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Articlé

Image analysis applied to morphological properties in wheat and oat cookies

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Abstract

The present study was conducted at the Center for Research in Food and Development in 2024. Image analysis is an essential tool that can be used in food process control. This study aimed to analyze, using imaging techniques, the morphological properties of cookies made with wheat and oats in different percentages and their relationship with cookie firmness. The texture profile of the dough obtained from the different formulations, and the weight, diameter, height, and firmness of the cookies were determined. A morphological characterization of the cookies was carried out by means of image analysis. These measurements focused on the overall color of the surface, as well as the characteristics of the surface and internal texture of the cookies through the analysis of the crumb. The results showed decreased firmness (151.96 N to 103.17 N) as the percentage of substitution increased, a similar behavior was observed in the weight and height of the cookie, whereas the diameter was not affected. Regarding the image analysis, greater cracking of the cookie surface was observed as the percentage of substitution increased. Color changes were observed in the crumb towards lighter areas, indicating a decrease in bubbles in the cookie crumb. Image analysis can be an important alternative to determine the quality of a finished product, in this case, a cookie.

Keywords:

cookie firmness, image segmentation, surface cracks.

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Introduction

There are many products made from soft wheat flour and leavening chemical agents; nevertheless, among the main products are cookies. Soft wheat flour is characterized by a lower protein content, lower granulometry, and lower ash or mineral content (Serna, 2003). These characteristics of flour favor the processes of manufacturing cookies; however, manufacturers frequently observe disparity in the functionality of soft wheat flour when used in various recipes and cookie-making processes.

From uncontrolled dimensions and densities of cookies, variation in texture and surface appearance, and sticky or very consistent doughs are examples of technological difficulties encountered during cookie making (Fustier *et al*., 2009). There is a growing interest in understanding the microstructure of food and its correlation with the textural and rheological attributes of food in the development of food products in academia and the food industry.

This knowledge about the rheology and microstructure of foods helps to minimize textural defects in processed foods and improve the perception of consumer satisfaction (Ahmed and Basu, 2022). For this reason, different methodologies have been implemented to control food processes or to establish analytical measurements of finished products that are easy to apply, fast and non-destructive, such as the use of image analysis.

This is a technique capable of interpreting and making a detailed analysis of the pixels of the images captured by a camera. This allowed vision systems to become automated structures that can analyze, identify, and read a series of characters through the analysis of the details capable of being extracted from an image.

In recent years, machine vision analysis, computer image processing and analysis systems, as a fast, non-destructive, and low-cost means, have gained many interesting applications in the food industry, they are also susceptible to industrial applications online and even the baking process can be monitored by these techniques (Abdollahi Moghaddam *et al*., 2015).

These methods have also been successfully applied for the identification and evaluation of quality (Gerrard *et al*., 1996; Abdullah *et al*., 2004; Brosnan and Sun, 2004; Du and Sun, 2004, 2006; Qiao *et al*., 2004, 2005; Pace *et al*., 2011; Shafiee *et al*., 2013), the classification and selection of fruits and vegetables, meat and fish, and bakery products (Mendoza and Aguilera, 2004; Blasco *et al*., 2009; Zapotoczny, 2011), as well as the detection and segmentation of surface defects (Bennedsen *et al*., 2005; Munkevik *et al*., 2007; Dammer *et al*., 2011; Atas *et al*., 2012). Based on the above, the objective of this study was to analyze, through imaging techniques, the morphological properties of cookies made with wheat flour and oat flour in different percentages and their relationship with cookie firmness.

Materials and methods

Raw material

The oat flakes (Granvita brand) were crushed in a mill (Pulvex 200 model, Mexico) to obtain a flour of 1 mm particle size. The cookie wheat flour was donated by Munsa Molinos from Cd. Obregón, Sonora. The rest of the ingredients, such as vegetable shortening, sugar, salt, baking soda, and dextrose, were purchased from a local store in Hermosillo, Sonora, Mexico.

Treatments

The mixtures of cookie wheat flour (CWF) with oat flour (OF) were in the following proportions: 95-5, 90-10 and 80-20 (w/w), respectively. In addition, it was considered to use only CWF as a control to establish the cookie obtained as a reference with respect to the rest of the formulations.

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Chemical composition of cookies

It was determined in the control cookie and in the cookies obtained from CWF-OF mixtures. The analyses of moisture, protein, crude fat, and ash were performed according to the following methods: 44-15A, 46-13, 30-25 and 08-01 (AACC, 2000); these analyses were performed in triplicate. The calculation of carbohydrates was made by subtracting the sum of the obtained percentages of moisture, protein, crude fat and ash from 100.

Preparation of the control cookie and the cookies of the different treatments

A cookie was made only with CWF (control) in addition to those made with the different ratios of CWF-OF mentioned above. Vegetable shortening (64 g), sugar (130 g), salt (2.1 g) and baking soda (2.5 g) were blended for 3 min in a blender (Model Artisan, KitchenAid 4.7 L, Mexico). Dextrose (33 g) and distilled water (16 ml) were added to continue blending for more 2 min, then flour (225 g) was added and mixed for 2 min at a low speed.

At the end of the kneading, the dough obtained was weighed and placed on a previously greased baking tray. A rolling pin was passed over until obtaining the desired height of the dough, then the circumferences were molded and cut to the desired diameter and finally baked for 10 min at 205 °C. The cookies obtained were left to cool to room temperature and stored in polyethylene bags for 1 h (method 10-50D, AACC 2000).

Dough analysis

Texture profile. The doughs obtained from the different CWF-OF mixtures were subjected to a texture profile (Texture Analyser TA-XT2 Godalming, Surrey, England) with the TA-25 attachment. Dough cylinders (3.8 cm high and 4.2 cm in diameter) were formed and 50% of their height was compressed. The test speed was 5 mm s^{-1}. The parameters obtained were firmness (N), adhesiveness (Ns), elasticity, cohesiveness, gumminess, and chewiness (Islas *et al*., 2012).

Cookie analysis

Cookie weight. An Ohaus Pioneer scale (PX3302 model/E, USA) was used.

Thickness and diameter. A Vernier (Mitutoyo model, 530 Series, Japan) was used to take these measurements. The measurements of weight, thickness, and diameter of the cookie are referenced in the same method of preparation (method 10-50D, AACC 2000).

Firmness. The TA-XT2 texture meter (Texture Analyser Stable Micro Systems, Surrey, UK) was used with the HDP/BS attachment. The test speed was 1.7 mm s^{-1}. The rupture distance was 5 mm (Fustier *et al*., 2009).

Morphological characterization by image analysis

The morphological properties of the cookies were analyzed using image analysis techniques in order to measure characteristics on which visual appreciation depends, as well as textural properties. These properties are essential to understand the effect of composition and processing on the product; however, they are difficult to quantify using traditional physicochemical methods.

In this research, the measurements focused on exploring the global color of the surface and the characteristics of the surface and internal texture of the cookies through the exploration of the crumb of the product. The digital images were captured using a 12 MP wide-angle camera: 26 mm, ƒ/1.5 aperture, sensor-shift optical image stabilization, 100% Focus Pixels, with a resolution of 2532 x 1170 pixels at 460 ppi, and stored in JPEG format. The different blocks of information that were extracted from the images were.

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RGB histograms

The study of pixel frequency histograms in the RGB (red, blue, and green) color space was applied to determine patterns of color change on the entire surface simultaneously.

Surface color texture

Surface color patterns were studied to determine the impact of changes in composition on the surface. To do this, 8-bit images were analyzed, segmenting them on the gray value 153, with the aim of quantifying the number of pixels belonging to the surface patterns produced by cracks in the product.

Internal structure analysis

The crumb of the cookies was analyzed using grayscale histograms to determine the number of pixels belonging to cereal and bubble structure. In this case, values tending to 0 represent pixels related to empty (dark) spaces, whereas pixels close to 255 represented those related to structure. Each analysis was performed on 10 cookie samples using the free software of Fiji (Schindelin *et al*., 2012).

Experiment design and statistical analysis

The design of experiments was completely random of one factor, the degree of substitution of CWF with OF. The results were analyzed by applying a multiple comparison procedure to determine which means are significantly different from others with a significance level of 95%. Fisher's least significant difference (LSD) procedure was used to discriminate between the means. Statistical analysis was conducted with the Statgraphics Centurion XVI Program (2010 StatPoint Technologies, Inc.)

Results and discussion

Chemical composition of cookies

Table 1 shows the results obtained from the proximate chemical analysis that was carried out on the cookie made only from cookie wheat flour (control) and those obtained from the different mixtures with oat flour. The values of protein and fat did not show significant differences ($p>0.05$) between the different cookies, there were differences only in the measurements of moisture and ash, although these were minimal compared to the control treatment.

Table 1. Proximate chemical analysis of cookies made with CWF and mixtures of CWF and OF.

	Components (%)				
Cookie	Moisture	Protein	Ash	Fat	Carbohydrates
Control	3.67 ±0.03 d	5.95 ±0.0 a	1.14 ±0.01 b	14.37 ±0.49 a	74.87
95% CWF-5% OF	3.74 ±0.03 c	5.91 ±0.12 a	1.15 ±0.02 b	14.63 ±0.29 a	74.57
90% CWF-10% OF	3.99 ±0 a	5.96 ±0.1 a	1.15 ±0.02 b	14.11 ±0.03 a	74.79
80% CWF-20% OF	3.9 ±0.02 b	5.77 ±0.11 a	1.19 ±0.01 a	14.68 ±0.43 a	74.46

CWF= cookie wheat flour; OF= oat flour; a, b, c= means with the same letter within the column are not significantly different ($p>0.05$). The measurements made are the average of three replications ± standard deviation. Carbohydrates were calculated by difference.

Maldonado and Pacheco (2000) made a cookie with a mixture of wheat flour and green banana flour; they observed very similar values when they analyzed carbohydrates and fat content; nevertheless, important differences were found when the percentage of protein was analyzed, which was higher by up to 3%. This explanation may be based on the compositional differences of the raw materials used in the production of the different cookies, mainly in the type of wheat flour used.

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Dough analysis

Table 2 shows the results of the texture profile performed on the doughs obtained from the control flour and the different mixtures of wheat flour and oat flour. Texture parameters can be considered of great importance in food quality control; specifically, the hardness in starchy products indicates their degree of freshness, whereas crunchiness provides information about their internal structure and compositional characteristics (Torres *et al*., 2015).

Table 2. Texture profile of the control dough and of the doughs obtained from mixtures of CWF and OF.

Dough	Firmness (N)	Adhesiveness (Ns)	Elasticity	Cohesiveness	Gumminess	Chewiness
Control	17.11 ±0.39 a	3.5 ±0.86 a	0.23 ±0.03 a	0.17 ±0.01 b	2.95 ±0.31 a	0.7 ±0.15 b
95% CWF-5% OF	15.33 ±0.65 ab	4.78 ±0.75 a	0.26 ±0.03 a	0.21 ±0.01 a	3.27 ±0.23 a	1.03 ±0.16 a
90% CWF-10% OF	15.79 ±1.82 ab	3.42 ±0.88 a	0.27 ±0.02 a	0.2 ±0.02 ab	3.15 ±0.53 a	0.77 ±0.13 ab
80% CWF-20% OF	14.52 ±1.91 b	3.39 ±1.71 a	0.31 ±0.09 a	0.19 ±0.01 ab	2.77 ±0.48 a	0.98 ±0.02 ab

CWF= cookie wheat flour; OF= oat flour; a, b= means with the same letter within the column are not significantly different ($p > 0.05$).The measurements made are the average of three replications ± standard deviation.

Texture assessment is usually based on the judgment of sensory panels; however, the use of an instrument, such as the texture profile analyzer (TPA), provides a quick and cost-effective way to measure texture under well-defined and controlled conditions (Szczesniak, 2002).

In this study, firmness values maintain a downward trend when using oat flour in the substitution of wheat flour; nonetheless, this behavior became more evident when 20% oat flour was used, where significant differences were observed compared to the control dough. On the other hand, the parameters of adhesiveness, elasticity, and gumminess were not affected by the different levels of substitution with oat flour.

Regarding the measurements of cohesiveness and chewiness, the observed behaviors show an important similarity. No significant differences ($p > 0.05$) were observed between the doughs obtained from the different mixtures of CWF with OF, but there was a significant difference ($p < 0.05$) when the substitution was analyzed, which was 5% compared to the control dough.

For their part, Blanco *et al*. (2019) used oat fiber in the production of cookies and observed important changes in the ability of the dough to lose water, associating this with the beta-glucans contained in oats. This may be related to the results obtained in dough firmness when performing the texture profile, where higher substitutions with OF can retain a greater amount of water in the doughs, with this being associated with the lower firmness values.

In their work, Wang *et al*. (2017) analyzed the effect on the rheological properties of wheat flours added with oat beta-glucans, their results also coincide with a decrease in the strength of the dough when increasing the proportion of beta-glucans. This behavior could be attributed to the weakening of the molecular network of gluten and starch, which is caused by the inhibition of the association between gluten and starch itself, related in part to the dilution of gluten, as well as by the state of the water, affecting the hydration properties of the doughs (Fustier *et al*., 2009).

Cookies analysis

The values obtained for weight, height, diameter, and firmness of the cookies are shown in Figure 1. Regarding cookie weight, the substitutions made with 10 and 20% OF showed significant differences ($p < 0.05$) compared to the control. The diameter of the cookie was not affected by any level of substitution; however, the height showed a decrease as the percentage of substitution

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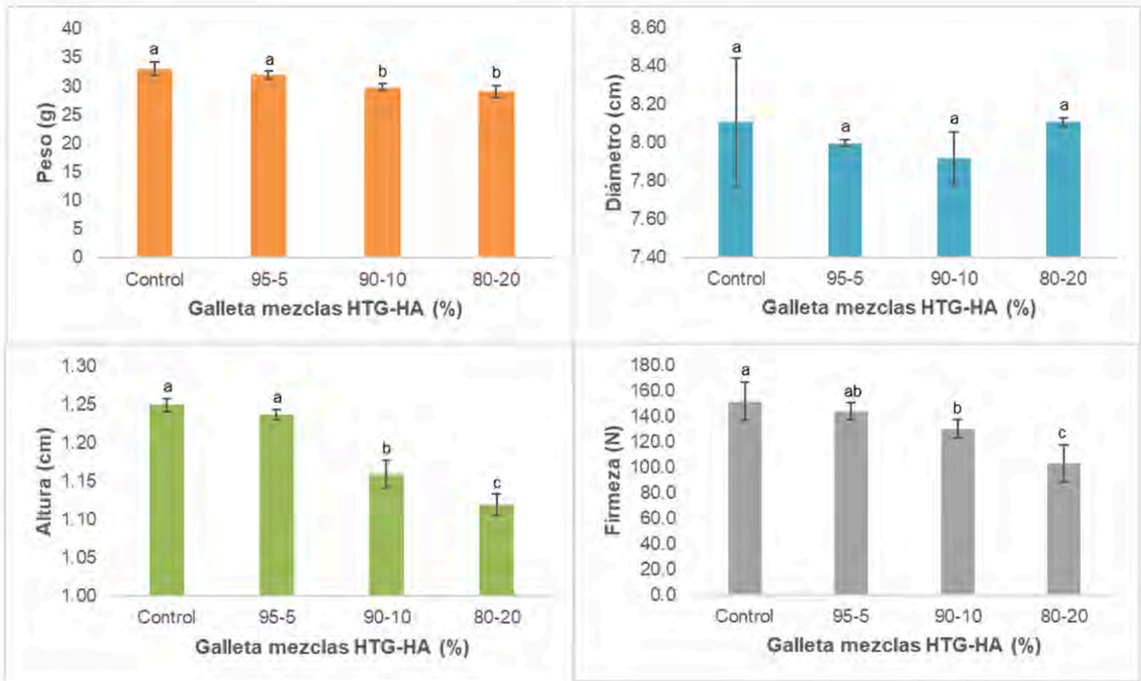
increased, with the lowest value of 1.12 cm being observed when using 20% OF. One of the most important parameters analyzed from a sensory point of view was firmness. A similar behavior to that of height was observed, firmness decreased at higher levels of substitution with OF.

Figure 1. Physical measurements in control cookies and in cookies made from mixtures of CWF and OF. CWF= cookie wheat flour; OF= oat flour.



Ahmed and Basu (2022) determined that particle size significantly regulates the rheological behavior of food, either in dispersion or in doughs; these same authors also have seen that a suspension/dough with the finest particle size behaves completely differently from a dough with coarse particles. On the other hand, it has also been reported that the texture of cookies is influenced by the relationship between geometry and water content and by the dependence of the mechanical properties of water content and sugar concentration (Slade and Levine, 1994).

Morphological characterization by image analysis

Image processing has the advantage of providing reproducible color measurements that allow the characterization of both macro and microstructural aspects of food. Surface color data based on RGB histograms are included in Figure 2. It is observed that the peaks of the three channels are higher in the case of control cookies.

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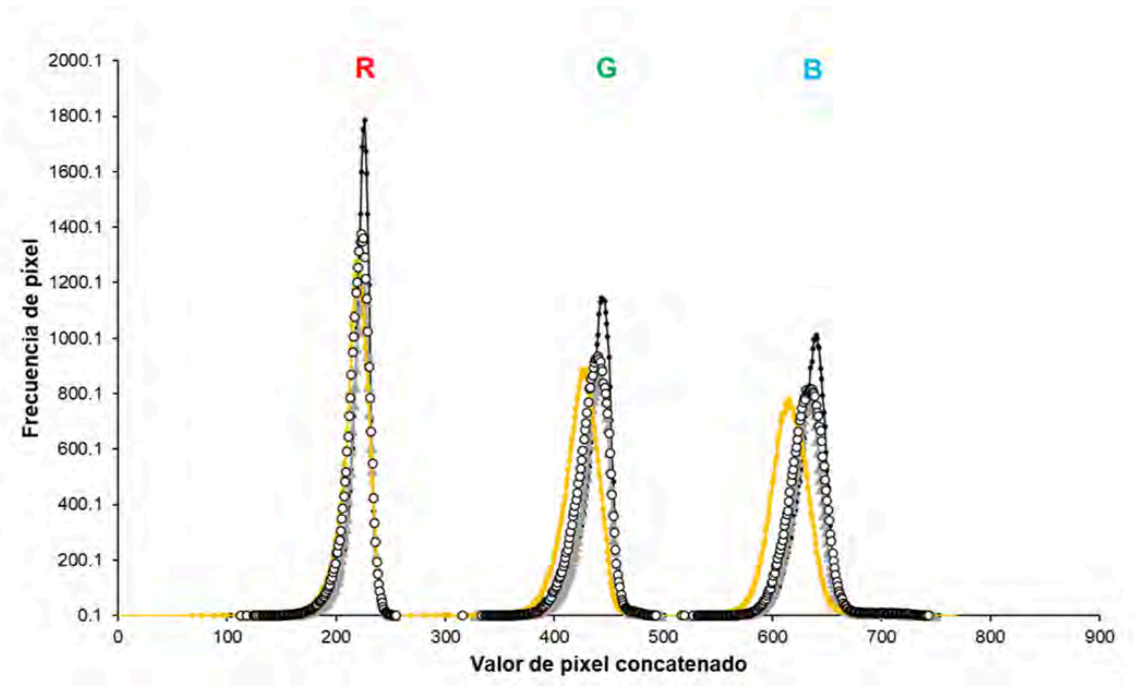
Figure 2. Study of average RGB color histograms of cookie surfaces. Black= control; white= 95% CWF-5% OF; gray= 90% CWF-10% OF; yellow= 80% CWF-20% OF.



This form represents reduced base distributions compared to the rest of the formulas, which indicated a more homogeneous overall color. That is, there are a large number of pixels at very close frequencies. This behavior is altered with the increase in the amount of oats. The blue (B) channel was the most affected, shifting the peak of this channel towards lower values (darkness).

The 80-20 formula presented the biggest change, showing a drastic increase in pixel dispersion at the base of the bell, accompanied by a decrease in the maximum peak value.

To locate the main causes of the surface color change in the real product, the images were segmented based on two types of pixels observed in the visual texture of the cookies: those belonging to the dough itself and those contained in the cracks derived from the addition of oats. Figure 3 shows the result of the segmentation of the image into the two indicated groups, and the increase in the area related to these cracks as the oat content increases can be observed.

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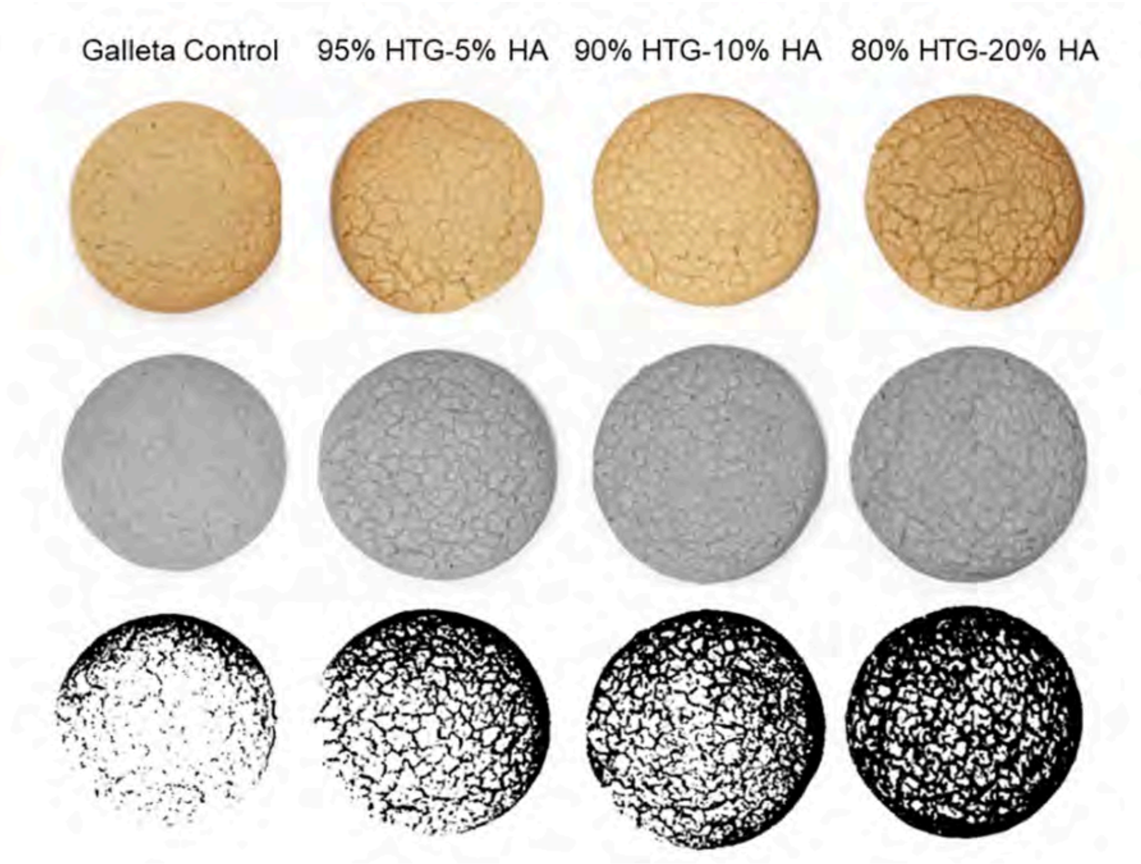
Figure 3. Real images (top). Real 8-bit grayscale images (middle). Images segmented on gray value= 153 (bottom). CWF= cookie wheat flour; OF= oat flour.



The relationship between the area corresponding to surface cracks, percentage of substitution, and hardness of the cookies is included in Figure 4. It shows the direct relationship of the phenomenon with the oat content and therefore with the effect on mechanical resistance. A higher amount of oats produces an increase in cracks on the surface, which lead to more fragile cookies.

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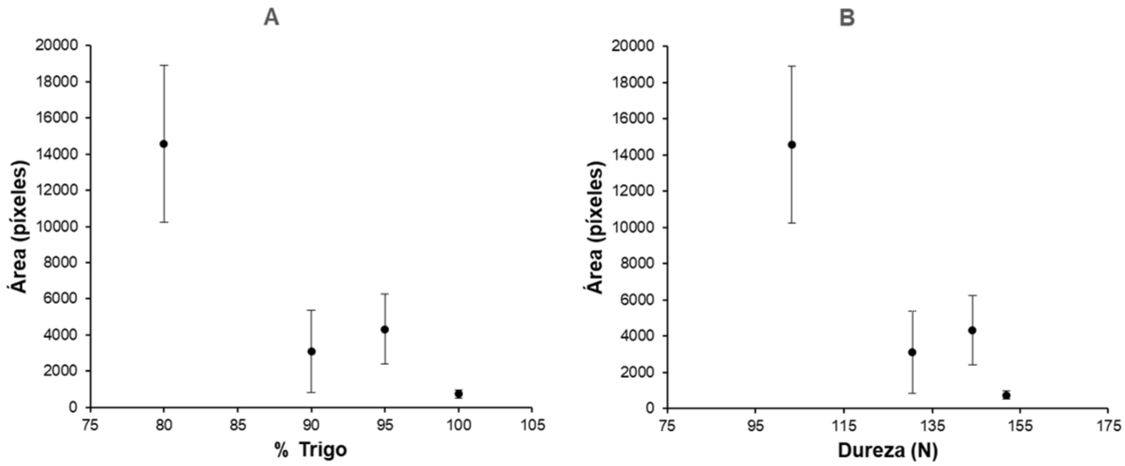
Figure 4. Correlation between (%) substitution (A) and cookie texture (B) with the area of pixels belonging to the surface cracks.



Studies by Inglett *et al*. (2015) observed a trend of decrease in the firmness of the cookie with the texture of the dough, which coincides with the results obtained in this research. Hoseney and Rogers (1994) attributed the firmness of cookies to the interaction of proteins and starch by hydrogen bonds.

In their research, Fustier *et al*. (2009) showed how a higher dough consistency resulted in higher values of cookie hardness. Nevertheless, this was not the case for the various mixtures of fractions that they themselves analyzed due to the complex interactions between their constituents; an increase in the consistency of the dough was not necessarily accompanied by an increase in the hardness of the cookies. This further indicates that the other ingredients in the dough (sugar, fat and water) used in each recipe exert an important influence on altering the final texture of the cookie.

The observed changes in the structural properties of cookie crumbs followed the pattern previously observed. Figure 5 shows how the increase in oat content caused the color to shift to lighter areas. In this case, pixels with values tending to 250 indicate crumb lightening, that is bubble removal. The elimination of wheat produces a reduction in the gas retention capacity, collapse of the dough and thus a greater number of pixels of light tones.

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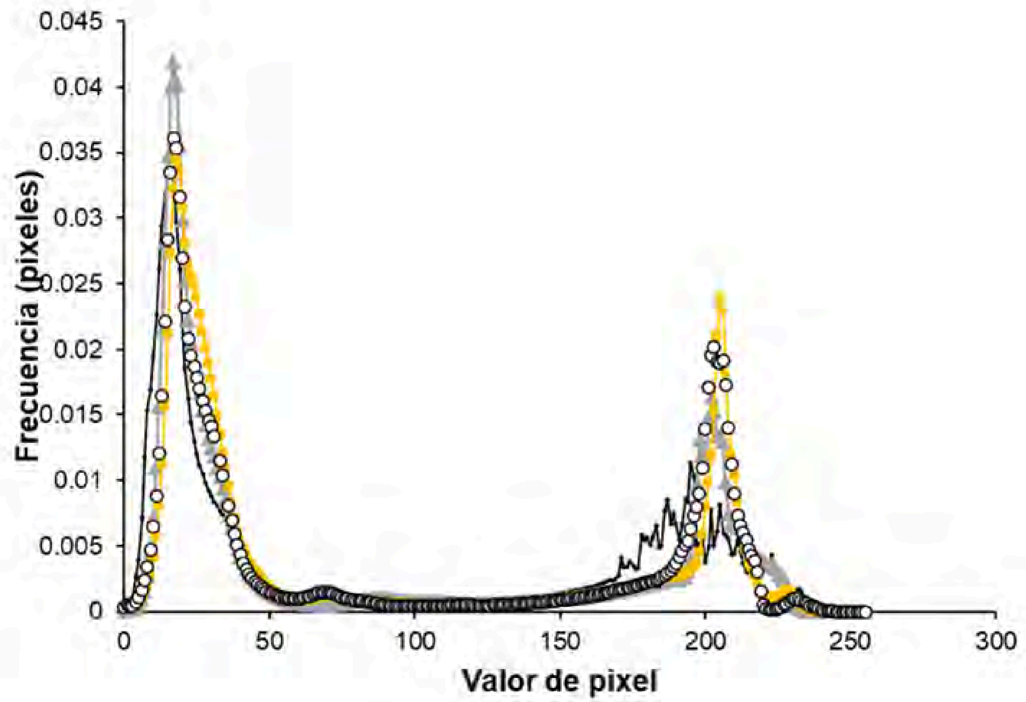
Figure 5. Study of average histograms of grays of cookie crumbs. Black= control; white= 95% CWF-5% OF; gray= 90%CWF-10% OF; yellow= 80% CWF-20% OF.



Conclusions

Through image analysis, it was possible to detect an increase in surface fissures in the cookie; at the same time, there was a decrease in the bubbles observed in the crumb, which resulted in a reduction in the firmness values in the cookies with higher percentages of oat flour substitution. Based on the above, it is possible to use image analysis as a quick alternative for morphological quality control in production processes of this type of cookie.

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