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Effect of cellulose ether emulsion and oleogel as healthy fat alternatives in cream cheese. Linear and nonlinear rheology, texture and sensory properties

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ABSTRACT

The suitability of oil-in-water (o/w) hydroxypropyl methylcellulose (HPMC)-based emulsions and oleogels to reduce total fat and saturated fat content in cream cheese was studied. The effect of HPMC emulsions and oleogels on spreadability, viscoelasticity, and sensory acceptability of cream cheese was evaluated. Small-amplitude oscillatory shear (SAOS) and large-amplitude oscillatory shear (LAOS) tests were performed to investigate linear and nonlinear rheology. All cheeses showed a predominance of G' versus G" with a light dependence of both moduli with frequency in the linear viscoelastic region (LVR). Fat replacement with emulsion or oleogel significantly reduces the values of G' and G" at the LVR, yield point, and flow point, and increases spreadability. This effect was greatest for the oleogel substitution. However, incorporation of emulsion or oleogel did not significantly affect tan δ, yield stress, yield strain, flow stress, and flow strain. The elastic and viscous evolution during the transition from SAOS to LAOS was similar in all cheeses, despite their differences in spreadability. At large deformation, all samples showed strain-stiffening and shear-thinning behavior. Similar sensory acceptability was found among the oleogel and emulsion cheeses and the control. The similar nonlinear rheological properties among cheeses do not explain the differences in spreadability properties, but explain their similar sensory acceptability. Furthermore, the purchase intention for oleogel and emulsion cheeses increases when consumers receive information on the type and amount of fat.

1. Introduction

Cream cheese is a semi-soft dairy product with a wide diversity in flavor and form that varies with the ingredients of the formulations (Wendin, 2000). Fat is an essential ingredient that provides many textures, spreadability, and with ease of being mixed with other constituents. However, excessive fat consumption, mainly saturated fat and *trans* fatty acids, can increase the risk of several chronic diseases such as obesity, cardiovascular disease, and cancer (Demirkesen & Mert, 2020; Espert, Hernández, Sanz, & Salvador, 2021). The growth of obesity has also increased consumer awareness to adopt healthier diet strategies, resulting in increased demand for low-fat foods (Espert, Salvador, & Sanz, 2020; Mert & Demirkesen, 2016). However, in cream cheese, fat reduction has been associated with textural and flavor changes that affect consumer's purchase intention (Ningtyas, Bhandari, Bansal, & Prakash., 2019). Ningtyas, Bhandari, Bansal, and Prakash. (2018) used β-glucan (BG) and phytosterols (PS) as fat substitutes, showing that BG increased the viscosity and hardness of reduced-fat cream cheese, whereas PS improved its spreadability. Zetzl, Marangoni, and Barbut (2012) directly used liquid oils rich in unsaturated fatty acids to replace saturated fats, but the textural properties of the final product were not satisfactory. The structure of these fat replacers differed from that of traditional solid fats, decreasing the sensory properties of cheese (Ningtyas, Bhandari, Bansal, & Prakash, 2019).

In previous studies, cellulose ether emulsions and sunflower oil-based oleogels have been used successfully to reduce total fat and saturated fat content in different foods (Espert et al., 2021). In comparison to butter: 55% saturated fat and 80% total fat, cellulose ether emulsions contains: 3.8% saturated fat and 47.5% total fat (sunflower oil) and oleogels contains: 96.7% total fat and 7.8% saturated fat, so replacement one by one of butter by oleogels reduces saturated fat, and replacement of butter by emulsion reduces saturated fat and total fat.

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Oleogelation represents a promising technique for structuring liquid oils into gels with a three-dimensional network (Patel et al., 2014), which possesses solid fat-like characteristics capable of replacing the traditional triacylglycerol crystalline fat network. Bemer, Limbaugh, Cramer, Harper, and Maleky (2016) explored the possibilities of oleogels prepared with rice bran wax or ethylcellulose incorporated with vegetable oil to be used in cream cheese products. The total fat content of all oleogel cream cheeses was reduced by 25% compared to the control, indicating that vegetable-based oleogels can effectively improve the fatty acid composition of cream cheese products. In another study, Clifford Park (2018) used rice bran wax (RBW) and high-oleic soybean oil oleogels as fat substitutes in cream cheese, stating that thermal processing and storage had a minor effect on the degradation of rice bran wax oleogels, which could contribute to their potential application in dairy products.

The composition of cheese deeply affects its texture. Variation in the composition of fat content can alter the balance between fat, protein, carbohydrate, and water, inducing a perceptible textural change (Banks & Weimer, 2007) and affecting the rheology, spreadability, and organoleptic properties of cream cheese in different dimensions. Small-amplitude oscillation shear (SAOS) is conducted in the linear viscoelastic area to measure the mechanical properties of food products (Bayarri, Carbonell & Costell, 2012). Ningtyas, Bhandari, Bansal & Prakash (2017) reported the impact of fat globules in the protein network on the texture and consumer acceptance of cream cheese. Cheese with different fat content had favorable viscoelasticity, non-Newtonian, and shear-thinning behaviors. However, the limitation of SAOS is that it cannot provide near-realistic information on viscoelasticity under large deformations related to food processing or oral processing once the amplitude exceeds the linear elastic region. Therefore, large-amplitude oscillation shear (LAOS) can fulfill these expectations and has become an ideal method to simulate food processing or variation of eating experience by controlling the amplitude and frequency to change the strength or timescale, so the type and intensity of physical movement in the sample is more realistic and closer to real conditions. Structural information provided by SAOS measurements are enlarge by LAOS. The nonlinear mechanical response of kashar cheese for different applications was explored at strain values ranging from 0.196% to 359% (Yildirim-Mavis et al., 2022). Zad Bagher Seighalani and Joyner (2019) compared the variability of different types of cheeses in terms of nonlinear viscoelastic parameters using Lissajous curves. Melito, Daubert, and Foegeding (2013) determined the nonlinear viscoelastic properties of reduced-fat and low-fat Cheddar cheeses and investigated their correlation with rheological, sensory, and oral processing properties. Furthermore, the preparation of vegetable oil oleogels was successfully used to produce cream cheese with a high unsaturated fat content and a low saturated fat content using carnauba wax (K. Moon, 2021) and rice bran wax or ethylcellulose (Bemer et al., 2016). Anvari & Joyner (Melito) (2019) also found that low-fat cheeses prepared with emulsions showed greater nonlinearity with smaller critical stress and modulus values under LAOS. Comprehensive reports on the effects and correlations of fat substitution on texture, rheological properties, and sensory characteristics of low-fat cream cheese products have not been reported. Therefore, the purpose of this study was to verify for the first time the feasibility of HPMC emulsions and oleogels as a substitute for saturated fat in cream cheese formulations and to understand the relevance of SAOS and LAOS in the texture and sensory acceptability of cream cheese. The effects of these fat replacers in cream cheese were investigated using a combination of SAOS, LAOS, spreadability, and sensory evaluation, to better understand the relationship between the structure of cream cheese and the final quality.

2. Materials and methods

2.1. Materials

Hydroxypropyl methylcellulose (HPMC) (29% methoxyl, 6.8% hydroxypropyl) was supplied by The Dow Chemical Company (Bomlitz, Germany). High-oleic sunflower oil (Deoleo S.A., Córdoba, Spain), whole milk (Gaza, Zamora, Spain), vinegar (Sabater, Murcia, Spain), butter (Central Lechera Asturiana, Spain) (composition per 100 g: 82 g of fat included 55 g of saturated fat, 0.4 g of sugar, 0.6 g of protein, and 0.03 g of salt), and salt were purchased from a local supermarket.

2.2. Preparation of emulsion, oleogel and fat blends

HPMC emulsion and oleogel were prepared, as previously reported by Wang et al. (2023). In summary, 3 g of HPMC powder was dissolved in 103 g of sunflower oil, then 94 g of cold water (10 °C) was gently added to the oil phase while continuously stirring with a Heidolph stirrer (Heidolph Instruments GmbH & Co. KG) at 300 min^{-1} for 2 min. The viscous emulsion formed was subsequently homogenized using an Ultra-Turrax T18 homogenizer (IKA, Germany) at 16,500 rpm for 1 min. The above emulsion (1.5% HPMC, 47% oil content, 51.5% water content, w/w) was then placed in a 60 °C drying oven (Binder GmbH, Germany) for 48 h to achieve a moisture content lower than 0.5%. The solid obtained after crushing was oleogel (3% HPMC and 97% oil content, w/w). For the preparation of 50/50 emulsion and fat blends (EM-50%) or 50/50 oleogel fat blends (OL-50%), 10 g of butter was semi-melted in a water bath at 40 °C and mixed with 10 g of oleogel or 10 g of emulsion and stirred uniformly. Cream cheese prepared with 100% butter as fat source was used as control, 100% emulsion and 100% oleogel prepared cream cheese were labeled as EM-100% and OL-100%, respectively.

2.3. Cream cheese-making process

Five hundred grams of whole milk was stirred and heated at 90 °C for 10 min. 10 g of vinegar was then added to adjust the acidity of the milk to pH 5.0, and the mixture was filtered with gauze over 30 min. 120 g of the solids collected (curd) were placed in a food processor (Thermomix 31, Vorwrek, Wuppertal, Germany) and 15 g of fat (butter, oleogel, emulsion, or fat blend) and 0.5 g of salt were added. Last, all ingredients were mixed at a speed of 200 rpm for 1 min to obtain the cream cheese. All cream cheeses were stored at 4 °C prior to all tests.

2.4. Spreadability

A TA.XT. plus texture analyzer (Stable Micro Systems Ltd. Surrey, UK) equipped with a 90° conical spread test probe (TA-425 TTC Spreadability RIG) was used for the experiments. Before measurement, the cream cheeses were filled bubble-free into the inner cavity of the cone sample holder and gently flattened with a spatula to avoid air incorporation. Sample temperature during the texture measurements was 10 °C. As during the holding process, the sample temperature increased to more than 10 °C, the sample inside the holder was placed again in the refrigerator at 4 °C for approximately 10 min, as the necessary time to achieve a sample temperature of 10 °C. The test conditions were as follow, test speed: 1 mm/s, test distance: 22.5 mm, and trigger force: 1.0 g. Measurements were conducted by pressing the sample between the two cones with a male cone and returning to the initial position to obtain force versus time data to calculate the maximum force and area under the curve. The maximum force represented the firmness of the sample. The area under the curve (AUC) represented the ease of the shearing process referred to as spreadability.

2.5. Rheological measurements

All rheological tests on cream cheese samples were conducted on a controlled stress rheometer model AR-G2 (TA Instruments, Montreal, QC, Canada) equipped with a 40 mm rough parallel plate geometry and a Peltier temperature control system. All samples were measured at 10 °C, with a 1 mm gap setting and 5 min of equilibration before each test. Three measurements were made on each sample from different batches. Strain sweeps were performed at 1 Hz in a strain amplitude of 0.01–1000%, and Fourier transform rheology and orthogonal stress decomposition (Ewoldt, Hosoi, & McKinley, 2008) were used on the raw waveform data to evaluate linear and nonlinear responses to strain. Frequency sweeps inside the linear viscoelastic region (LVR) were performed from 10 to 0.01 Hz. The information of yield point and flow point of all samples were recorded. γ_y, and σ_y were the value of the shear stress and strain at the linearity limit of the LVE region (yield point). γ_f, and σ_f were the value of the shear stress and strain at the crossover point ($G' = G''$, flow point).

2.6. Sensory evaluation

Ninety students and fellows from the Institute of Agrochemistry and Food Technology (IATA-CSIC) were invited to evaluate the sensory characteristics of cream cheese. The sensory test was conducted in a standardized sensory evaluation room with 10 separate booths. Samples were prepared the day before and refrigerated at 4 °C. Five samples identified with a random computer-assigned code were tested. A nine-point hedonic scale from 1 (extremely disliked) to 9 (extremely liked) was used to measure the appearance, texture, taste, spreadability, and overall rating acceptability of the cream cheese, as well as the flavor of cream cheese coated with crackers. All participants will be required to read and sign the informed consent form prior to the start of the test. Before each test, participants were notified to take a 30-s interval and rinse their mouth before evaluating the next sample to minimize interference between samples.

A questionnaire with a 5-point scale was used to assess the intention to purchase cream cheese, with 0 indicating that it would not be purchased and 5 indicating it would definitely be purchased. First, participants were evaluated without being given information about the cream cheese recipe. Similarly, a 30s interval was required between each sample and mouth rinsing before the next sample could be evaluated. The second part of the test was carried out with the participants being informed about the cream cheese recipe information and the steps were the same as in the first part.

2.7. Data analysis

The rheological data were processed with TRIOS 5.4 software (TA Instruments, USA). The results were analyzed by one-way analysis of variance (ANOVA) using the XLSTAT software system (2019.2.2). Significant differences between means ($p \leq 0.05$) were analyzed with Tukey's test. Data were represented as mean ± deviation (SD). All tests were repeated at least three times to ensure the accuracy of the experimental data. Principal Component Analysis (PCA) was performed to correlate instrumental parameters and sensory attributes.

3. Results and discussion

3.1. Spreadability

Spreadability is a texture property required in cream cheese. It represents the ease of distributing the cheese in a layer over a surface. Spreadability is negatively correlated with firmness (maximum force) and with the area under the penetration curve. Higher values of firmness and area under the curve (AUC) indicate a lower spreadability. The firmness and AUC values of the different formulations studied are shown in Table 1. Cream cheese prepared with 50% emulsion or 50% oleogel did not significantly differ from the control. The lowest firmness and area were found with complete replacement of butter by oleogel (OL-100%). The replacement of butter by the emulsion also significantly decreases the firmness and area values at 100% replacement compared to the control, although the effect was lower than for the oleogel. In OL-50% and EM-50%, only the AUC value corresponding to OL-50% was significantly lower than that of the control. Furthermore, the 100% emulsion cream cheese was not significantly different from 50% oleogel cream cheese. The increase in cheese spreadability due to the total replacement of butter by the oleogel and the emulsion could be explained by a casein matrix-breaking effect, or as a reduction of the fat crystal in butter, which increased softness, as speculated by other authors. Bemer et al. (2016) reported that cheese made from oleogel using RBW or ethylcellulose had higher spreadability. The increased size of the fat globules would weaken the interaction between the proteins in the internal network, resulting in a softer texture of the cheese product (Noronha et al.,2008; O'Riordan, & O'Sullivan, 2008). Anvari and Joyner (2019) considered that emulsions with negative charges or neutralized interfaces inhibited the interaction between casein and oil phases during cheese making, reducing the strength of the casein network. Using hydrocolloids as fat substitutes in cheese decreases the density and continuity of the matrix. By binding to water molecules and forming colloidal lumps or networks throughout the protein matrix, the fat replacers based on hydrocolloids act as casein matrix-breakers (Everett & Auty, 2008). Joyner, Francis, Luzzi, and Johnson (2018) suggested that flowable emulsions could weaken cheese structure as flocculated droplets generated more and larger voids in the microstructure of the cheese, which disrupted the continuity of the casein matrix, resulting in the internal microstructure of the cheese being more vulnerable to rupture, causing the cheese to become softer (Anvari and Joyner, 2019). However, other studies have found an improvement in the cheese firmness caused by some hydrocolloids (Hosseini-Parvar, Matia-Merino, & Golding, 2015). The increase in spreadability due to the total replacement of butter by the oleogel and the emulsion could also be explained due to the disruption of the underlying structure of the colloidal network constructed by shortening the crystalline particles (Patel et al.,2020; Nicholson, & Marangoni, 2020), thus reducing the mechanical properties of cream cheese and making it softer. Spreadability was an essential factor to be considered in the improvement of cream cheese formulations because favorable spreadability not only benefited the production and processing of cream cheese, but also made the cream cheese smoother and easier to spread uniformly, which would enhance the texture and aesthetics of the food products, and thus increased the attractiveness of the cream cheese products to the consumers.

3.2. Amplitude sweeps of cream cheeses

To comprehensively analyze the effect of emulsion and oleogel on

Table 1
Mean values of the spreadability test parameters of the different cream cheeses at 10 °C.

Samples	Firmness (N)	AUC (N s)
Control	86.27 ± 14.25^{A}	170.47 ± 29.40^{A}
OL-50%	77.99 ± 7.19^{AB}	135.29 ± 19.20^{B}
EM-50%	89.01 ± 5.79^{A}	151.45 ± 6.86^{AB}
OL-100%	54.37 ± 6.49^{C}	94.37 ± 7.67^{C}
EM-100%	65.26 ± 3.69^{B}	132.46 ± 10.40^{B}

* Control: cream cheese prepared with butter; OL-50%: cream cheese prepared with 50% oleogel and 50% butter; EM-50%: cream cheese prepared with 50% emulsion and 50% butter; OL-100%: cream cheese prepared with 100% oleogel; EM-100%: cream cheese prepared with 100% emulsion. Different letters in the same column represent significant differences according to Turkey test ($p < 0.05$).

the viscoelastic properties of cream cheese, the variation of the storage modulus (G') and loss modulus (G") of the cheese during a strain amplitude sweep was studied (Fig. 1). All cream cheese samples presented a predominance of G' versus G" in the LVR. In both oleogel and emulsion cheeses, a decrease in G' was observed with an increasing level of butter substitution. Like the spreadability parameters, at 100% butter substitution, both G' and G" of cream cheese prepared with oleogels were lower than those prepared with emulsions. Section 3.1 mentions that the breaking effect in the cheese protein matrix explains this, especially for the oleogel over the emulsion.

To characterize the LVR, mean values of constant storage modulus (G'_0) and loss tangent ($\tan \delta_0$) corresponding to the plateau region were calculated (Table 2). The highest G'_0 values were found in the control cheese with no significant differences compared with 50% oleogel cheese. The increase in replacement from 50% to 100% significantly decreases G'_0 for both oleogel and emulsion, indicating a decrease in network rigidity compared to the control cheese. Values of $\tan \delta_0$ in the linear region were between 0.22 and 0.24, implying a solid-like behavior, with no significant differences among samples.

Above a critical strain value, both G' and G" decreased when strain amplitude increased, denoting the end of the LVR. To quantify the extension of the LVR, values of yield stress (σ_y) and corresponding strain (γ_y) were calculated (Table 2). The yield point was calculated considering a 5% deviation from the plateau (Mezger, 2020). These yield values determine the starting point for weakening of gel strength (Yousefi & Razavi, 2015). No significant differences in σ_y and γ_y were found among samples, indicating that all types of cheese require similar stress to reach the same strain value and that the extent of their linear behavior response is similar. Yield stress values between 30 and 40 Pa had to reach small strain values, from 0.3% to 0.5%.

At higher strain values, a crossover between G' and G" defined as the flow point, was observed. The values of flow point, the corresponding strain (γ_f) and stress (σ_f) are also shown in Table 2. Like to G'_0, the values of the flow point (G' = G") decrease with increasing butter replacement, although no significant differences were found between the control and the sample with 50% oleogel. Furthermore, there was no significant difference between the three cream cheese groups prepared from 50%-emulsion as well as 100% emulsion and 100% oleogel, but the G' values were significantly lower than those of the control and 50% oleogel groups. No clear differences were found in γ_f and σ_f among cheeses, probably associated to the high coefficient of variation of these parameters, values of around 1000 Pa were required to reach a deformation of approximately 110%.

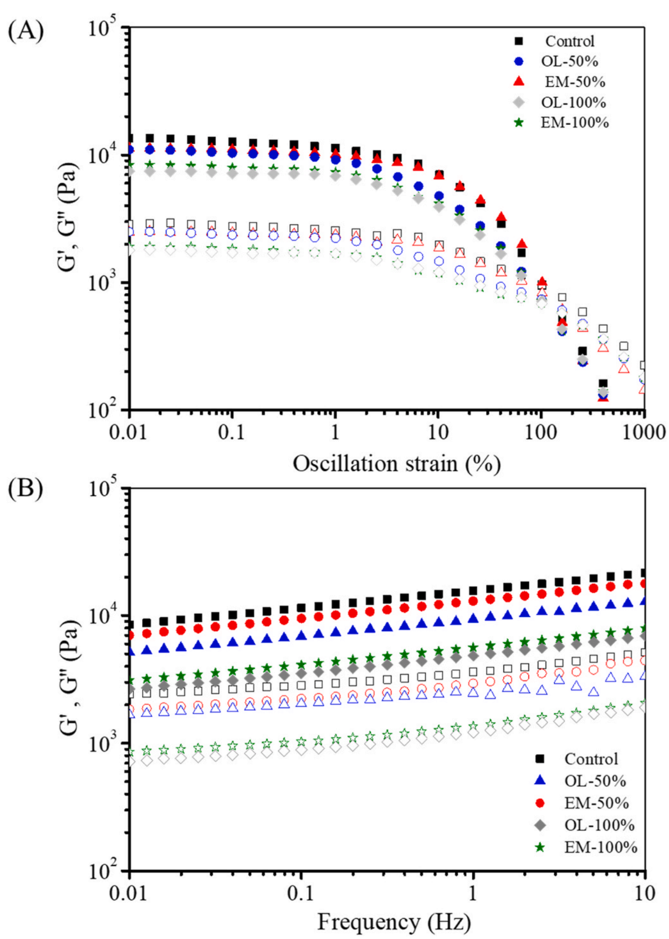

Fig. 1. Strain sweep (A) and frequency sweep (B) of the different cheeses, ■ represents G′, □ represents G".

3.3. Frequency sweep of cream cheeses

The effect of frequency in the values of G' and G" in the linear region was shown in Fig. 1b. For all formulations, the values of G' were always higher than G" along the complete frequency sweep studied with a light dependence of both G' and G" when frequency increased, revealing a cheese viscoelastic behavior typical of soft gels. Addition of oleogel and emulsion to replace butter in cream cheeses decreased G' and G" values, and the effect increased by increasing butter replacement. No changes in the ratio G"/G' associated with butter replacement were observed (Table 2), where no significant differences of $\tan \delta_0$ calculated at 1 Hz were found between the control and the oleogel and emulsion cheeses.

3.4. Laos rheology analysis of cream cheeses

In oscillatory strain sweep tests conducted over a wide deformation strain amplitude range (from 0.01 to 1000%), both the linear and nonlinear deformation regimes of all cheese are shown (Fig. 1a). Due to the light frequency dependence of both G' and G" observed in the frequency sweep (Fig. 1b), measurements were conducted only at a single frequency of 1 Hz.

To further investigate the rheological behaviors of samples in the strain amplitude range from SAOS to LAOS, Lissajous–Bowditch plots (Joyner & Meldrum, 2016; Szopinski & Luinstra, 2016) were used to qualitatively analyze the elastic and viscous variation of samples over the strain interval, providing insight into the structural transformation of the material under large deformations and consequently anticipate the behaviors of the material during processing and application. Strain values of 0.1%, 100%, and 1000% were selected to investigate the transition from linear to nonlinear behavior of cream cheese. The total stress response as a function of strain (elastic Lissajous–Bowditch curves) and the total stress as a function of strain rate (viscous Lissajous–Bowditch curves) are shown in Fig. 2A and B, respectively. These curves show separately the elastic and viscous stress contributions. The elastic Lissajous–Bowditch plots for all cream cheeses were elliptical at 0.1% strain, indicating an ideal viscoelastic behavior. The viscoelastic behavior of cream cheese shifted from the linear to the nonlinear region as the strain increased to 100% (near the intersection of G' and G"). The gradual enlargement of the ellipse area indicated an enhancement of nonlinear behavior for all samples resulting from the input of strain energy, leading to the energy dissipation (Yazar, Caglar Duvarci, Yildirim Erturk, & Kokini, 2019). Finally, the elastic Lissajous–Bowditch plot of all cream cheeses varied from an ellipse to a sub-parallelogram as the strain rose to 1000%, which indicated an increase of viscous dissipation and a transfer from an elastic to a viscous predominant behavior (Fuongfuchat et al., 2012). Joyner and Meldrum (2016) believed that the nonlinearity increase observed at higher strains could be attributed to microstructural deformation, which resulted in permanent deformation and fluidity and exhibited a viscous dominant behavior in Lissajous.

The viscous Lissajous–Bowditch curve represents the stress as a

Table 2
Mean values of parameters that characterize strain sweeps for the different cheeses studied. G_0' and tan δ_0 correspond to the storage modulus and loss angle for the plateau region in LVR and γ_y, γ_f, σ_y, σ_f correspond to the strains and stresses at the yield point and the flow point, respectively.

Sample	LVR-Yield point				Flow point		
	G_0' (Pa)	tan δ_0	γ_y (%)	σ_y (Pa)	G' = G" (Pa)	γ_f (%)	σ_f (Pa)
Control	11,760 ± 863^{A}	0.22 ± 0.01^{A}	0.31 ± 0.14^{A}	37.40 ± 8.42^{A}	805 ± 121^{A}	101 ± 6^{B}	1180 ± 119^{AB}
OL-50%	11,039 ± 841^{A}	0.23 ± 0.00^{A}	0.37 ± 0.05^{A}	42.01 ± 5.53^{A}	869 ± 118^{A}	109 ± 8^{AB}	1357 ± 238^{A}
EM-50%	8401 ± 534^{B}	0.23 ± 0.00^{A}	0.44 ± 0.09^{A}	37.59 ± 7.38^{A}	604 ± 28^{B}	119 ± 8^{A}	1021 ± 34^{BC}
OL-100%	5771 ± 862^{D}	0.24 ± 0.00^{A}	0.49 ± 0.11^{A}	29.72 ± 10.25^{A}	587 ± 60^{B}	109 ± 2^{AB}	909 ± 103^{C}
EM-100%	7250 ± 310^{C}	0.23 ± 0.01^{A}	0.35 ± 0.10^{A}	28.93 ± 7.06^{A}	612 ± 43^{B}	116 ± 10^{AB}	1003 ± 61^{BC}

* Control: cream cheese prepared with butter; OL-50%: cream cheese prepared with 50% oleogel and 50% butter; EM-50%: cream cheese prepared with 50% emulsion and 50% butter; OL-100%: cream cheese prepared with 100% oleogel; EM-100%: cream cheese prepared with 100% emulsion. Different letters in the same column represent significant differences according to Turkey test ($p < 0.05$).

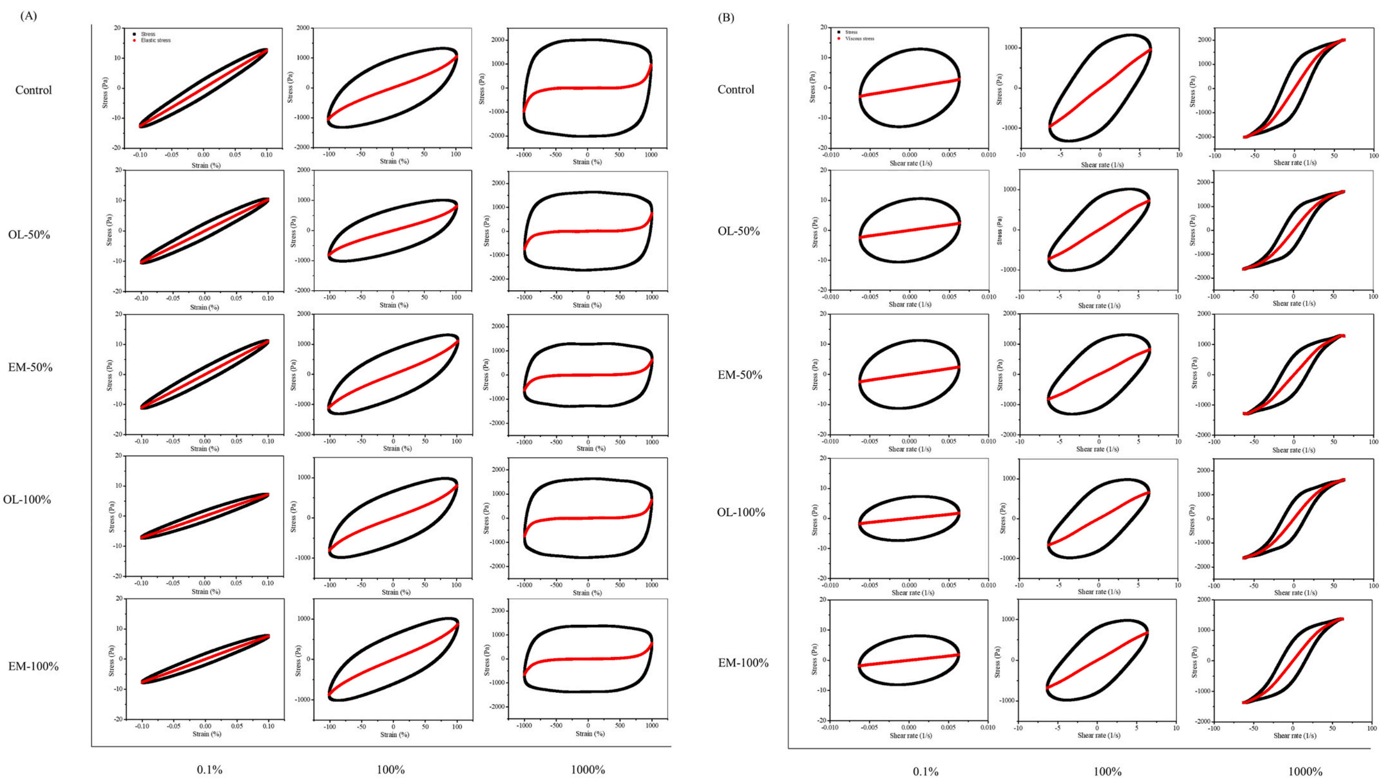

Fig. 2. Lissajous–Bowditch curves for cream cheeses for 0.1, 100 and 1000% strain amplitudes, (A) is normalized elastic Lissajous–Bowditch (stress-strain) and (B) is viscous Lissajous–Bowditch (stress-strain rate).

function of the strain rate. The variation in the viscosity of cream cheese in the strain interval is shown in Fig. 2B. All cream cheeses exhibited a deformed elliptical shape at low strain rates, as strain grew, the elliptical area gradually decreased and ultimately inclined to an S-shape, which indicated a nonlinear behavior of the sample with viscous shear thinning (Ewoldt et al., 2008; Li et al., 2021; Szopinski & Luinstra, 2016). At the highest strains, the rheological behavior of cream cheese is more flow-oriented (Yazar et al., 2019).

To evaluate the nonlinear behavior of samples over the entire strain range, Ewoldt, Winter, Maxey, and McKinley (2010) defined the stress-stiffness ratio (S-value) and shear-thickening ratio (T-value). The S ratio corresponds to the relative differences in the *minimum strain elastic modulus*, G'_M, and the *large strain elastic modulus*, G'_L; and T ratio corresponds to differences in the *minimum strain rate viscosity*, η'_M and the *large strain rate viscosity*, η'_L (Ewoldt et al., 2008; Yazar et al., 2019).

$$S = \frac{G'_L - G'_M}{G'_L}$$

$$T = \frac{\eta'_L - \eta'_M}{\eta'_L}$$

$S > 0$ shows intracycle strain stiffening, which means deformation rate decreases when increasing strain; $S < 0$ shows intracycle strain softening, i.e. deformation rate increases when increasing strain. In contrast, $T > 0$ represents intracycle shear thickening (increasing viscosity with increasing strain rate) and $T < 0$ corresponds to intracycle shear thinning (decreasing viscosity with increasing strain rate) (Duvarci et al.,2017; Yazar, & Kokini, 2017).

As shown in Fig. 3, the S values of all samples remained approximately 0 in the LVR (strain <10%), and then the S values of all cream cheeses exhibited a strain-stiffening behavior as the strain increased. Similar results were shown by Precha-Atsawanan, Uttapap, and Sagis (2018). In terms of T values, in all samples, a decrease is observed with increasing strain ($T < 0$), showing a remarkable shear-thinning behavior. The absolute value of T was always much lower than the value of S during the large deformation occurrence, indicating that the nonlinear behavior of cream cheese under large deformation was strain stiffening predominant.

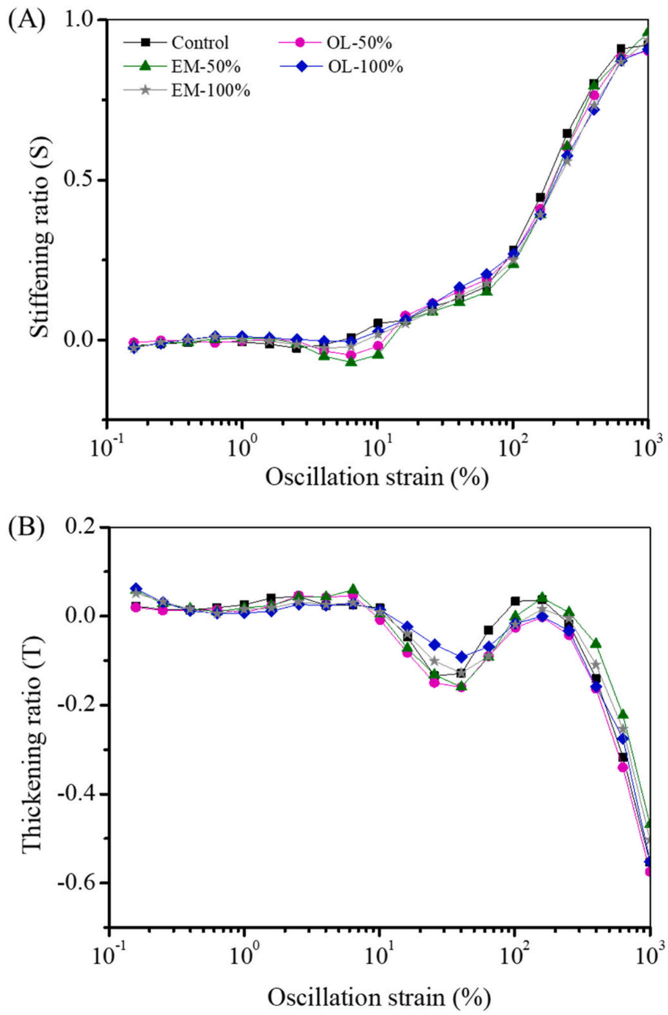

Fig. 3. Variation of Stiffening ratio (plot A) and Thickening ratio (plot B) with strain of cream cheese prepared with the different fat sources.

3.5. *Sensory evaluation*

The mean values of the sensory acceptability scores for the appearance, texture, spreadability, and flavor of the cream cheese are shown in Table 3. No significant differences among the different type of cheese were found in appearance ($p > 0.05$). In terms of texture, the average score of the OL-100% group was significantly different from the average scores of the OL-50%, EM-50% and EM-100% groups. Oleogel cream cheese (100%) showed the significantly lowest flavor acceptability, this may be due to the fact that the flavor of the oleogel itself had some effect on the cream cheese, but did not appear in the other samples. As for spreadability, all samples prepared with oleogel and emulsion exhibited significantly higher spreadability compared to the control group, which was consistent with the previous instrumental texture results. Regarding the flavor of the cream cheese with cracker spread and the overall score, it was shown that there was no significant unfavorable effect of emulsion or cream on the cream cheese, and even the flavor with cracker was significantly higher for the 50% oleogel and 50% emulsion cheeses compared to the control group. Moreover, cream cheeses produced with 100% emulsion or oleogel could completely replace the conventional fat in cream cheese as their flavor scores with cracker and total scores were not significantly different from the control group.

Fig. 4 shows the purchase intention of consumers before and after being informed of the cream cheese fat formulation. The percentage of unwillingness to buy control, 50% oleogel, and 50% emulsion cheese increased after consumers were informed about the type of fat, whereas the percentage of probably or definitely would purchase decreased. In contrast, the percentage of definitely would purchase for 100% emulsion-prepared cream cheese increased from 18.5% to 25%, followed by cheese with 100% oleogel, which increased from 9.8% to 15.2%. This increase in purchase intention of the emulsion and oleogel cheeses indicates the importance given by consumers to the nutritional aspects, especially for a healthier fat profile with a reduction in the content of saturated fatty acids.

The correlation among instrumental texture parameters, rheological parameters inside and outside the linear viscoelastic region and the consumers acceptability were studied by PCA (Fig. 5). The first two components explained 70.93% of the overall variability. The first dimension (F1) accounted for 46.39% of the variability and separate the samples according to their emulsion and oleogel content. The control and the samples with 50% replacement (EM-50% and OL-50%) are closely displayed in the right side of the plot and associated to the

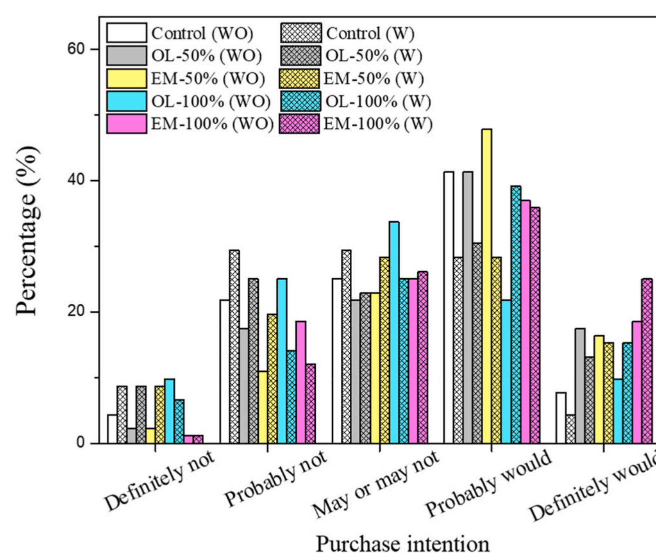

Fig. 4. Intention to purchase the different cream cheeses. WO means that the test was carried out without information about cream cheese recipe. W means that the test was conducted with the information about cream cheese recipe.

Table 3
Sensory acceptability scores for the different cream cheeses.

Sample	Appearance	Texture	Flavor (only cheese)	Spreadability (cheese with cracker)	Flavor (cheese with cookie)	Total score
Control	6.48 ± 1.49^{A}	6.16 ± 1.64^{AB}	6.46 ± 1.35^{AB}	6.28 ± 1.72^{C}	6.70 ± 1.29^{B}	6.50 ± 1.35^{BC}
OL-50%	6.80 ± 1.30^{A}	6.77 ± 1.42^{A}	6.79 ± 1.30^{AB}	7.65 ± 1.16^{AB}	7.26 ± 1.19^{A}	6.99 ± 1.24^{AB}
EM-50%	6.73 ± 1.50^{A}	6.53 ± 1.54^{A}	6.90 ± 1.23^{A}	7.37 ± 1.50^{B}	7.23 ± 1.23^{A}	7.15 ± 1.21^{A}
OL-100%	6.82 ± 1.34^{A}	5.73 ± 1.88^{B}	5.44 ± 1.66^{C}	7.32 ± 1.45^{B}	6.54 ± 1.46^{B}	6.04 ± 1.62^{C}
EM-100%	7.71 ± 1.35^{A}	6.46 ± 1.55^{A}	6.36 ± 1.51^{B}	7.10 ± 0.96^{B}	6.79 ± 1.23^{AB}	6.68 ± 1.45^{AB}

* Control: cream cheese prepared with butter; OL-50%: cream cheese prepared with 50% oleogel and 50% butter; EM-50%: cream cheese prepared with 50% emulsion and 50% butter; OL-100%: cream cheese prepared with 100% oleogel; EM-100%: cream cheese prepared with 100% emulsion. Different letters in the same column represent significant differences according to Turkey test ($p < 0.05$).

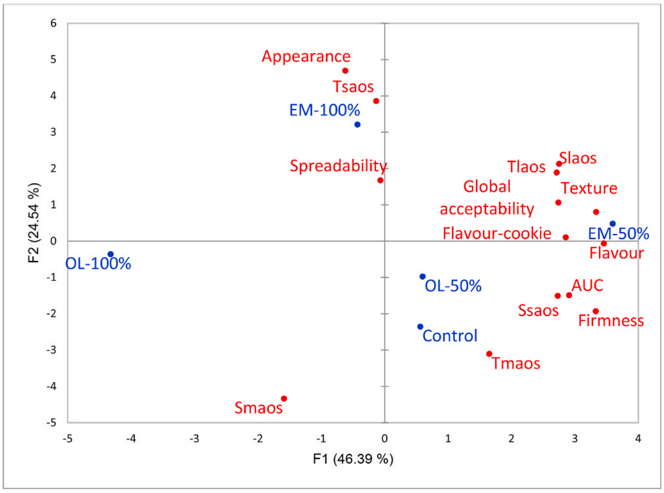

Fig. 5. Principal Component Analysis (PCA) of samples, texture instrumental parameters, rheology parameters and sensory acceptability.

instrumental parameters: Firmness, AUC, Slaos, Tlaos, Ssaos and Tmaos, and to the sensory parameters: global acceptability, texture acceptability and flavor acceptability. The EM-100% appear separated in the positive part of the second component (24,54%) associated to spreadability, appearance acceptability and Tsaos. Finally, sample OL-100% appear separated in the negative part of F1 and not related to any of the instrumental and sensory parameters.

The results above demonstrated the feasibility of replacing fat with oleogels or emulsions in cream cheese manufacturing. The increase in the purchase intention after the nutritional information was given to the consumer supports the potential of oleogel and emulsion replacers as alternatives to conventional solid fat in dairy products.

4. Conclusions

This study validated the feasibility of employing HPMC oleogels and emulsions as substitutes for traditional fats in the production of cream cheese with reduced saturated fatty acids (oleogels and emulsions) and low-fat cream cheese (emulsions). The impact on spreadability, linear and nonlinear rheological behavior, and consumer acceptance of the products was assessed. The results indicated that oleogels and emulsions could enhance the spreadability of cream cheese, making it easier to spread. Rheological tests revealed that the mechanical strength of cream cheese decreased with an increasing proportion of oleogels and emulsions. Furthermore, under the same proportion, the storage modulus of oleogel cream cheese was smaller than that of emulsion cream cheese, suggesting a softer texture. Lissajous curves illustrated the transition from linear viscoelastic response to nonlinear response within the range of 0.1%–1000%. All cream cheese samples exhibited nonlinear strain-stiffening and shear-thinning behavior, with no discernible differences between the different cheeses in the nonlinear region. Sensory evaluations showed that cream cheese prepared with oleogels and emulsions had minimal negative effects compared to the control group and even improved scores in spreadability, cream cheese flavor on biscuits, and overall assessment. Purchase intention assessments also indicated an increased willingness to buy cream cheese prepared with 100% emulsion and 100% oleogel after participants were informed about the type and amount of fat in the formulations. This study demonstrated the significant potential of replacing traditional fats with HPMC emulsions and oleogels in cream cheese formulations, providing insights into the development of healthier, low-saturated fatty acid or low-fat cream cheeses without compromising product quality.

CRediT authorship contribution statement

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

Declaration of competing interest

The authors of the article titled "**Effect of cellulose ether emulsion and oleogel as healthy fat alternatives in cream cheese. Linear and nonlinear rheology, texture and sensory properties**" declare that there is no conflict of interest.

Data availability

The authors are unable or have chosen not to specify which data has been used.

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References

Anvari, M., & Joyner (Melito), H. S. (2019). Concentrated emulsions as novel fat replacers in reduced-fat and low-fat Cheddar cheeses. Part 2. Large amplitude oscillatory shear behavior. *International Dairy Journal, 91*, 137–146. https://doi.org/10.1016/j.idairyj.2018.08.018

Banks, J., & Weimer, B. (2007). Producing low fat cheese. *Improving the Flavour of Cheese*, 520–536.

Bayarri, S., Carbonell, I., & Costell, E. (2012). Viscoelasticity and texture of spreadable cheeses with different fat contents at refrigeration and room temperatures. *Journal of Dairy Science, 95*(12), 6926–6936. https://doi.org/10.3168/jds.2012-5711

Bemer, H. L., Limbaugh, M., Cramer, E. D., Harper, W. J., & Maleky, F. (2016). Vegetable organogels incorporation in cream cheese products. *Food Research International, 85*, 67–75. https://doi.org/10.1016/j.foodres.2016.04.016

Clifford Park, H. L. B. (2018). Oxidative Stability of rice bran wax oleogels and an oleogel cream cheese product. *J Am Oil Chem Soc, 95*, 1267–1275. https://doi.org/10.1002/aocs.12095

Demirkesen, I., & Mert, B. (2020). Recent developments of oleogel utilizations in bakery products. *Critical Reviews in Food Science and Nutrition, 60*(14), 2460–2479. https://doi.org/10.1080/10408398.2019.1649243

Duvarci, O. C., Yazar, G., & Kokini, J. L. (2017). The comparison of Laos behavior of structured food materials (suspensions, emulsions and elastic networks). *Trends in Food Science & Technology, 60*, 2–11. https://doi.org/10.1016/j.tifs.2016.08.014

Espert, M., Hernández, M. J., Sanz, T., & Salvador, A. (2021). Reduction of saturated fat in chocolate by using sunflower oil-hydroxypropyl methylcellulose based oleogels. *Food Hydrocolloids, 120*, Article 106917. https://doi.org/10.1016/j.foodhyd.2021.106917

Espert, M., Salvador, A., & Sanz, T. (2020). Cellulose ether oleogels obtained by emulsion-templated approach without additional thickeners. *Food Hydrocolloids, 109*, Article 106085. https://doi.org/10.1016/j.foodhyd.2020.106085

Everett, D. W., & Auty, M. A. (2008). Cheese structure and current methods of analysis. *International Dairy Journal, 18*(7), 759–773. https://doi.org/10.1016/j.idairyj.2008.03.012

Ewoldt, R. H., Hosoi, A. E., & McKinley, G. H. (2008). New measures for characterizing nonlinear viscoelasticity in large amplitude oscillatory shear. *Journal of Rheology, 52*(6), 1427–1458. https://doi.org/10.1122/1.2970095

Ewoldt, R. H., Winter, P., Maxey, J., & McKinley, G. H. (2010). Large amplitude oscillatory shear of pseudoplastic and elastoviscoplastic materials. *Rheologica Acta, 49*, 191–212. https://doi.org/10.1007/s00397-009-0403-7

Fuongfuchat, A., Seetapan, N., Makmoon, T., Pongjaruwat, W., Methacanon, P., & Gamonpilas, C. (2012). Linear and non-linear viscoelastic behaviors of crosslinked tapioca starch/polysaccharide systems. *Journal of Food Engineering, 109*(3), 571–578. https://doi.org/10.1016/j.jfoodeng.2011.10.022

Hosseini-Parvar, S. H., Matia-Merino, L., & Golding, M. (2015). Effect of basil seed gum (BSG) on textural, rheological and microstructural properties of model processed cheese. *Food Hydrocolloids, 43*, 557–567. https://doi.org/10.1016/j.foodhyd.2014.07.015

Joyner, H. S., Francis, D., Luzzi, B., & Johnson, J. R. (2018). The effect of storage temperature on blue cheese mechanical properties. *Journal of Texture Studies, 49*(3), 309–319. https://doi.org/10.1111/jtxs.12301

Joyner, H. S., & Meldrum, A. (2016). Rheological study of different mashed potato preparations using large amplitude oscillatory shear and confocal microscopy. *Journal of Food Engineering, 169*, 326–337. https://doi.org/10.1016/j.jfoodeng.2015.08.032

Li, Q., Xu, M., Xie, J., Su, E., Wan, Z., Sagis, L. M. C., et al. (2021). Large amplitude oscillatory shear (Laos) for nonlinear rheological behavior of heterogeneous emulsion gels made from natural supramolecular gelators. *Food Research International, 140*, Article 110076. https://doi.org/10.1016/j.foodres.2020.110076

Melito, H. S., Daubert, C. R., & Foegeding, E. A. (2013). Relationships between nonlinear viscoelastic behavior and rheological, sensory and oral processing behavior of Commercial cheese: Relationships between behaviors of cheese. *Journal of Texture Studies, 44*(4), 253–288. https://doi.org/10.1111/jtxs.12021

Mert, B., & Demirkesen, I. (2016). Reducing saturated fat with oleogel/shortening blends in a baked product. *Food Chemistry, 199*, 809–816. https://doi.org/10.1016/j.foodchem.2015.12.087

Mezger, T. (2020). *The rheology handbook: For users of rotational and oscillatory rheometers*. European Coatings.

Moon, K. (2021). Solid fat replacement with Canola oil-carnauba wax oleogels for dairy-free imitation cheese low in saturated fat. *Foods, 10*(6), 1351. https://doi.org/10.3390/foods10061351

Ningtyas, D. W., Bhandari, B., Bansal, N., & Prakash, S. (2017). A tribological analysis of cream cheeses manufactured with different fat content. *International Dairy Journal, 73*, 155–165. https://doi.org/10.1016/j.idairyj.2017.06.005

Ningtyas, D. W., Bhandari, B., Bansal, N., & Prakash, S. (2018). Texture and lubrication properties of functional cream cheese: Effect of β-glucan and phytosterol. *Journal of Texture Studies, 49*(1), 11–22. https://doi.org/10.1111/jtxs.12282

Ningtyas, D. W., Bhandari, B., Bansal, N., & Prakash, S. (2019). Sequential aspects of cream cheese texture perception using temporal dominance of sensations (TDS) tool and its relation with flow and lubrication behaviour. *Food Research International, 120*, 586–594. https://doi.org/10.1016/j.foodres.2018.11.009

Noronha, N., O'Riordan, E. D., & O'Sullivan, M. (2008). Influence of processing parameters on the texture and microstructure of imitation cheese. *European Food Research and Technology, 226*(3), 385–393. https://doi.org/10.1007/s00217-006-0549-9

Patel, A. R., Cludts, N., Bin Sintang, M. D., Lewille, B., Lesaffer, A., & Dewettinck, K. (2014). Polysaccharide-based oleogels prepared with an emulsion-templated approach. *ChemPhysChem, 15*(16), 3435–3439. https://doi.org/10.1002/cphc.201402473

Patel, A. R., Nicholson, R. A., & Marangoni, A. G. (2020). Applications of fat mimetics for the replacement of saturated and hydrogenated fat in food products. *Current Opinion in Food Science, 33*, 61–68. https://doi.org/10.1016/j.cofs.2019.12.008

Precha-Atsawanan, S., Uttapap, D., & Sagis, L. M. (2018). Linear and nonlinear rheological behavior of native and debranched waxy rice starch gels. *Food Hydrocolloids, 85*, 1–9. Linearandnonlinearrheologicalbehaviorofnativeanddebranchedwaxyricestarchgels.

Szopinski, D., & Luinstra, G. A. (2016). Viscoelastic properties of aqueous guar gum derivative solutions under large amplitude oscillatory shear (Laos). *Carbohydrate Polymers, 153*, 312–319. https://doi.org/10.1016/j.carbpol.2016.07.095

Wang, Q., Espert, M., Larrea, V., Quiles, A., Salvador, A., & Sanz, T. (2023). Comparison of different indirect approaches to design edible oleogels based on cellulose ethers. *Food Hydrocolloids, 134*, Article 108007. https://doi.org/10.1016/j.foodhyd.2022.108007

Wendin, K. (2000). Dynamic analyses of sensory and microstructural properties of cream cheese. *Food Chemistry, 71*(3), 363–378. https://doi.org/10.1016/S0308-8146(00)00200-4

Yazar, G., Caglar Duvarci, O., Yildirim Erturk, M., & Kokini, J. L. (2019). Laos (large amplitude oscillatory shear) applications for semisolid foods. In *Rheology of semisolid foods* (pp. 97–131). Springer.

Yildirim-Mavis, C., Ozmen, D., Yakisik, E., Toker, O. S., Palabiyik, I., & Kaner, O. (2022). Evaluation of kashar cheese meltability by tack and large amplitude oscillatory shear (Laos) tests. *International Dairy Journal, 127*, Article 105242. https://doi.org/10.1016/j.idairyj.2021.105242

Yousefi, A. R., & Razavi, S. M. (2015). Dynamic rheological properties of wheat starch gels as affected by chemical modification and concentration. *Starch-Stärke, 67*(7–8), 567–576. https://doi.org/10.1002/star.201500005

Zad Bagher Seighalani, F., & Joyner, H. (2019). Wear: A new dimension of food rheological behaviors as demonstrated on two cheese types. *Journal of Food Engineering, 263*, 337–340. https://doi.org/10.1016/j.jfoodeng.2019.07.016

Zetzl, A. K., Marangoni, A. G., & Barbut, S. (2012). Mechanical properties of ethylcellulose oleogels and their potential for saturated fat reduction in frankfurters. *Food & Function, 3*(3), 327. https://doi.org/10.1039/c2fo10202a