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Replacing solid fat in croissant dough using xanthan gum-based oleogels. Impact on rheological properties and final product quality

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ABSTRACT

Healthier croissants prepared with xanthan gum-based oleogels have been evaluated by mechanical and sensory properties. Blends containing oleogel and conventional fat (shortening, SH) (50/50) were used as fat source in the croissant doughs. The shortening/oleogel (SH/OG) blends and doughs were rheologically characterized by Small and Large Amplitude Oscillatory Shear (SAOS-LAOS) tests, whereas both doughs and baked croissants were characterized by penetration and Texture Profile Analysis (TPA) tests. Acceptability and purchase intention tests of the selected croissants was also carried out, as well as discriminatory tests to confirm whether there were differences between the samples. Different oleogels were tried, combining four food structuring agents (whey protein (WP), polysorbate Tween (TW), soy lecithin (SL) and locust bean gum (LBG)) with xanthan gum (XG) in order to structure sunflower oil.

Viscoelastic moduli presented differences depending on the structuring agent used in the oleogels. SH control was firmer than all blends. However, this pattern was not reproduced in the croissant doughs. The control dough, formulated only with the shortening had an intermediated behaviour in oscillatory shear. Indeed, in texture it presented the lowest values, with a hardness similar to that of the lecithin blend. However, doughs formulated with LBG or WP blends showed the highest values for both hardness and viscoelasticity. Baked croissants formulated with SL blend presented a crumb appearance and an airy structure similar to the control. Croissants formulated with the other blends were more compact and had higher hardness values. Therefore, formulation containing SL blend was selected for further analysis. Control and SL-based doughs followed the same pattern when large deformations were applied: shear stiffening and shear thinning behaviour. Regarding sensory analysis in final croissants, no differences in appearance, texture, flavour and overall liking were obtained. There was also no difference in purchase intention, so that the formulation with SL oleogels was optimal for the healthier croissants proposed.

1. Introduction

Due to health concerns, the food industry has been forced to reduce the use of unhealthy fats in processed foods. However, conventional saturated fats are essential in achieving desirable technological properties and product quality in baked goods (Garvey, O'Sullivan, Kerry, & Kilcawley, 2020), making their reduction a significant challenge. Laminated bakery products (croissants, Danishes and puff pastry) are one of the most difficult applications for replacing conventional solid fats. Croissants are high fat bakery product that often contain approximately 30% fat by weight, so the properties provided by the fat will have a significant influence on the overall quality of the products (Mattice & Marangoni, 2017). This type of product is created by rolling out and folding alternating layers of fat and dough. To achieve this structure, it is necessary to use fats with high plasticity, firmness, and melting point (Renzetti, de Harder, & Jurgens, 2016; Wickramarachchi, Sissons, & Cauvain, 2015). The fats must be soft and spreadable to facilitate layering without tearing the dough layers, but not so soft to leak out under the pressure (Mattice & Marangoni, 2017). The main types of laminating fat used for puff pastry are butter, shortenings and margarines. Traditionally, butter was the main fat used to make croissants because of its exceptional flavour profile, but it has been replaced by

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other fats, mainly due to their high cost and processing temperature limitations (to achieve good lamination with butter, the temperature needs to be held at 15–20 °C) (Macias Rodriguez & Marangoni, 2018). The wide melting profiles of shortenings and margarines, combined with a considerable solid content at high temperatures, facilitate the plasticity and good workability required of fat during lamination (Wickramarachchi et al., 2015). However, the high proportion of saturated fat in both butter and shortenings and margarines (50–60%) (Robledo de Dios, Dal Re Saavedra, Villar Villalba, & Pérez-Farinós, 2015; Wickramarachchi et al., 2015), and even the presence of *trans*-fatty acids in these industrially hydrogenated fats (Dhaka, Gulia, Ahlawat, & Khatkar, 2011), make it necessary the use healthier fat alternatives.

Vegetable oils that are rich in unsaturated fatty acids have a liquid consistency and lack a solid phase, which makes them unsuitable for use as a raw material in the production of puff pastry. However, the structuring of liquid oils with oleogelifying agents has become increasingly important in recent years as a source of plastic fat with low saturated fat content. These agents have been applied to a variety of products, such as ice cream, meat derivatives, cookies, cakes, and chocolate (Martins, Vicente, Pastrana, & Cerqueira, 2020; Patel et al., 2014). Although there are studies on the application of oleogels to baked foods, no research has been conducted on their application to flaky or laminated doughs (Demirkesen & Mert, 2020; Gutiérrez-Luna, Astiasarán, & Ansorena, 2022; Wickramarachchi et al., 2015; Yazar & Rosell, 2023). Studies typically aim to reduce saturated fats in cookies and cakes by using waxes to structure vegetable oils, such as canola, olive, soybean, flaxseed, or rapeseed oil (Blake & Marangoni, 2015; Hwang, Singh, & Lee, 2016; Luo et al., 2019; Mert & Demirkesen, 2016a, 2016b; Patel et al., 2014). However, these studies have not achieved full fat replacement, and partial replacement has resulted in impaired sensory and mechanical properties of the final product.

Our group designed a solid-like oleogel by combining a hydrophilic polymer (xanthan gum) with various food-grade structuring agents capable of gelling vegetable oil (Espert, Hernández, Sanz, & Salvador, 2022). The resulting system retains the nutritional profile of the liquid oil but is a viscoelastic solid at room temperature. Rheological and stability evaluations suggested potential applications for these oleogels. This study examined the potential use of oleogels as a partial replacement for shortening in croissant dough. Blends (50/50) of shortening (SH) and oleogel (OG) were prepared and applied to the dough. The rheological and textural properties of both systems (blends and croissant doughs) were characterized, and the texture and sensory properties of the baked product were analyzed.

2. Materials and methods

2.1. Materials and ingredients

The oleogel was prepared using high oleic sunflower oil (Capicua) obtained from Compañía Oleicola SAU (Spain), xanthan gum (XG) (Satiaxane C911, 1500 mPa s viscosity in a 1% aqueous solution at 25 °C) from Cargill (France); polysorbate Tween 80® (P1754), TW, from Sigma-Aldrich Chemical Company (St Louis, MO); whey protein (WP) from Weider Global Nutrition S.L. (Germany); locust bean gum (LBG) (Viscogum® BE, Cargill, France); and pure soy lecithin (SL) from Diexpa (Spain). To prepare the blends and croissants, the following ingredients were used: Hojaldambar® B90 shortening (Vandemoortele Ibérica S.A., Barcelona, Spain), pasteurized egg product (Derivados de Ovos, S.A., Pombal, Portugal), whole milk (Gaza, Zamora, Spain), fresh yeast (Lallemand, Madrid, Spain), wheat flour W400-450 (Molí de Picó, Valencia, Spain), sugar (Disem, Valencia, Spain), and salt.

2.2. Preparation of oleogels and blends

The oleogels were produced using an indirect method that started with oil/water emulsions. These emulsions consisted of sunflower oil, water, and xanthan gum (XG). A structuring agent was added to create a stable emulsion that could dry efficiently. Different molecules were used, including whey protein (WP), Tween 80 polysorbate (TW), soy lecithin (SL), and locust bean gum (LBG). The emulsions were prepared following the methodology described in Espert et al. (2022). They consisted of 73% water, 20% high oleic sunflower oil, 2% xanthan gum, and 5% structuring agent. The oleogel was obtained by dehydrating the emulsions using the emulsion template method, as also described in Espert et al. (2022).

The shortening/oleogel (50/50) blends were formulated using oleogel as a substitute for commercial shortening. To achieve this, the solid fat was first melted at 60 °C in a thermostatic bath (Precisterm, J.P. Selecta, Barcelona) to remove the memory of fat crystals. Then, it was allowed to cool to below 40 °C, and the oleogel was gradually added using a stirrer (Heidolph Instruments, Germany) at minimum speed. Each formulated blend was then poured into small silicone molds (bonbonniere-type), cooled, and stored at 4 °C for 24 h until further use. For the control, the melted fat was directly molded and stored under identical conditions.

A total of four oleogel-fat blends were prepared and then samples were coded as follows: WP blend, TW blend, SL blend, LBG blend; always comparing with a 100% SH control.

2.3. Preparation of puff pastry dough

The dough preparation was adapted from a traditional recipe. The pastry was made with 250 g of strong flour, 15 g of yeast, 35 g of sugar, 125 g of cold whole milk, 60 g of pasteurized egg, 2 g of salt, and 125 g of fat (25 g for the initial dough preparation and 100 g to prepare the fat block that will be introduced later in the folding of the dough). The dough was prepared following the protocol previously used by Espert, Wang, Sanz, and Salvador (2023), which included mixing, kneading, resting, and baking. Five types of pastry doughs were prepared, including a control with 100% shortening (control dough), 50/50 shortening-oleogel blend with whey protein (WP dough), 50/50 shortening-oleogel blend with Tween (TW dough), 50/50 shortening-oleogel blend with soy lecithin (SL dough), and 50/50 shortening-oleogel blend with locust bean gum (LBG dough).

2.4. Rheological measurements

This study investigated the rheological behaviour of oleogel-fat blends and doughs. Rheological measurements were conducted using an AR-G2 controlled stress rheometer (TA Instruments, Crawley, England) with serrated plate geometry (40 mm diameter) and an axial gap of 2 mm. The temperature was set to 20 °C for all tests. Equilibration time of 5 min was allowed for the samples in the measurement cell before each test.

Stress sweeps were performed at a frequency of 1Hz for blends (1–5000 Pa) and doughs (1–3000 Pa). The linear viscoelastic region (LVR) was characterized by the constant storage modulus in the plateau region (G_0') and yield stress (σ_y), which corresponded to the stress value for a 5% deviation.

Frequency sweeps were conducted in the range of 0.01–10 Hz, at a stress amplitude within the LVR.

To characterize the non-linear response of doughs, strain amplitude tests were performed at a fixed frequency of 1 Hz, ranging from 0.01% to 1000%. The elastic and viscous curves of Lissajous-Bowditch plots were analyzed at three values of strain amplitude. The strain-hardening (S) and shear-thickening (T) ratios were calculated from the Chebyshev coefficients obtained by Fourier transform analysis for all applied strain amplitudes (Ewoldt, Hosoi, & McKinley, 2008).

The rheological data were processed using TRIOS 5.4 software (TA Instruments, USA). All tests were performed in triplicate on samples prepared on different days, and a duplicate of each batch was made (6 measurements in total).

2.5. Instrumental texture characterization

A TA-XT Plus Texture Analyzer (Stable Micro Systems, Ltd., Godalming, Surrey, UK) equipped with Texture Exponent 32 software was used to conduct texture measurements. All tests were performed using a 30 kg load cell. A Texture Profile Analysis (TPA) was carried out on the raw dough, and for the baked croissant, a penetration test was performed in addition to the TPA.

Each formulation was prepared three times on different days. Three samples, either fresh or baked dough, were measured from each batch, resulting in nine determinations for each formulation. All samples were kept at room temperature (20 ± 1 °C).

2.5.1. TPA test

The instrumental texture evaluation using TPA was performed on dough (40 mm diameter) and baked dough (whole croissant). The samples were compressed using a 75 mm diameter aluminum cylinder probe (P/75) with two complete compression-decompression cycles or two uniaxial compression cycles. A compression (strain) of 40% was applied to the doughs and 50% to the baked dough, at a test speed of 1.0 mm/s, with a waiting time of 5 s between the two cycles. The three primary textural parameters, namely hardness, springiness, and cohesiveness (Pons & Fiszman, 1996), were obtained from the force-time curves.

2.5.2. Penetration test

Penetration tests were performed on baked dough (whole croissant) using the Volodkevich probe (Volodkevich bite jaw HDP/VB), which simulates the action of an incisor tooth biting through food. A depth of 30 mm was penetrated into the baked dough at a speed of 1.0 mm/s. The area under the curve (AUC) (N s) was recorded from the force-time profiles obtained and was considered as the hardness index of baked flaky dough.

2.6. Macroscopic appearance of baked croissants

To compare the appearance of baked dough, a high-performance full-HD digital microscope (0.8–750 × optical magnification) (EVOCam II, Vision Engineering Ltd., England) was used. Identical preparation and observation settings were employed for all images. A slice of baked croissant was cut and placed on a black surface, and overhead LED lighting was used. The samples were observed at an optical magnification of 5.61. The study examined the central slice of a croissant, with a focus on its crust and crumb. The findings offer insights into the distinctions and similarities between oleogel-based puff pastry and control puff pastry, particularly in terms of the flakiness and honeycombing of the crumb.

2.7. Sensory evaluation of baked croissants

The evaluation sessions included untrained panelists and consumers aged 22 to 65 who were employees and students at the Instituto de Agroquímica y Tecnología de Alimentos (IATA-CSIC). The sensory evaluation took place in separate booths with standardized lighting and temperature. Each portion of baked dough (croissant) was presented on a small plate, coded with a three-digit random number. Consumers were provided with a cup of mineral water for mouth rinsing between tastings.

2.7.1. Triangle discrimination test

A triangular discrimination test was conducted to determine whether detectable differences existed between two samples of baked dough. The test was conducted with a panel of 30 untrained consumers aged 22–65 years. The consumers were presented with three samples simultaneously, two from the baked dough with SL blend (SL dough) and one control dough, and viceversa. To avoid any positional bias, each sample was coded with a 3-digit random number and randomly presented. The study presented consumers with triads of croissant samples, each with three possible combinations: AAB, ABA, BAA, BBA, BAB, and ABB. Participants were informed that two of the samples were identical and one was different. They were then asked to taste the samples from left to right and identify the odd sample based on differences in crumb appearance, crumb color, texture, and flavour. The results were analyzed using the corresponding table following a one-sided hypothesis with a significance level of 5% (Roessler, Pangborn, Sidel, & Stone, 1978).

2.7.2. Overall acceptability and purchase intention

Ninety-nine participants, all regular consumers of pastries and bakery products, took part in the study. They were asked to rate their acceptability using a nine-point hedonic acceptability scale, ranging from 1 ('dislike extremely') to 9 ('like extremely'). Purchase intention was evaluated using a five-point scale ranging from 1 ('definitely would not buy') to 5 ('definitely would buy').

2.8. Statistical analysis

Means and standard deviations of rheology, texture and acceptability experimental values were calculated. One-Way analysis of variance (ANOVA) was applied to study the differences among samples. Least significant differences were calculated by Tukey's test (significance $p < 0.05$). The analysis was performed using XLSTAT 2020 software (Addinsoft, Barcelona, Spain).

3. Results and discussion

3.1. Characterization of oleogel-fat blends and doughs

3.1.1. Effect of oleogel on rheological properties of blends

Fig. 1 displays the viscoelastic response of each blend. The storage modulus, G', and loss modulus, G'', parameters were plotted as a function of stress amplitude (Fig. 1A) and as a function of frequency in LVR (Fig. 1B). The parameters characterizing the linear viscoelastic zone, G'_0 and σ_y, are presented in Table 1.

The results indicated significant differences in the storage modulus of the linear viscoelastic zone, G'_0, mainly between the shortening control and the SL blend. The G'_0 values of the other blends fall within an intermediate range, with the blends containing LBG and WP being the most similar to shortening control. However, extension of linear viscoelastic region, indicated by values of yield stress, σ_y, did not follow this trend, since the higher σ_y corresponded to the shortening control, and TW and SL blends (Fig. 1A).

The mechanical spectra (Fig. 1B) indicated that the oleogel-fat blends exhibited solid-like behaviour ($G' > G''$) consistently across all samples. The difference in magnitude between the viscoelastic moduli was significant. Sample with the strongest structure was the shortening control, which produced spectra with higher G' and G'' values. This lower viscoelasticity in blends compared to the shortening was likely due to the higher liquid oil content and lower content of higher melting triacylglycerides (TAGs) (Silow, Zannini, & Arendt, 2016). In contrast, SL and TW blends had lower viscoelastic values and were more frequency-dependence, indicating a weaker gel structure, particularly SL blend. A similar pattern was observed in the initial oleogels: the oleogel containing SL had the lowest viscoelasticity, while the oleogel containing LBG had the highest values (Espert et al., 2022). It stood out the blend made with SH and SL oleogel was more frequency dependent than the initial oleogel containing SL. The viscoelastic moduli decreased after mixing the oleogel with shortening. This was not expected, since it was assumed that when mixing the oleogel with shortening (solid fat) the resulting blend would be stiffer than the single oleogel.

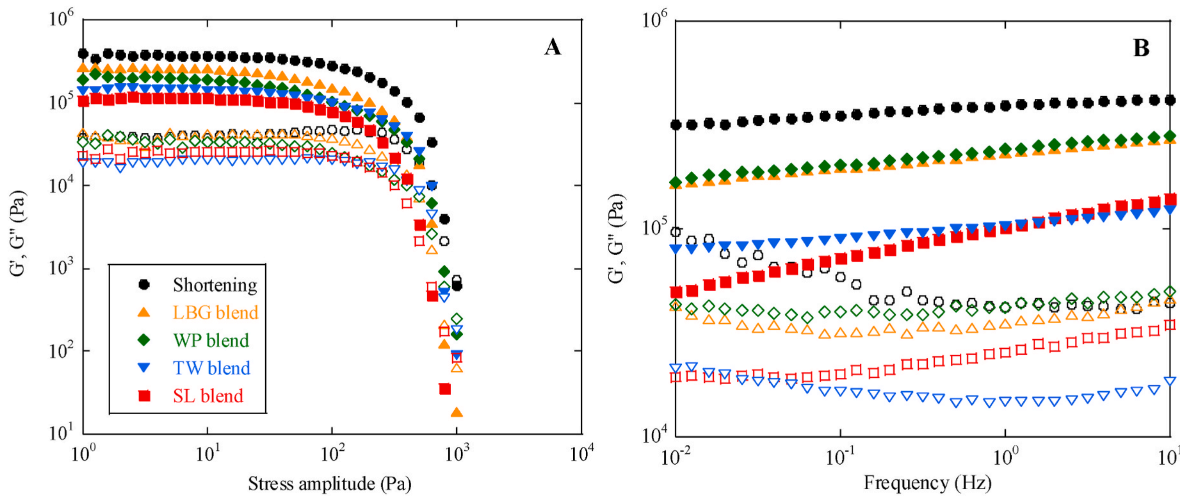

Fig. 1. Oscillatory measurements of blends (shortening + oleogel) compared to control (100% shortening). Oleogels with different structuring agents: SL: soy lecithin, LBG: locust bean gum, WP: whey protein, TW: Tween. Storage modulus (G′): filled symbols and loss modulus (G″): open symbols. **A**: stress sweeps; **B**: frequency sweeps.

Table 1
Effect of oleogel type on rheological parameters of the different SH/OG blends.

BLEND	G'_0 (Pa)	σ_y (Pa)
CONTROL	316000^{a} (±44000)	26.4^{a} (±3.1)
TW	162000^{bc} (±15000)	18.2^{ab} (±0.4)
WP	255000^{ab} (±37000)	12.2^{b} (±1.2)
SL	119600^{c} (±4300)	19.5^{ab} (±1.6)
LBG	294000^{ab} (±25000)	17.2^{b} (±1.4)

^{abc}Different superscript letters in each column denote significant differences ($p < 0.05$).

Table 2
Effect of SH/OG blend on rheological parameters of croissant doughs.

DOUGH	G'_0 (Pa)	σ_y (Pa)
CONTROL	30900^{bc} (±3300)	12.8^{c} (±0.7)
TW	20300^{cd} (±1030)	18.6^{b} (±0.9)
WP	39000^{ab} (±1700)	17.3^{b} (±0.3)
SL	16900^{d} (±370)	22.3^{a} (±1.1)
LBG	49000^{a} (±3500)	23.9^{a} (±0.4)

^{abcd}Different superscript letters in each column denote significant differences ($p < 0.05$).

3.1.2. *Effect of oleogel-fat blends on rheological properties of doughs*

Fig. 2 displays the viscoelastic response of the doughs made with blends. A distinct trend was observed in the laminated doughs compared to oleogel-fat blends.

Table 2 presents the parameters characterizing the LVR in these systems, G'_0 and σ_y. Despite being the stiffest, the shortening control exhibited lower viscoelasticity than the LBG or WP doughs when incorporated into the dough. The storage modulus values of the blends were higher than those of the doughs, with the SL and TW doughs being the softest. The control dough had a significantly lower linear zone extension (σ_y). In contrast, the doughs elaborated with SL and LBG blends presented the greatest extension of the LVR (Fig. 2A).

Regarding the mechanical spectra (Fig. 2B), the croissant doughs exhibited a greater dependence of the G′ and G″ moduli on frequency compared to the SH-OG mixtures. Two distinct groups can be observed, with similar values between them. Doughs containing SL and LBG blends showed lower values of the viscoelastic moduli and higher frequency dependence than the samples with TW and WP blends. The control

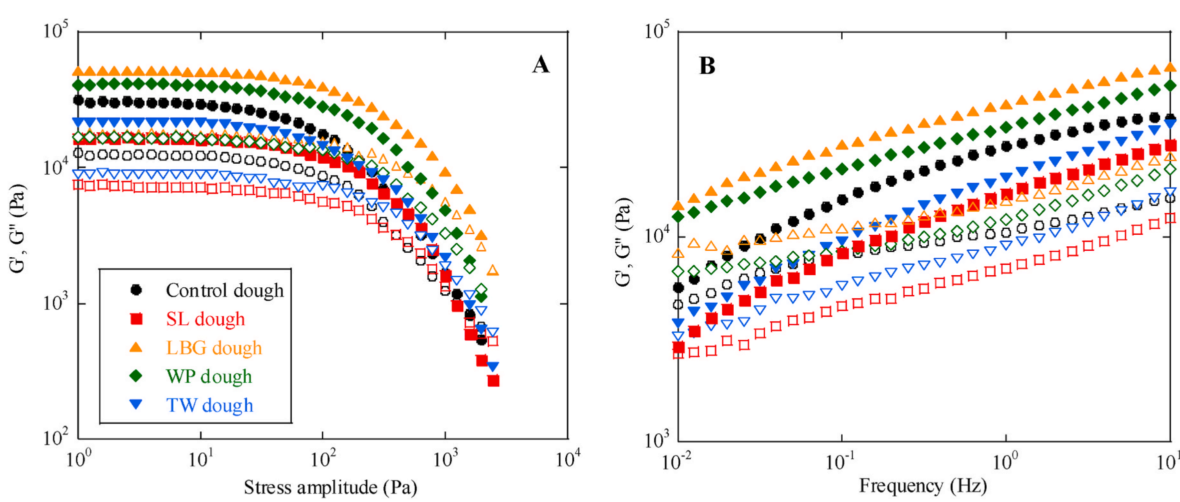

Fig. 2. Oscillatory measurements of reformulated doughs (containing shortening + oleogel) compared to control dough (100% shortening). Oleogels with different structuring agents: SL: soy lecithin, LBG: locust bean gum, WP: whey protein, TW: Tween. Storage modulus (G′): filled symbols and loss modulus (G″): open symbols. **A**: stress sweeps; **B**: frequency sweeps.

dough exhibited intermediate behaviour between the two groups.

3.1.3. TPA of doughs

The TPA analysis compared the texture of doughs formulated with blends versus those formulated with 100% shortening. Table 3 summarizes the results for hardness, springiness, and cohesiveness. The results identified two distinct groups. The SL dough, TW dough, and control dough exhibited similar and significantly lower hardness than the WP and LBG doughs. The textural tests confirmed the viscoelastic structuring pattern. Furthermore, the TW and SL doughs had higher springiness and cohesiveness compared to the LBG and control dough. In contrast, the LBG dough was harder, less elastic, and had lower resistance to the second compression. The WP and TW doughs presented similar elasticity and cohesiveness.

3.2. Characterization of baked croissants

3.2.1. Appearance of baked croissants

This study used macro-photography to examine the appearance of the crumb and crust of the different doughs. Fig. 3 displays the appearance of the croissants at two magnifications.

The SL croissant was very similar to the control croissant prepared with SH, with an airy crumb and a pleasant flakiness in the crust. The appearance of the SL croissants suggested that they are airy and soft, with hollow areas. In contrast, the TW, WP, and LBG croissants presented a denser crumb and a compact appearance. Moreover, croissants formulated with TW and LBG blends showed a crust that lacks flakiness and appears more bread-like. The croissant formulated with WP blend showed some flakiness in the crust, although not as marked as in the control croissant.

Qualitatively, the croissant that differed the most from the control croissant was the one formulated with the LBG blend. This was probably because the initial LBG oleogel was more consistent than the other oleogels, probably due to a more compact structural network (Espert et al., 2022). This may have provided a croissant with a more compact, less airy and less layered crumb.

3.2.2. Texture of baked croissants

The texture of croissants formulated with oleogel and those formulated with shortening was compared using TPA analysis and penetration tests. Table 4 summarizes the results obtained in terms of hardness, elasticity, cohesiveness (TPA) and area under the curve (AUC, penetration).

Results for firmness (AUC) indicated that croissants formulated with WP and LBG were firmer in texture, requiring greater force to bite into, whereas the control croissant and those formulated with TW and SL were softer. The firmness of croissants increased as the number of flaky crumb layers decreased. This effect was more pronounced in LBG croissants. It stood out that croissants formulated with SL blend presented better cohesiveness compared to the other croissants and the use of oleogel did not affect the elasticity of the final croissants.

The croissant made with WP blend showed the highest compressive resistance, probably due to its clearly denser and more compact crumb. Croissants made with SL blend were the softest. However, those made with LBG blend, TW blend and control showed intermediate values.

Table 3
Effect of SH/OG blend in instrumental hardness, springiness and cohesiveness of fresh dough.

DOUGH	HARDNESS (N)	SPRINGINESS	COHESIVENESS
CONTROL	5.39^{b} (±0.98)	0.49^{b} (±0.12)	0.55^{b} (±0.06)
TW	8.34^{b} (±1.66)	0.92^{a} (±0.08)	0.77^{a} (±0.08)
WP	14.56^{a} (±2,22)	0.84^{a} (±0.03)	0.68^{ab} (±0.07)
SL	6.04^{b} (±0.77)	0.97^{a} (±0.44)	0.77^{a} (±0.02)
LBG	14.16^{a} (±1.69)	0.61^{b} (±0.04)	0.58^{b} (±0.05)

^{ab}Different superscript letters in each column denote significant differences ($p < 0.05$).

3.2.3. Sensory evaluation of baked croissants

Fat is a crucial ingredient in bakery products as it affects texture, mouthfeel, volume, color, and flavour (Garvey et al., 2020). A discriminative sensory test (triangular test) was conducted to determine if there were any differences between croissants made with solid fat and reformulated croissants. The triangular test is a commonly used analysis to evaluate products that are sufficiently homogeneous and to determine if there are differences between them (Barbieri et al., 2018). In this study, control and SL-blend croissant samples were presented to the panellists. These samples were chosen because the croissant with the SL blend showed similar structural and textural behaviour to the control. This study used crumb appearance and color, texture, and flavour as descriptors. According to Roessler et al. (1978), 30 triangle test responses would require at least 15 correct responses to be considered significant at the 95% confidence level. The study found that the panelists were able to distinguish between shortening-based and oleogel-based croissants in terms of appearance (19 correct responses), crumb color (20 correct responses), and texture (19 correct responses). However, no significant differences were observed in the flavour attribute (10 correct responses). It is important to note that this type of test only determines the panelists' ability to detect differences between samples. To determine the reasons for these differences and assess the acceptability of the croissants, an acceptability test was conducted with 99 consumers. The test evaluated appearance, texture, flavour, and overall liking. As depicted in Fig. 4, there were no significant differences in any of the evaluated attributes between the control croissant and the croissant formulated with oleogel blend. Therefore, although the consumers detected flavour differences between the two samples, the acceptability level was the same for both.

In terms of purchase intention, no significant differences were found between the samples either. The SL blend croissant scored 3.66 and the control croissant 3.55, based on a five-point scale. 18.8% of consumers would "definitely buy" the reformulated croissant with SL blend, and 42.4% would "probably buy" it. Therefore, 61.2% would buy it with a high probability. Regarding the control, 12.9% of consumers "would definitely buy it" and 45.9% "would probably buy it". That is, 58.8% would buy it.

3.3. Non-linear behaviour of selected doughs

After determining the optimal croissant formulation at the laboratory scale and characterizing it sensorially, it became necessary to evaluate the response of the doughs under real processing deformations. To ensure that a fat meets its desired functionality, it is necessary to analyze the full linear and non-linear rheological response, with particular emphasis on the non-linear response, as all processing and product uses involve large deformations (Macias-Rodriguez & Marangoni, 2017). Fourier transform rheology was applied to strain amplitude oscillatory tests in order to compare the response of croissant doughs (control and SL dough) in non-linear region (LAOS).

Lissajous-Bowditch plots were created to display both elastic (stress-strain) and viscous (stress-shear rate) properties (Fig. 5). The three strain amplitudes considered were 0.04% (within the LVR), 100% (close to the flow point, G' = G") and 250%. These plots illustrated the significant difference between the linear and non-linear regimes. At 0.04% strain, the Lissajous curves exhibited an ellipsoidal shape with a short semi-minor axis and small area, indicating linear viscoelastic behaviour as stated by Huang, Guo, and Zhang (2023). Both the control and SL dough showed a similar area with a closed form, representing an elastic response of stress versus strain in LVR. As the strain increased, the elliptical shape distorted into a parallelogram with a significant increase in area. The given data indicates a non-linear behaviour with increasing dissipation of the mechanical energy in one cycle. According to Liu, Jiang, Xu, and Jiang (2023), the weakening of viscoelastic networks can

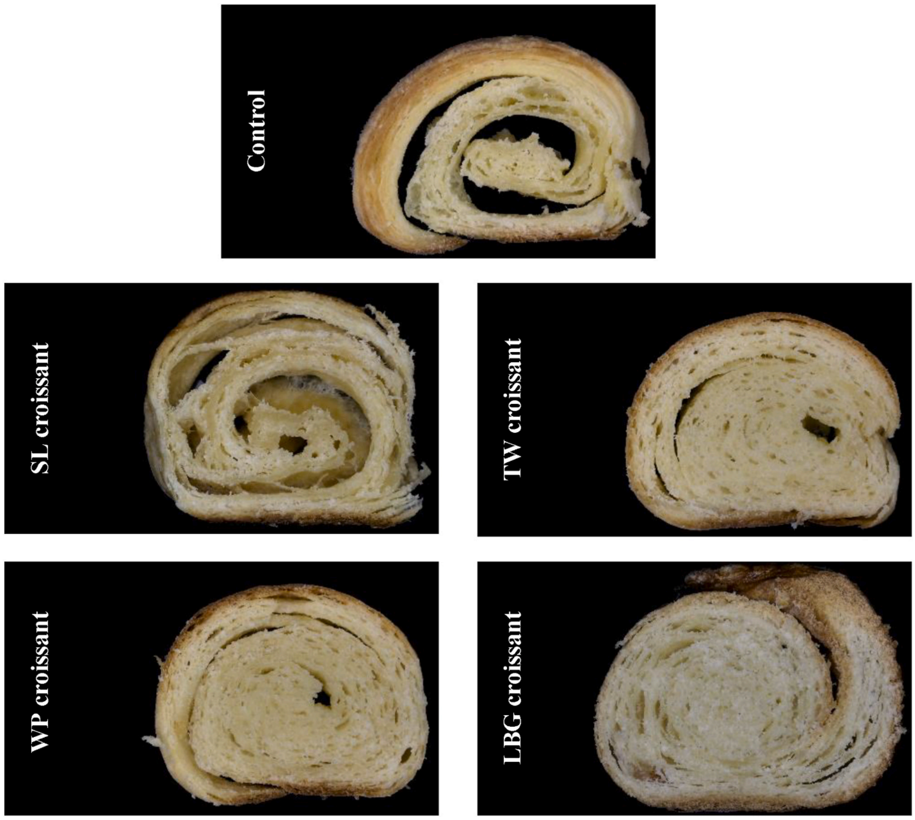

Fig. 3. Appearance of the different sliced croissants. Magnification 5.61x.

Table 4
Effect of SH/OG blend in TPA and penetration values of baked croissants.

CROISSANT	HARDNESS (N)	SPRINGINESS	COHESIVENESS	AUC (N s)
CONTROL	38.28[ab] (±4.71)	0.74[a] (±0.06)	0.34[b] (±0.04)	220.86[b] (±33.75)
TW	32.61[b] (±1.38)	0.72[a] (±0.02)	0.42[b] (±0.02)	210.55[b] (±1.95)
WP	41.52[a] (±1.83)	0.76[a] (±0.02)	0.44[ab] (±0.02)	323.70[a] (±39.90)
SL	19.28[c] (±1.39)	0.76[a] (±0.02)	0.53[a] (±0.02)	189.25[b] (±22.58)
LBG	38.92[ab] (±1.54)	0.79[a] (±0.01)	0.45[ab] (±0.05)	362.83[a] (±5.49)

[abc]Different superscript letters in each column denote significant differences ($p < 0.05$).

cause stress-strain curves to rotate clockwise, indicating a shift from elasticity-dominated to viscosity-dominated behaviour. Furthermore, changes in viscous Lissajous curves were observed in a similar way in both doughs. At large deformations, the shape of the object changed from an ellipse to a rhombus, indicating a more non-linear viscous response (Huang et al., 2023).

To obtain information for the entire strain range, we determined the strain hardening (S) and shear thickening (T) ratios (Duvarci, Yazar & Kokini, 2017). These ratios are considered a dimensionless index of non-linearity (Wang & Selomulya, 2022). Fig. 6 displays the S and T parameters for both doughs, which turned to be very similar. Up to approximately 10% strain, the S and T parameters were equal to zero, which is in accordance with the linearity of the elastic and viscous components and the ellipsoid shape of the Lissajous plots. Beyond the linear region, the S values increased up to values close to 1 at the largest strain amplitude of 1000%. This corresponds to intracycle strain stiffening behaviour ($S > 0$). On the other hand, negative T values were

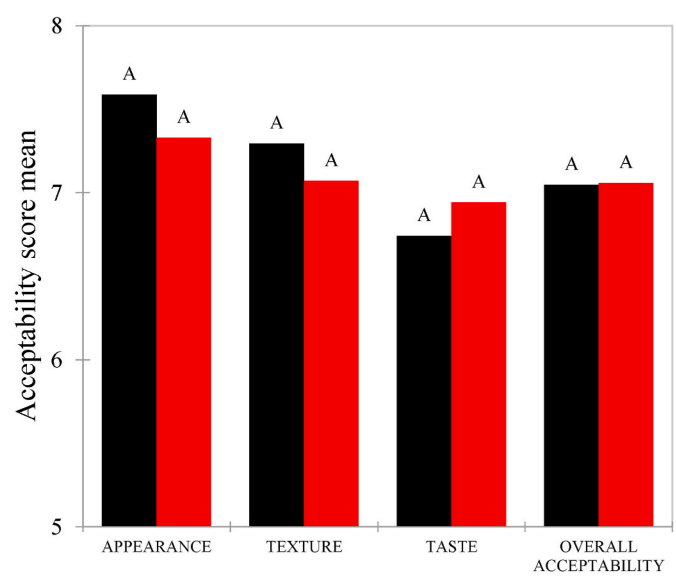

Fig. 4. Consumer acceptability of control croissant (■) and SL croissant (prepared with dough containing soy lecithin-based oleogels) (■).

observed for both dough samples at high strains, indicating an intracycle shear thinning behaviour (T values < 0). This behaviour reflected the shear thinning response at large strains, which might be due to further breakdown of the dough structure.

4. Conclusions

The aim of this work was to investigate to what extent the presence of sunflower oil oleogel-XG and different structuring agents affected the

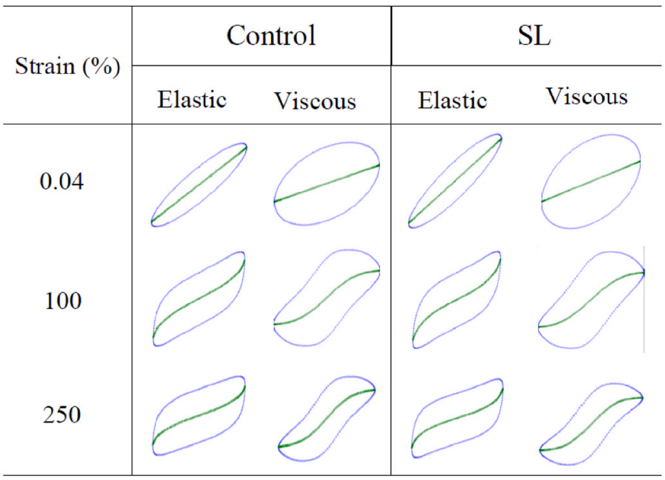

Fig. 5. Normalized elastic (stress-strain) and viscous (stress-strain rate) Lissajous-Bowditch curves of control dough (100% shortening) and reformulated dough (containing soy lecithin-based oleogels, SL). Total stress (—), elastic stress and viscous stress (—).

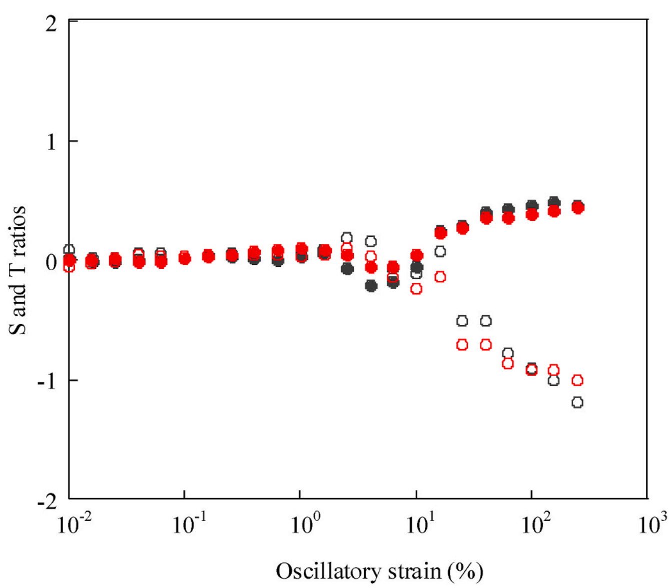

Fig. 6. Strain-stiffening ratio, S (filled symbols) and shear-thickening ratio, T (open symbols) as a function of oscillatory strain amplitude for control dough (●) and SL dough (prepared with dough containing soy lecithin-based oleogels) (●).

rheological properties and sensory quality of reformulated croissants, comparing with a control croissant with commercial shortening. After mechanical characterization of doughs and baked croissants formulated with oleogel-fat blends, formulations containing SL were chosen as the optimal ones. The behaviour of the SL dough was identical to that of the control dough when subjected to real processing deformations, deduced from LAOS measurements. These high deformations applied to the dough allow to know its behaviour during processing, which is crucial to know the real viability of the reformulated dough. Therefore, the dough elaborated with SL blend turned out to be a healthier alternative to the traditional dough. As for the final baked croissants, both texture and appearance of the crumb of croissants containing SL blend were the most similar to the conventional croissants. Sensory analysis corroborated these results in terms of both acceptability and purchase intention. The results obtained in this work could be useful for the design of laminated doughs that provide a more unsaturated lipid profile, with technological and sensory characteristics similar to the conventional product.

CRediT authorship contribution statement

M. Espert: Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **A. Salvador:** Writing – review & editing, Supervision, Investigation, Funding acquisition, Conceptualization. **T. Sanz:** Supervision, Investigation, Funding acquisition, Conceptualization. **M.J. Hernández:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors of the article titled "**Replacing solid fat in croissant dough using xanthan gum-based oleogels. Impact on rheological properties and final product quality**" declare that there is no conflict of interest.

Data availability

The authors do not have permission to share data.

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