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Análisis morfométrico de pan adicionado con harina de semilla de papaya (*Carica papaya*) utilizando ImageJ como técnica digital

Morphometric analysis of bread added with papaya seed flour (*Carica papaya*) using ImageJ as a digital technique

Elizabeth Mérida-Lira[1]; Javier Piloni-Martini[2]; Aurora Quintero-Lira[1]; Sergio Soto-Simental[2] Víctor Manuel Martínez-Juárez[2]; Fabián Ricardo Gómez-de-Anda[2]; Víctor Johan Acosta-Pérez[2] *

[1] Área Académica de Ingeniería Agroindustrial e Ingeniería en Alimentos Instituto de Ciencias Agropecuarias, 43600 Tulancingo de Bravo, Hgo, México.

[2] Área Académica de Medicina Veterinaria y Zootecnia Instituto de Ciencias Agropecuarias, 43600 Tulancingo de Bravo, Hgo, México.

ORCID de los autores:
E. Mérida-Lira: https://orcid.org/0009-0002-0889-3950
J. Piloni-Martini: https://orcid.org/0000-0002-1367-5010
A. Quintero-Lira: https://orcid.org/0000-0003-4638-6028
S. Soto-Simental: https://orcid.org/0000-0002-6923-0926
V. M. Martínez-Júarez: https://orcid.org/0000-0002-3834-9545
F. R. Gómez-de-Anda: https://orcid.org/0000-0001-6314-099X
V. J. Acosta-Peréz: https://orcid.org/0000-0001-9564-659X

ABSTRACT

Structural composition of bread crumb, as well as its volume, are important factors in fresh bread characterization. ImageJ was used as a digital technique to evaluate the morphometry, color, and alveolar constitution in crumb. Wheat bread was made with partial replacement of papaya seed flour in percentages ranging from 5% to 30%. Morphometric analysis allowed characterizing the circularity (between 0.8433 ± 0.00 and 0.8833 ± 0.01), radius aspect (between 1.03 ± 0.01 and 1.10 ± 0.01), and roundness (between 0.9000 ± 0.02 and 0.9700 ± 0.01), which were not statistically significant ($p < 0.05$). However, the alveolar count was higher in the control (399.00 ± 66.09), compared to bread added with papaya seed flour (155.33 ± 23.71-211.00 ± 158.07). When color determining, values showed tendencies towards red with maximum values in control treatment with 214.83 ± 23.32 pixels. In dimensions values, a decrease in these was observed, being affected by percentage increase in papaya seed flour. Therefore, papaya seed flour addition showed effects that can be evaluated using digital techniques as a non-invasive tool.

Keywords: ImageJ; morphometry; breadcrumbs; *Carica papaya*; seed flour.

1. Introduction

The current trend of making bakery products added with flour from different vegetable sources as new ingredients is due to the nutritional improvements in these foods (Maietti et al., 2021; Milla et al., 2021). The use of mixed or compound flours in baking favors the partial replacement of wheat flour, this has allowed the manufacture of a several food products with better nutritional content and bioactive compounds with high antioxidant capacity, in addition these foods contribute to the development of a better quality of life in consumers, by reducing the hyperglycemic effects of bread consumption or by addressing specific problems such as wheat consumption for celiac patients (Bohl et al., 2024; Komeroski et al., 2021). Among the quality parameters in baking, analyzes of flour and dough, the baking test, the volume of the loaves and the quality of the crumb (alveoli) are carried out, the last two being most important to determine the quality of the bread

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* Autor correspondiente: victor_acosta@uaeh.edu.mx (V. J. Acosta-Pérez)

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given interventions such as the addition of alternative flours (Genevois & de Escalada Pla, 2021). The porosity or alveoli of the bread refer to the cavities in the bread crumb, coming from the gas bubbles that accumulate during the fermentation process carried out by the yeasts (Grenier et al., 2021). The alveolate in a bread will depend on some parameters such as the fermentation time, the cereal used, the amount of yeast, the hydration of the dough and the kneading (Curti et al., 2023; Di Renzo et al., 2024). Likewise, the addition of alternative components in the preparation of doughs can influence the alveolate and morphometry of the breads obtained during baking (Hernández-López et al., 2023). Given the constant innovation of bakery products, fast, non-invasive and cheap techniques are required to assess the quality of bread crumbs, where image analysis has been used as an objective and highly reliable method (Gonzalez Viejo et al., 2022; Olakanmi et al., 2023). This method has been used to quantify porosity, through different digital techniques, in addition, image analysis can provide quantitative information about baked goods, such as size, shape and color (Archandani et al., 2022). Therefore, the objective of this research was to evaluate the effect of the percentage substitution of papaya seed flour (HSPa) on the baking quality parameters of color and the alveolar structure in the bread crumb, through the use of the free software ImageJ, from a particle analysis as a digital tool in the development of bakery products.

2. Methodology

2.1 Obtaining papaya seed flour (*Carica papaya*)

The seeds were obtained from the fruit of *Carica papaya*, they were washed with a jet of water to eliminate the remains of mucilage and pulp. They were placed in metal trays with brown paper and covered with a sky blanket to be dried in the sun (22 ± 2 °C), once dry they were stored in Ziploc™ hermetic plastic bags. Papaya seed meal was obtained from 2.5 kg of seed on a dry basis. The seeds were ground in a ME-700Y single-phase pulverizer mill (Semillas de vida, Cuernavaca, Morelos, México). The obtained ground material was sieved through a Tyler No. 32 sieve with a pore diameter of 0.425 mm (Tyler, Monterrey, NL, Mexico). To reduce the particle size, the flour was ground two more times and sieved with a Tyler No. 60 mesh sieve with a pore diameter of 0.246 mm (Tyler, Monterrey, NL, Mexico). The flour obtained was stored in hermetic Ziploc™ plastic bags (Mérida Lira et al., 2023).

2.2 Bread making

Commercial Osasuna wheat flour (HT) from the Elizondo mills (10.38% moisture, 0.27% ash, 12.27% protein, 1.07% ether extract, 0.061% crude fiber, 75.93% carbohydrates) was used as control bread to make the breads. Replaced by HSPa (6.59% moisture, 9.18% ash, 21.61% protein, 22.22% ethereal extract, 24.46% crude fiber, 15.92% carbohydrates) in percentages of 5% – 30%. The formulation was as follows: 160 g flour, 103 mL warm water, 3 g yeast (Tradipan®), 1.3 g salt (La Fina), 2 g sugar (standard), 5 g butter (La Gloria unsalted) and 2 g of powdered milk (Nido®). All the ingredients were incorporated manually until a homogeneous mass was obtained, 23 g portions were made by placing them in a previously greased cupcake baking mold (Wilton 2105-6819 non-stick 26.2 x 41.5 cm), the tray was covered with self-adhesive plastic placing it in a fermentor (Infrico, F848) at 30 °C for 40min, 70% RH, were steam baked (Hornos América, H3mil) at 180°C until cooked (Mérida Lira et al., 2023).

2.3 Taking pictures

For each treatment, including the control, 3 images of each view of the bread (top, side and bottom) and three images of the crumb were obtained. The photographs were obtained with a standardized size of 1280 x 720 pixels in jpg format, at a distance of 20 cm between the lens and the surface where the samples were placed, following concepts of image standardization. The photographs were captured with the help of an amzoom® camera coupled to a 2X stereoscopic microscope (EcolineMatic SZ 745). To establish the pixel-millimeter reference scale, the image of a magnetic stirrer of known size was used, calculated using the measurement bar provided by the microscope software (Gómez-de-Mariscal et al., 2021).

2.4 Morphometric analysis

The morphometric analysis of the loaves and the alveoli in the bread crumb were carried out by processing photographs in jpg format. by automated identification of particle contours and particle analysis using the free-use software ImageJ from the National Institutes of Health, USA in its version 1.5e (Cuervas-Mons et al., 2019). The parameters selected for its quantification were area, perimeter, circularity, Feret, radius aspect, roundness and solidity of the particles. Image processing included the auto-adjustment of brightness, conversion of images to 8-bit images, converting images to black and white format, the delimitation of contours and the analysis of particles, all through image processing by ImageJ. For the bread samples, the particle contours corresponding to the top, side and bottom views (Figure 1) were analyzed in triplicate, while in the crumb n particles were analyzed corresponding to the number of pores detected by the particle analysis.

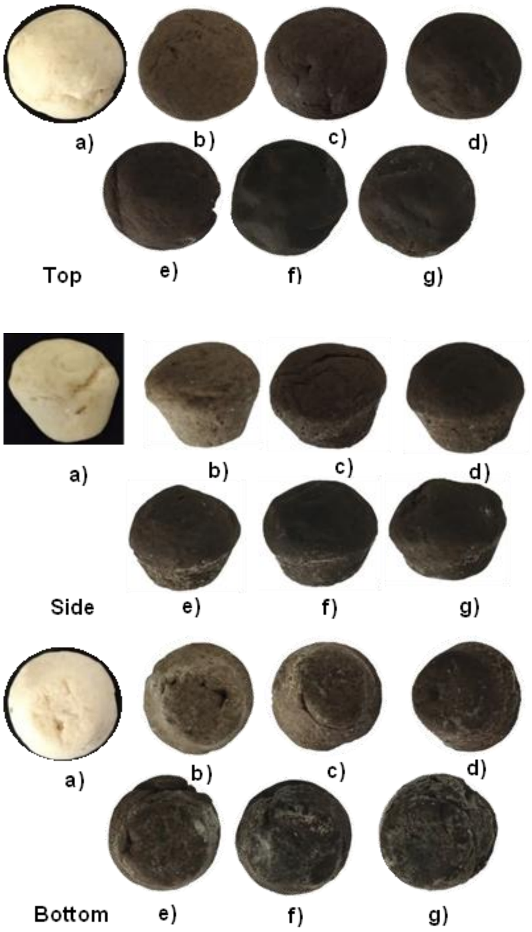

Figure 1. Top, side and bottom view of bread a) Control bread = 100% HT, b) Bread5% HSPa + 95% HT. c) Bread10% HSPa + 90% HT. d) Bread15% HSPa + 85% HT. e) Bread20% HSPa + 80 % HT. f) Bread25% HSPa + 75% HT. g) Bread30% HSPa + 70% HT.

2.5 Color analysis

Images in jpg format were analyzed as described by Hartig (2013). The images were selected without scaling processing, for each bread image and each crumb image, 5 areas were selected using the ImageJ software with a measurement of 10,000 pixels for the analysis, it was selected to analyze and later to analyze by histogram, this tool allowed to visualize the distribution of frequencies, of the pixels corresponding to the colors of the RGB system (Reds, Greens and Blues) and the balance of these colors, through the average of pixels. The data is expressed as the average number of pixels corresponding to each value obtained from 15 repetitions per treatment.

2.6 Statistical analysis

The experimental design corresponded to a completely random arrangement, the results were obtained with an n = 3 and n for loaves and alveoli for the morphometric analysis, while for color evaluation an n=15 was obtained for both types of sample, the analysis statistical analysis was performed by analysis of variance (ANOVA) Yij= m + ti+ gj + eij., with a comparison of Tukey (normal distribution data) and Scheffé (F distribution data) means for variables with significant treatment effect ($p < 0.05$). The correlation between the size of the loaves and the percentage addition of HSPa was calculated using a linear regression model (equation 1) and the Pearson correlation index (equation 2) with values between -1 and 1, where values close to -1 indicate a negative correlation. A standardized score data normalization was performed on the pore perimeter variable using equation 3.

$$y = ax + b \tag{1}$$

$$\frac{\sum_{i=1}^{n}(x_i - \tilde{x})(y_i - \tilde{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \tilde{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \tilde{y})^2}} \tag{2}$$

$$[X - \mu]/\sigma \tag{3}$$

3. Results and discussion

3.1 Morphometric description of bread

The morphometric analysis showed a negative correlation between the percentage addition of HSPa and the size of the loaves (Table 1), the R^2 values were between 0.8634 (top view) and 0.8801 for the lateral view, indicating a greater dependence of the lateral size of the bread with respect to the addition of flour, it has previously been reported that the values of volume, weight and specific volume can decrease when partially substituting wheat flour (Bouaziz et al., 2010; Giami, 2003), breads added with date flour, registered smaller sizes (5.01 ± 0.01) compared to the control (8.26 ± 0.00) before a substitution of 3%, while box bread registered a decrease in volume from 6.25 to 2.04 cm^3/g before 25% addition of pumpkin seed flour (Bouaziz et al., 2010; Giami, 2003), in the same way, the Pearson index values indicate a negative correlation where the higher the percentage aggregation of HSPa, a decrease in the size of the bread is observed in the three views evaluated, with values from -0.929 to -0.938, confirming a greater effect in the decrease in size in the side view of the bread. This may be due to the reduction of gluten in the bread formulation by integrating addition of HSPa, limiting the interactions between proteins (gliadins and glutenins) of wheat flour. In addition, papaya seed fibers can limit bread expansion during the fermentation process. However, the reduction in specific volume can be compensated by obtaining firmer textures in the breads obtained (Mérida Lira et al., 2023).

Table 1
The correlation values are calculated between the morphometric measurements of the area and the observed substitution of the values of wheat flour by HSPa.

Bread view analysis	Top	Side	Bottom
Linear regression (R^2)	0.8634	0.8801	0.8713
Pearson index	-0.929	-0.938	-0.933

The parameters that complement the morphometric analysis of the bread are described in table 2, the circularity parameters (between 0.8433 ± 0.00 and 0.8833 ± 0.01), radius aspect (between 1.03 ± 0.01 and 1.10 ± 0.01) and roundness (between 0.90 00 ± 0.02 and 0.9700 ± 0.01), showed that the breads present low values for the parameters that define a spherical shape, even when the data correspond to the upper and lower view, in addition, it was observed that the percentage HSPa, does not affect these characteristics in obtaining bread, since the values did not present statistical significance for these values between the treatments. However, obtaining these parameters can help characterize innovation processes in bakeries, seeking to standardize the products under study (Binte Abdul Halim et al., 2023). On the other hand, the perimeter values maintained a downward trend as the percentage addition of papaya seed meal increased ($p < 0.05$), where the control treatment showed the highest values with 223.78 ± 5.35, 223.62 ± 2.82 and 216.77 ± 9.72 mm for the top, side and bottom views respectively. The Feret index showed a similar behavior with values of 69.23 ± 2.88, 70.72 ± 1.04 and 67.43 ± 3.61 for the upper, lateral and lower views of the control, respectively. Previously, breads with the addition of 10% pomegranate seed showed a decrease in length (129.5 mm) and height (50.7 mm), compared to control bread (131.7 and 68.5 respectively) (Gül & Şen, 2017). Finally, the solidity index was 0.99 with no differences between treatments, evidencing an analysis of homogeneous particles (Cuervas-Mons et al., 2019).

Table 2
Morphometric data for breads with partial replacement of wheat flour by HSPa, data expressed in mm.

View	Treatment	Perimeter	Circularity	Feret	Radius aspect	Roundness	Solidity
Top	Control bread	223.78±5.35^{a}	0.8533±0.01^{a}	69.23±2.88^{a}	1.08±0.05^{a}	0.9233±0.05^{a}	0.9900±0.00^{a}
	Bread5%	214.00±2.35^{b}	0.8766±0.00^{a}	66.58±0.55^{a}	1.04±0.01^{a}	0.9600±0.01^{a}	0.9900±0.00^{a}
	Bread10%	220.65±2.52^{ab}	0.8800±0.01^{a}	68.03±0.70^{a}	1.05±0.01^{a}	0.9533±0.00^{a}	0.9900±0.00^{a}
	Bread15%	202.32±0.32^{c}	0.8800±0.01^{a}	62.24±0.17^{b}	1.04±0.00^{a}	0.9566±0.00^{a}	0.9900±0.00^{a}
	Bread20%	194.26±4.17^{cd}	0.8766±0.00^{a}	59.87±1.62^{bc}	1.04±0.01^{a}	0.9600±0.01^{a}	0.9900±0.00^{a}
	Bread25%	193.21±1.84^{cd}	0.8800±0.01^{a}	59.84±1.28^{bc}	1.05±0.02^{a}	0.9533±0.02^{a}	0.9900±0.00^{a}
	Bread30%	187.62±4.16^{d}	0.8766±0.00^{a}	57.74±1.71^{c}	1.03±0.02^{a}	0.9666±0.01^{a}	0.9900±0.00^{a}
Side	Control bread	223.62±2.82^{a}	0.8433±0.00^{a}	70.72±1.04^{a}	1.11±0.02^{a}	0.9000±0.02^{a}	0.9866±0.00^{a}
	Bread5%	208.05±4.02^{bc}	0.8467±0.02^{a}	64.90±0.28^{bc}	1.06±0.04^{a}	0.9433±0.03^{a}	0.9866±0.00^{a}
	Bread10%	216.20±5.54^{ab}	0.8500±0.02^{a}	67.37±1.31^{b}	1.05±0.03^{a}	0.9467±0.03^{a}	0.9866±0.00^{a}
	Bread15%	198.96±0.46^{cd}	0.8666±0.00^{a}	61.82±0.56^{cd}	1.05±0.02^{a}	0.9500±0.01^{a}	0.9900±0.00^{a}
	Bread20%	183.14±0.12^{de}	0.8767±0.02^{a}	59.85±0.44^{d}	1.08±0.05^{a}	0.9267±0.04^{a}	0.9900±0.00^{a}
	Bread25%	188.97±2.54^{e}	0.8733±0.00^{a}	58.82±1.29^{d}	1.04±0.01^{a}	0.9700±0.01^{a}	0.9900±0.00^{a}
	Bread30%	184.42±4.40^{e}	0.8533±0.01^{a}	58.77±1.96^{d}	1.10±0.01^{a}	0.9066±0.01^{a}	0.9900±0.00^{a}
Bottom	Control bread	216.77±9.72^{a}	0.8733±0.02^{a}	67.43±3.61^{a}	1.06±0.04^{a}	0.9433±0.03^{a}	0.9900±0.00^{a}
	Bread5%	205.18±3.87^{ab}	0.8600±0.03^{a}	62.55±0.43^{bc}	1.03±0.01^{a}	0.9700±0.01^{a}	0.9866±0.00^{a}
	Bread10%	207.70±2.29^{a}	0.8833±0.01^{a}	64.38±0.43^{ab}	1.04±0.01^{a}	0.9533±0.01^{a}	0.9900±0.00^{a}
	Bread15%	193.56±0.75^{bc}	0.8800±0.00^{a}	59.32±0.17^{cd}	1.03±0.01^{a}	0.9700±0.01^{a}	0.9900±0.00^{a}
	Bread20%	192.42±4.00^{bc}	0.8766±0.01^{a}	59.65±0.75^{cd}	1.03±0.02^{a}	0.9667±0.02^{a}	0.9900±0.00^{a}
	Bread25%	189.81±5.64^{c}	0.8733±0.01^{a}	58.63±1.48^{cd}	1.06±0.01^{a}	0.9400±0.01^{a}	0.9900±0.00^{a}
	Bread30%	187.15±4.04^{c}	0.8633±0.02^{a}	57.47±1.06^{d}	1.05±0.01^{a}	0.9533±0.00^{a}	0.9900±0.00^{a}

HT= wheat flour. HSPa= papaya seed flour. Control bread = 100 % HT. Bread 5% HSPa + 95% HT. Bread 10% HSPa + 90% HT. Bread 15% HSPa + 85% HT. Bread 20% HSPa + 80% HT. Bread 25% HSPa + 75 % HT. Bread 30% HSPa + 70% HT. The data show the means of three repetitions ± standard deviation, different superscripts per column indicate statistically significant differences ($p < 0.05$) between treatments. Statistical analysis was performed by comparing the parameters of each view between treatments. The parameters of circularity, Feret, roundness and solidity are expressed as indices calculated by particle analysis.

3.2 Description of color in bread

The color of food is a decisive attribute in the acceptance of the product by the consumer (Hasan et al., 2024). In bread, the color is given from the concentration of Maillard reaction by-products in the crust, this when amino and carbonyl groups are concentrated in the crust of the bread associated to the moisture in the bread is reduced during baking (Ahanchi et al., 2024). The color parameters were evaluated for each view of the bread (Figure 2a, 2b and 2c), in general a tendency to red colors was observed in the bread with maximum values in the control treatment of 214.83 ± 23.32 pixels, and a minimum value for the bread25% treatment with 40.27 ± 9.58 pixels, the lowest color trend corresponded to the blue value where the control treatment presented the highest value with 167.09 ± 26.87 pixels, while all the treatments with percentage addition of HSPa were statistically lower ($p < 0.05$) with values between 32.32 ± 7.42 pixel (bread10%) and 44.10 ± 11.00 pixel (bread5%). The general perception of breads added with HSPa was obtaining darker breads, this trend has been reported from the use of whole wheat, to replace wheat flour (Gómez et al., 2020), until the addition of germinated wheat (Al-Hooti et al., 2002), and other natural additives such as anthocyanins present in blue variety wheat (Francavilla & Joye, 2022), these changes are attributed to the decrease in luminosity and increase in the values of a (green to red) and b (blue to yellow). In general, the Bread5% treatment presented statistical values that position it as the most similar to the control, while the rest of the bread added with HSPa were statistically lower with a tendency to develop a dark brown bread, where the dark color of the seed can induce this color in bread (Sugiharto, 2020).

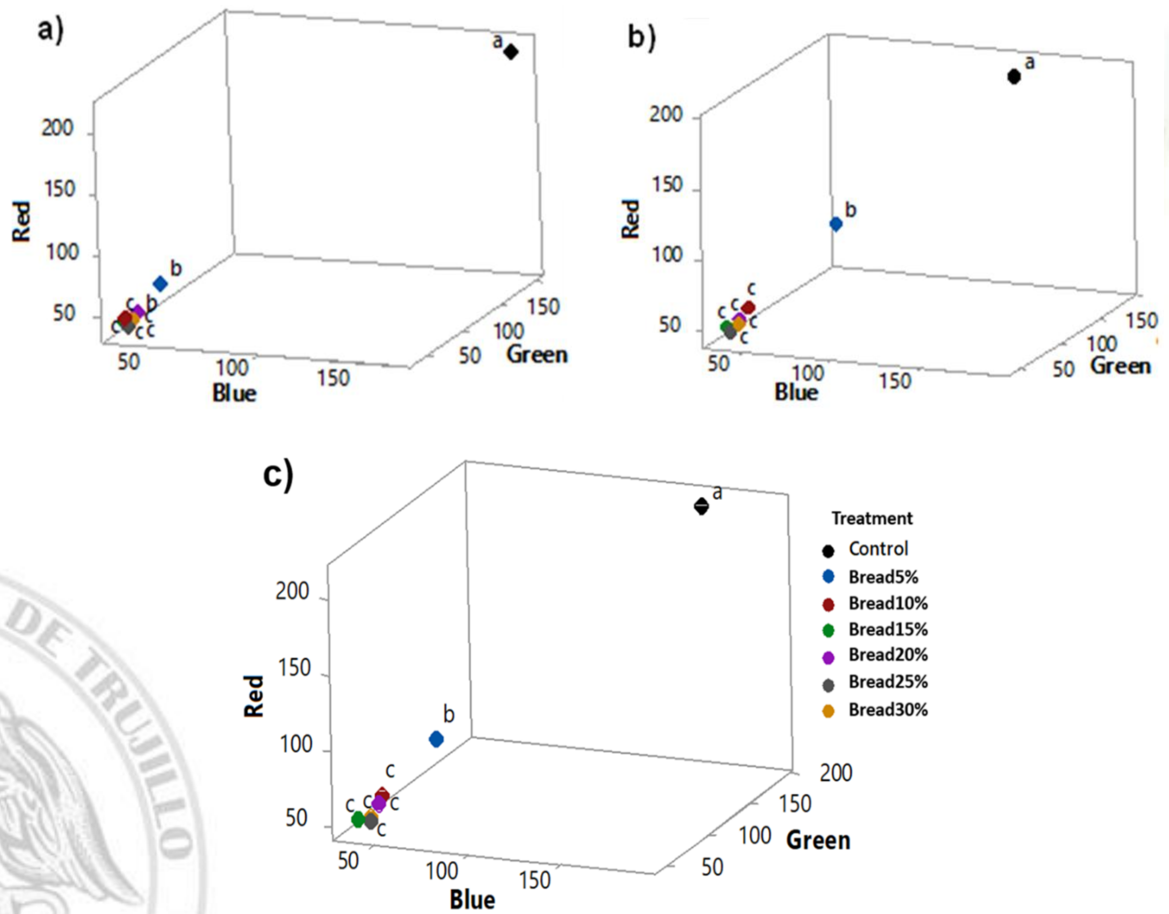

Figure 2. Color parameters for the breads: a) top, b) side and c) bottom view, the points express the mean of 3 repetitions, where different superscripts express statistically significant differences ($p < 0.05$). HT= wheat flour. HSPa= papaya seed flour. Control= 100% HT. Bread5% HSPa+95% HT. Bread10% HSPa + 90% HT. Bread15% HSPa + 85% HT. Bread20% HSPa + 80% HT. Bread25% HSPa + 75% HT. Bread30% HSPa + 70% HT.

3.3 Morphometric description of the breadcrumb

The formation of alveoli in bread depends on the interaction that exists between components such as wheat proteins (gluten), the starch present (its water absorption capacity) and humidity (formation of water lamella in the dough) in the formation of dough for baking (Grenier et al., 2021). In this study, obtained and processed imagens for the bread for the characterization of alveoli by particle analysis (Figure 3).

Table 3 shows the results, the trend when comparing the treatments with the control bread was the decrease in pore size as a higher percentage of HSPa was added, bread20% treatment presented the smallest alveolar size in the study (0.0475 ± 0.08 mm^2) and where again the control treatment showed the largest alveoli (0.0968 ± 0.16 mm^2), the results obtained are lower than those reported by Dessev et al. (2020), who evaluated alveoli at different baking conditions and managed to report alveoli in a range of sizes between 0.7 and 0.9 mm. Likewise, analysis of particles (1001) and the alveolar mean (333.66 ± 218.04) was carried out of bread30% treatment, showing values close to those present in the control (1197 and 399.00 ± 66.09) These results are similar to those reported by Bicalho et al., (2019) who reported a maximum of 339 alveoli in breads added with taro mucilage. In all cases, the evaluation of the alveoli in the bread becomes relevant because their characteristics may be linked to the texture obtained in the bread, where the smaller the alveolar size, the greater the resistance of the loaves for handling and transport (Al-Hooti et al., 2002; Bertrand et al., 2020; Dessev et al., 2020).

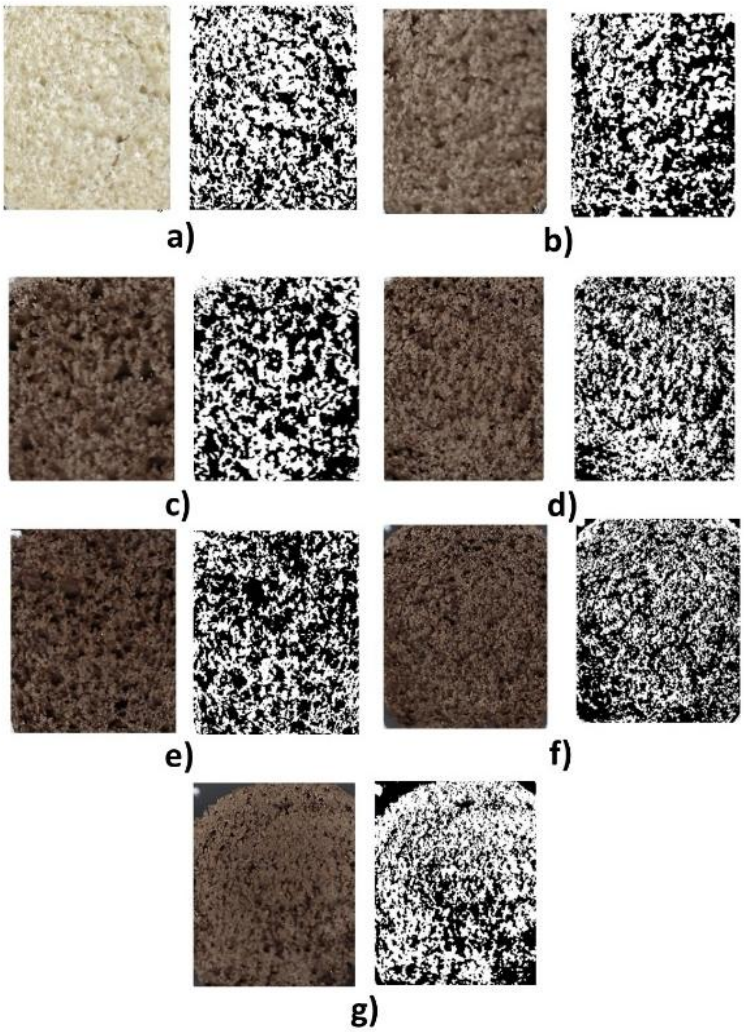

Figure 3. Images obtained from bread and its corresponding contour identification image for alveolar composition by particle analysis using the Image J program. HT= wheat flour. HSPa= papaya seed flour. a) Control bread= 100% HT, b) Bread5% HSPa + 95% HT. c) Bread10% HSPa + 90% HT. d) Bread15% HSPa + 85% HT. e) Bread20% HSPa + 80% HT. f) Bread25% HSPa + 75% HT. g) Bread30% HSPa + 70 %HT.

Table 3
Morphometric data for breads with partial replacement of wheat flour by HSPa, data expressed in mm

Treatment	No. particles	Alveolar media	Perimeter	Circularity	Feret	Radius aspect	Roundness	Solidity
Control bread	1158	399.00±66.09^{a}	1.09±1.36^{a}	0.6935±0.25^{c}	0.6067±0.98^{a}	1.80±0.70^{a}	0.6236±0.19^{a}	0.8044±0.12^{cd}
Bread5%	466	155.33±23.71^{a}	0.33±0.77^{b}	0.7346±0.25^{ab}	0.4729±0.77^{bc}	1.77±0.74^{a}	0.6377±0.20^{a}	0.8189±0.12^{ab}
Bread10%	542	180.66±49.50^{a}	0.35±0.75^{b}	0.7318±0.25^{b}	0.5491±1.13^{ab}	1.76±0.68^{a}	0.6367±0.19^{a}	0.8191±0.12^{ab}
Bread15%	496	165.33±104.50^{a}	0.33±0.75^{b}	0.7367±0.24^{ab}	0.3840±0.48^{cde}	1.77±0.67^{a}	0.6316±0.20^{a}	0.8161±0.12^{abc}
Bread20%	486	162.00±77.48^{a}	0.27±0.65^{bc}	0.7650±0.24^{a}	0.3274±0.35^{e}	1.76±0.63^{a}	0.6347±0.20^{a}	0.8259±0.12^{a}
Bread25%	633	211.00±158.07^{a}	0.31±0.72^{c}	0.7274±0.27^{b}	0.4284±0.69^{cd}	1.77±0.65^{a}	0.6343±0.20^{a}	0.7986±0.14^{d}
Bread30%	1001	333.66±218.04^{a}	0.46±0.84^{c}	0.7377±0.26^{ab}	0.3718±0.56^{de}	1.75±0.64^{a}	0.6377±0.20^{a}	0.8063±0.13^{bcd}

The data shows the means of n repetitions ± standard deviation, different superscripts per column indicate statistically significant differences ($p < 0.05$) between treatments. The parameters of circularity, Feret, roundness and solidity are expressed as indices calculated by particle analysis. HT= wheat flour. HSPa= papaya seed flour. Bread Control= 100% HT. Bread5% HSPa + 95% HT. Bread10% HSPa + 90% HT. Bread15% HSPa + 85% HT. Bread20% HSPa + 80% HT. Bread25% HSPa + 75% HT. Bread30% HSPa + 70% HT.

In addition, the perimeter parameters of the particles were obtained where the bread10% treatment showed the alveoli with the highest value with 2.43 ± 10.04, when HSPa was added, as well as circularity (0.6935 ± 0.25) and roundness (0.6236 ± 0.19) of the control treatment showed the development of alveoli with oval morphometry, a situation that coincides with a higher value in the radius aspect (1.80 ± 0.70), so that when adding HSPa the alveoli presented a greater tendency to roundness, up to 0.7650 ± 0.24 in bread20% (Table 3), results similar to those reported by Scheuer et al. (2015), where they reported values of 0.807 ± 0.007 before fat substitution in baking presented the lowest alveolar proportion in its analyzed structure with a solidity of 0.7986 ± 0.14, values higher than those reported for untreated wheat bread, which has reported an average of 70.2% porosity, indicating that the breads in this study, it tends to develop a smaller size than other reports (Dessev et al., 2020). However, the alveolate proportion is high. The results of the present study may also be dependent on the ingredients of the dough and its processing conditions (Barros et al., 2022; Cao et al., 2022), the activity of yeast, fermentation temperature and gas bubble formation (Sun et al., 2023; Vicente et al., 2024). As well as the quality and quantity of the protein present in wheat flour (Ferreyra et al., 2021).

3.4 Color description in breadcrumbs

The color in the crumb showed a trend similar to that present in the evaluated bread, where the control presented values of 205.89 ± 5.21, 196.99 ± 6.15 and 170.06 ± 7.72 for red, green and blue respectively, while the treatments added with papaya seed meal showed statistically lower values ($p < 0.05$) for both red (75.69 ± 3.22 to 118.25 ± 9.919) and green (57.01 ± 2.83 to 99.62 ± 10.93) and blue (47.77 ± 2.54 at 85.81 ± 10.44), These values are lower than those reported by Gonzalez-Viejo et al. (2022), where breads made with Emmer wheat flour yielded values of 143.33, 113.33 and 80.50 for RGB, which indicates the development of darker breads, as well as what reported by Pečivová et al. (2014), who added grape seed flour, before the addition, obtained in a qualitative way the darkest bread before the addition of 10% of alternative flour. On the other hand, the bread5% treatment was the one that maintained color parameters closest to the control, although it was statistically lower ($p < 0.05$), while the bread20% treatment showed the greatest tendency to dark coloration and even less RGB balance, when it did not present the highest addition of papaya seed meal (Figure 4). The development of this coloration in bread may be associated with the presence of pigments such as β-cryptoxanthin, α-carotene, β-carotene and lycopene, present in papaya seeds, where it has also been observed that they increase as the fruit matures (Ovando-Martinez et al., 2018).

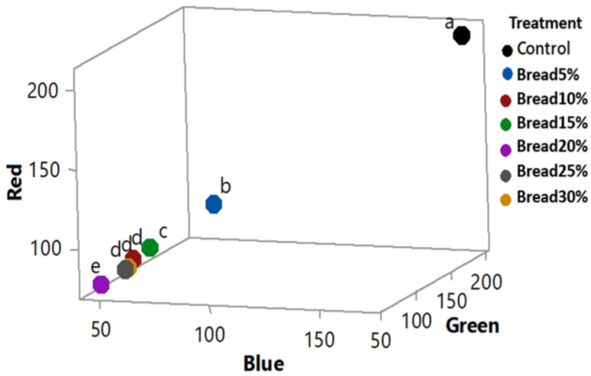

Figure 4. Color parameters (n = 15) in breadcrumbs added with papaya seed flour, different letters indicate significant difference in RGB balance ($p < 0.05$). HT= wheat flour. HSPa= papaya seed flour. Control bread= 100% HT. Bread5% HSPa + 95% HT. Bread10% HSPa + 90% HT. Bread15% HSPa + 85% HT. Bread20% HSPa + 80% HT. Bread25% HSPa + 75% HT. Bread30% HSPa + 70% HT.

The results obtained in this research indicate that the use of computerized (artificial) vision techniques to measure the color of food is viable in bakery products (Olakanmi et al., 2023). Likewise, these computational techniques that are developed in combination with a digital camera and processing software of images have been used to provide a least expensive and most versatile method of measuring the morphometric and alveolar characteristics of bread (Ali et al., 2021).

4. Conclusions

The data obtained indicated that the color and the porosity of the crumb, showed dependence with the percentage of substitution of wheat flour by HSPa. Furthermore, no substantial modification of the morphometric characteristics of the breads was found. The use of computer-based image processing techniques presents advantages such as objectivity, consistency and efficiency to quantitatively characterize the properties of color, size and shape in the evaluation of food quality, these techniques allow preserving the precision of measurements and they help to reduce the inconsistency in the subjectivity of manual measurements, offering flexibility in their application since highly expensive equipment is not required. Due to these characteristics, its use can be an important tool in decision-making in product innovation in the food area. In the same way, the use of digital tools for image analysis as a means of quantifying color and alveolar composition of bread, can broaden the perspective as a viable method of evaluation since it allows determining the relationship between physical parameters and bakery quality for different types of bread. Finally, the use of HSPa can be suggested as an unconventional ingredient, for the preparation of bakery products, its use allows obtaining breads that do not alter their morphometric characteristics, with a dark brown coloration and with the presence of alveoli of smaller in size, but with a higher percentage presence in the composition of the bread. In the same way, this allows the use of fruit fractions that are considered rights in the agricultural industry, as sources of fiber and other components of high biological value such as pigments, more studies are recommended to continue with the characterization of the potential use of the seeds of papaya and other fruits in the food industry.

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