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Whey-Bread, an Improved Food Product: Evaluation of Textural Characteristics

Short Title: TEXTURE CHARACTERISTICS OF WHEY-BREAD

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Abstract

The diversity in bread all around the world is enormous and enriched breads are a trend to follow in the next years. The aim of this work was to develop new breads incorporating whey residue, and the final products were analysed for their textural properties, as compared with a basic wheat bread. For measurement of texture two types of teste were used (compression and puncture). The results showed that the whey residue could be used to produce bread with good textural properties, particularly for an improved recipe. The improved whey bread showed good textural characteristics, which remained practically unchanged after 24 h, being this true for the properties evaluated through the compression test (hardness, chewiness, resilience, cohesiveness, springiness) and through the puncture test (external firmness, inner firmness, stickiness, adhesiveness). Finally, very strong correlations were found between cohesiveness and resilience and between adhesiveness and stickiness.

Key words: compression test, puncture test, residue valorisation, textural properties.

Introduction

Bread is undoubtedly recognized as one of the most extensively consumed basic foods worldwide. Due to variable chemical composition of flours and utilized baking processes, breads form a food group with highly heterogeneous structures. White wheat bread is a commodity usually baked of starchy endosperm flour. During dough mixing, wheat gluten proteins are transformed into a network in which carbon dioxide generated by yeast fermentation is retained thus producing an expansion during fermentation and baking (Gao, Tay, Koh, & Zhou, 2018; Pentikäinen et al., 2014).

The mechanical properties of the crumb and the crust determine the textural characteristics of bread. Furthermore, the mechanical properties are related to the structural and physical characteristics of the bread matrix. A sequence of texture sensations is perceived by people while chewing bread due to the continuous transformation of its structure, mostly due to the particle size reduction and saliva impregnation processes (Gao et al., 2018; Gao, Wong, Lim, Henry, & Zhou, 2015; Jourdren et al., 2016; Pentikäinen et al., 2014).

According to a United Nations report, the world population is expected to surpass 9.2 billion by 2050, which brings unquestionably a great challenge of how to feed such an enormous population. Therefore, the efficient use of the available resources is a must that needs to be addressed with urgency. The concept of circular economy contemplates the reutilization and recycling of all types of waste. Therefore, the utilization of organic residues for the production of value added products either for the food, pharmaceutical or cosmetic industries allows the application of the circular economy concept on organic waste management and contributes to the development of a bio-based economy. Many residues and by-products of the food industry can be utilized to produce new foods and/or ingredients with additional nutritional value and improved bioactive properties (de Oliveira, da Silva Lucas, Cadaval, & Mellado, 2017; Keegan, Kretschmer, Elbersen, & Panoutsou, 2013; Pleissner et al., 2016).

The dairy industry is responsible for the generation of large quantities of liquid effluents, which are also typically characterized by a high organic load (Akhlaghi et al., 2017). According to a report about European Commission statistics (European Commission, 2017), the overall amount of dairy products generated in the EU-28 area accounted for more than 100 million tonnes in 2016. Among the main dairy products manufactured that contribute for this waste generation are drinking milk (30.7% of the overall production in 2016), cheese (9.6%), acidified milk (7.9%), cream (2.8%), powder products (2.8%) other products (2.8%), other miscellaneous fresh products (2.6%) and finally butter and other yellow fat products (2.4%) (Akhlaghi et al., 2017; European Commission, 2017).

Because there is a growing need to minimize industrial waste by preferably reutilizing the residues and transforming them into products with commercial value, and in particular addressing the needs of some dairy facilities in the central region of Portugal which produce cheese from sheep milk, the traditional Serra da Estrela cheese, it is important to find alternative ways to use the whey residues originating in such dairy facilities. Hence, the objectives of this work were to develop new added-value bakery products incorporating whey residue, in order to take advantage of a resource with nutritional relevance and at the same time minimizing environmental impacts by finding alternative ways to use this residue. Additionally, the textural characteristics of the developed products (breads) were evaluated shortly after baking, and again after 6 and 24 hours to observe the evolution of those properties along time.

Material and methods

Preparation of the breads

Basic wheat bread

The water (1700 mL) was warmed at a temperature of about 30 ºC, and 40 mL of the warm water was used to dissolve the yeast (40 g of fresh yeast), which was then left to stand for five minutes. After that 2 kg of refined flour type 65 and 40 g of salt were mixed with the water and the yeast. The dough was beaten until the desired elasticity and homogeneity were achieved (about 12-15 min). The dough was left in a stove at 35 ºC for 20 min to ferment. At the end of the elapsed time, the loaves with about 100 grams each were moulded in a round shape, and were taken for more 15 minutes to the stove. Finally, they were baked in the oven, previously heated to 240 ºC, for twenty minutes. In the first minutes of the baking process 2 steam baths were performed, to avoid early formation of the crust.

Bread with whey residue

The procedure for the production of this bread was similar to the one described for the *basic wheat bread*, however some changes were made in the formulation. The same amount of flour was used (2 kg), but the water was replaced by whey residue (1045 mL) and the amount of fresh yeast was changed to 60 g. Also, because the whey residue is obtained from the productive process of making cheese and whey cheese, and therefore already contains some incorporated salt, no salt was added when making the bread. Figure 1 shows the whey residue used, which is considered a waste in the cheese and whey cheese making industry.

Figure 1. Whey residue from the cheese and whey cheese making industry.

Improved whey bread

The procedure was basically similar to that used for other breads, but more changes were introduced in the formulation so as to produce bread with better nutritional value. Table 1 shows the formulation used to produce the *improved whey bread*. The pumpkin seeds were slightly dehydrated (approximately 10 min at 240 ºC) before incorporation into the dough. The various seeds and the oat flakes were used to produce o cover on the surface of the bread before going to bake in the oven.

Table 1. Amount of ingredients used to produce the improved whey bread.

Ingredient	**Amount (unit)**	**Ingredient**	**Amount (unit)**
Refined wheat flour (type 65)	500 (g)	Pumpkin seeds	129 (g)
Whole wheat flour	1500 (g)	Chia seeds	8 (g)
Whey residue	1200 (mL)	Poppy seeds	5 (g)
Fresh yeast	60 (g)	Sesame seeds	9 (g)
Oat flakes	11 (g)		

Figure 2 shows the three types of bread produced.

Figure 2. The three varieties of bread produced for the study.

For the tests, all bread samples were left at room temperature during the first 30 minutes after oven baking and again after 6 h, but to stay for the night until the next day (24 h after baking) they were left inside a closed common plastic bag.

Evaluation of texture by compression test

For the assessment of the textural characteristics a texturometer TA-XT2 (Stable Microsystems) was used and two types of test were performed: compression test and puncture test.

The texture profile analysis was carried out by a compression test involving two compression cycles between parallel plates performed on the samples using a flat compression probe 75 mm in diameter (P/75), with 5 seconds of interval between cycles. The parameters used for the test were: 30 kg force load cell, pre-test, test and post-test speeds equal to 1.0 mm/s, distance 4 mm and trigger force 0.1 N. The textural properties: hardness, resilience, springiness, cohesiveness and chewiness were calculated after equations (1) to (5) (see Figure 3) (Correia et al., 2017):

$$\text{Hardness (N)} = F_1 \quad (1)$$

$$\text{Resilience (\%)} = (A_5/A_4) \times 100 \quad (2)$$

$$\text{Springiness (\%)} = (T_2/T_1) \times 100 \quad (3)$$

$$\text{Cohesiveness (\%)} = (A_2/A_1) \times 100 \quad (4)$$

$$\text{Chewiness (N)} = F_1 \times (T_2/T_1) \times (A_2/A_1) \quad (5)$$

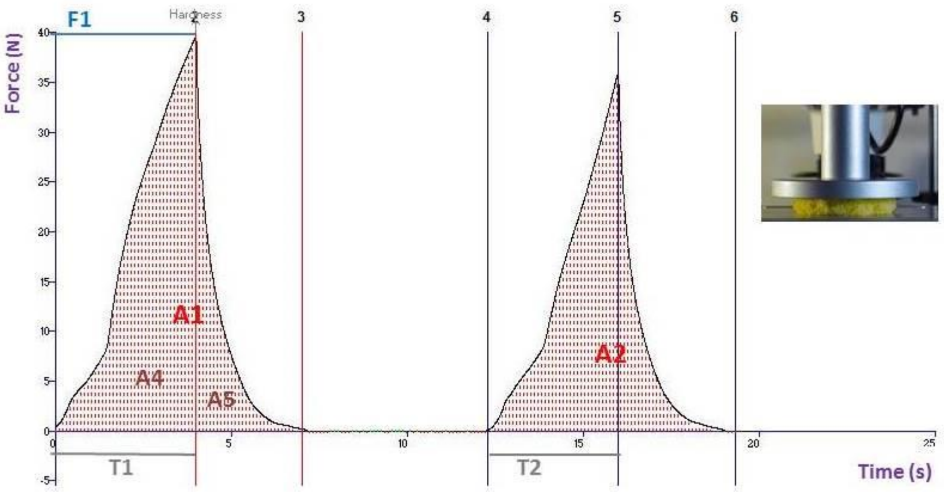

Figure 3. Example of a texture profile analysis for bread, obtained by compression with a P/75 probe.

For these textural evaluations 8 units of each type of bread were used, and for each bread one measurement was made on the top and another on the bottom faces of the bread. Furthermore, the samples were evaluated 30 minutes after baking, and again 6 hours and 24 hours later, since this is a bread without preservatives, destined to be consumed within 24 hours of baking, preferably. The results were processed using Exponent software TEE from Stable Micro Systems.

Evaluation of texture by puncture test

To undertake the puncture test a drilling rig with 2 mm diameter was used. The pre-test speed was 2 mm/s and the test and post-test speeds were 1 mm/s. The perforation distance was 10 mm and the trigger force 0.05 N. The texture parameters evaluated with this test were: crust firmness, flesh firmness, adhesiveness and stickiness, as indicated in Figure 4, and defined in equations (6) to (9):

Crust firmness (N) = *maximum force* (6)

Inner firmness (N) = *average force between 1 and 2* (7)

Adhesiveness (N.s) = *negative area* (8)

Stickiness (N) = *minimum force* (9)

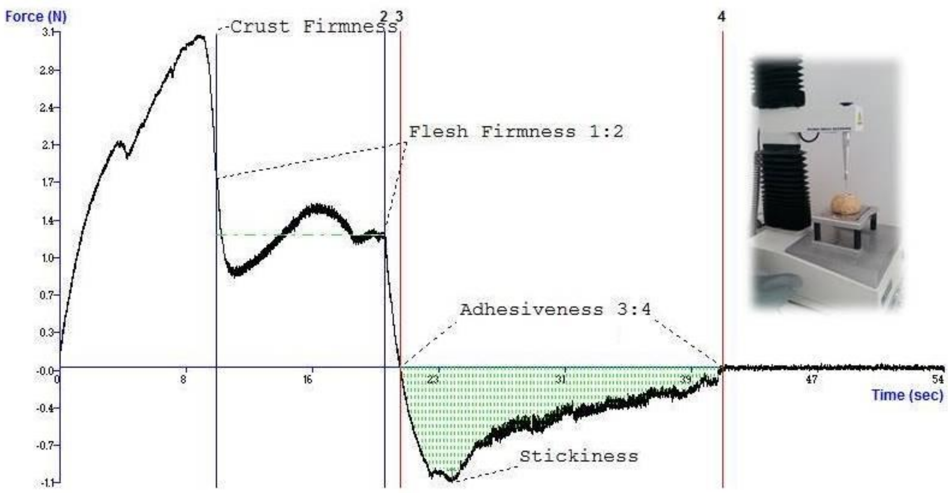

Figure 4. Example of a texture profile for bread, obtained by puncture with a P/2 probe.

For these textural evaluations 8 units of each type of bread were used, and for each bread six measurements were made on the top and another six on the bottom faces of the bread. The results were also processed with TEE software.

Statistical analysis

To validate the results obtained for the mean values calculated, a comparison of means was performed by an analysis of variance (ANOVA), with the Post-Hoc Tukey HSD (Honestly Significant Difference) test for identification of differences between samples. Also the Pearson correlation coefficients were used to evaluate the possible associations between properties. For absolute value of $r = 0$ there is no correlation, for $r \in]0.0, 0.2[$ the correlation is very weak, for $r \in [0.2, 0.4[$ the correlation is weak, for $r \in [0.4, 0.6[$ the correlation is moderate, for $r \in [0.6, 0.8[$ the correlation is strong, for $r \in [0.8, 1.0[$ the correlation is very strong, for $r = 1$ the correlation is perfect (Maroco, 2012; Pestana & Gageiro, 2014).

For all statistical analyses was used the software SPSS version 24 (IBM, Inc.) and the level of significance considered was 5% ($p < 0.05$).

Results and discussion

Textural properties – compression test

The textural properties evaluated by the compression test were hardness, resilience, springiness, cohesiveness and chewiness. Hardness represents the force necessary to compress a food between the teeth or between the palate and the tong. Chewiness measures the energy required to disintegrate a food to a state suitable to swallow. Springiness is associated with the ability to recover shape after compression, being equal to the rate at which the product returns to the initial point after removal of the deforming force. Resilience is the energy used when applying a force to a material without occurring rupture, with or without any residual strain, and corresponds to an instant springiness. Cohesiveness represents the internal forces inside the food that stop the sample from disintegrating (Cruz, Guiné, & Gonçalves, 2015; R. P. F. Guiné, Henriques, & Barroca, 2014; Raquel P. F. Guiné, Almeida, Correia, & Gonçalves, 2015).

Figure 5 shows the mean values of the textural properties evaluated by the compression test and the corresponding standard deviation. The results were subject to a statistical analysis to verify if significant differences were found in the mean values for each property.

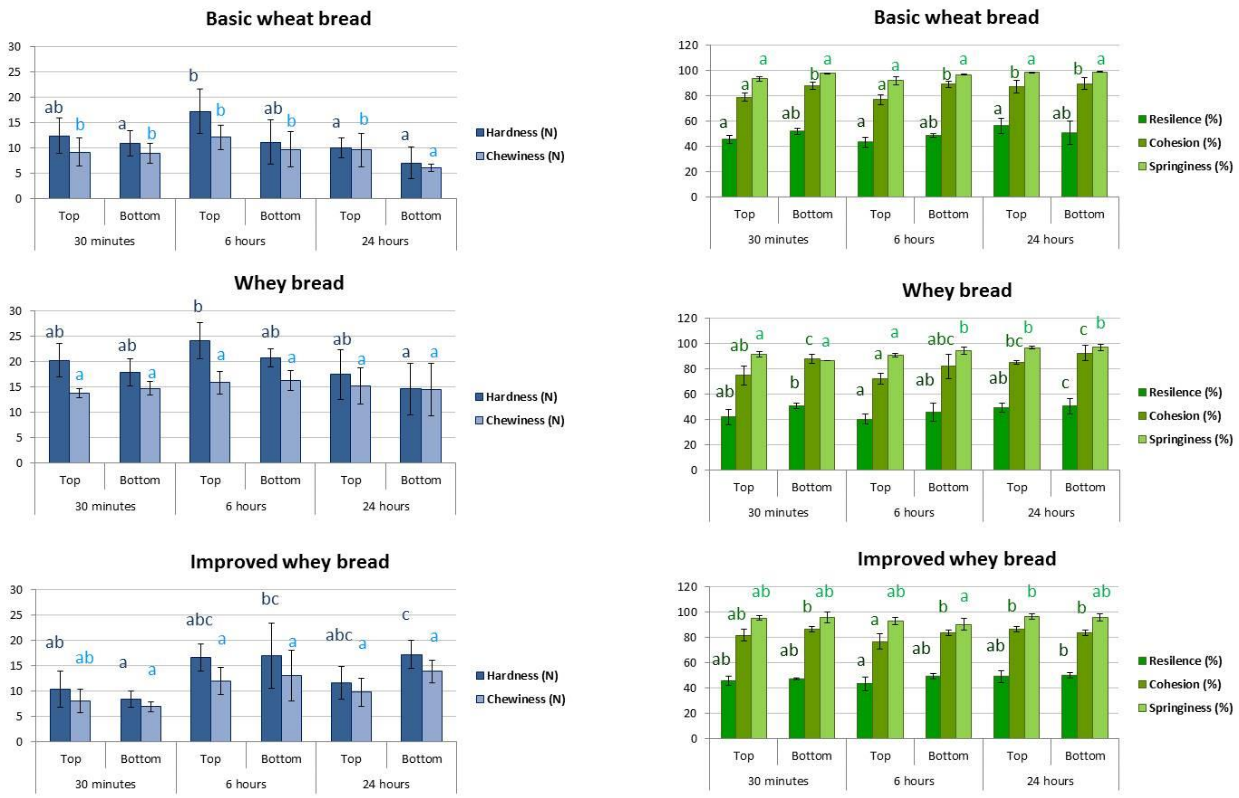

Figure 5. Textural properties evaluated by the compression test, separated according to the sides of the bread samples (Bars with the same letter are not significantly different: ANOVA with Tukey post-hoc test, $p > 0.005$).

The results in Figure 5 show that the *whey bread* presented in general highest hardness and chewiness as compared with the *basic wheat bread* and the *improved whey bread*. The *improved whey bread*, which is intended to be marketed, presented uniform hardness and chewiness considering both sides of the loaf (the top and the bottom), varying from 8-10 and 6-8 N, respectively, 30 minutes after oven baking. Furthermore, as time elapsed the texture became harder after 6 hours and remained similar after 24 hours. This is important, since it is expected that the bread is consumed within 24 hours after baking, for optimum textural characteristics. As for resilience, cohesiveness and springiness, the 3 types of bread were not much different, and no apparent differences were seen also between the top and bottom sides of the loaves.

Figure 6 shows the results obtained for the textural properties of the compression tests, but considering the bread samples as whole, i.e., not differentiating the top from the bottom sides. The results indicate that the *improved whey* bread was softer after 30 min of baking, but regained some firmness after some hours and maintained it for 24 hours, this being evident on the values of hardness and chewiness, which were 15 and 12 N, respectively. According to Ozturk and Mert (2018) solubilized proteins, which are present in the whey residue, can produce a more homogenous structure, providing softer products. On the other hand, as time passes the texture of bread is expected to change, namely by increasing hardness (Barbosa-Ríos et al., 2018).

Considering the other textural properties, the differences between types of bread or times of evaluation were not so representative. Ozturk and Mert (2018) observed that springiness values in samples of gluten-free corn breads decreased over time, indicating elasticity loss, but that was not the case with the present breads analysed, who were able to maintain the textural properties for a period of 24 hours, which is the expected period for consumption at optimum conditions of bread formulated without preservatives.

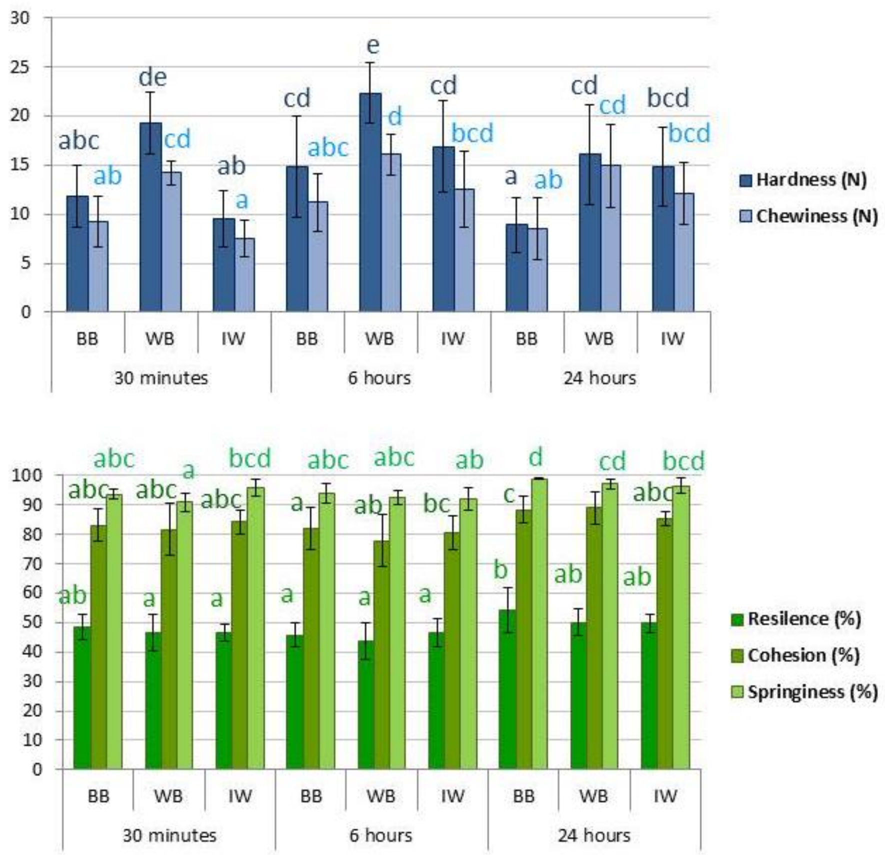

Figure 6. Textural properties evaluated by the compression test, considering each bread sample as a whole (Bars with the same letter are not significantly different: ANOVA with Tukey post-hoc test, p > 0.005). Legend: BB = basic wheat bread, WB = whey bread, IW = improved whey bread.

Textural properties – puncture test

The puncture test gives information about the external and internal firmness, i.e., the resistance of the crust and of the inner crumbs, as well as the stickiness and adhesiveness. Adhesiveness corresponds to the negative area after the probe was removed from the sample and corresponds to the force required to remove the material that adheres to a specific surface (e.g., lips, palate, teeth). Stickiness is also related to adhesiveness and corresponds to the minimum force (negative value) registered by the probe right before starting to retract from the sample.

The results presented in Figure 7 correspond to the evaluation of the bread loaves separately as top and bottom faces, and they indicate that the crust firmness was always higher when compared to the inner firmness, which is in accordance with the fact that during baking a crust is formed on the bread producing a harder surface. However, it was observed that after 24 h the firmness tended to diminish for all types of bread. It was reported that bread crust loses its crispness within a few hours after baking due to water uptake from the soft and moist crumb, and hence, the crispy texture of the crust is directly related to the water uptake kinetics (Meinders & van Vliet, 2011). The *improved whey bread* allowed a better preservation of both the external and inner firmness, as compared with the other bread samples evaluated. The adhesiveness was considerable for all three types of bread, but stickiness was low in all cases. The *improved whey bread* showed a more uniform trend for adhesiveness along time when compared to the *basic wheat bread* or the *whey bread*.

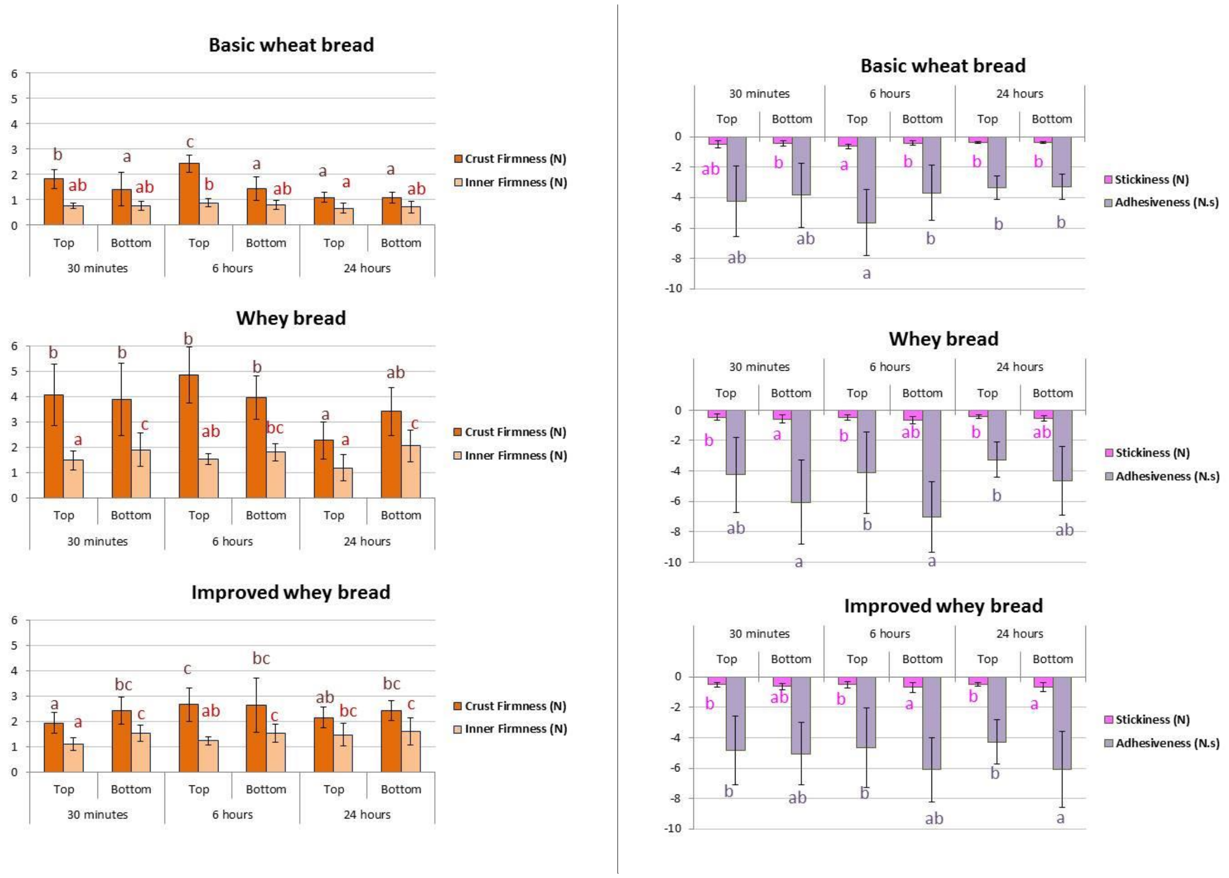

Figure 7. Textural properties evaluated by the puncture test, separated according to the sides of the bread samples (Bars with the same letter are not significantly different: ANOVA with Tukey post-hoc test, p > 0.005).

Figure 8 presents the values obtained for the textural properties through the puncture test, but considering each bread sample as a whole. The sample *whey bread* was the hardest, for all moments of evaluation, being significantly different from the others in terms of external and internal firmness. Regarding the *improved whey bread*, the firmness was just slightly increased from the 30 min to the 6 h and after that was kept approximately constant, which indicates its suitability for preservation of the desired textural properties. This sample (IW) also showed a constant adhesiveness and stickiness over the time of evaluation, thus confirming the ability to maintain the textural characteristics for the desired period of 24 h.

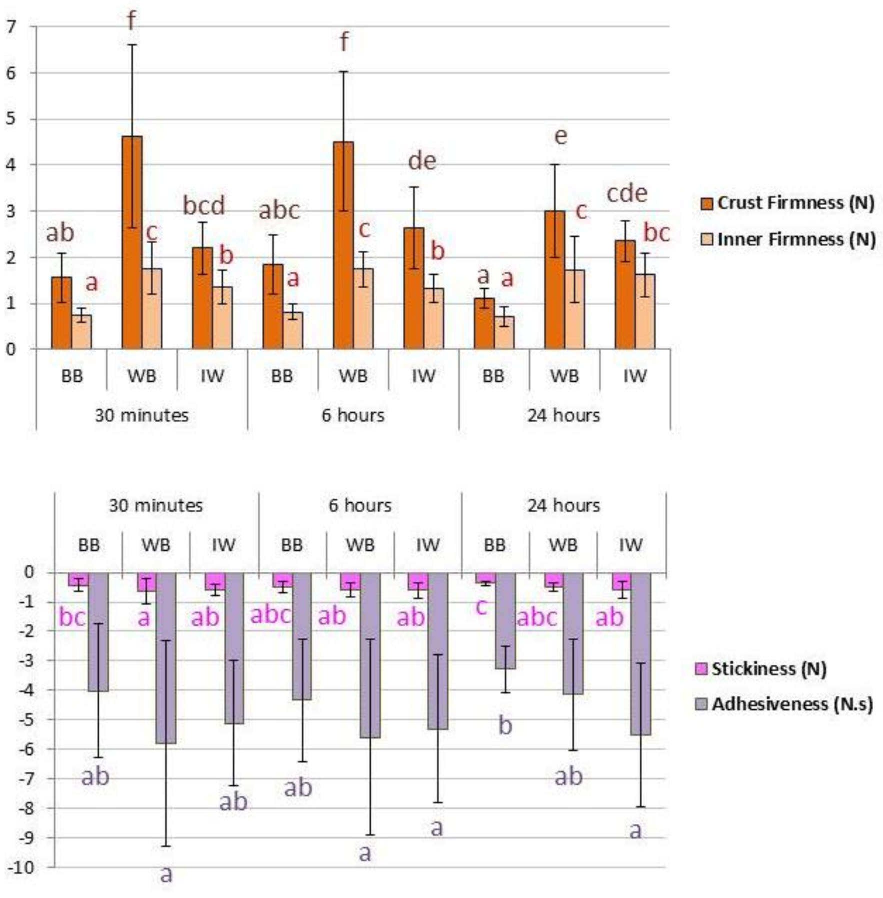

Figure 8. Textural properties evaluated by the puncture test, considering each bread sample as a whole (Bars with the same letter are not significantly different: ANOVA with Tukey post-hoc test, $p > 0.005$). Legend: BB = basic wheat bread, WB = whey bread, IW = improved whey bread.

Correlations

Table 1 presents the Pearson correlations between the textural variables studied, i.e., those obtained with the compression test and with the puncture test. Generically, the properties from the compression test do not correlate with those from the puncture test, which would be predictable given the highly different nature of each test: one corresponding to compression on the surface and the other comprising penetration inside the sample. On the other hand, for each of the tests separately, there are important correlations, as highlighted for example by the correlation between cohesiveness and resilience ($r = 0.939$) for the compression test and between adhesiveness and stickiness ($r = 0.858$) for the puncture test, which are considered very strong ($0.8 \leq r < 1$). There are also some strong correlations ($0.6 \leq r < 0.8$) like in the case of the chewiness and hardness ($r = 0.637$) and springiness and cohesiveness ($r = 0.639$), in the compression test, or even between internal firmness and crust firmness ($r = 0.767$) for the puncture test.

Table 1. Pearson correlations between the textural properties

		Compression test					Puncture test			
		HA	RE	CO	SP	CH	CF	IF	ST	AD
Compression	HA	1								
	RE	0.052	1							
	CO	-0.013	0.939**	1						
	SP	-0.099	0.577**	0.639**	1					
	CH	0.637**	0.444**	0.414**	0.594**	1				
Puncture	CF	0.504**	0.133	-0.092	-0.126	0.273**	1			
	IF	0.424**	0.055	0.070	-0.092	0.287**	0.767**	1		
	ST	-0.130	0.020	-0.013	0.156	0.011	-0.378**	-0.381**	1	
	AD	-0.104	0.061	0.034	0.161	0.062	-0.321**	-0.267**	0.858**	1

Notes:

HA = Hardness, RE = Resilience, CO = Cohesiveness, SP = Springiness, CH = Chewiness, CF = Crust firmness, IF = Inner Firmness, ST = Stickiness, AD = Adhesiveness.

**Correlation is significant at the 0.01 level.

Conclusions

This work allowed concluding that whey residue can be used to produce bread with good textural properties, and an improved formulation with whey residue and some other functional ingredients was developed. The improved whey bread tended to become harder after 6 h of baking but did not change any more after 24 h. Resilience, cohesiveness and springiness were not variable with time over an evaluation period of 24 h. Furthermore, the textural properties of the puncture test (external and internal firmness, stickiness and adhesiveness) were approximately constant over time. Finally, some very strong correlations were encountered between the textural properties evaluated, namely between cohesiveness and resilience and between adhesiveness and stickiness.

Implications and future work

The success in utilizing the whey residue originating from the numerous dairy facilities the used sheep milk to produce cheese in the central region of Portugal has a first impact by greatly minimizing the amount of liquid effluents that are sent every day to the sewage treatment plants, thus minimizing the environmental impact and reducing operating costs for treatment of residues. Furthermore, for the owners of the dairy facilities this provides additional revenue, because they sell the whey residue instead of discarding it. Regarding the bakery industries, they are able to produce bread with whey residue, especially by following the improved formulation hereby developed, and this bread proved to have good textural properties, and therefore may have good acceptability by the consumers.

Because this work focused on developing bread products and evaluating at first the textural properties, the work undertaken so far should be complemented with further work to evaluate the chemical and nutritional properties, having in mind that it was developed an improved recipe with potentially functional ingredients. Also, the developed products could be submitted to a sensory analysis for a better knowledge of the acceptability by the potential future consumers. Finally, other bakery products could be developed incorporating whey residue, like biscuits or cookies.

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References

Akhlaghi, M., Boni, M. R., De Gioannis, G., Muntoni, A., Polettini, A., Pomi, R., … Spiga, D. (2017). A parametric response surface study of fermentative hydrogen production from cheese whey. *Bioresource Technology*, *244*, 473–483. https://doi.org/10.1016/j.biortech.2017.07.158

Barbosa-Ríos, J. A., Castillón-Jardón, J., Guadarrama-Lezama, A. Y., Alvarez-Ramirez, J., Meraz, M., & Carrillo-Navas, H. (2018). Effect of new generation enzymes addition on the physical, viscoelastic and textural properties of traditional Mexican sweet bread. *Journal of Cereal Science*, *79*, 160–167. https://doi.org/10.1016/j.jcs.2017.10.012

Correia, P., Guiné, R., Correia, A. C., Gonçalves, F., Brito, M., & Ribeiro, J. (2017). Physical, chemical and sensory properties of kiwi as influenced by drying conditions. *Agricultural Engineering International*, *19*(3), 203–212.

Cruz, A. C., Guiné, R. P. F., & Gonçalves, J. C. (2015). Drying Kinetics and Product Quality for Convective Drying of Apples (cvs. Golden Delicious and Granny Smith). *International Journal of Fruit Science*, *15*(1), 54–78. https://doi.org/10.1080/15538362.2014.931166

de Oliveira, L. M., da Silva Lucas, A. J., Cadaval, C. L., & Mellado, M. S. (2017). Bread enriched with flour from cinereous cockroach (Nauphoeta cinerea). *Innovative Food Science & Emerging Technologies*, *44*, 30–35. https://doi.org/10.1016/j.ifset.2017.08.015

European Commission. (2017). Milk and milk product statistics. Eurostat.

Gao, J., Tay, S. L., Koh, A. H.-S., & Zhou, W. (2018). Dough and bread making from high- and low-protein flours by vacuum mixing: Part 3. Oral processing of bread. *Journal of Cereal Science*, *79*, 408–417. https://doi.org/10.1016/j.jcs.2017.12.002

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. https://doi.org/10.1016/j.jfoodeng.2015.07.022

Guiné, R. P. F., Henriques, F., & Barroca, M. J. (2014). Influence of drying treatments on the physical and chemical properties of cucumber. *Journal of Food Measurement and Characterization*, *8*(3), 195–206. https://doi.org/10.1007/s11694-014-9180-9

Guiné, Raquel P. F., Almeida, I. C., Correia, A. C., & Gonçalves, F. J. (2015). Evaluation of the physical, chemical and sensory properties of raisins produced from grapes of the cultivar Crimson. *Journal of Food Measurement and Characterization*, *9*(3), 337–346. https://doi.org/10.1007/s11694-015-9241-8

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. https://doi.org/10.1039/C5FO01286D

Keegan, D., Kretschmer, B., Elbersen, B., & Panoutsou, C. (2013). Cascading use: a systematic approach to biomass beyond the energy sector. *Biofuels, Bioproducts and Biorefining*, *7*(2), 193–206. https://doi.org/10.1002/bbb.1351

Maroco, J. (2012). *Análise Estatística com o SPSS Statistics* (5ª Ed.). Brazil: Report number.

Meinders, M. B. J., & van Vliet, T. (2011). Oscillatory water sorption dynamics of bread crust. *Food Research International*, *44*(9), 2814–2821. https://doi.org/10.1016/j.foodres.2011.06.027

Ozturk, O. K., & Mert, B. (2018). The effects of microfluidization on rheological and textural properties of gluten-free corn breads. *Food Research International*, *105*, 782–792. https://doi.org/10.1016/j.foodres.2017.12.008

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. https://doi.org/10.1016/j.foodres.2014.09.034

Pestana, M. H., & Gageiro, J. N. (2014). *Análise de Dados para Ciências Sociais – A complementaridade do SPSS* (6ª ed.). Brasil: Edições Sílabo.

Pleissner, D., Qi, Q., Gao, C., Rivero, C. P., Webb, C., Lin, C. S. K., & Venus, J. (2016). Valorization of organic residues for the production of added value chemicals: A contribution to the bio-based economy. *Biochemical Engineering Journal*, *116*, 3–16. https://doi.org/10.1016/j.bej.2015.12.016