



Texture study of gluten-free cookies added with fibre by instrumental, image and sensory analysis

Maite Gagneten^{1,2} · Facundo Pieniazek³ · Diego Archaina^{4,6} · Valeria Messina^{3,6} · Daniela Salvatori^{5,6} · Carolina Schebor^{1,2,6} 

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Abstract

The alternative starches and flours used in gluten-free bakery in replacement of wheat have very low quantities of fibre. As a consequence, the resulting products have a poor nutritional profile in terms of this nutrient, and present technological difficulties and quality challenges related to texture. In this work, the texture of gluten-free cookies added with a source of fibre, and its impact in consumer's perception was studied. Due to the complexity of texture, its description was assessed through three different methods: instrumental force/deformation measurements, image analysis, and sensory evaluation, in order to reach a better representation of the product's texture and to compare the different techniques' capacity to describe it. The instrumental method showed that the control cookie presented a higher maximum force (F_{max}), indicating that this sample was significantly more resistant to fracture, while the cookie added with fibre showed a lower deformation before fracture (ΔF_{max}), which corresponds to a more fragile structure. The results obtained by image texture analysis using the Gray Level Co-occurrence Matrix method were consistent with those determined by instrumental analysis. Good correlations were reached between the instrumental firmness and the five image parameters, showing the capacity of image attributes to predict mechanical properties of the samples. Sensory analysis with consumers showed a good acceptability of the product, but was not as useful to detect small differences between cookies. The study of texture through different techniques could be an interesting approach to attain complementary information, providing a more comprehensive perspective of this multifaceted attribute.

Keywords Gluten-free cookies · Fibre · Texture · Image analysis · Microscopy · Sensory evaluation

✉ Carolina Schebor
cschebor@di.fcen.uba.ar

¹ Instituto de Tecnología de Alimentos y Procesos Químicos (ITAPROQ), CONICET - Universidad de Buenos Aires, Buenos Aires, Argentina

² Departamento de Industrias, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Buenos Aires, Argentina

³ Centro de Investigaciones Científicas y Técnicas para la Defensa (UNIDEF-CITEDEF-MINDEF), Buenos Aires, Argentina

⁴ Instituto de Ciencia y Tecnología de los Alimentos de Entre Ríos (ICTAER), CONICET - Universidad Nacional de Entre Ríos, Gualeguaychú, Entre Ríos, Argentina

⁵ Instituto de Investigación y Desarrollo en Ingeniería de Procesos, Biotecnología y Energías Alternativas – PROBIEN (CONICET – Universidad Nacional del Comahue), Neuquén, Argentina

⁶ Members of CONICET, Buenos Aires, Argentina

Introduction

Celiac disease is an autoimmune syndrome that causes inflammation of the intestine of patients with this pathology upon gluten ingestion. Gluten is formed from the gliadin and the prolamine present in wheat, rye, barley, and oats [1]. The only treatment for celiac disease consists in following a strict gluten free diet for life. This pathology is being increasingly diagnosed all around the world as a consequence of new eating habits, a better understanding of the disease, and improved analysis methods [2, 3].

Gluten plays a fundamental role in bakery as it is responsible for the elastic and extensive properties of dough [1]. It contributes to the formation of the protein structure that retains gas during fermentation and provides amino-groups that promote the occurrence of Maillard reaction, giving baked products the desired colour and flavour [4]. For these reasons, developing gluten-free bakery products that meet

the consumers' quality standards may become a big challenge. In addition, starches used in replacement of wheat have small amounts of dietary fibre, so most of the gluten free bakery products lack sufficient quantity of this nutrient [5].

Texture is a key attribute for consumer's acceptance. Its measurement is, therefore, of great importance for the development of new products. However, this attribute is one of the most difficult parameters to describe and its determination presents many difficulties for food and materials scientists [6, 7]. According to the norm ISO 11036 1994 [8], texture is the result of the combination of geometrical, mechanical and surface properties of a material, perceptible by means of mechanical, tactile, visual and hearing receptors [9–11]. Since it is a property experienced by humans, only humans can perceive and describe it [12]. Due to its highly complex nature, specific sensory profiling methods have been created for texture description [8]. According to aforementioned norm, mechanical texture of food can be classified into primary parameters: hardness, cohesiveness, viscosity, springiness, adhesiveness; and secondary parameters: fracturability, chewiness, gumminess. Although sensory evaluations based on psychophysics, may be the most accurate approach to study texture of food, they are complicated to carry out, very time consuming, expensive, and may require specialized training of the sensory panel for the specific type of product. These disadvantages often make sensory methods not suitable for routine tests [10]. For the development of new products, sensory analyses with untrained panels can be performed to study how the texture of the product is perceived and accepted by consumers. The most common sensory techniques used today include discriminatory methods, descriptive evaluations, preference and hedonic tests [13]. Among these, descriptive methods with 5- or 9-points hedonic scales are the most commonly used [14].

Alternately, instrumental measurements are usually employed as a faster and simpler alternative to sensory analysis, attempting to describe the characteristics of a material as close as possible to human perception [9, 15]. Texture evaluation methods using instruments have been classified into three types: fundamental, empirical, and imitative techniques. Although fundamental methods, based on material science, provide well defined physical properties, they often fail to describe the human perception phenomena of texture. On the contrary, empirical techniques can be better related to texture from practical experiences [10]. Among these methods, force/deformation measurements are the most common approaches to determine textural parameters through instrumental techniques, offering the advantages of low costs in instrumentation, ease of carrying out experiments, and simple interpretation of results [16]. The determination of the mechanical properties of cookies is generally approached

through different methods. In the three bending points' assays [17–19] the complete fracture of the biscuit by the hand or the first bite with frontal teeth are represented. On the other hand, when using penetration tests [20, 21], the force/deformation profile as the probe presses through the food material can be related to the force generated by teeth pressing into the surface of the biscuit and then crushing it between the molars [22]. More recently, acoustic studies gained attention as a complementary measurement to describe texture of crispy foods [15, 23, 24].

An interesting alternative for analysing the texture of food products is to use statistical processing together with computerized image analysis [25, 26]. In texture analysis through image methods, the changes in the scattered light that occur from structural changes in the surface of an object can be studied and used to estimate the texture of the material [27]. The Gray Level Co-occurrence Matrix (GLCM) can be described as a set of spatial dependent probability distribution matrices of gray intensities. From these matrices, different features that emerge from the relation between intensities of neighbouring pixels and their relative orientation can be used to describe the texture of the image [28]. GLCM was first proposed by Haralick et al. [29] for the classification of land use categories. Since then, various applications of GLCM techniques in different fields such as material science [30], medicine [31] and agriculture [32] have been studied. GLCM has been successfully employed in the characterization of food, since it allows the precise quantification of textural parameters in highly irregular structures like those of many food materials [33]. Park et al. [26] used a GLCM approach over hyperspectral microscope images to investigate postharvest blueberry softening and were able to characterize parenchyma cell textures in terms of firmness. Khojastehnazhand and Roostaei [28] extracted texture features from digital images using GLCM algorithm together with different supervised (Support Vector Machine and Artificial Neural Network) and unsupervised (Principal Component Analysis) modelling methods to classify different wheat varieties. Moreover, when microscopy techniques such as Scanning Electron Microscopy (SEM) are used together with images analysis, they become complementary tools to evaluate some important attributes such as texture and its correlation with food material microstructure [33].

Understanding texture properties is essential for the development of novel or non-traditional foods. Taking into account the difficulties to describe texture by one unique technique and the need to address the connection between objective measurements, sensory perceptions, and subjective consumer preferences, the aim of this work was to study the texture of two gluten-free cookies through three different approaches: an instrumental force/deformation method, image analysis by GLCM statistical method, and sensory evaluation with consumers.

Materials and methods

Materials

A commercial gluten-free chocolate cookie mix and the ingredients of the same commercial product were obtained from Tecnología Alimentaria Rioplatense (Buenos Aires, Argentina). All the other ingredients were acquired at local markets. The reagents were analytical grade.

Gluten-free cookies production

Two different gluten-free cookie formulations were prepared following the procedure described by Gagneten et al. [34]. A control cookie (C cookie) was performed as follows: the dry ingredients (corn starch, rice flour, sugar, cocoa powder, chocolate flavour, vanilla flavour, sodium bicarbonate, and salt) were mixed and the cookie dough was prepared according to the recipe indicated in the commercial product by adding eggs and butter. Then, the dough was kneaded, rolled, cut with a round cookie cutter and cooked in an electric oven at 150 °C for 9 min. Once cooled, they were stored in plastic bags until analysis. The other cookie recipe consisted of the same ingredients as stated above but with the addition of 3.75% of a powder ingredient obtained from a blackcurrant by-product in replacement of part of the rice flour and corn starch, to enhance its fibre content (B cookie). The addition level of the fibre powder ingredient was determined by a sensory test conducted with an untrained internal panel of 8 persons [35]. Cookies with different proportions of the ingredient (between 0.4 and 6%) were tested, and the highest level of addition that was accepted by the panel was chosen for the study, being the flavour and the colour of the product the properties that were most rejected in the higher addition levels.

Cookies characterization

The water content, water activity (a_w), crude protein content, fat content, total dietary fibre (TDF), and insoluble dietary fibre (IDF) were determined according to Gagneten et al. [34]. The dimensions of the cookies were determined with a gauge. The results of three measurements of each replicate were informed.

Texture analysis

Mechanical properties

Fracture properties of the cookies were determined 24 h after baking using a universal testing machine Instron 3342

(Instron Corporation, Massachusetts, USA) and Instron Bluehill Material Testing Software. A penetration test was performed using a 3 mm diameter stainless steel probe of blunt tip and each assay was ended when the sample was completely traversed. The test was performed at a speed of 0.5 mm/s, a time interval (data acquisition) of 100 ms and a 500 N load. The force vs. deformation curves were obtained and the following parameters were determined: Maximum force (F_{max}); Distance at maximum force (ΔF_{max}); and the Work to fracture (W), or total energy needed for fracture. The measurements were performed in ten replicates and the mean \pm standard deviations were informed.

Image texture analysis

Scanning electron microscopy Scanning electron microscopy (SEM) was used to study the microstructure of the cookies. Samples were cross sectioned using a scalpel. A portion of the interior of the cookies was mounted on an aluminium support and coated with gold nanoparticles using a sputter coater (Cressington Scientific Instruments 108). Observations of the samples at magnification of $\times 1000$, $\times 2000$ and $\times 5000$ were obtained for image analysis.

Eighteen images from each sample at each magnification were taken using an acceleration voltage of 3.00 kV. Brightness and contrast are the most important variables to be controlled during the acquisition of images; therefore, these parameters were kept constant for each magnification [36]. Samples were analysed in triplicates.

Gray level co-occurrence matrix (GLCM) and image texture analysis Texture parameters [energy (ASM), contrast (CON), correlation (COR), homogeneity (HOM) and entropy (ENT)] were calculated from SEM images using the Gray Level Co-occurrence Matrix method (GLCM).

The textural feature angular second moment, also called energy or ASM, measures the texture uniformity or orderliness of an image [37]. ASM values indicate directional uniformity in the image. The textural feature CON is a measure of the intensity contrast between a pixel and its neighbour over the whole image, so its value is 0 for a constant image [38]. CON can be seen as a dynamic range of gray level or sharpness of edges. Regarding COR, it measures the degree of correlation between a pixel and its neighbour within the entire image. Its range lies between -1 for perfectly negatively and $+1$ for a perfectly positively correlated images. Correlation measures the joint probability of occurrence of pixel pairs in GLCM. The textural feature ENT shows how often a pixel with gray-level value i occurs horizontally adjacent to a pixel with the value j [39]. ENT statistically evaluates the randomness which characterizes the texture of a certain image. ENT is higher when all entries in $p(i, j)$ are

of similar magnitude, and smaller when the entries in p are unequal [40]. HOM presents the level of uniformity on each image. High values of HOM show an increase of smoothness and uniformity of the image.

The five image texture features (COR, ASM, HOM, ENT and CON) were calculated using MATLAB 8.4 (The Math Works, Inc., MA, USA) according to Pieniazek and Messina [25].

Sensory analysis

To analyse the sensory perception of the texture, a study with consumers was carried out in specially designed cabins [41] at the sensory analysis laboratory of the Facultad de Bromatología, Universidad Nacional de Entre Ríos. 95 consumers between 18 and 70 years comprised of students, staff of the university, and members of a celiac association from Entre Ríos (ACELA) were surveyed after signing a written informed consent. C and B cookies were coded with a three-digit number and placed in white plates for the consumers to evaluate. Three tests were conducted: an intensity level of attributes test; a satisfaction level of attributes test; and a global satisfaction test [42]. The cookies were evaluated for their hardness, crunchiness and fragility using a 7-point hedonic scale that ranged from “like extremely” to “dislike extremely” for the satisfaction tests (satisfaction level of attributes, and global satisfaction); and a 5-point scale that ranged from “very low” to “very high” for the intensity level test.

Statistical analysis

ANOVA analysis and the Tukey's test were carried out to evaluate differences ($p < 0.05$) between samples using GraphPad Prism 6 software (CA, USA, 2014). Regression equations and correlation coefficients (R^2) between instrumental and image texture features were obtained using

SPSS-Advanced Statistics 13 software (SPSS Inc., Chicago, IL).

Results and discussion

Cookies characterization

Pictures of C and B cookies are shown in Fig. 1, while Table 1 shows the physicochemical properties and proximate composition of the cookies. When comparing both samples, protein and fat contents did not show significant differences. However, the main variations were observed for the fibre content, being TDF of the B cookie 2.5 times higher than that of the C cookie, while IDF was three times higher for the B cookie. On the other hand, although the B cookie had a significantly higher water content, no significant differences ($p < 0.05$) were observed on the water activity (a_w). Also, no significant differences were found regarding the geometrical characteristics of the cookies, being the diameter and the thickness equal to 29.4 ± 5 mm and 5.5 ± 5 mm, respectively.

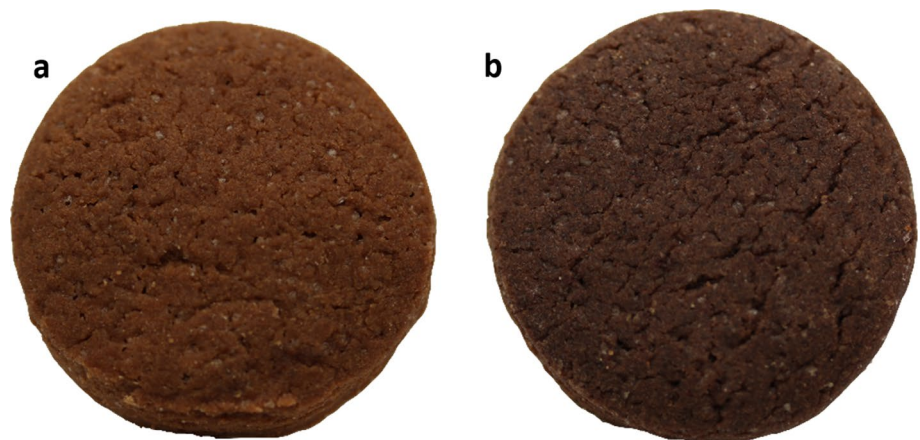
Table 1 Physicochemical properties and proximate composition of B- and C-cookies

Property	C-cookie	B-cookie
Water content (%)	9.4 ± 0.1^a	11.1 ± 0.4^b
a_w	0.738 ± 0.009^a	0.741 ± 0.001^a
Dietary fibre (% d.b.)		
TDF	1.7 ± 0.4^a	4.2 ± 0.7^b
IDF	0.9 ± 0.1^a	2.7 ± 0.9^b
Protein content (g/100 g d.b.)	5.29 ± 0.09^a	5.31 ± 0.04^a
Fat content (g/100 g d.b.)	21 ± 2^a	22 ± 1^a

d.b. dry basis

Rows with different lowercase letters are significantly different ($p < 0.05$)

Fig. 1 Digital camera images of C-cookie (a) and B-cookie (b)



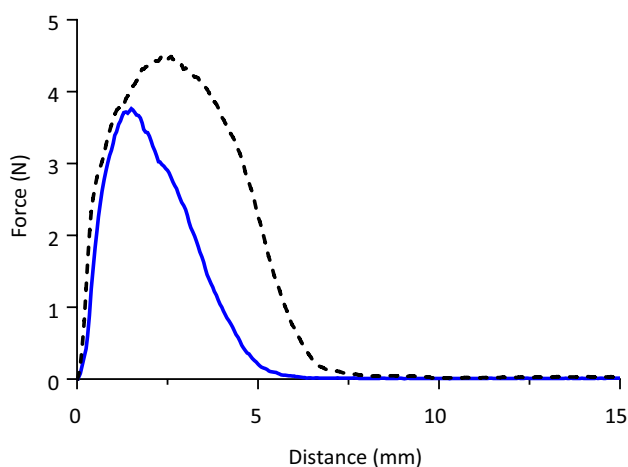


Fig. 2 Force vs. deformation curves for C-cookie (black, dashed line) and B-cookie (blue full line) (Color figure online)

Table 2 Mechanical parameters obtained from the force vs. deformation curves obtained from the penetration tests

Sample	Maximum force (N)	Distance at maximum force (mm)	Work (J)
C-cookie	4.5 ± 0.3^b	2.1 ± 0.3^b	15 ± 1^b
B-cookie	3.6 ± 0.3^a	1.4 ± 0.2^a	9.5 ± 0.9^a

Values with different lowercase letters are significantly different ($p < 0.05$)

Mechanical properties

Figure 2 shows the force/deformation curves obtained from the penetration tests of the two cookies. For both samples, the force increased gradually while the tip descended through the sample, until it reached a maximum value after which the force dropped due to fracture of the material. The small peaks in the curves can be related to local fractures of small structures or layers in the material. Table 2 shows the mean values of the evaluated mechanical parameters. The maximum force (F_{\max}) is related to the material resistance to penetration or firmness [5]. The distance at which the force reaches its maximum value (ΔF_{\max}) indicates the sample deformation before rupture or deformability [43]. The mechanical work (W) or energy required to break the sample, which corresponds to the area under the curve up to F_{\max} , is related to sample toughness.

Low force values were obtained for both samples. However, the control cookie presented a higher F_{\max} indicating that this sample was significantly more resistant to fracture than B cookie. Although similar initial slopes were observed for both cookies (4.0 ± 0.4 computed as the slope of the force/deformation curves for the first 10% of the force), suggesting comparable rigidity in both samples, B cookie

showed a lower ΔF_{\max} , which corresponds to a more brittle or fragile structure. Differences in the mechanical response of the materials were also observed through the W values, which were higher for the control sample as a consequence of its more rounded and higher peaks. The differences observed between the two samples may be attributed to the higher water and fibre content of B cookie. However, it is likely that the water in this type of products would be strongly associated to the matrix components, hence it might not be affecting the texture of the product. This could be supported by the fact that the water activity values were not significantly different between the two cookies. Therefore, the difference in texture could be mainly attributed to the higher fibre content in B cookie.

The determination of textural parameters in high carbohydrate food products is particularly difficult due to their heterogeneous composition and uneven structure [44]. The texture of baked biscuits is primarily attributable to starch gelatinization and supercooled sugar [1]. However, other ingredients, such as fat, gums and other hydrocolloids, used in gluten free bakery play a fundamental role for texture improvement. Also, due to the large variety of starches that might be used to prepare gluten free products, the textural and organoleptic characteristics of them may differ significantly. Nevertheless, the F_{\max} values determined in this study were in the range of those reported by other authors for different type of cookies. Kulthe et al. [45] analysed cookies added with millet flour and reported F_{\max} values of 3.76–17.39 N depending on the percentage of addition and the millet variety. Cherătoiu et al. [46] studied corn and oat gluten-free cookies and found F_{\max} values between 1.8 and 4.21 N. Torres González et al. [44] studied lemon cookies made with corn flour and informed F_{\max} values of 6.97–16.38 N.

Furthermore, the effect of fruit powder addition over the textural properties of cookies has been studied by different authors, showing different results and tendencies. Asadi et al. [17] studied the effect of different addition levels of concentrated fibre powder obtained from chiku (*Manilkara zapota* L.) on the texture of cookies, and informed a significant decrease in the sample hardness when the fibre concentrate content increased. Mildner-Szkudlarz et al. [18] also reported a decrease in the hardness and resistance of the samples when the content of a white grape powder was augmented. On the contrary, Aziz et al. [47] studied the effect of apricot addition on textural characteristics of cookies and found that the hardness of the samples augmented when the fruit powder was added. Likewise, Rocha Parra et al. [19] informed an increase in F_{\max} of sugar-snap cookies when grounded dry apple pomace was added to the formulation. On the other hand, Uysal et al. [48] described different texture responses when wire-cut cookies were added with fibre of different sources: hardness decreased in samples added

with apple and wheat bran fibres, while the opposite was observed when lemon or wheat fibres were studied. These differences might be due to modifications in the microstructure of the material as a consequence of the fibre content and its specific properties. Fibre (especially soluble dietary fibre) competes with starch for water, limiting the water availability and therefore reducing the gelatinization degree of the latter [49]. This might also depend on the chemical structure of the fibres and the botanical source of the starches. The cited authors also reported that fibre addition did not prevent the formation of air bubbles in the structure of the cookies but affected their size by the end of the baking process, resulting in fewer but larger bubbles.

The number of peaks, defined as force variations of more than 0.02 N, can be related to the crispness of the material in these kind of products [21]. Although neither of the two samples showed curves with a high level of judgness, the control cookie exhibited a higher number of peaks than B cookie, suggesting that the first one had a slightly crunchier texture.

Image texture analysis

Gray Level Co-occurrence Matrix (GLCM) is an emerging empirical method that correlates the image parameters (CON, COR, ASM, HOM y ENT) with the global texture of a material or with specific texture parameters determined by different instrumental methods [33, 50].

In order to conduct the image texture analysis, the first step was to select the more appropriate method to acquire the images. This analysis can be done over macroscopic images (digital camera or scanned images), or with microscopic images obtained by optical microscopy or SEM [33, 38, 39]. In this research, SEM images were obtained with three magnifications: $\times 1000$, $\times 2000$ and $\times 5000$.

Figure 3 shows SEM images of samples at $\times 1000$, $\times 2000$ and $\times 5000$. The microscopic images showed independent rounded particles, and continuous irregular structures of different sizes. This organization might be constituted of non-gelatinized starch granules surrounded by a complex matrix of proteins, gelatinized starch and melted/re-solidified fat [51, 52].

When the image texture parameters obtained from the SEM pictures at different magnifications were compared (Table 3), non-statistically significant differences were found between $\times 1000$ and $\times 2000$. In contrast, at $\times 5000$ magnification, significant differences were found probably due to the loss of information from the surface structure, which showed arrays of bigger orders. In general, results revealed that at $\times 1000$, images analysis showed to be more homogeneous due to a better correlation among neighbouring pixels, lower degree of local variations, and high linearity and smoothness. Therefore, the $\times 1000$ magnification was chosen for further analysis, with the additional benefit that a less powerful equipment is needed to get these images in comparison with higher magnification engagement.

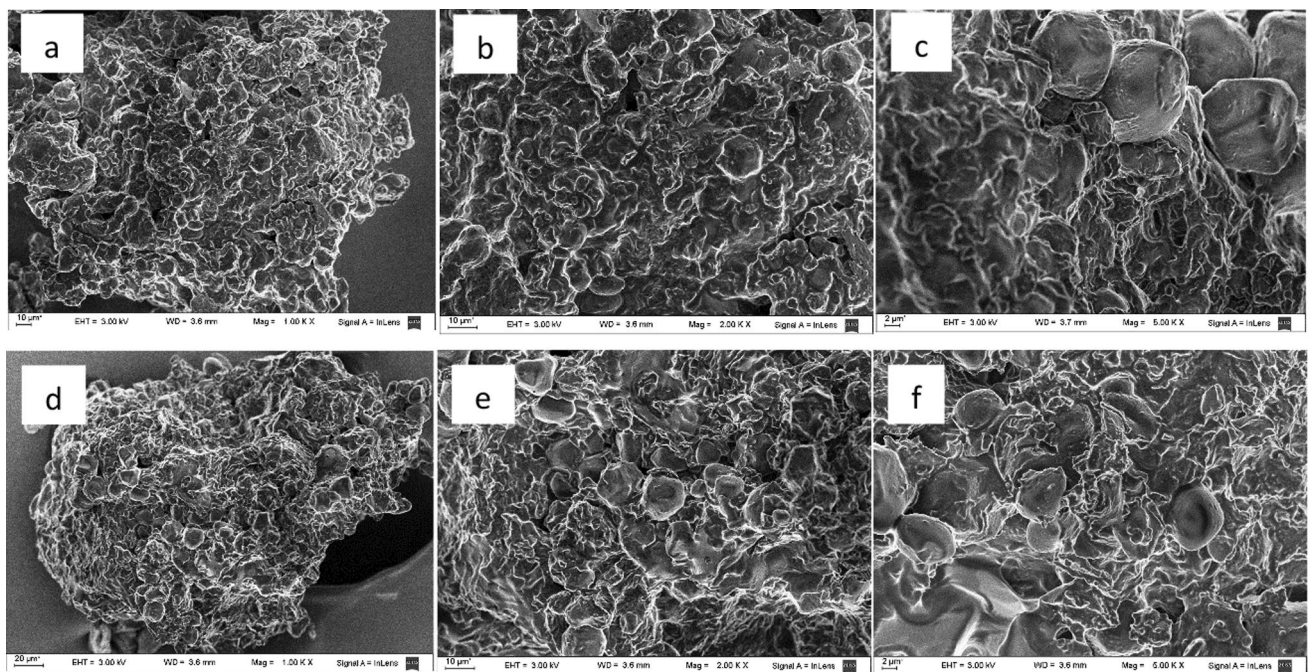


Fig. 3 SEM images of the C-cookie (**a–c**) and the B-cookie (**d–f**) obtained with three magnifications: $\times 1000$ (**a, d**); $\times 2000$ (**b, e**); and $\times 5000$ (**c, f**)

Table 3 Image texture parameters obtained for SEM×1000,×2000 and×5000 images

Method	Texture parameters				
	CON	COR	ASM	HOM	ENT
SEM×1000	0.80 ^b	0.84 ^a	0.09 ^a	0.75 ^a	7.45 ^b
SEM×2000	0.86 ^b	0.84 ^a	0.09 ^a	0.75 ^a	7.46 ^b
SEM×5000	0.66 ^a	0.83 ^a	0.13 ^b	0.78 ^b	7.17 ^a

Lowercase letters in the same column indicate that means are significantly different ($p < 0.05$) (Tukey's Test). Correlation (COR), Energy (ASM), Entropy (ENT), Homogeneity (HOM), Contrast (CON)

Table 4 Comparison of image texture parameters between C- and B-cookies obtained from SEM×1000 images

Sample	Texture parameters				
	CON	COR	ASM	HOM	ENT
C-cookie	0.89 ^a	0.84 ^a	0.37 ^a	0.74 ^a	7.48 ^a
B-cookie	0.74 ^b	0.84 ^a	0.19 ^a	0.76 ^a	7.42 ^a

Lowercase letters in the same column indicate that means are significantly different ($p < 0.05$) (Tukey's Test). Correlation (COR), Energy (ASM), Entropy (ENT), Homogeneity (HOM), Contrast (CON)

Table 4 shows image texture parameters obtained for the samples. Lower values in CON represent a reduction of local variation of pixels, while high values of CON are related to higher hardness. As it can be appreciated, CON values were higher for C-cookie when compared to B-cookie, which reveals a harder texture. ASM is correlated to the uniformity and homogeneity of the image. Higher ASM can be related to a rougher surface. This parameter was also higher for C-cookie when compared to B-cookie, although the difference was not found to be significant. These findings are consistent with those determined by instrumental analysis in which C-cookie showed a higher F_{max} and larger number of peaks. COR, HOM and ENT did not show significant differences among them.

Table 5 Multiple regression model of instrumental and image texture determined by SEM images with the three different magnifications

Sample	Parameter	MLR equation	R^2
C	F_{max}	$F = 14.83 + 2.18[\text{CON}] + 30.05[\text{COR}] + 5.50[\text{ASM}] - 21.98[\text{HOM}] - 2.94[\text{ENT}]$	0.95
B	F_{max}	$F = 58.97 - 12.50[\text{CON}] + 30.11[\text{COR}] + 62.88[\text{ASM}] - 123.25[\text{HOM}] + 2.12[\text{ENT}]$	0.97

Maximum force (F_{max}), Correlation (COR), Energy (ASM), Entropy (ENT), Homogeneity (HOM), Contrast (CON)

Correlation between instrumental and image texture

In order to evaluate the capability of image analysis to study the texture of cookies, a linear trend with a linear correlation under evaluated conditions were analysed with instrumental (F_{max}) versus image features (F_{max} versus CON, COR, ASM, ENT and HOM) for each sample. The relation between instrumental texture F_{max} versus each image feature, COR, ASM, ENT, HOM, and CON, showed good correlations coefficients for C-cookies (0.913, 0.851, 0.889, 0.876 and 0.859, respectively) and for B-cookies (0.887, 0.897, 0.891, 0.861 and 0.873, respectively). Karimi [39] studied the texture of bread by an instrumental penetration test, and observed a high correlation between the instrumental texture parameter F_{max} , and image texture parameters (GLCM). In previous works of the group, Pieniazek et al. [53] also reported similar results. High correlations were observed between instrumental texture parameters (hardness, chewiness, gumminess, adhesiveness), and image texture parameters (CON, ASM, ENT, HOM, COR) in cooked and freeze-dried lentils. Therefore, data retrieved from image parameters showed to be useful to estimate instrumental texture.

In the present work, multiple linear regression (MLR) was also performed. MLR between image parameters (CON, ASM, ENT, HOM, COR) and instrumental texture (F_{max}) showed the capability of image texture parameters to predict mechanical texture parameters with coefficients of regression equation statistically significant ($p < 0.05$) (Table 5). Based on the obtained R^2 values, the model explained 0.95 for C-cookie and 0.97 for B-cookie of the variability associated with instrumental and image texture parameters. These results show that image texture analysis acquired by SEM can be used as a useful tool in order to evaluate instrumental firmness.

Sensory analysis

Since texture is a complex sensory property, which cannot be easily described by a unique instrumental technique, sensory analysis plays a fundamental role in this type of characterization [7]. Using the appropriate methodology to analyse the response of consumers, sensory studies can

provide information about the complex interaction of the senses that result in the perceived texture [54].

The results of the attributes' intensity test (Fig. 4) showed that both cookies were overall described by a low hardness and crunchiness, and high fragility, in accordance with the instrumental texture analysis (Fig. 2). Although the mechanical properties and image analysis exhibited significant differences in the texture properties of the samples, these changes were not perceived by the majority of the consumers, who punctuated both cookies very similarly. The human jaw is prepared to process a great variety of foods of very different levels of hardness and firmness [55]. Therefore, considering the low F_{\max} values determined for the studied cookies, the magnitude of the differences between both cookies might

have not been perceptible for most people. Doporto et al. [21] analysed the texture of gluten-free cookies and stated that the relationship between the sensory perception of some attributes and the textural parameters determined by instrumental assays might not be very clear. This is frequently due to an imprecise interpretation of the terms used to describe textural attributes when working with panels of untrained consumers. Kohyama et al. [10] explained that frequent inconsistencies between instrumental and sensory results can be attributed to the non-equilibrium nature of food texture perception phenomena and the non-linear relationship between the magnitude of what humans can perceive and the intensity of the physical stimuli from food. Moreover, temperature and moisture changes that occur during oral processing are not considered in conventional instrumental methods and can influence the results.

Regarding crispiness, Andreani et al. [15] studied the correlation between sensory crispiness and the mechanical measurement of this property, and concluded that there was no high linear correlation between them. The authors suggested that acoustic measurements have better correlation with this texture characteristic.

The results of the satisfaction level of attributes test are shown in Fig. 5. Consumers found the texture of the B cookie more likable than the control cookie as the hardness and crunchiness parameters shifted from a "dislike slightly" and "indifferent" to "indifferent" and "like slightly" respectively. Regarding fragility, positive appraisals predominated and a slight increase of answers in the "Like" category for B cookie were observed, in detriment of the "indifferent" answers.

The global satisfaction test showed more than 79% of the surveyed population rated the cookies in the liking categories, showing that both samples were overall accepted by consumers.

Conclusions

The two studied cookies showed differences in their force/deformation profiles that resulted in a less rigid, more fragile and less crispy texture for the fibre enriched cookie in comparison to the control one. These textural differences were also found with the GLCM method, by which lower CON and ASM values were determined for the enriched cookie, corresponding to a lower hardness and roughness. Overall, the results reached in this work showed that image analysis by means of the Gray Level of Co-occurrence Matrix method was capable of discriminating between the two cookies and suggest that this technique could be used as a routine, non-destructive method to estimate the firmness of the cookies as an alternative to F_{\max} values determined by force/deformation instrumental

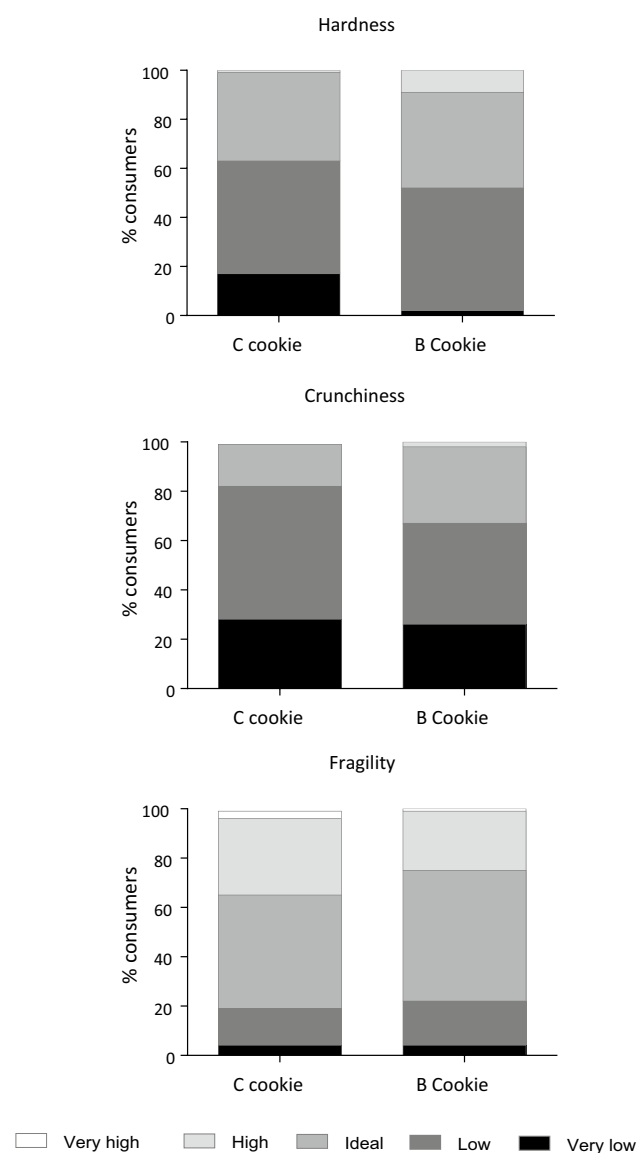


Fig. 4 Intensity level for each attribute perceived in the attributes' intensity test

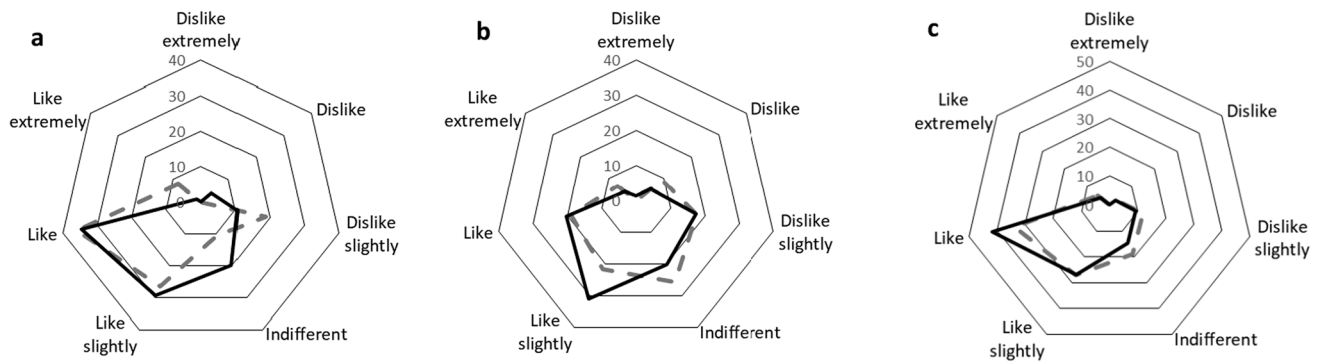


Fig. 5 Results of the satisfaction level of attributes test for the hardness (a), crunchiness (b) and fragility (c) for C-cookie (dashed gray line) and the B-cookie (solid black line), expressed as the percentage of surveyed population

methods. Moreover, the present results enlarge the evidence presented in other works of the group [33, 36, 53] and reported by other authors [26, 39], that prove that this method is a promising alternative to predict texture of different types of food and discriminate between samples. Also, it was found that for cookie texture studies high magnification degrees, $\times 5000$ or above, might not be the best choice since details from the superficial structure may correspond to bigger size orders and can be lost. Furthermore, it was verified that the method was sensible enough to detect changes in the texture of the samples even at levels that might not be perceived by the majority of consumers. Sensory analysis with consumers was valuable to determine the acceptability level of different attributes and global acceptability, but was not as useful to detect small texture differences between samples.

It could be concluded that the addition of dietary fibre from a fruit powdered ingredient was successfully achieved, without considerably altering the texture perception nor their global acceptance of the product among consumers. Overall, the combination of techniques to evaluate cookies texture is an interesting approach as different information can be acquired, which can give a more complete outlook of this complex feature. Although sensory tests may be more truthful to describe the texture characteristics, understood as the human perception of mechanical, geometrical and surface properties of a product, instrumental and image methods can provide more sensitive alternatives to detect differences due to different products formulations or processes. Instrumental (by image or mechanical techniques) and sensory studies complement each other to describe the textural parameters of this type of bakery products: while the first ones provide a faster and easier way to obtain precise and objective values to characterize a product, the second one is more suitable to describe the appreciation and preference of the product and represents a real result of the consumers point of view that takes into account the subjective sensitive perception of humans [14].

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Data availability Research data will be shared upon request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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