Relationship between dough rheology and quality characteristics of rice based breads with oil or shortening

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Abstract

One of the main problems with gluten-free breads is their texture and their rapid staling. Fats are widely used for the improvement of texture and other quality parameters in gluten-free breads. The effect of oil and shortening in rice-breads quality and its correlation with dough rheology has been analysed. The inclusion of oil increased the specific volume of the breads and reduced their hardness, particularly with lower levels of hydration, whereas shortening did not modify specific volume or reduced it when hydration levels were higher. Oil, at levels of up to 30%, reduced the cohesiveness, springiness and resilience of breads, as well as the brightness of the crust, and increased the a* and b* values. Breads with oil also exhibited a greater number of pores per cm^2, especially in doughs with higher levels of hydration. An inverse correlation between G' and G'' and bread specific volume has been observed, being the reciprocal-Y model a better predictor than the linear model to relate the bread specific volume.

Keywords: Gluten-free bread; dough rheology; fat; response surface methodology

PRACTICAL APPLICATIONS

This study showed that the type and quantity of fat added in rice based breads affect the bread quality in a different way. In general, it can be said that the incorporation of up to 20% oil improved rice based breads. Oil increased the specific volume, the a* and b* parameters of the crust and the cell density. It also decreases hardness, cohesiveness, springiness, resilience and the L* parameter. Converse to breads made with oil, the addition of shortening can negatively affect the quality of the breads. Moreover, the correlation analysis has demonstrated that the study of dough rheology could be a good predictor of gluten-free bread quality.

1 Introduction

The relationship between dough rheology and quality characteristics of wheat based breads is widely proved. The rheological behaviour of wheat based doughs have been analysed by fundamental rheology techniques or specific empirical dough testing instruments such as alveograph or farinograph. In wheat breads, dough rheology is highly related with the gluten network. However, in gluten-free doughs, although several studies include rheological analyses, their information has been rarely used for predicting bread characteristics (Lazaridou and Biliaderis, 2009). In some of those studies a trend that relates a lower dough consistency with greater bread specific volume has been observed. Nevertheless, a deep study about those relationships has been never carried out. The use of fats and oils in the elaboration of wheat dough is common practice. According to Sluimer (2005), the addition of small amounts leads to greater flexibility and workability of the doughs, greater final volume, a finer alveolar structure and a softer final texture. The addition of fats and oils also delays starch retrogradation due to the formation of amylose-lipid complexes, prolonging the shelf-life of the breads. Some of the effects of fats and oils are based on the interactions between these products and starch, but most of their effects are due to interactions with the gluten network and the complex structure of wheat dough. Then the effects on the preparation of gluten-free breads may therefore be completely different.

Although the addition of fats and oils is also common practice in commercial gluten-free bread, as evidenced by the wide variation in the fat content of these products (with values of up to 26g / 100g [Matos and Rosell, 2011]), very few studies have been performed on the addition of fats and oils to gluten-free doughs, and most have only examined the addition of small amounts of these ingredients. Gluten-free doughs are more like batters than dough with gluten and Brooker (1993) showed that fats can play an important role in the stabilization of bubbles in batters. This fact may explain the observation by Eggleston *et al.* (1992) that margarine increased the air trapped during mixing in dough made with cassava flour. Similarly, Gujral *et al.* (2003), studying the addition of less than 10% oil to rice dough, noted that it reduced dough consistency and produced breads with a higher volume and lower hardness. Hart *et al.* (1970) and Milde *et al*. (2012) reported that the addition of vegetable fats improved softness in sorghum and tapioca starch breads. It has also been observed that rice bread is drier and crumblier than wheat bread and that it shows greater retrogradation during storage than wheat bread (Kadan *et al.* 2001); the use of oils or fats could therefore significantly improve rice bread quality. However, Schoenlechner *et al.* (2010) found no significant effect when incorporating fat into the formulas of gluten-free bread with amaranth. The addition of oil and fats also modifies the rheology of gluten-free dough (Lorenzo, *et al.* 2009; Moreira *et al.* 2012). This can impair dough control or its behaviour in the different phases of the baking process. The water content of the formulas can be changed in an attempt to compensate for these effects.

In the present study, it has been used response surface analysis to optimize the amount of oil or fat and the water content in a formulation of rice bread. Volume, weight loss, texture (initial and at 7 days), crumb and crust colour and alveolar structure have been analysed in the breads obtained. The rheological behaviour of the gluten-free batters has been studied and it has been correlated with bread quality parameters such as specific volume and hardness.

2 Materials and methods

2.1 Materials

Rice flours were supplied by Harinera Castellana S.A. (Medina del Campo, Valladolid, Spain). A particle size between 132 and 200 microns was chosen based on the results of previous studies (de la Hera *et al.* 2013). The protein content of the flour was 7.54g/100g, starch 73.6g/100g and amylose 22.56g/100g. Salt, sugar and sunflower oil were purchased from the local market. Fat (Argenta crema, Puratos, Barcelona, Spain), dry yeast (Saf-instant, Lesaffre, Lille, France) and hydroxypropyl methylcellulose (HPMC) (Vivapur K4M, J. Rettenmaier & Söhne, Rosenberg, Germany) were used.

2.2 Methods

2.2.1 Flour measurements

Flours were analysed according to AACC methods (2012). Protein content (AACC method 46-30) was determined using a Leco TruSpec®N nitrogen/protein analyser (St. Joseph, Michigan, USA). The total starch and amylose content were measured using the polarimetric method (AACC, 76-20).

2.2.2 Gluten-free breadmaking

A straight-dough process was employed, using a Kitchen-Aid Professional mixer (KPM5, KitchenAid, St. Joseph, Michigan, USA) with the K45DH dough hook. The following ingredients (as % on flour basis) were used in both formulas: sucrose (5%), salt (1.8%), instant yeast (3%) and HPMC (2%). Due to the influence of the addition of oil and fat on dough consistency, the oil and fat content was optimized with dough hydration by means of a response surface analysis. In the case of the oil, breads were prepared with 0%, 10%, 20% and 30% oil. In the case of fats, breads were prepared 0%, 5%, 10% and 15% fat, as breads with a higher content were of poor quality (lower specific volume and higher hardness). All breads were prepared with 70%, 85% and 100% water. The instant yeast was first rehydrated in half the volume of water. The doughs were kneaded for 8 minutes at speed 2 and 250 g of each dough was then moulded into aluminium pans of 232 x 108 x 43.5 mm. The pans were placed into a proofing chamber at 30ºC and 90% relative humidity for 90 minutes. After proofing, the breads were baked in an electric oven for 40 minutes at 190ºC. They were then demoulded, cooled for 50 minutes at room temperature and packed into sealed polyethylene bags to prevent dehydration.

2.2.3 Dough rheology

The rheological behaviour of doughs was studied using a Thermo Scientific Haake RheoStress 1 controlled strain rheometer (Thermo Fisher Scientific, Schwerte, Germany) and a Phoenix II P1-C25P water bath that controlled analysis temperature (set at 25ºC). The rheometer was equipped with parallel-plate geometry (60-mm diameter titanium serrated plate-PP60 Ti) with a 3-mm gap. After adjustment to the 3-mm gap, the excess batter was removed and vaseline oil (Panreac, Panreac Química SA, Castellar del Vallés, Spain) was applied to cover the exposed sample surface. In oscillatory tests, dough was rested for 300 seconds before measuring. Samples (without yeast) were analysed in duplicate. First, a strain sweep test was performed at 25ºC with a stress range of 0.1–100 Pa at a constant frequency of 1 Hz to identify the linear viscoelastic region. On the basis of the results obtained, a stress value included in the linear viscoelastic region was used in a frequency sweep test at 25ºC with a frequency range of 100–0.1 Hz. Values of elastic modulus (G' [Pa]), viscous modulus (G'' [Pa]), complex modulus (G* [Pa]) and tg (δ) (G''/G') were obtained for different frequency values (ω [Hz]) (Dobraszczyk and Morgenstern, 2003).

2.2.4 Evaluation of bread quality

The evaluation of bread quality was done 24 hours after baking. Bread volume was determined using a laser sensor with the Volscan profiler 300 volume analyser (Stable Microsystems, Surrey, UK). The bread specific volume was calculated as the ratio between the volume of the bread and its weight. Weight loss was measured as the difference between the weight of the moulded dough and the weight of the bread after baking. Measurements were performed in duplicate.

Crumb texture was determined using a TA-XT2 texture analyser (Stable Microsystems, Surrey, UK) with the "Texture Expert" software. A 25-mm diameter cylindrical aluminium probe was used in a 'Texture Profile Analysis' (TPA) double compression test to penetrate to 50% of the depth at a speed of 2 mm/s and with a 30-second delay between the first and second compressions. Hardness (N), cohesiveness, springiness and resilience were calculated from the TPA graph. Measurements were made on two central whole slices (30 mm thickness) from two breads from each elaboration. Texture was measured at 24 hours and 7 days.

Crumb grain characteristics of the breads were assessed using a digital image analysis (DIA) system. Images were acquired at 300 dots per inch (spatial resolution was 0.0843 mm^2/pixel) with a 1236USB Artec scanner (Ultima Electronics Corp., Taiwan). The analysis was performed on 34 x 34 mm squares taken from the centre of a slice. Images were processed using Leica QWin Pro V3.1 software (Leica Microsystems Imaging Solutions Ltd., UK). A cluster analysis method known as the "K-means algorithm" was used on each slice examined to obtain an optimum gray-level threshold to divide images into regions of cells and surrounded cell wall material. After cell detection, feature extraction was performed for each slice analysed. The following crumb grain characteristics were studied: mean cell area (mm^2), cell density (cells/cm^2; higher levels denote finer structure), cell to total area ratio (or void fraction, computed as the percentage of the total analysed square occupied by detected cells) and mean cell wall thickness (in mm; calculated as the averaged mean intercellular distance of neighbouring cells sampled). Crumb grain parameters were measured in triplicate.

Colour was measured using a Minolta spectrophotometer CN-508i (Minolta, Co.LTD, Tokio, Japan). Results were expressed in the CIE L*a*b* colour space and were obtained using the D65 standard illuminant, and the 2º standard observer. Colour determinations on two breads from each formula were made 4x5 times on each slice of bread: crumb and crust colour was checked at four different points on each piece of bread and each point was measured five times.

Bread texture, colour and crumb grain characteristics were only analysed in oil based breads due to the poor results observed in bread made with shortening.

2.2.5 Statistical analysis

Response surface methodology was used to examine differences between the parameters. Two full factorial experimental designs were performed, one for oil and one for shortening, with one replicate and two factors. The factors analyzed were water content (three levels) for both designs and amount of oil (four levels) or fat (four levels), according to design. There were thus 24 elaborations for each design.

3. Results and discussion

The equations obtained after the analysis of response surface method for each parameter as well as the equation fit (r^2) are shown in table 1 (bread with shortening) and table 2 (bread with sunflower oil).

Table 1: Final equation in terms of coded factors for bread with shortening

	Cte	A (oil)	B (water)	AA	AB	BB	R^2	R^2 ajust
G'	1.05068E6		-20812.4		28.6067	103.665	99.24	99.02
G''	185590.		-3526.72		9.92533	16.9161	99.12	98.88
G*	1.06629E6		-21091.3		30.0337	104.929	99.24	99.02
tg (δ)	0.294882	-0.002106	-0.005062	0.0002208		0.000056	97.45	96.74
Specific volume	5.83	0.19	-0.18		-0.0027	0.0016	93.14	90.72
Weight loss	19.87	-1.55	-0.14		0.0139		91.52	88.53
Firmness	766.91		-15.57	-0.0693	0.0589	0.0787	98.04	97.35

Only significant coefficients (95 %) are shown

3.1. Dough rheology

Figure 1 shows the results obtained through dynamic oscillatory tests. G' was higher than G'' in all gluten-free formulations, suggesting a solid-like behaviour of all gluten-free doughs. tg (δ) values were higher than 0,1 (soft gel) for all doughs (results no showed). As it could be expected, water content reduced G', G'' and G* values, since de la Hera *et al.* (2013); Mancebo *et al.* (2015b) and Ronda *et al.* (2015) observed similar results on rheological behaviour when the hydration content was modified in gluten-free doughs. This phenomenon can be attributed to the lower consistency of doughs made with more water than those made with a higher presence of other ingredients. However, the effect of fat on rheological behaviour depended in turn on the type of fat (oil or shortening). The inclusion of shortening hardly modified the values of G', G'' and G*, whereas the addition of sunflower oil had a similar effect to water (less marked), reducing the values of G', G'' and G*. This opposite trend as a function of the type of lipid incorporated or of its percent of solids at room temperature, was also observed by Lorenzo *et al.* (2009) when incorporating sunflower oil or margarine in pie-crust doughs. This effect could be due to the different consistency of the lipids. It was also noticed that the effect of oil addition was reduced when the hydration level increased.

Table 2: Final equation in terms of coded factors for bread with sunflower oil

	Cte	A (oil)	B (water)	AA	AB	BB	R^2	R^2
G’	881466.0	-	-16839.4		60.742	80.877	97.6	96.9
G’’	160670.0	-	-2944.42		13.508	13.588	98.0	97.4
G*	895492.0	-	-17081.4		62.206	81.930	97.6	96.9
tg (δ)	0.123293		-				96.9	96.0
Specific	-32.37	0.29	0.75	-	-002	-004	89.6	85.9
Weight loss	-43.74		1.37		0.003	-0.007	94	91.8
Firmness	439.65	-7.35	-8.37	0.051	0.061	0.040	79.4	72.2
Cohesivene	0.5399	-	0.0007				91.5	88.5
Springiness	2.68	-0.03	-0.04	0.000		0.0002	93.2	90.8
Resilience	0.4079	-	-0.0001				94.7	92.9
Firmness 7	913.31	-15.96	-17.31	0.11	0.13	0.08	80.3	73.3
Cohesivene	0.3262	-					66.1	54.2
Springiness	3.25	-0.01	-0.06	0.000		0.0003	83.0	77.1
Resilience 7	0.5488	-		0.000			51.4	34.3
Crust L*	124.58	-2.97		0.013	0.0240		89.9	86.4
Crust a*	-62.10	0.88		-	-	-	95.0	93.2
Crust b*	-79.82	0.97		-		-	90.1	86.6
Crumb L*	175.21	-0.55	-2.10		0.0136		76.7	68.5
Crumb a*	3.39						30.5	5.94
Crumb b*	83.71		-1.57	0.004	0.0051	0.0081	83.7	78.0
Mean pore	-0.76	0.098	0.0194	0.000	-		75.4	66.7
Pores/cm^2	-49.24		1.97				60.6	46.7

Only significant coefficients (95 %) are shown

3.2. Bread properties

Figure 2 shows the spatial representation of how the values of specific volume and hardness of the loaves vary after modification of the water and oil or shortening content. It can be seen that while volume decreased slightly after the addition of shortening—an effect that became more noticeable with increasing amounts of water in the formulation—the addition of oil at levels of up to 30% increased bread volume, particularly in formulations with the lowest water content. It is in agreement with the observations of Gujral *et al*. (2013) and Milde *et al.* (2012) in breads with a lower oil content and low water content. In addition, the bread volume increase by oil incorporation coincided with reduced values of G’, G’’ and G* in our study. The limited effect of the addition of shortening agrees with the findings reported by Schoenlechner *et al.* (2010). It can also be seen that the specific volume of breads with a low oil or shortening content increased with increasing water content of the formulation. In terms of hardness, the addition of shortening was found to have a minimal effect, and it even led to an increase in hardness when a greater water content. The addition of oil, on the other hand, reduced hardness, although this effect was minimized by increasing the amount of water in the formulation, and the combination of the highest percentages of oil and water content was associated with a slight increase in hardness. The first conclusion that may be drawn from these observations is that the effect of the addition of oil or shortening to rice bread is completely different from the effect of these same additions to wheat breads, in which an improvement in bread volume is only observed with low percentages of fat (less than 5%) and in which the addition of large amounts drastically reduces the volume (Sluimer, 2005). This finding confirms that the mechanism whereby gases formed during fermentation are retained, increasing the volume of the loaves, differs in the two types of bread-baking. In conventional baking (wheat breads), this gas retention correlates with the gluten network, and large amounts of oil or fat weaken this network; rice bread, on the other hand, is derived from a batter that is stabilized by the presence of hydrocolloids, and an excessive consistency is not suitable for that dough. The positive effect of increasing the water content of rice-bread formulations has already been reported in previous studies (Ylimaki *et al.* 1988; McCarthy *et al*. 2005; de la Hera *et al.* 2013). The incorporation of oil may help to reduce the consistency of the dough (Gujral *et al*. 2003; Moreira *et al.* 2012), as does the increase in the humidity of the dough (Lazaridou *et al*. 2007), thus improving their expansion. In Figure 2 it may be observed that in dough without oil, an increase in the water content of the formulation translates into an increase in the specific volume of breads; however, as oil content increases, the optimal percentage of water falls. This may be because a minimum consistency is necessary; de la Hera *et al.* (2013) have previously reported that an excess of water in the formulation could be detrimental to the volume of breads, especially in prolonged fermentation. The addition of shortening can increase the G* (increase the consistency of the dough) or, at least, not reduce it, so the effect on volume is not observed. These breads also presented a crude and irregular alveolar structure and an oral sensation of excessive shortening, so further analysis of other parameters was ruled out.

Figure 3 shows the variation in weight loss and in the texture parameters of the breads with oil. It may be observed that weight loss during baking increased as the amount of water increased. This would appear logical, as the greater the water content of the dough, the easier it will be for evaporation to take place during baking. However, weight loss is also significantly influenced by the volume of the breads, as this will affect the surface area for evaporation. Indeed, a significant correlation of 99.9% (r = 0.72) was found between the specific volume and weight loss. For its part, the addition of oil barely affected weight loss during baking, and oil was not actually a significant factor in the weight loss equation.

With regard to the texture parameters, it has already been commented that changes in the hardness of breads was closely related to changes in specific volume, as we detected a significant inverse correlation of 99.9% (r =-0.72) between the two parameters; so hardness is reduced by increasing the specific volume. This correlation has already been reported by Martínez *et al.* (2013) in a study on the texture of gluten-free bread. The other parameters show very similar changes, with significant correlations of 99.9%

between them, and r values of 0.89 (springiness-cohesiveness), 0.92 (springiness-resilience) and 0.95 (cohesiveness-resilience). These correlations were also observed in the study by Martínez *et al.* (2013), although the values of the coefficients of correlation were somewhat lower. The incorporation of oil had a much greater effect on cohesiveness, springiness and resilience than was observed on increasing the percentage of water, which barely affects these texture parameters. In all cases, the addition of oil produced a fall in these parameters, although the reduction was more pronounced with the lower percentages of oil. From around 15% or 20%, the different texture parameters stabilize. We also studied the increase in hardness over time (data not shown). This parameter showed a very high correlation with initial hardness (r = 0.997), as already reported by Martinez *et al.* (2013), indicating that breads that are initially softer are also those that better maintain this condition; the incorporation of oil thus helps to increase the shelf-life of breads, but only when the water content of the dough was lower. The values of cohesiveness, resilience and springiness decreased over time, and while the amount of water had almost no effect, the incorporation of oil caused these values to be lower, although the differences were not as pronounced as with the initial texture.

Figure 4 shows the changes in the crust and crumb colour parameters. The colour of the bread is an important parameter for consumers and affects the acceptability of bread. Colour is one of the parameters that define a gluten-free bread (Pagliarini, *et al.* 2010; Matos and Rosell, 2012). The incorporation of oil led to a fall in crust brightness, and this was more evident with smaller amounts of water in the formulation; oil addition increased the a* and b* parameters, giving more intense brown tones. This is a positive effect because gluten-free breads have excessively pale colours if we compare them with the breads that contain gluten. This effect may occur because a reduction in the presence of water favours Maillard reactions, and hence the formation of brown pigment in the crust (Purlis, 2010). However, the influence of the oil on crumb colour was much less intense, with almost no change in the a* and b* parameters and only a slight increase in lightness. The crumb does not exceed 100°C and Maillard reactions would not therefore have occurred, so crumb colour is due mainly to the colour of the ingredients, and darker oils could therefore have had a greater influence on this colour. The amount of water in the formulation hardly affected crumb and crust colour, and an increase in water content was only found to increase the brightness of the crust in breads with a high oil content, thus confirming the influence of water on Maillard reaction activity.

Moisture content had a very clear effect on alveolar structure, increasing the number of alveoli per square centimetre; this effect was enhanced by a higher oil content and, therefore, a lower dough consistency. The average size of the alveoli also increased with increasing water content in the formulation, but this effect was minimized by the addition of oil, and was virtually undetectable with higher percentages of oil. The observed effect of the water content of the formulation on alveolar structure coincides with the findings of other authors investigating gluten-free breads (Schoenlechner *et al.* 2010; Tsatsaragkou *et al.* 2012).

According to our findings, lower G* values (related to lower dough consistency) can influence not only the creation of air bubbles in the initial batter (increasing them), but also their expansion, which is facilitated up to a certain limit of G* values.

3.3 Correlation analysis between dough rheology and bread quality

After analysing the relationship between dough rheology and bread specific volume, it was found out that the lower the G', G'' and G* and the higher tg δ were, the greater bread specific volume and lower hardness (table 3). In general, a trend of an increase in the volume as dough consistency is reduced has been observed in different studies, even though this relationship has not been studied deeply. This interrelationship was observed in studies on the influence of dough hydration (Nishita *et al.* 1976), when starchy ingredients were changed (Mancebo *et al.* 2015a), when different hydrocolloids were added (Mancebo *et al.* 2015b) or when new ingredients were incorporated in the formula (Martínez *et al.* 2014; Rocha-Parra *et al.* 2015). In our study, a high correlation among all rheological parameters was observed, even displaying r values of 0.99 among G', G'' and G*, being these parameters better predictors than tg δ for bread quality. It would indicate that doughs with higher G', G'' and G* cannot expand properly in the fermentation and baking steps, and a reduction of G* to allow this expansion would be necessary. After a more exhaustive analysis, the linear model was observed not to be the most suitable for relating the rheological parameters with the bread specific volume, since although the latter increased as G', G'' and G* decreased, this increase is stronger as G' and G'' reach values close to 10000. This could be expected, since there must be a minimum bread volume corresponding to the doughs without expansion. Thus, values of r^2 of 74.19% between bread specific volume and G' can be obtained through a reciprocal-Y model (Y=1/(a+b*X), versus a r^2 value of 60.15% obtained through a linear model. If breads made from oil and breads made from shortening are analysed separately (Figure 5), r^2 values obtained by the reciprocal-Y model are 81.48% and 86.59% for breads made with oil and shortening respectively. It was also noted that, the increase of the volume as G' values are reduced is more intense in breads made with oil, thus the influence of oil or shortening addition on the specific volume of breads go beyond its influence on dough rheology. It is observed that G' values lower than 10000 from doughs made with oil gave rise to breads with lower specific volume than those from doughs with G' values around 20000, despite the observed trend of the increase of specific volume as G' values are reduced. In these breads, a slight volume reduction in the last fermentation or first baking stages was observed. Ronda *et al*. (2015), in a study on gluten-free breads enriched with beta-glucans, already observed that, after an increase of the bread specific volume as water content in the formulation was increased, reducing G', a decrease of the volume when water content was increases in excess was produced. This could indicate that there are minimum values for the rheological parameters from which doughs are too weak to keep the expansion, effect which can depend on the fermentation times and therefore on dough expansion.

Table 3. Correlation analysis between dough rheology and bread quality

	Firmness	G’	G”	G*	Tg δ
Specific volume	-0.788	-0.810	-0.818	-0.811	0.678
Firmness		0.872	0.877	0.872	-0.621
G’			0.997	1.000	-0.866
G”				0.997	-0.863
G*					-0.866

Correlations are significant at the $p \leq 0.001$

4 Conclusions

A high correlation between the rheological parameters and bread specific volume and firmness was observed. Moreover the reciprocal-Y model was the best predictor to relate bread specific volume and G’, G’’ and G*. Nevertheless, this correlation should be studied for each formulation taking into account the processing variables. In general, it can be said that the incorporation of up to 20% oil increases the volume of the loaves, the a* and b* parameters of the crust and the cell density. It also decreases hardness, cohesiveness, springiness, resilience and the L* parameter. Converse to breads made with oil, the addition of shortening can negatively affect the quality of the breads.

Ethical statements

The authors declare that they do not have any conflict of interest. This study does not involve any human or animal testing. Written informed consent was obtained from all study participants.

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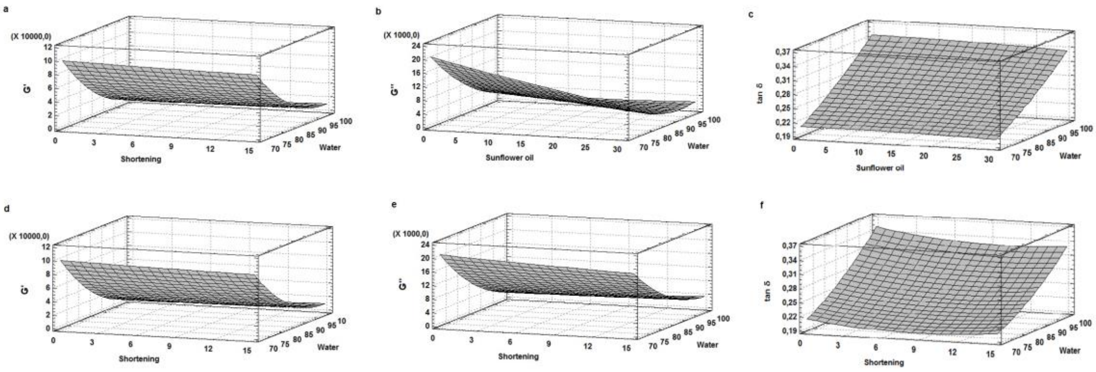

Figure 1. Dynamic oscillatory test of the effect of sunflower oil or shortening and water content on G’ (a,d), G’’ (b,e) and G* (δ) (c,f): (a, b, c) sunflower oil vs. water; (d, e, f) shortening vs. water.

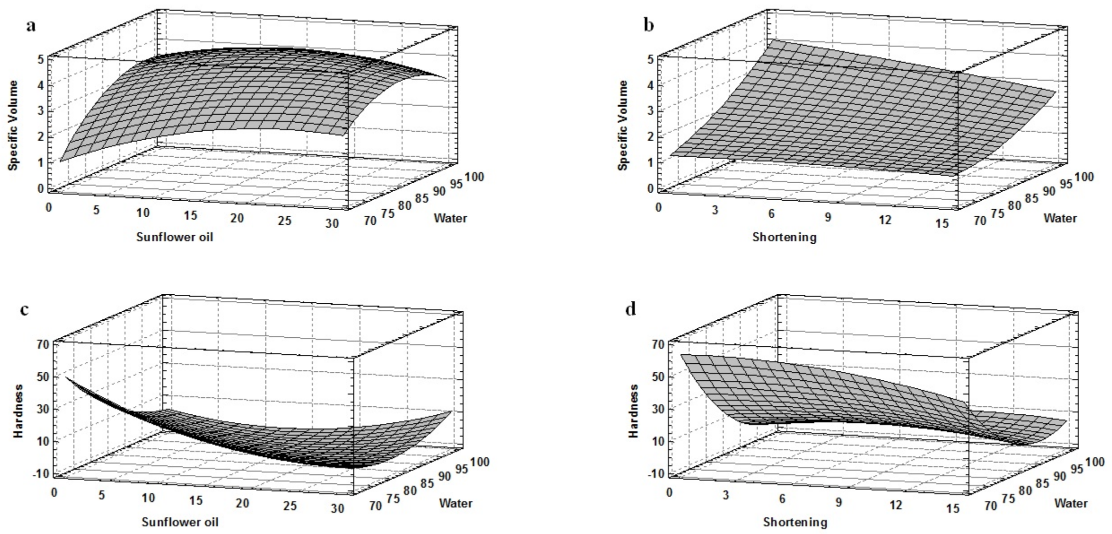

Figure 2. Effect of sunflower oil or shortening and water content on specific volume (a, b) and hardness (c, d) of breads: (a, c) sunflower oil vs. water; (b, d) shortening vs. water.

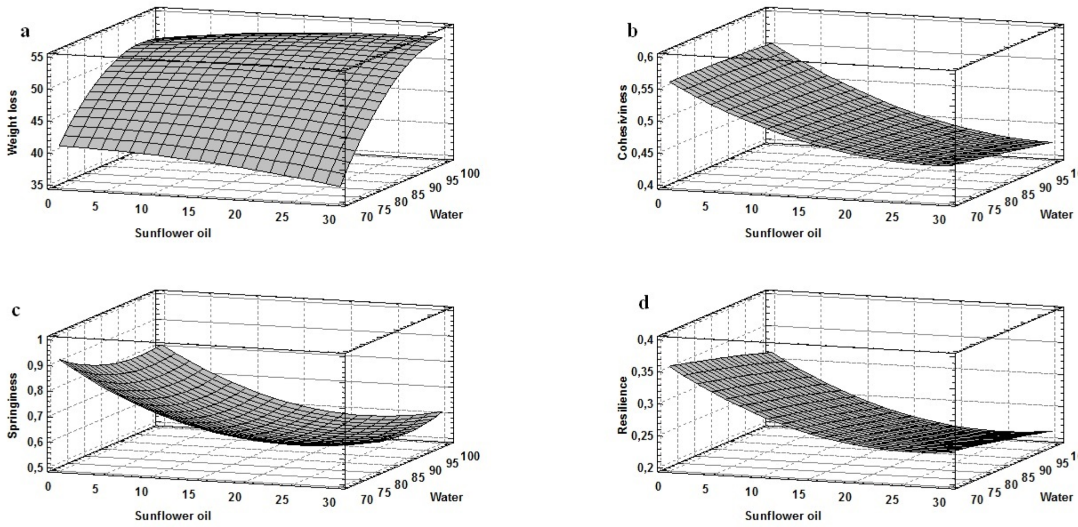

Figure 3. Effect of sunflower oil and water content on weight loss, cohesiveness, springiness and resilience: (a) Weight loss; (b) Cohesiveness; (c) Springiness; (d) Resilience.

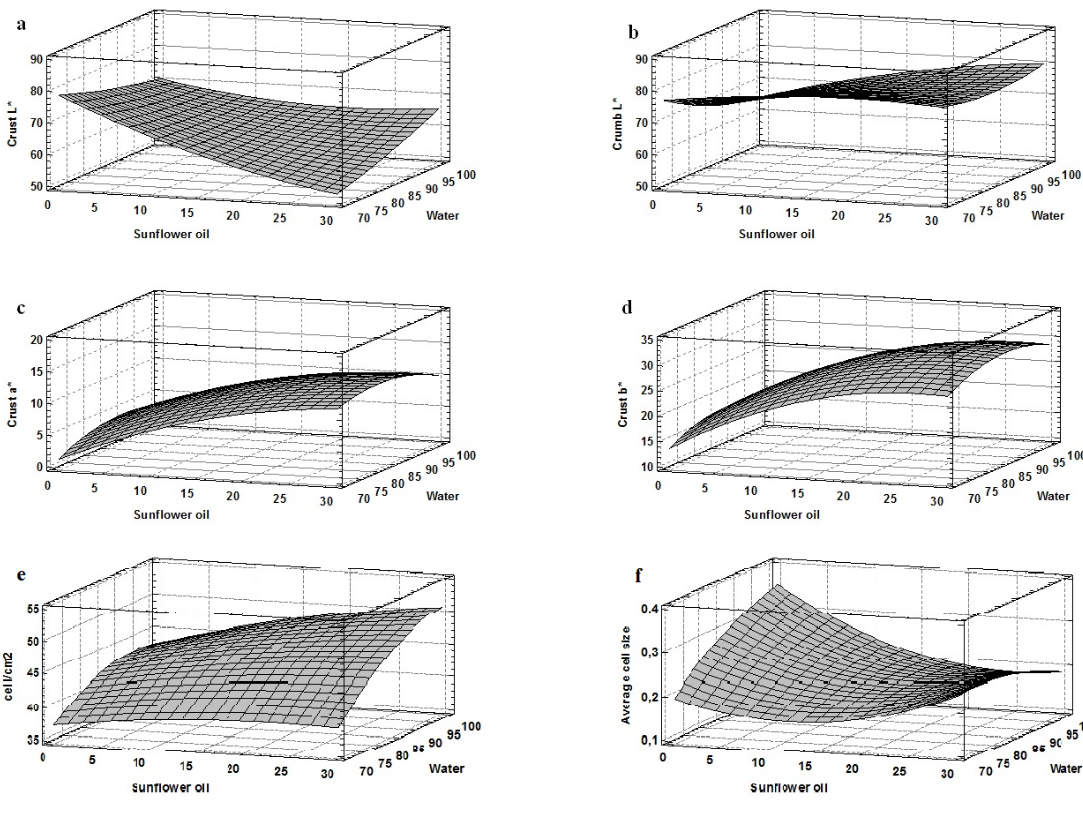

Figure 4. Effect of sunflower oil and water content on colour parameters of crumb and crust: (a) Crust L*; (b) Crumb L*; (c) Crust a*; (d) Crust b* (e) Number of pores per cm^2; (f) Average cell size.

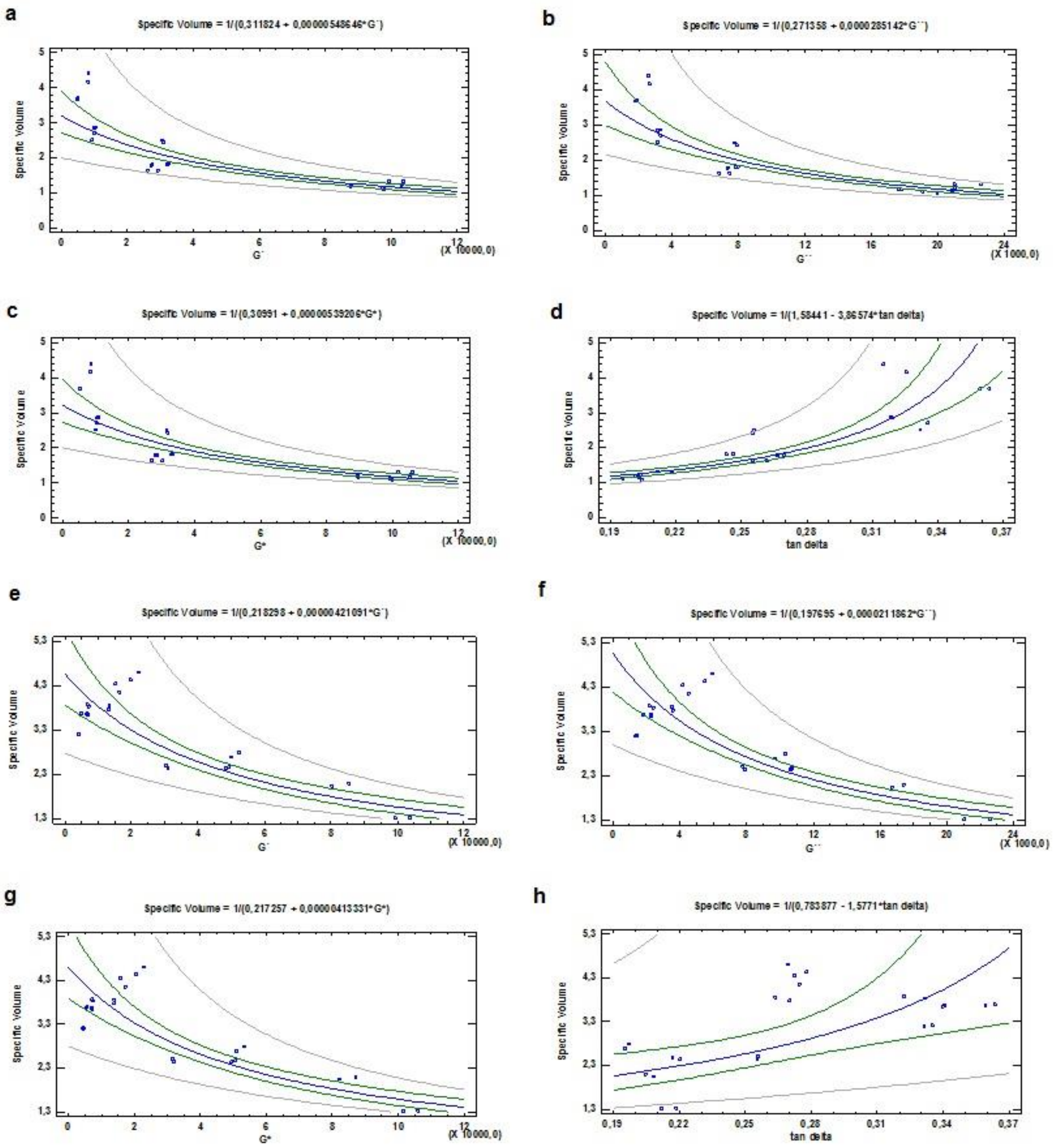

Figure 5. Reciprocal-Y-model analysis of the effect of sunflower oil (a, b, c, d) and shortening (e, f, g, h) on G’ (a, e), G’’ (b, f), G* (c, g) and tg (δ) (d, h).