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RESEARCH

Sunflower Oil-based Oleogel as Fat Replacer in Croissants: Textural and Sensory Characterisation

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Abstract

Croissants are made using solid fats that predominantly contain saturated fatty acids and *trans* fatty acids. In this study, an oleogel consisting of sunflower oil structured with hydroxypropyl methylcellulose was used as a conventional fat replacer in puff pastry thus improving its nutritional profile. Oleogel (OG)-shortening (SH) blends were prepared as a fat replacer for partial (50, 60, 70%) and full shortening (100%) substitution. These replacements implied a reduction of up to 45% of saturated fat and an increase of up to 47% of unsaturated fat, especially monounsaturated fatty acids. Physical characterisation was conducted using texture profile analysis and penetration tests to evaluate the oleogel effect on a baked croissant matrix structure. Sensory analysis was also performed to evaluate the organoleptic properties of the croissant. Shortening replacement using oleogel resulted in croissants with lower saturated fat content, lower bite firmness, and a texture profile similar to croissants made with commercial shortening. The presence of oleogel up to 100% did not contribute negatively to the firmness or springiness of the croissants, although they became chewier and more cohesive as the oleogel increased. In terms of sensory perception, the SH50:OG50 croissant sample was the most similar to the solid fat control. The use of sunflower oil-cellulose-based oleogel was suitable for the formulation of puff pastry products with a healthier fat profile while maintaining the physical and sensory characteristics of conventional croissants.

Keywords Oleogel · Shortening replacer · Hydroxypropyl methylcellulose · Croissant · Texture

Introduction

Laminated dough products, such as croissants, have many plastic fats rich in saturated fatty acids. Their unique structure is composed of alternative thin fat and dough layers and provides a desirable light, delicate, and flaky texture when baked, highly appreciated by consumers (Simovic et al., 2009). Puff pastry fat must have certain specific structural characteristics, such as predetermined plasticity, firmness, and solid fat content profile (Simovic et al., 2009). Laminated dough products comprise many thin, alternating layers of fat and dough formed by repeated rolling and folding. Therefore, fats used in laminated dough production are often referred to as "roll-in fats". Upon baking, the layering causes each individual dough layer to bake separately, creating the characteristic visual separation of the layers and the flaky texture (Mattice & Marangoni, 2017). Thus, fat plays a key role in puff pastry and cannot be replaced without adversely affecting aspects such as appearance, texture, structure, and flavour of the reduced-fat puff pastry (Pimdit et al., 2008).

Butter is the traditional fat used for puff pastry, but its high costs and difficult handling during industrial processing have led to the development of fat blends specifically manufactured for its replacement (Silow et al., 2016). These fat blends are mainly derived from vegetable oils and fats and offer improved processability (fat plasticity). However, processes that confer these oils a solid texture, such as partial hydrogenation, generate a high proportion of *trans* fatty acids, which are associated with increased risks of several conditions, including coronary heart disease, cancer, diabetes, allergies, and poor foetal development (Simovic et al., 2009; Wickramarachchi et al., 2015). Other alternatives like complete hydrogenation, transesterification, or using vegetable oils or fats do not contain *trans* fatty acids but are

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rich in saturated fatty acids. Therefore, there is a need in the food industry to develop environmentally friendly and cost-effective strategies to reduce or replace highly saturated fat.

There are several approaches to reducing the fat in pastry products, based on carbohydrate, protein, or fat mimetics. These attempts reported poor success when a single fat replacer was used to achieve all the functions of fat in puff pastry (Wickramarachchi et al., 2015). In particular, fat replacement in laminated pastries (such as croissants) has been a long-standing goal in industry.

In terms of nutrition and health, the ideal scenario would be to use liquid oil, rich in unsaturated fatty acids, to replace solid fat rich in saturated fatty acids. Nevertheless, it cannot generally be directly replaced with liquid oils without negatively impacting the physical and organoleptic properties of the end product (Mert & Demirkesen, 2016; Wang et al., 2016). The application of vegetable oil produces baked goods with greasier and less crispy characteristics and decreases the storage stability of the products, mainly due to oil oxidation (Jang et al., 2015). Furthermore, the mechanical behaviour of a fat substitute must be solid-like during initial deformation, followed by viscous liquid flow once the network deforms at the yield point—the melting temperature of the shortening substitute must be greater than the working temperature of the dough. Moreover, the consistency of the shortening material must be like the dough to obtain a flaky pastry (Blake & Marangoni, 2015). Gabriele et al. (2008) attempted to develop an emulsion formulated using olive oil, emulsifier, and hydrophilic thickener agents as shortening replacer in puff pastry production, but the large differences in rheological properties showed the need for further improvement of this replacer.

A way of using liquid oil to replace solid fat is to impart a solid consistency using an indirect oleogelification process using hydrocolloids. Oleogels can be defined as the structured solid-like materials in which a high amount of liquid oil is entrapped within a self-standing, anhydrous, thermoreversible, three-dimensional network of gelator molecules (Demirkesen & Mert, 2020). They have great potential to replace solid fat in food products for the improvement of nutritional profile (Davidovich-Pinhas et al., 2016). While it has been used in foodstuffs such as chocolates, confectionery fillings, ice creams, cream cheese, frankfurters, emulsions, cookies, and cakes (Demirkesen & Mert, 2020), no papers in which oleogels were used to replace fat in puff pastry products have been found in the literature search (Gutiérrez-Luna et al., 2022).

Recently, sunflower oil oleogels structured exclusively with cellulose ether have shown promising mechanical and oil retention properties (Espert et al., 2020). In this work, sunflower oil-cellulose ether-based oleogels are used for the partial or total replacement of the solid fat used in the production of croissants. The textural and sensory properties of the reformulated croissants were compared with a commercial roll-in shortening-based product to evaluate the effect of the oleogel in the final quality of croissants.

Materials and Methods

Materials

The materials used for the production of the oleogel include sunflower oil (high oleic acid content) (Capicua, Compañía Oléicola, SAU, Sevilla, Spain), hydroxypropyl methylcellulose (HPMC) (Methocel® F4M Food Grade, 29 g/100 g methoxyl and 6.8 g/100 g hydroxypropyl (The Dow Chemical Co., Bomlitz, Germany)), and water. Laminating shortening (Hojaldambar® B90, Vandemoortele Ibérica S.A., Barcelona, Spain), pasteurised egg product (Derivados de Ovos, S.A., Pombal, Portugal), whole milk (Gaza, Zamora, Spain), fresh yeast (Lallemand, Madrid, Spain), strong wheat flour W400-450 (Molí de Picó, Valencia, Spain), granulated sugar (Disem, Valencia, Spain), and salt were used to prepare the croissants.

Preparation of the Oleogel

Oleogels were prepared using the emulsion template approach with cellulose ether (HPMC) as the only structuring agent according to the methodology described in Espert et al., (2020). An emulsion of oil (47% w/w) in water (51.5% w/w) stabilised with hydroxypropyl methylcellulose (1.5% w/w) was prepared under specific conditions. First, cellulose ether was dispersed in the oil using a Heidolph stirrer (RZR 1) (Heidolph Instruments, Germany) at 280 rpm for 5 min. Water at 10 °C was gradually added to hydrate the mixture under continuous stirring for 30 s. After, the mixture was homogenised using a high-energy dispersing unit (Ultraturrax T-18, IKA, Germany) at 6500 rpm for 15 s and at 17,500 rpm for 60 s. This emulsion was subjected to total evaporation of the aqueous phase in a forced convection oven at 60 °C (Binder GmbH, Germany). Subsequently, the dried product was sheared using an A320R1 mincer (Moulinex, Groupe SEB, France), giving a final oil-concentrated oleogel (approx. 98%).

Preparation of the SH-OG Blend

Different blends were prepared by partially (50, 60, and 70%) and totally (100%) replacing shortening (SH) with oleogel (OG) (SH50:OG50, SH40:OG60, SH30:OG70, and SH0:OG100). A shortening system without the addition of oleogel (SH100:OG0) was used as a control.

To prepare the SH:OG blends, the shortening was melted in a thermostatic water bath (JP Selecta S.A., Barcelona, Spain) at 65 °C to eliminate the memory of fat crystals. It was then tempered at 45 °C to proceed with the blending.

Shortening was mixed with the oleogel under continuous stirring at the lowest speed (Heidolph RZR 1, Heidolph Instruments, Germany). The blend obtained was finally spread on an aluminium mould and stored at a refrigeration temperature (4 °C). To obtain the control blend, the shortening was placed between two baking papers and spread out, forming a rectangle using a rolling pin, giving it the same shape as the mixtures. It was also stored at 4 °C.

Preparation of Croissant Dough

The proportions used for the preparation of the croissant dough were 250 g of wheat flour, 15 g of yeast, 35 g of sugar, 125 g of cold whole milk, 60 g of pasteurised eggs, 2 g of salt, and 125 g of fat (100%, 50%, 40, 30, and 0% for the blends SH100:OG0, SH50:OG50, SH40:OG60, SH30:OG70, or SH0:OG100, respectively).

To prepare the dough, part of the total fat (25 g) (shortening or SH:OG blend), sugar, salt, and pasteurised egg were mixed for 10 s at speed 6 using a food processor (Thermomix TM31, Vorwrek, Wuppertal, Germany). Subsequently, the yeast was diluted in cold milk and added with the flour to the previous mixture, mixing for 20 s at speed 6.

After obtaining the dough, it was kneaded by hand for 10–15 min to obtain a homogeneous dough, which was then wrapped in plastic film and kept in the refrigerator for 8 h. After the refrigeration time, the dough was extended using a rolling pin and then the rest of the fat (shortening or previously prepared SH-OG blend ("Preparation of the SH-OG Blend") was incorporated into the centre of the extended dough for laminating (Fig. 1). To start the lamination step, the dough was folded to retain the SH: OG blend inside. It was turned 90° horizontally and spread again with the rolling pin from the centre to the sides to spread the fat uniformly. The dough was then folded into three layers and allowed to rest in the refrigerator for 20 min. The rolling and folding steps were repeated three more times until four folds were complete. Then, the folded dough was sheeted (3.0 mm in thickness) with a sheeting machine (Parber, Bilbao, Spain) and cut into 7 cm triangles. In each triangle, a 2-cm vertical cut was made in the middle of the base and rolled into the characteristic croissant shape. The raw croissants were then subjected to a controlled fermentation at room temperature for 1 h. Finally, the croissant surface was brushed with pasteurised egg, placed in a preheated oven (De Dietrich, France), and baked at 180 °C for approximately 20 min.

Texture Characterisation of Croissants

The texture of the baked croissants was determined using a TA-XT Plus texture analyser equipped with Texture Exponent software (Stable Microsystems, Godalming, UK).

Tests were conducted at room temperature (20 ± 1 °C) 24 h after preparation. Ten croissants per formulation were used for measurement to ensure the reproducibility, and three repetitions of each sample were evaluated on different days.

To evaluate the firmness of the croissant, penetration tests were conducted using Volodkevich bite jaws (HDP/VB) to simulate the action of an incisor tooth biting through a croissant. A penetration distance of 30 mm was used at a speed of 1 mm s^{-1} (croissant height around 38–40 mm). Hardness was calculated as the maximum penetration force obtained (*N*).

A texture profile analysis (TPA) test was also conducted to see how the samples behave when being chewed. Double compression tests were performed using a 75-mm diameter aluminium plate (P/75). The test speed was 1 mm s^{-1} with a strain of 50% of the original sample height and a 5 s interval between the two compression cycles. From the TPA curves, the three primary texture parameters were obtained: hardness (the peak force during the first compression cycle), springiness (the height that the food recovers during the time that elapses between the end of the first bite and the start of the second bite), cohesiveness (the ratio of the positive force

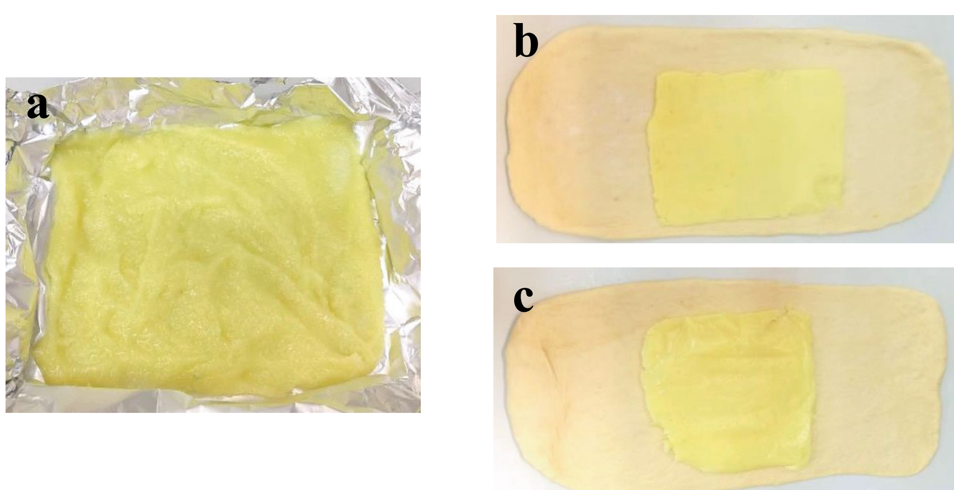


Fig. 1 The visual appearance of the fat-oleogel blend (SH50:OG50) **a** and the doughs prepared for lamination, with the control blend (SH100:OG0) **b** and with the fat-oleogel blend (SH50:OG50)

area during the second compression portion to the positive force area during the first compression), and chewiness (hardness × cohesiveness × springiness).

Sensory Evaluation

The sensory analysis of the croissant samples was conducted using a free choice profile (FCP) analysis. A total of 10 consumers were recruited from the "Instituto de Agroquímica y Tecnología de Alimentos" (IATA-CSIC). Consumers gave written informed consent before the start of the study.

The selection of this methodology was based on its no demand for a training stage and the ability to perform individual sessions. In fact, the main advantage of FCP over conventional profiling is that an agreed complex and scientific vocabulary need not to be defined and untrained consumers may be used as panellists. In FCP, each consumer develops an individual list of terms to describe the samples, and the consumers must be able to detect differences between samples and verbally describe and quantify the perceived attributes (Oreskovich et al., 1991). To obtain the individual descriptors, a repertory grid methodology (RGM) was used. RGM involves triadic or dyadic comparisons of products in one-on-one interviews in which consumers elicit their own set of "constructs" to describe similarities and differences between particular products (Russell & Cox, 2003).

The analysis was conducted in two sessions. In the first session, the individual vocabulary of each consumer was generated to indicate the descriptors that characterised samples using the repertory grid method (Tarancón et al., 2013). For this purpose, each consumer received two samples of croissants (SH100:OG0 and SH0:OG100), and they were asked to describe differences and similarities in terms of appearance, texture, and taste. An individual list of attributes was obtained from each consumer, which was then used to evaluate each croissant sample in a second session. In this session, consumers were asked to rate their own list of attributes for each of the five croissant samples (SH100:OG0, SH50:OG50, SH40:OG60, SH30:OG70, and SH0:OG100) using a 10-cm unstructured line scale with the anchors "Not perceived/not much" and "Very intense/very much" for each attribute.

In both sessions, samples were presented with random three-digit codes for each sample and served at room temperature. Mineral water was provided to clean the palate between samples.

Statistical Data

The raw data obtained were statistically analysed using a one-way analysis of variance (ANOVA) to evaluate the effects of the different percentages of SH or OG on the mechanical properties of the croissants. To analyse the significant differences between the different samples, Tukey's test was applied (significance at $p < 0.05$). The results from the free choice profile analysis were analysed using the generalized procrustes analysis (GPA) technique.

Statistical analyses were performed using XLSTAT software (2019.2.2, Addinsoft, Barcelona, Spain).

Results

Visual Appearance

The croissants were cut transversely, and photos were taken to compare the internal and external structures. Figure 2 shows that there are no major differences in the lamination of the croissants baked with the different SH:OG blends. However, the crumb differs between the control croissant (100% shortening) and the SH:OG blend croissants. This difference is probably due to the control dough having more air in its structure than the rest of the doughs, due to its higher solid fat content. Demirkesen and Mert (2020) stated that the plasticity of shortening incorporates air bubbles during mixing, giving a smooth texture and a high volume in bakery products. As is evident, the control croissant has large air cells that separate the crumb into three large layers. However, the presence of oleogel (at all concentrations) reduces the aerated texture of the crumb and provides a more compact internal structure with thinner cell walls. There were no significant differences in the crust's appearance among the different oleogel substitutions.

Texture Analysis

Firmness Determination

Firmness is a useful parameter to describe the texture and internal structure of puff pastry (Silow et al., 2016). The peak firmness or maximum force peak for each croissant type is presented in Table 1. This peak firmness describes the force applied to completely bite through the sample. A representative penetration profile of each sample (*N* versus time) is shown in Fig. 3, which shows that all croissants break during the test, although the maximum peak force was not produced simultaneously. Samples with the highest fat content (SH100:OG0) provided the highest force values, indicative of the firmest texture. This could be due to the characteristic firmness of solid puff pastry fat at room temperature (20 ± 1 °C). However, the lowest firmness values were observed in sample SH0:OG100 (Table 1), suggesting that oleogel in the croissants decreases the force required for penetration. This might be related to the absence of solid fat crystals in the

Fig. 2 The visual appearance of the croissants obtained with different SH/OG ratios (SH, shortening; OG, oleogel)

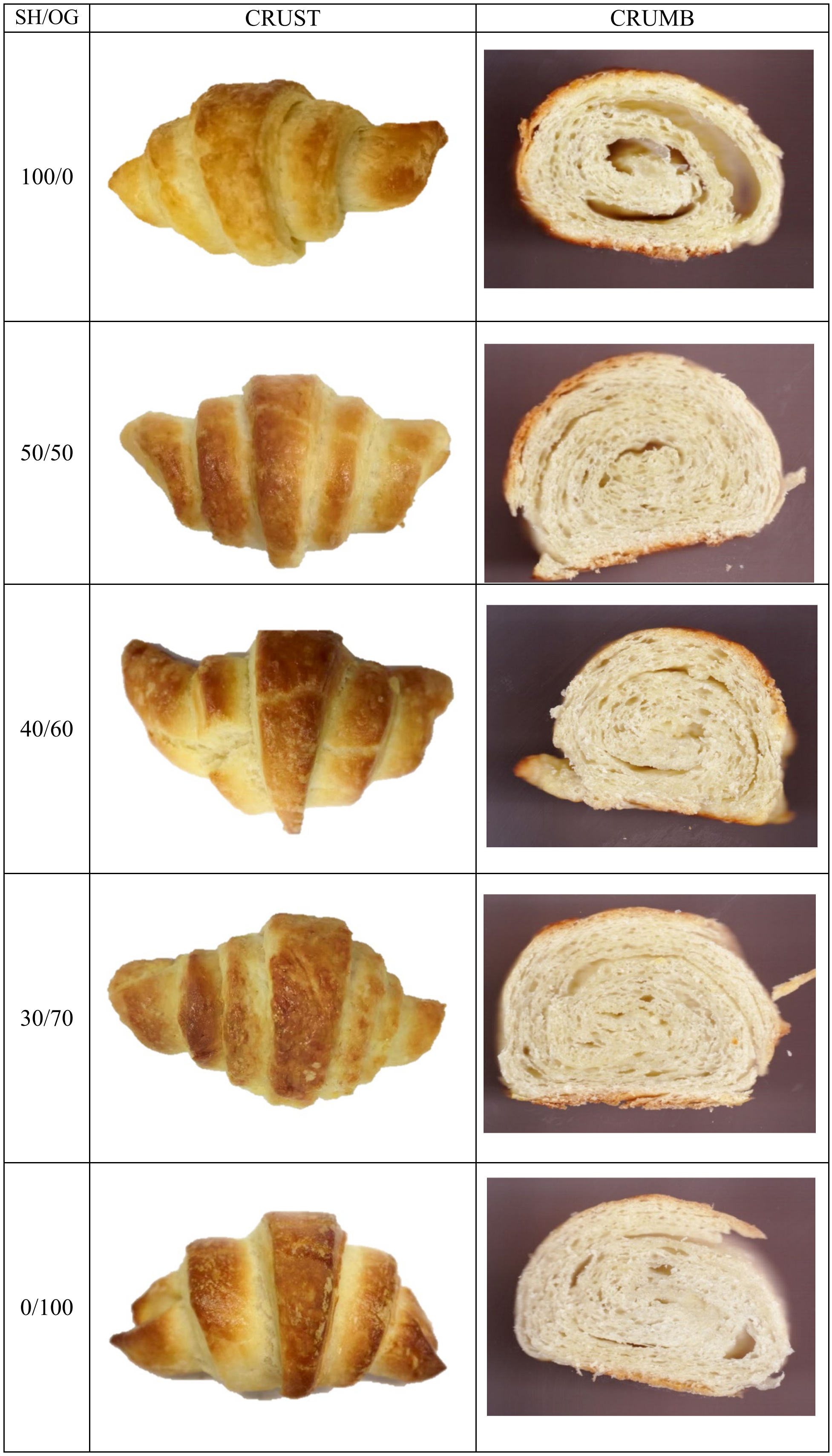


Table 1 Texture values obtained from penetration and TPA measurements for the croissants formulated with different SH:OG ratios

SH:OG ration	Penetration	TPA			
	Maximum peak firmness (N)	Hardness (N)	Springines	Cohesiveness	Chewiness
100:0	7.91A (2.40)	27.68A (2.67)	0.77A (0.04)	0.43C (0.02)	9.29B (1.20)
50:50	6.32AB (1.84)	27.13A (3.24)	0.82A (0.04)	0.47BC (0.02)	10.53AB (1.80)
40:60	6.16AB (1.92)	26.28A (2.37)	0.78A (0.02)	0.48B (0.02)	9.89B (1.41)
30:70	4.87B (1.06)	25.87A (3.91)	0.85A (0.18)	0.50AB (0.02)	11.73AB (3.28)
0:100	4.79B (1.31)	28.82A (2.71)	0.84A (0.01)	0.53A (0.04)	12.92A (1.36)

Values in parentheses are standard deviations

SH Shortening, *OG* Oleogel

[ABC]Values with the same letter in the same column indicate that there are no significant differences between samples ($p<0.05$) according to Tukey's test

fat blend, leading to a lower consistency in the croissant matrix, which translated into a softer croissant texture. As the concentration of oleogel increases, the firmness of the croissants decreases, although no significant differences were found in force values among the croissants formulated with SH-OG blends. Therefore, despite their more compact appearance, a reduction in croissant firmness occurs when oleogels are added to croissants. These results are not in line with previous studies on baked products. Jung et al. (2020) explained that the dense crumb structure of bread reformulated with oleogel would cause a significant increase in firmness. Although few studies focus on using oleogels as a fat substitute in puff pastry, Sim et al. (2021) recently found that ethyl cellulose oleogels (extensively characterised in recent years) failed to generate a puff pastry cake with a suitable texture. In baked products such as biscuits or cakes, the use of oleogels results in products with firmer texture (Kim et al., 2017; Mert & Demirkesen, 2016; Sim et al., 2021).

Texture Profile Analysis

Figure 4 and Table 1 show the TPA representative curves and parameter data for the tested croissants, respectively. No significant differences ($p<0.05$) were found in the hardness and springiness of the croissants. Although some works show that the use of oleogels significantly affects the texture of the baked product, especially the hardness (Hwang et al., 2016;

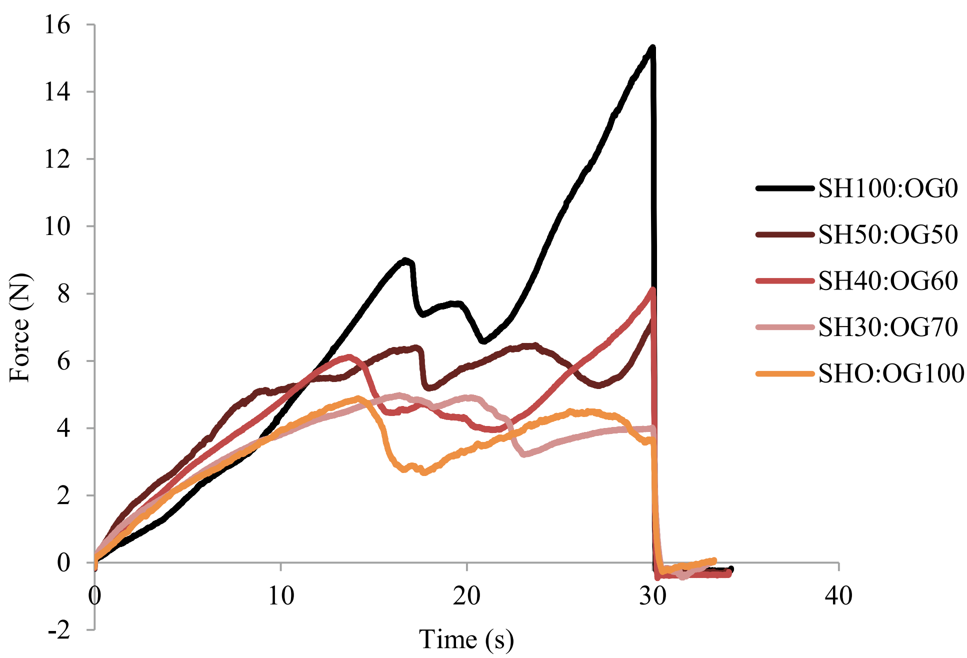


Fig. 3 Penetration profile (force vs time) of the different croissants formulated (SH Shortening, OG Oleogel)

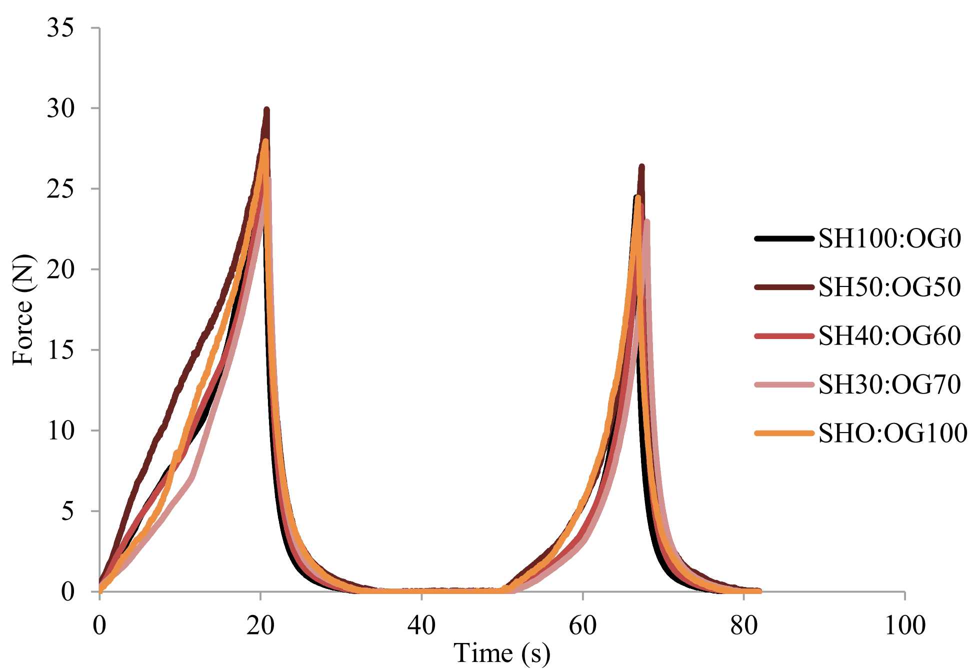
Kim et al., 2017), the use of this oleogel did not show a change in the hardness and elasticity of the final product, even at a 100% replacement of traditional fat. However, an increase in oleogel proportions resulted in an increase in the cohesiveness, especially when compared to the control sample. Cohesiveness quantifies the internal strength of the food structure and provides information on the ability of a material to stick to itself (Lu et al., 2010). Higher cohesiveness values in samples with more oleogel would indicate that more energy was required for the second compression. The higher cohesiveness of the oleogel croissant could be related to their more compact crumb structure. The low saturated fat content makes the fat melt rapidly during baking without facilitating the lift. This leads to loss of lift and flakiness. Compared to the control, the oleogel croissant's more compact network is more difficult to crumble. In contrast, the lower cohesiveness values in the control croissant could be explained by the presence of a crumb with a more aerated structure. Chewiness represents the amount of energy needed to disintegrate food to swallow. The TPA results also showed an increase in chewiness values with an increase in the proportion of oleogel, indicating that these samples offer greater resistance to chewing, as expected from the values of hardness, cohesiveness, and appearance of the croissant crumb. Patel et al. (2014) and Pehlivanoglu et al. (2018) also showed an increase in chewiness when using liquid oil structured by shellac or wax in baked cakes. Therefore, the oleogel used in this study could replace shortening without significant changes in hardness and springiness, even at 100% replacement. However, it led to a slight increase in cohesiveness and chewiness.

Sensory Analysis

The consumers used a wide variety of terms to describe the differences among samples (voluminous, uniform/regular, compact, brown colour, laminated, glossy, brioche, crunchy, butter, croissant taste, and firm/hard). The two-dimensional generalised procrustes analysis (GPA) plot obtained from the analysis of the consumer assessment of the different croissants is shown in Fig. 5. The individual sensory attributes explained by each dimension and the number of times they were mentioned are listed next to each dimension.

Dimension 1 accounted for 51.33% of the total variance, indicating that most differences between croissants perceived were explained by this dimension and were mainly related to the descriptors of appearance, texture, and taste. In the positive part of this dimension, descriptors such as "laminated/airy appearance", "voluminous appearance", "crunchy texture", "buttery flavour", and "typical croissant flavour" appeared, which referred mainly to SH100:OG0 croissants and, to a lesser extent, to croissants with SH50:OG50. Whereas on the negative side of this axis, terms such as "uniform/regular appearance", "compact", "brown colour", and "brioche flavour" appeared, which characterised the samples SH40:OG60, SH30:OG70, and SH0:OG100. These results are related to the crumb appearance and TPA data which revealed that increasing oleogel concentration resulted in higher crumb compaction and thus increased cohesiveness and chewiness.

Fig. 4 TPA curves for the different croissants formulated (SH, shortening; OG, oleogel)



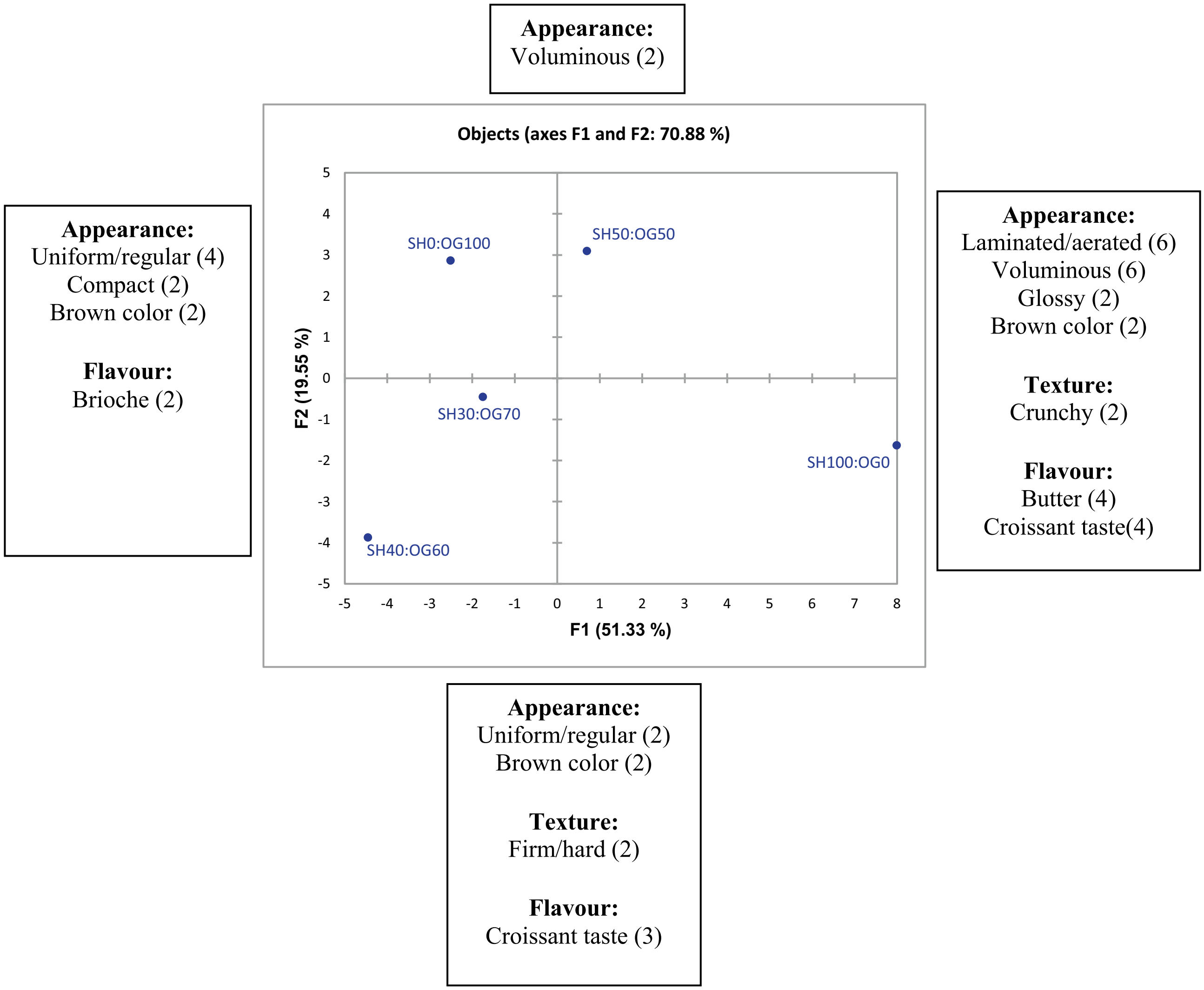


Fig. 5 Two-dimension GPA plot of the differences between croissants perceived by consumers. Descriptors correlated ($R > 0.6$) with the two dimensions of the average space are listed on the boxes, and the number of times that the descriptor was mentioned, if more than once (SH Shortening, OG Oleogel)

Dimension 2 accounted for 19.55% of the total variance. The positive part of this axis was mainly related to appearance, highlighting the descriptor "bulky", which was described in croissants SH50:OG50 and SH0:OG100, whereas in the negative part, descriptors from all the categories studied (appearance, texture, and flavour) appeared, highlighting "typical croissant flavour", which surprisingly was named in all the study samples, except in sample SH0:OG100.

Therefore, it can be concluded that the samples prepared with the different percentages of oleogel presented similar descriptors to the control, although they were much more compact, with the sample prepared with SH50:OG50 being the most similar to the control. These results are in agreement with those obtained by Simovic et al. (2009), who concluded that by maintaining a minimum amount of margarine (55%) in the formulation of laminated doughs, better sensory results were obtained. Likewise, no negative descriptors were found for the samples, except for the mention of the term firm/hard in the samples with the highest percentage of oleogel, although it only had a frequency of mention of two.

Conclusions

The partial and complete substitution of conventional shortening with a sunflower oil-cellulose-based oleogel resulted in croissants with improved lipid profile (45% reduction in saturated fat and 47% increase in unsaturated fatty acids), lower bite firmness, and texture behaviour similar to that of the selected commercial shortening. Oleogel incorporation of up to 100% did not contribute negatively to the firmness or springiness texture of the croissants. However, as the level of fat replacement by oleogel increased, the croissants became chewier and more cohesive. Regarding sensory perception, croissants made with the SH:OG blend presented similar descriptors to the control, although they were considered more compact. The SH50:OG50 croissant sample was the most similar to the solid fat control.

These results demonstrated sunflower oil-cellulose-based oleogels could be effective in replacing shortening at up to 100% without significant deterioration in the textural properties of croissants. Therefore, the substitution of solid conventional fat by structured vegetable oil can be a promising strategy to reduce the consumption of saturated and *trans* fats in puff pastry bakery products, while maintaining the functional and sensory properties provided by hard stock lipids.

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Author Contribution M. Espert: conceptualization, methodology, formal analysis, writing—original draft, preparation, writing—review and editing. Q. Wang: conceptualization, methodology, formal analysis, writing—original draft. T. Sanz: conceptualization, methodology, investigation, and, funding acquisition. A. Salvador: conceptualization, methodology, investigation, funding acquisition, supervision, writing—review and editing.

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Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on request.

Declarations

Conflict of Interest The authors declare no competing interests.

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