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Mastication of crisp bread: Role of bread texture and structure on texture perception

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ABSTRACT

Texture and structure of breads have been related to oral processing (FOP) performance and sensory perceptions, but moisture content might play a significant role. To evaluate the real impact of breads texture and structure, eliminating the possible role of moisture content, different toasted breads were investigated. Four commercial toasted sliced breads (white bread -WHB-, whole wheat bread -WWB-, non-added sugar bread -NSU-, non-added salt bread -NSA-) with similar ingredients but different texture and structure were selected. Texture and structure were instrumentally and sensory evaluated, besides FOP (total chewing time, number of chews until swallowing, chewing frequency, and mouthful) and bolus properties (moisture, saliva to bread ratio, hardness, adhesiveness, and cohesiveness). Toasted breads showed significant differences in hardness, cutting strength, and porosity, but panelists did not discriminate among them. FOP results indicated that harder samples (NSU) required longer mastication and a number of chews, and open crumb structures (WWB, WHB) with higher cell areas required less mastication. Also, bolus characteristics were affected by bread types, and bread with lower crumb hardness (WHB) produced more cohesive bolus. Having toasted breads allowed to eliminate possible influence of moisture content differences on sensory perception, mouthful and bolus water incorporation during mastication.

1. Introduction

Digestion performance of foods is becoming of utmost interest due to increasing understanding of the relationship among food-nutrition-health (Lovegrove et al., 2017). Digestion involves very complex processes along the oro-gastrointestinal tract, but all food changes start in the mouth where food is subjected to physical and biochemical changes. Specifically, food oral processing (FOP) involves mastication, salivation, bolus formation, enzyme digestion, and swallowing (Puerta et al., 2021). Considering the importance of bread on the human diet, the study of its oral processing has been the focus of several researches. Particularly, investigations have been centered on bread mastication performance through the duration of chewing or the number and frequency of bites (Mao et al., 2016; Pentikäinen et al., 2014), the textural bolus properties like adhesiveness, hardness, or cohesiveness (Jourdren, Panouillé, et al., 2016), the rheological behavior of boluses (Le Bleis, Chaunier, Della Valle, Panouillé, & Réguerre, 2013), or even the salivary amylase activity during oral digestion (Joubert et al., 2017). Currently, it is known the strong correlation between the mastication parameters of fresh wheat breads having different crumb structures and textures with their oral processing behavior (Aleixandre, Benavent-Gil, & Rosell, 2019; Gao, Wong, Lim, Henry, & Zhou, 2015). Similar relationship was observed with the structural properties and mastication work of different wheat and rye fresh breads (Pentikäinen et al., 2014). Image texture analysis allowed to identify the different degradation underwent by breads depending on their structure and composition (Tournier, Grass, Zope, Salles, & Bertrand, 2012). Likewise, Jourdren, Panouillé, et al. (2016) pointed out the effect of bread structure on oral processing, but stressing the role of bread composition, especially water content, in the bolus properties. That opens a reasonable doubt about the real impact of bread structure on mastication because evaluations have been always carried out in fresh breads, where water plays a crucial role as plasticizer.

Those physical and biochemical processes taking place during mastication are also intimately connected to texture perception, owing to the different stimuli induced by food breakdown and bolus formation. In fact, significant differences in texture perception have been observed among fresh breads with different structures (Gao, Ong, Henry, & Zhou, 2017). Nevertheless, Jourdren, Saint-Eve, et al. (2016) found that bolus properties and more specifically bolus hydration and texture had more

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impact on texture perception than bread structural properties. Considering the high moisture content of the bread and the variability among breads, bolus hydration might be significantly affected by the moisture content of the bread and some texture perception might be hindered due to the water content. Therefore, till now there is no study focused on assessing to what extent the bread texture in absence of water is affecting mastication and texture perception.

The objective of the present study was to better understand the effect of bread properties on consumers' perception and mastication, but to reduce the impact of bread moisture content, toasted breads were selected. Four commercial toasted sliced breads (white, whole meal, low in salt, low in sugar) with rather similar composition and shape were selected. Relationships between bread properties, sensory and instrumentally analyzed, and sensory perception during oral processing were evaluated.

2. Materials and methods

2.1. Bread samples and characterization

Four types of commercial toasted sliced breads were purchased from a local Spanish market, including white bread (WHB), whole wheat bread (WWB), no added sugar bread (NSU), and no added salt bread (NSA). Toasted sliced breads were from the same brand to reduce their variability to composition, keeping the breadmaking process.

The ingredient composition and nutrition facts of commercial breads were obtained from the label (Table 1). Samples were stored in sealed plastic containers to prevent moisture changes during the study.

Table 1
Ingredients and nutrition facts (g/100 g) of toasted sliced breads according to producer's labels.

Sample	Ingredients	Fat	Carbohydrate	Sugars	Protein	Salt
WHB	Wheat flour 88%, yeast, vegetal oil (sunflower) 2.5%, glucose and fructose syrup, sugar, salt, malted barley flour, wheat gluten, flour treatment agent: ascorbic acid.	4.6	73	4.9	11	1.2
WWB	Whole wheat flour 58%, wheat flour, yeast, glucose and fructose syrup, vegetal oil (sunflower) 2.9%, wheat gluten, salt, malted barley flour, flour treatment agent: ascorbic acid.	5.6	59	3.8	17	1
NSU	Wheat flour 91%, wheat gluten, yeast, vegetal oil (sunflower) 2.6%, flour treatment agent: ascorbic acid.	5	72	2.9	13	0.05
NSA	Wheat flour 88%, yeast, glucose and fructose syrup, vegetal oil (sunflower) 2.5%, wheat gluten, malted barley flour, flour treatment agent: ascorbic acid.	4.5	71	5.8	13	0.04

Characterization of bread samples included moisture content, texture, and structural properties. Moisture content was analyzed following the ICC standard method ICC 110/1 (ICC, 1994). The textural characteristics of toasted bread samples such as hardness and cutting strength were measured using the TA.XT-Plus Texture Analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with a 5 Kg load cell. A compression test was applied to toasted bread slices, using a 20 mm cylindrical aluminum probe. All bread slices had the same dimensions (10 mm × 6 mm × 1 mm, length × width × thickness). Five compression/slice were performed at a test speed of 0.5 mm/s and compressing up to 50% of the bread slice height. The maximum peak of the force-distance plot was interpreted as hardness. Cutting strength was measured using the 3 mm knife blade at a test speed of 2 mm/s, following the conditions reported for crispy products like biscuits (Hedhili et al., 2021; Prakash et al., 2018). Bread structure analysis was carried out using ImageJ software following the methodology described by Morreale, Garzón, and Rosell (2018). Bread porosity (%), calculated as total cell area and total slice area ratio in percentage, and mean and median cavities or cells area (mm^2) were determined.

2.2. FOP assessment

Fourteen healthy subjects (10 females and 4 males), students, and teachers from University participated in the study (30.64 ± 6.73 years, mean ± SD). Number of subjects in the study is important but the range of participant in similar FOP studies varied between 10 and 20 (Joubert et al., 2017), thus the number selected for this study falls within reported values. Selection criteria were availability for the duration of the study, good dental status, and no reported salivary or masticatory disorders. The participants provided signed consent to their participation in the study, and they did not receive compensation for their participation.

The study was conducted according to Helsinki Ethical Guidelines and adapted for food sensory analysis at the Food Technology and Biotechnology Department at Faculty of Technology and Metallurgy, University Ss Cyril and Methodius in Skopje, Republic of North Macedonia. The study was approved by the Faculty Committee (University Ss Cyril and Methodius).

For FOP analyses, the participants were instructed to bite bread samples, naturally chew them and, to indicate the swallowing moment. Parameters collected were the total chewing time (s), number of chews until swallowing, chewing frequency, and mouthful (g) as the portion of food ingested for chewing. The total chewing time (s) was calculated as the duration between the first chew and the swallowing time, which was recorded with a digital chronometer (Brannan, S. Brannan & Sons, limited, Cleator Moor, UK). The chronometer was activated after biting the bread slice and stopped when it was swallowed. The number of chews until swallowing were measured as the number of opening and closing movements of the maxilla, and the chewing frequency represents the number of chews per second (Huang, Liu, Muo, & Chang, 2021). Bread slice was weighted before and after biting and the weight difference between them was referred as mouthful.

2.3. Characterization of bolus properties

The participants masticated each sample and spitted it when they felt it was ready to swallow. Chewed samples were immediately analyzed. Bolus moisture (%) and saliva impregnation (g/g bread, W.W.) were determined as previously described by Pentikäinen et al. (2014). Boluses were dried in an oven at 105 °C overnight determining their water content, and saliva impregnation was determined by the difference between bolus moisture and the bread moisture. A Texture Profile Analysis (TPA) was used to characterize the bolus, following the procedure described by Jourdren, Panouillé, et al. (2016) was performed using a TA.XT-Plus Texture Analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with a 5 Kg load cell. Bolus was loaded into a 3 cm height poly-methyl methacrylate cup and subjected to compression, with a 20 mm cylindrical aluminum probe, test speed of 0.83 mm/s, and compressing up to 65% of the bolus height and resting time of one second between compressions. Data from three replicates were averaged. Hardness, adhesiveness, and cohesiveness parameters were obtained from the analysis.

2.4. Sensory assessment

A descriptive sensory evaluation focused on bread texture properties was performed following international standards (ISO, 4121:2003). In one session, participants were presented in a completely randomized way with the samples labeled with 3-digit codes. Participants evaluated successively the toasted breads, rinsing the mouth with water after each sample and leaving 2 min between sample analysis. The definition of the texture attributes (hardness, crispness, crunchiness, pastiness, grittiness, dry mouthfeel) was given to the panelists, using the terms previously reported (Callejo, 2011). Specifically, hardness was defined as the force required to break the bread with the incisors. Crispness was referred as the high pitched sound produced when the teeth crack the product during mastication, with multiple fractures at low force loads. Crunchiness was defined as the low-pitched sound produced on bread fracture during mastication. Pastiness was referred as the mouthfeel of ball or paste formation. Grittiness was the presence of small dry particles which tend to scrape off the tongue. Finally, dry mouthfeel was evaluated as the feeling of dryness in the mouth. Hardness, crispness, and crunchiness gave information about bread texture attributes, while pastiness, grittiness, and dry mouthfeel were related to bolus properties. The intensity of all sensory impressions was scored using a 7-point categoric scale (1 = extremely low intensity, 2 = very low intensity, 3 = moderate low intensity, 4 = neither intense nor not intense, 5 = moderate high intensity, 6 = very high intensity, 7 = extremely high intensity).

2.5. Statistical data analyses

All samples were analyzed in duplicate and results averaged. Statistical analyses were assessed by using Statgraphics Centurion XV (Statistical Graphics Corporation, Rockville, MD, USA). Descriptive statistics and one-way analysis of variance (ANOVA) were performed to evaluate significant differences among bread samples at 95% confidence interval using Fisher's least significant differences (LSD) test. Pearson correlation coefficient (r) and P-value were used to indicate correlations. The data were analyzed by multivariate data analysis in the Principal Component Analysis (PCA) to discriminate among samples.

3. Results and discussion

3.1. Bread characteristics

Four wheat toasted breads were used to identify possible relationships between instrumental and sensory texture and the effect on mastication without the influence of the moisture content. Breads with very close composition and similar shape were selected: white bread, whole wheat bread, non-added sugar bread, and non-added salt bread. According to their labels (Table 1), toasted breads were based on wheat flour, yeast, sunflower oil, wheat gluten, and ascorbic acid. Main differences were the inclusion of whole wheat flour in WWB, the absence of salt and sugar in NSU and NSA, and also the absence of syrup in NSU. Concerning the nutrition facts, as expected WWB bread showed the highest fat and protein values and the lowest carbohydrate content. NSA had the highest sugar content followed by WHB, WWB, and NSU. Salt contents were similar between WHB and WWB (1.2–1 g/g), and NSU and NSA (0.05–0.04 g/g).

As expected toasted breads had very low moisture content (4.32–5.58%) (Table 2), compared to fresh breads (33–37%) (Jourdren, Panouillé, et al., 2016). Therefore, the low moisture content of these breads would allow assessing the impact of texture and structure without the possible interference of the water plasticizing effect. Despite their similarities in ingredients and composition, they showed significant ($P < 0.05$) differences in hardness and cutting strength (Table 2). NSU and WWB had harder structure (47.15 ± 1.65 and 36.24 ± 5.24 N, respectively) than WHB and NSA breads. Cutting strength values were higher in low-salt breads: NSU and NSA samples (42.64 ± 2.95 and 46.10 ± 3.03 N, respectively). Likely, sugar and salt content affected the inner bread structure since a negative relationship was observed between sugar content and hardness ($r = -0.7808$; $P < 0.001$) and salt content and cutting strength ($r = -0.8145$; $P < 0.001$). In fact, Lynch, Dal Bello, Sheehan, Cashman, and Arendt (2009) observed a reduction in bread hardness as the salt content increase when comparing fresh breads with different salt content. Image analysis of the crumb corroborated their different structure (Fig. 1). Crumb porosity (%) was higher in WWB bread (33.74 ± 0.41%), which also showed the lowest median cell area.

Table 2
Bread characteristics and their performance during FOP (FOP) and the resulting bolus properties of different types of toasted breads (WHB: wheat bread; WWB: whole wheat bread; NSU: non-sugar added wheat bread; NSA: non-salt added wheat bread).

	WHB	WWB	NSU	NSA
Bread characteristics				
Moisture content (%)	4.32 ± 0.05[a]	5.58 ± 0.06[c]	4.55 ± 0.04[b]	4.38 ± 0.01[a]
Hardness (N)	22.70 ± 1.99[a]	36.24 ± 5.24[c]	47.15 ± 1.65[d]	29.18 ± 2.31[b]
Cutting strength (N)	34.80 ± 1.02[a]	31.02 ± 5.70[a]	42.64 ± 2.95[b]	46.10 ± 3.03[b]
Porosity (%)	30.51 ± 0.70[b]	33.74 ± 0.41[c]	21.35 ± 0.83[a]	30.21 ± 0.95[b]
Cell area (mm^2)				
Mean	0.54 ± 0.06	0.46 ± 0.04	0.46 ± 0.05	0.53 ± 0.01
Median	0.030	0.012	0.021	0.016
FOP				
Mastication time (s)	14.81 ± 3.02[a]	13.87 ± 2.83[a]	17.80 ± 3.71[b]	15.58 ± 3.18[ab]
Number of chews	14.00 ± 2.86[a]	16.72 ± 3.34[b]	19.92 ± 3.91[c]	18.00 ± 3.75[bc]
Chewing frequency (s^{-1})	1.07 ± 0.22[a]	1.22 ± 0.25[b]	1.16 ± 0.24[ab]	1.28 ± 0.26[b]
Mouthful (g)	1.54 ± 0.31	1.38 ± 0.28	1.51 ± 0.30	1.52 ± 0.30
Bolus properties				
Moisture (%)	51.73 ± 5.46	53.87 ± 5.33	52.92 ± 7.03	52.17 ± 5.62
Saliva to bread ratio (g/g bread, W.W.)	0.47 ± 0.09	0.47 ± 0.09	0.48 ± 0.09	0.48 ± 0.09
Hardness (N)	6.20 ± 1.17[a]	6.93 ± 1.31[ab]	8.17 ± 1.54[b]	7.42 ± 1.40[ab]
Adhesiveness (N·s)	6.90 ± 1.30[b]	2.80 ± 0.54[a]	2.90 ± 0.55[a]	5.90 ± 1.11[b]
Cohesiveness	0.48 ± 0.09[c]	0.32 ± 0.06[a]	0.39 ± 0.07[a]	0.43 ± 0.08[b]

Values followed by different letters within rows are significantly different ($P < 0.05$). Mean ± SD (n = 3).

3.2. Sensory evaluation

Having the focus on texture perception, a sensory evaluation was performed using descriptive sensory analysis (Fig. 2). In general terms, attributes related to bread texture perception (hardness, crispiness, and crunchiness) obtained higher scores than attributes related to bolus characteristics (pastiness, grittiness, and dry mouthfeel). In toasted breads, crispiness and crunchiness are desirable attributes, and high scores are related to freshness. However, differences observed in

Fig. 1. Images of toasted sliced breads. A: WHB: wheat bread; B: WWB: whole wheat bread; C: NSU: non-sugar added wheat bread; D: NSA: non-salt added wheat bread.

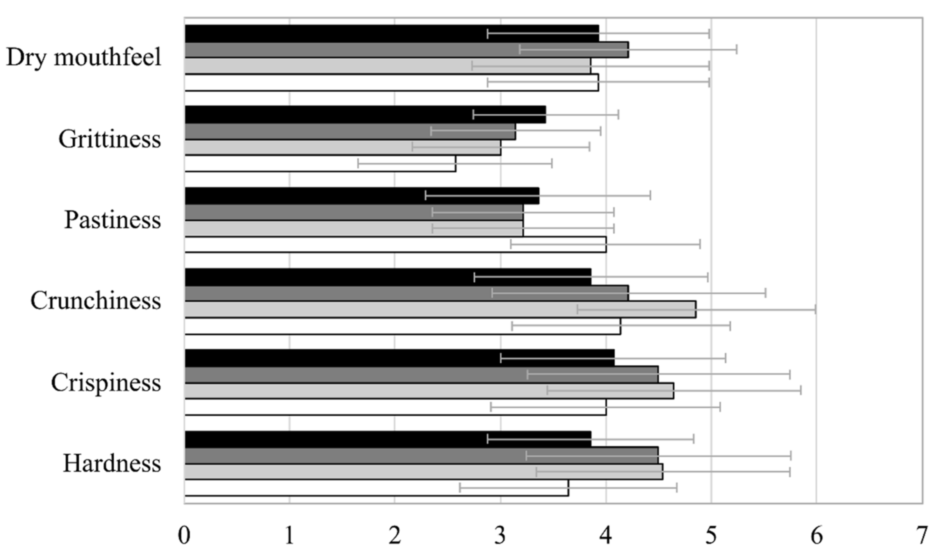

Fig. 2. Sensory evaluation of texture of toasted sliced bread samples (MEAN ± SE): WHB: wheat bread; WWB: whole wheat bread; NSU: non-sugar added wheat bread; NSA: non-salt added wheat bread.

hardness and cutting strength were not perceived by panelists. The difficulty to perceive differences in crispy products has been previously reported (Saeleaw & Schleining, 2011). Conversely, different oral texture perceptions have been reported in fresh breads and attributed to bread texture and structure (Panouillé, Saint-Eve, Déléris, Le Bleis, & Souchon, 2014). Therefore, the low moisture content of toasted breads led to high hardness and cutting strength, and differences observed when assessing instrumental texture were not perceived and discriminated by panelists.

3.3. Characterization of FOP and bolus properties

The statistical analysis of FOP characteristics and bolus properties indicated that both bread type and panelist significantly affected ($P < 0.05$) mastication time, number of chews, and chewing frequency (Table 2). Conversely, Tournier et al. (2012) found no differences between bread types but variations between subjects when analyzed the chewing rate of baguette, rye bread, and toasted bread. Nevertheless, the role of the individuality of human beings on FOP had been long described (Chen, 2009). Regarding the mastication time, in general, was lower than the 20 s described for fresh breads (Le Bleis, Chaunier, Montigaud, & Della Valle, 2016), and similar to the mastication times and the number of chews (13.8 ± 0.5 s with 17.8 ± 0.8 chews) reported for white toasted breads (Van Eck et al., 2019).

Focusing on bread effect, NSU required longer mastication (17.80 ± 3.71 s), being higher the number of chews required to swallow the sample (19.92 ± 3.91 chews). Mastication time was shorter for WHB and WWB, although the number of chews was higher for WWB, likely the bran presence induced this difference. Chewing frequency was lower for WHB (1.07 ± 0.22 chews/s). In fresh breads, a high positive correlation between closed porosity and total mastication work has been reported (Pentikäinen et al., 2014), observing longer mastication time and high number of chews in breads with lower porosity or small pore size. Following that reasoning, a bread structure with lower porosity, like NSU sample, might be related with a denser structure, which is reflected in the major mastication effort required.

Mouthful was significantly ($P < 0.001$) influenced by individuals but no bread type. The average value of mouthful was 1.49 ± 0.07 g, which was lower than values (3–5 g) described in FOP studies with fresh wheat breads (Gao et al., 2015; Hoebler, Devaux, Karinthi, Belleville, & Barry, 2000). Very weak ($r < 0.4$) significant correlations were found between FOP results and bread composition or texture properties, revealing that the crumb structure of toasted breads had weak impact on FOP. It has been reported that crumb texture and structure have an important role in FOP (Aleixandre et al., 2019), but present results with toasted breads suggested that crumb moisture content might be responsible for possible differences.

Bolus properties comprising saliva inclusion and texture properties were evaluated (Table 2). No significant differences were found among the boluses water content and saliva to bread ratio. But in those parameters, significant differences were found between individuals ($P < 0.001$) (data not shown), which might be expected because salivary flow rate varies within a person over time and among individuals (Ghezzi, Lange, & Ship, 2000). Bolus moisture ranged from 51.73 (WHB) to 53.87% (WWB), in agreement with values found for fresh breads (Le Bleis et al., 2016), and close to the values (56–58.5%) obtained by Le Bleis et al. (2013) at swallowing point of diverse commercial white breads. The same trend was described to saliva to bread ratio results, with an average range of 0.47–0.48 g/g bread (W.W.). During mastication, foods required appropriate lubrication and agglomeration to facilitate bolus swallowing. The lower water content of breads, the more mastication time and chews are needed to reach the swallowable state (Mao et al., 2016). Drier products, like cereal flakes, required more saliva than breads to form the bolus keeping the needed hydration level of the bolus (Alam et al., 2017). However, no correlation was found between bolus moisture and mastication frequency, confirming that salivation and chewing cycles are independent (Tournier, Grass, Septier, Bertrand, & Salles, 2014).

Regarding texture properties of the bolus, significant differences were observed in the hardness of NSU (8.17 ± 1.54 N) and WHB (6.20 ± 1.17 N). About bolus adhesiveness and cohesiveness, WWB and NSU had lower values than WHB and NSA. Bolus cohesiveness was similar to cracker bolus (Van Eck et al., 2019), but harder and more adhesive. There was no relationship between FOP parameters and the mechanical characteristics of boluses, thus individual mastication performance (chewing times or number of chews during food mastication) did not affect boluses texture. Again, looking to understand the possible role of bread crumb structure, correlations were calculated with bolus properties. Significantly moderate negative correlation was observed between crumb hardness and bolus adhesiveness ($r = -0.4526$; $P < 0.001$). Similarly, crumb structure, specifically mean cell area was positively correlated with bolus adhesiveness ($r = 0.5727$; $P < 0.001$) and cohesiveness ($r = 0.4587$; $P < 0.001$). Therefore, crumb microstructure significantly affected bolus texture, although also initial food composition might affect hardness and adhesiveness of bolus (James et al., 2011).

3.4. Texture, FOP and sensory correlations

Bread structure and texture characteristics, mastication properties, and sensory parameters were subjected to statistical analysis, and a principal component analysis was carried out to display the global effect (Fig. 3). Two components explained 86% of the total data variance, describing 49% and 37% of the variation in the principal components 1 and 2, respectively. Component 1 along the x-axis allowed the discrimination among the different types of toasted breads, despite their close structure and composition. Specifically, WHB was located in the right upper part of the score plot, hence was strongly discriminated by bolus texture, except hardness, pastiness sensation, which was related to the high values of mean and median (P50) cell area. WWB was in the right upper part of the plot, reflecting its higher moisture content. It must be highlighted that even at the low moisture content observed in toasted breads, moisture was correlated with the perceived hardness and crunchiness. NSA and NSU were grouped in the lower part of the score plot, related to bread instrumental texture (hardness and cutting strength), mastication properties (mastication time or the number of chews), and sensory perception of dry mouthfeel and grittiness. Jourdren, Saint-Eve, et al. (2016) described how sensory attributes during ingestion of fresh breads were more affected by bolus variations than the initial bread characteristics. Similar conclusions were described by Puerta et al. (2020), correlating perceived sensations at the beginning of consumption with food characteristics, but the remaining sensations were explained by oral attributes. In this study, even though some texture perceptions were impacted by bolus texture or bread moisture, also bread texture and mastication properties contributed to panelist sensations.

4. Conclusions

The study carried out with toasted breads allowed to discriminate the impact of bread texture and structure on food oral processing and sensory perceptions, without the possible interference induced by the moisture content. Four different toasted sliced bread made with similar ingredients showed divergences in texture and structure properties. Despite the absence of moisture content in the toasted breads, textural differences among the breads were not perceived by panelists, thus texture differences induced by slight changes in formulations were not sufficient to be detected by panelists. Concerning FOP results, bread structure and texture dominated mastication behavior. Bread crumbs with lower porosity required major mastication efforts. Overall, it can be concluded that crumb bread structure has great impact on bolus adhesiveness, and instrumental bread texture significantly affects

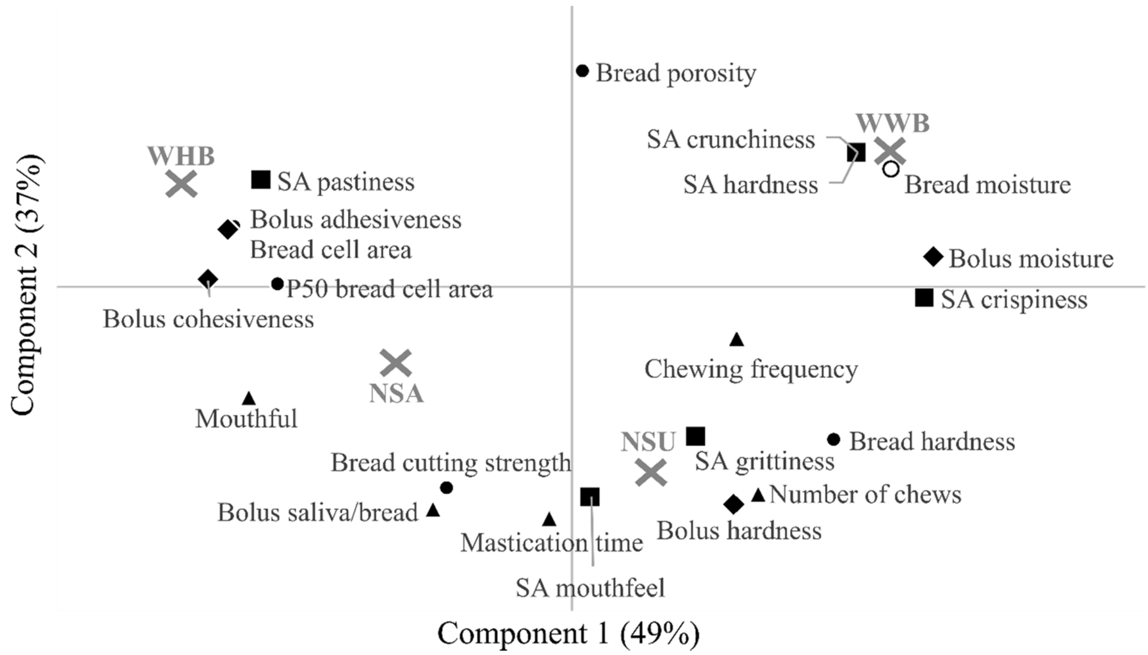

Fig. 3. Correlation loadings plot and scores plot from a principal component analysis (PCA) of the combination of bread moisture, bread texture and structure, mastication, bolus properties, and sensory evaluation. WHB: wheat bread; WWB: whole wheat bread; NSU: non-sugar added wheat bread; NSA: non-salt added wheat bread.

mastication performance.

CRediT authorship contribution statement

Andrea Aleixandre: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft. **Yaiza Benavent-Gil:** Methodology. **Elena Velickova:** Supervision, Writing - review & editing, Funding acquisition. **Cristina M. Rosell:** Conceptualization, Funding acquisition, Investigation, Supervision, Data curation, Writing - review & editing.

Declaration of Competing 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.

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References

Alam, S. A., Pentikäinen, S., Närväinen, J., Holopainen-Mantila, U., Poutanen, K., & Sozer, N. (2017). Effects of structural and textural properties of brittle cereal foams on mechanisms of oral breakdown and in vitro starch digestibility. *Food Research International, 96*, 1–11.

Aleixandre, A., Benavent-Gil, Y., & Rosell, C. M. (2019). Effect of Bread Structure and In Vitro Oral Processing Methods in Bolus Disintegration and Glycemic Index. *Nutrients, 11*(9), 2105.

Callejo, M. J. (2011). Present situation on the descriptive sensory analysis of bread. *Journal of Sensory Studies, 26*(4), 255–268.

Chen, J. (2009). Food oral processing—A review. *Food hydrocolloids, 23*(1), 1–25.

Gao, J., Ong, J. J.-X., Henry, J., & Zhou, W. (2017). Physical breakdown of bread and its impact on texture perception: A dynamic perspective. *Food Quality and Preference, 60*, 96–104.

Gao, J., Wong, J. X., Lim, J. C.-S., Henry, J., & Zhou, W. (2015). Influence of bread structure on human oral processing. *Journal of Food Engineering, 167*, 147–155.

Ghezzi, E., Lange, L., & Ship, J. (2000). Determination of variation of stimulated salivary flow rates. *Journal of Dental Research, 79*(11), 1874–1878.

Hedhili, A., Lubbers, S., Bou-Maroun, E., Griffon, F., Akinyemi, B. E., Husson, F., & Valentin, D. (2021). Moringa Oleifera supplemented biscuits: Nutritional values and consumer segmentation. *South African Journal of Botany, 138*, 406–414.

Hoebler, M., Devaux, A., Karinthi, C., Belleville, J., & Barry, C. (2000). Particle size of solid food after human mastication and in vitro simulation of oral breakdown. *International Journal of Food Sciences and Nutrition, 51*(5), 353–366.

Huang, Y.-F., Liu, S.-P., Muo, C.-H., & Chang, C.-T. (2021). The impact of occluding pairs on the chewing patterns among the elderly. *Journal of Dentistry, 104*, 103511.

ICC. (1994). International Association for Cereal Chemistry (ICC). Standard No 110/1.

ISO. (4121:2003). Sensory Analysis. Evaluation of Food Products by Methods Using Scales. International Organization for Standardization, Geneva, Switzerland.

James, B., Young, A., Smith, B., Kim, E., Wilson, A., & Morgenstern, M. P. (2011). Texture changes in bolus to the "point of swallow" - fracture toughness and back extrusion to test start and end points. *Procedia Food Science, 1*, 632–639.

Joubert, M., Septier, C., Brignot, H., Salles, C., Panouillé, M., Feron, G., & Tournier, C. (2017). Chewing bread: Impact on alpha-amylase secretion and oral digestion. *Food & Function, 8*(2), 607–614.

Jourdren, S., Panouillé, M., Saint-Eve, A., Déléris, I., Forest, D., Lejeune, P., & Souchon, I. (2016). Breakdown pathways during oral processing of different breads: Impact of crumb and crust structures. *Food & Function, 7*(3), 1446–1457.

Jourdren, S., Saint-Eve, A., Panouillé, M., Lejeune, P., Déléris, I., & Souchon, I. (2016). Respective impact of bread structure and oral processing on dynamic texture perceptions through statistical multiblock analysis. *Food Research International, 87*, 142–151.

Le Bleis, F., Chaunier, L., Della Valle, G., Panouillé, M., & Réguerre, A. L. (2013). Physical assessment of bread destructuration during chewing. *Food Research International, 50*(1), 308–317.

Le Bleis, F., Chaunier, L., Montigaud, P., & Della Valle, G. (2016). Destructuration mechanisms of bread enriched with fibers during mastication. *Food Research International, 80*, 1–11.

Lovegrove, A., Edwards, C. H., De Noni, I., Patel, H., El, S. N., Grassby, T., … Shewry, P. R. (2017). Role of polysaccharides in food, digestion, and health. *Critical Reviews in Food Science and Nutrition, 57*(2), 237–253.

Lynch, E. J., Dal Bello, F., Sheehan, E. M., Cashman, K. D., & Arendt, E. K. (2009). Fundamental studies on the reduction of salt on dough and bread characteristics. *Food Research International, 42*(7), 885–891.

Mao, Q., Sun, Y., Hou, J., Yu, L., Liu, Y., Liu, C., & Xu, N. (2016). Relationships of image texture properties with chewing activity and mechanical properties during mastication of bread. *International Journal of Food Engineering, 12*(4), 311–321.

Morreale, F., Garzón, R., & Rosell, C. M. (2018). Understanding the role of hydrocolloids viscosity and hydration in developing gluten-free bread. A study with hydroxypropylmethylcellulose. *Food hydrocolloids, 77*, 629–635.

Panouillé, M., Saint-Eve, A., Déléris, I., Le Bleis, F., & Souchon, I. (2014). Oral processing and bolus properties drive the dynamics of salty and texture perceptions of bread. *Food Research International, 62*, 238–246.

Pentikäinen, S., Sozer, N., Närväinen, J., Ylätalo, S., Teppola, P., Jurvelin, J., … Poutanen, K. (2014). Effects of wheat and rye bread structure on mastication process and bolus properties. *Food Research International, 66*, 356–364.

Prakash, K., Naik, S. N., Vadivel, D., Hariprasad, P., Gandhi, D., & Saravanadevi, S. (2018). Utilization of defatted sesame cake in enhancing the nutritional and functional characteristics of biscuits. *Journal of Food Processing and Preservation, 42* (9), e13751.

Puerta, P., Garzón, R., Rosell, C. M., Fiszman, S., Laguna, L., & Tárrega, A. (2021). Modifying gluten-free bread's structure using different baking conditions: Impact on oral processing and texture perception. *LWT, 140*, 110718.

Puerta, P., Laguna, L., Villegas, B., Rizo, A., Fiszman, S., & Tarrega, A. (2020). Oral processing and dynamics of texture perception in commercial gluten-free breads. *Food Research International, 134*, 109233.

Saeleaw, M., & Schleining, G. (2011). A review: Crispness in dry foods and quality measurements based on acoustic–mechanical destructive techniques. *Journal of Food Engineering, 105*(3), 387–399.

Tournier, C., Grass, M., Septier, C., Bertrand, D., & Salles, C. (2014). The impact of mastication, salivation and food bolus formation on salt release during bread consumption. *Food & Function, 5*(11), 2969–2980.

Tournier, C., Grass, M., Zope, D., Salles, C., & Bertrand, D. (2012). Characterization of bread breakdown during mastication by image texture analysis. *Journal of Food Engineering, 113*(4), 615–622.

Van Eck, A., Hardeman, N., Karatza, N., Fogliano, V., Scholten, E., & Stieger, M. (2019). Oral processing behavior and dynamic sensory perception of composite foods: Toppings assist saliva in bolus formation. *Food Quality and Preference, 71*, 497–509.