moister in the center than in the edges' of the snacks. This is relevant, since the concentration of moisture at the center of the snack could negatively affect acceptance by consumers, the conservation, and the shelf life of the products. For final moisture, a correlation of 0.80 between the final moisture and the temperature of baking was found. Also, was found a correlation of −0.66 between de final moisture and the baking time. No correlations ($p < 0.05$) were found between moisture or DCP content and the coordinate values of L *, a *, and b *. This agrees with what was found by Rajchasom (2014). A correlation of −0.74 was found between baking temperature and the b * parameter.

The values of b * of the snacks were higher than those of the doughs. Values of L * of snacks were less than those of the dough. Consequently, the BI values of the baked samples were also higher than those of the doughs. Only in the cases of sample C at 220 and 235°C, a decrease in the BI of the sample concerning the value of the dough was observed. In sample A, the BI value of snacks increased regarding the dough at all temperatures (Table 3). Sample D showed less difference between the BI values of dough and baked snacks.

Among the different samples of baked snacks at different times, neither a definite trend in the BI values concerning the proportion of DCP in the samples nor concerning the baking temperature was observed (Table 3).

The faster development of coloration in the samples with DCP could be due to higher water diffusion coefficients compared to the sample out of DCP. Higher water diffusion coefficients facilitate accelerated evaporation of water in the samples with DCP. This would allow for an earlier start of the caramelization of sugars and the Maillard reaction. The starting point of the color parameters, that is, the color of the dough, could also be a determining factor for this behavior.

TABLE 4 Total color difference (ΔE) between baked snacks and between each snack and its dough

°C	Sample	Time (min)	B	C	D	Dough	Time (min)	B	C	D	Dough
190	**A**	14	35.05	26.29	26.83	19.86	14	1.76	3.19	4.15	19.86
	B			15.26	14.89	42.41	9		3.64	2.53	11.18
	C				2.08	31.60	8			4.48	7.21
	D					28.12	9				6.57
205	**A**	9	44.12	21.28	55.82	15.50	9	2.34	5.68	2.92	15.50
	B			22.96	14.71	47.73	6		4.88	1.73	7.41
	C				34.77	22.97	5			3.23	7.16
	D					53.26	7				3.80
220	**A**	9	43.24	54.83	50.93	16.53	9	3.48	3.23	3.03	16.53
	B			21.42	10.18	48.73	6		6.52	5.26	9.89
	C				16.26	58.31	5			3.58	1.72
	D					50.00	7				0.87
235	**A**	7	25.48	43.48	16.06	9.29	7	3.27	5.10	1.44	19.29
	B			27.23	11.26	34.11	5		3.14	3.50	7.35
	C				28.96	48.78	4:30			4.70	3.96
	D					21.92	6				3.45

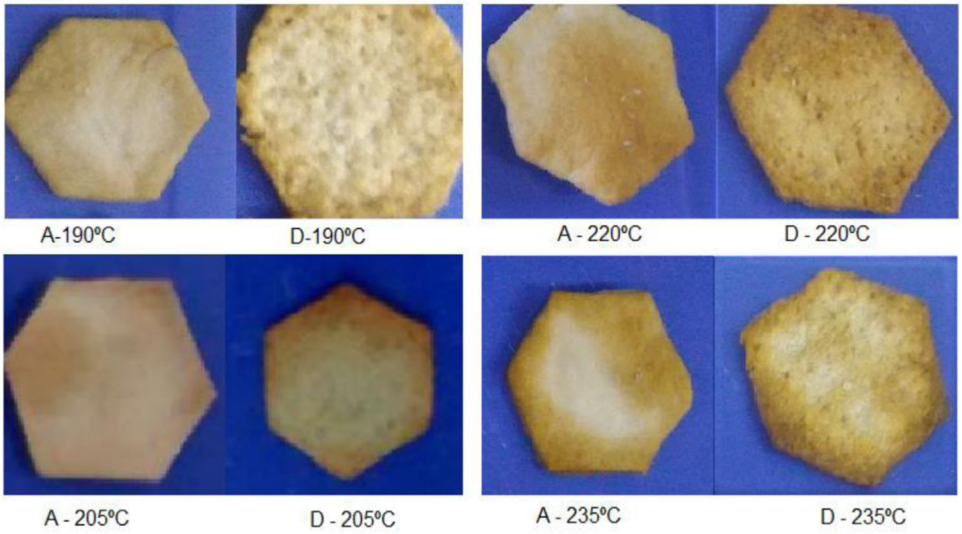

FIGURE 5 Final appearance of products baked at different temperatures

Regarding the baked snacks at different times, in Table 4, it can be seen that the most prominent variation between the color of the dough and the color of the snacks was given for sample A. The color difference between doughs and snacks decreased as the proportion of DCP increased. In other words, in the case of sample D, the color of the dough has the smaller total color difference with their baked products than sample A.

The color difference between samples A and D at all temperatures was always less than five points. In other words, the variation of baking time could bring the color of the DCP sample closer to the wheat flour control sample. In this sense, for sample D, achieving a color similar to that of the control sample always required less baking time. That could translate into lower energy costs at this stage of production. For the other samples, it was also possible to decrease the total color difference with sample A. However, sample C showed the largest ΔE values with sample A.

Although colorcould be evaluated, it was not possible to value the uniformity of color in the samples by the employed techniques. In the photograph shown in Figure 5, it can be seen how the homogeneity of color varies between samples.

4 | CONCLUSION

The kneading and baking processes were able to reduce the color difference that was found between the wheat flour and DCP samples. The smallest total color difference between samples A and D was obtained by employing a bake temperature of 235°C, while the largest difference was obtained at 190°C. However, the final moisture at 235°C was greater than 5%. So, the better option, in this case, is to bake at 220°C. The browning index after baking did not maintain the tendency to increase with the proportion of DCP that it showed in flours and doughs, also reflecting the decrease in ΔE.

The use of DCP to produce baked foods that maintain a similar color to products made from wheat flour is possible by reducing the baking time. This would not negatively affect the final moisture of the product, as values of less than 5% (dry basis) were achieved. Hence, the pregelatinization of starches could be a mechanism than can be used to improve the quality of products with substitutions greater than 50% for wheat flour. Still, more research about other sources of starches, and other physicochemical, functional, and organoleptic characteristics are needed.

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AUTHOR CONTRIBUTIONS

Amanda Cazzaniga: Conceptualization, data curation, formal analysis, investigation, methodology, project administration, writing – original draft, visualization, writing – review and editing. M. M. Brousse: Conceptualization, founding acquisition, project administration, resources, supervision, writing – review and editing. R. A. Linares: Conceptualization, founding acquisition, project administration, resources, supervision, writing – review and editing.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The datasets analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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