**Comparing λ -carrageenan and an inulin blend as fat replacers in carboxymethyl
cellulose dairy desserts. Rheological and sensory aspects.**

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Abstract

Carbohydrate-based fat replacers are of growing interest because, besides their physicochemical properties, they also have health-friendly characteristics. The study reported here aims to compare the effect of adding both λ -carrageenan and a blend (50:50) of short and long-chain inulin on the rheological behaviour and sensory properties of low-fat carboxymethyl cellulose (CMC) semi-solid dairy desserts. Low-fat samples with 0.03% λ -carrageenan or with 9% of the inulin blend displayed similar rheological behaviour to the full-fat control sample, i.e. there were no significant differences in either flow (σ_0 , K , η_{10} and n) or viscoelasticity (G' , G'' , $\tan \delta$ and η^* at 1 Hz and $\eta^*_{8\text{Hz}}$ at 8 Hz). In general, samples with the same rheological behaviour but different fat content were perceived as having similar thickness, creaminess and smoothness. However, the substitution of fat by λ -carrageenan or inulin influenced both perceived sweetness and flavour.

Keywords: λ -carrageenan, inulin blend, fat, dairy desserts, rheology, sensory properties.

Introduction

Sodium carboxymethyl cellulose (CMC) is being used as an alternative thickener to starch in semisolid dairy products (Jellema, Janssen, Terpstra, de Wijk, & Smilde, 2005) due to its technological and nutritional advantages. Studies have paid less attention to the sensory and rheological properties of CMC-milk systems than to the starch-milk systems, although some information has been published regarding the effect of CMC concentration on flavour and textural properties of custard desserts (Jellema et al., 2005; Van Ruth, de Witte and Uriarte, 2004). Less information exists regarding how the elimination or reduction of fat affects rheological and sensory characteristics of CMC-milk systems. In previous works (Bayarri, Dolz & Hernández, 2009a; Bayarri, González-Tomás, & Costell, 2009b), the viscoelastic properties of aqueous and milk systems with CMC were studied by oscillatory and creep-recovery tests. Both the type of dispersing media (water, skimmed and whole milk) and the CMC concentration clearly affected the viscoelastic behaviour of samples. In general, when fat content decreased, elasticity did so too.

The elimination or reduction of fat in dairy foods modifies its composition and structure as well as the expected interactions among components, giving rise to, in most cases, perceptible changes in colour, flavour and, especially in texture (Guinard, Zoumas-Morse, Mori, Uatoni, Panyam & Kilara, 1997; González-Tomás, Bayarri, Taylor & Costell, 2007). Certain ingredients are commonly used to compensate or reduce the problems associated with the reduction or elimination of fat content in foods, such as effects on texture. There are several types of fat replacers and in each case the selection depends on the composition and characteristics of each food (Sandrou & Arvanitoyannis, 2000). Among fat replacers, carbohydrate-based substances such as starch, cellulose, pectin, inulin, xanthan gum or

50 carrageenan, are of growing interest because, besides their physicochemical properties, they
51 also have health-friendly characteristics (Warrand, 2006).

52 In general, the most suitable structure-forming hydrocolloids for dairy products are
53 considered to be carrageenans, mainly κ and ι -carrageenan, due to their ability to combine
54 and form double helices and their interaction with casein (Michon, Chapuis, Langendorff,
55 Boulenguer, & Cuvelier, 2005; Spagnuolo, Dalglish, Goff, & Morris, 2005). Lambda-
56 carrageenan does not form gels in aqueous solutions; however, λ -carrageenan is able to form
57 gels in the presence of milk due to its interaction with casein micelles (Langendorff,
58 Cuvelier, Michon, Launay, Parker, & De Kruif, 2000; Shchipunov and Chesnokov, 2003).
59 To the best of the authors' knowledge, there is no information available about the influence
60 of λ -carrageenan as a fat replacer in low-fat CMC-milk semisolid desserts.

61 Inulin is a linear non-digestible polysaccharide of β -(2-1) linked fructose residues with a
62 terminal glucose residue unit. In addition to its beneficial effects on health as a dietetic fibre
63 and as a prebiotic ingredient (Flamm, Glinsmann, Kritchevsky, Prosky, & Roberfroid, 2001)
64 it can be used as a low-calorie sweetener, fat substitute or texture modifier (Tungland &
65 Meyer, 2002). These properties are linked to the polymerization degree of its chain. Long-
66 chain inulin is more thermally stable, less soluble and more viscous than native and short-
67 chain inulins (Wada, Sugatami, Terada, Ohguchi & Miwa, 2005) and it has been used as a
68 fat replacer in several dairy products. Villegas, Carbonell & Costell (2007) showed that to
69 obtain low-fat milk beverages with a similar thickness and creaminess to those perceived in
70 whole-milk beverages, long-chain inulin must be added at a concentration above 8%.
71 González- Tomás, Coll-Marqués & Costell (2008) observed that by adding 7.5% of long-
72 chain inulin to low-fat starch-based custard desserts, they obtained similar viscoelastic
73 properties to the whole-milk sample with the same starch concentration. Meanwhile, the
74 addition of long-chain inulin improved creaminess and consistency of low-fat custards,

mimicking those of full-fat custard, but also reduced smoothness and increased the sensation of roughness (González- Tomás, Bayarri & Costell, 2009). The latter effect is probably due to the presence of small crystals or crystal aggregates of long-chain inulin in the product. Because the crystallization process of inulin depends on both the inulin chain size and the initial inulin concentration (Bot, Erle, Vreeker, & Agterof, 2004) we hypothesised that reducing long-chain inulin concentration would decrease the formation of inulin crystals, even though by lowering long-chain inulin concentration, its fat-replacing ability can be expected to decrease. One possibility is to use a blend of short and long-chain inulin as fat replacer. In a previous work (Tárrega, Rocafull and Costell, 2010) addition of inulin blends to low-fat samples was not enough to completely emulate the rheological behaviour of the full fat-custard. However the low-fat sample with the inulin blend 50:50 was perceived to have the same creaminess and thickness than the full-fat sample. From the nutritional point of view, the mixture of short and long-chain inulin in the ratio 50:50 affords some extra advantages in addition to improving prebiotic effectiveness. This blend ratio has been shown to enhance calcium absorption and bone mineralization in pubertal adolescents (Abrams et al., 2005) and to reduce the amount of gas produced while increasing or maintaining the ability to support beneficial bacteria in the colon (Ghoddusi, Grandison, Grandison, & Tuohy, 2007). In addition, the prebiotic effect of inulin could be boosted by supplementing it with CMC in dietary treatments (Júskiewicz and Zdunczyk, 2004). These authors observed that when a diet of inulin supplemented with CMC was given to rats, it led to an increase in the size of the caecum, lower pH and ammonia concentration in the digestive tract as well as a greater production of short-chain fatty acids.

The study reported here aims to compare the effect of adding both λ -carrageenan and a blend (50:50) of short and long-chain inulin on the rheological behaviour of low-fat

carboxymethyl cellulose semi-solid dairy desserts. Therefore, low-fat samples with similar rheological behaviour to full-fat samples were selected and their sensory properties were compared.

2. Materials and Methods

2.1. Sample preparation and composition

Samples were prepared with carboxymethyl cellulose (CMC) (Akucell AF3265 Akzo Nobel, Amersfoort, The Netherlands), sucrose, commercial whole (25% w/w protein, 39% w/w carbohydrate, 26% w/w fat and 1.2% w/w calcium) and skimmed (34% w/w protein, 52% w/w carbohydrate, 1% w/w fat and 1.2%w/w calcium) milk powder (Central Lechera Asturiana, Siero, Spain), vanilla aroma (375 48A Lucta S.A., Barcelona, Spain), yellow-orange colorant (Vegex NC 2c WS mct, CHR Hansen S.A., Barcelona, Spain), λ -carrageenan (Satiagum™ ADC 25, Barcelona, Spain) and two types of inulin that differed in the average chain length: long chain length (≥ 23 monomers) (Frutafit® TEX!) and short chain length inulin (7-9 monomers) (Frutafit® CLR), both of which were provided by Sensus (Brenntag Química, Barcelona, Spain).

Whole and skimmed milk were prepared in advance by dissolving 13.5 % (w/w) whole and skimmed milk powder, respectively, in mineral water to obtain a final fat content of 3.5% and 0.14%, respectively. Milk powder was dispersed in mineral water, at 250 rpm and 85 °C for 10 min, with the help of a magnetic stirrer and a hot plate (Ared, Velp Scientifica) and stored at 4 $\pm$ 1°C overnight to ensure complete hydration of the milk proteins. To prepare samples, a dry blend of sugar with CMC was added to the rehydrated milk, with the colorant, and stirred (Heidolph RZR 1, Germany) at room temperature for 35 min. Five min

before the end vanilla aroma was added. Samples were transferred to a closed flask and stored ($4\pm 1^{\circ}\text{C}$; 24 h) prior to measurements. Low-fat samples containing λ -carrageenan were prepared in the same way except that λ -carrageenan powder was added to the skimmed-rehydrated milk together with the dry blend of sugar and CMC. Long chain length inulin and short chain length inulin were mixed in the ratio of 50:50 and low-fat samples were prepared by dispersing skimmed-milk powder and the corresponding inulin concentration in mineral water just before the aforementioned heat treatment.

Low-fat samples were prepared at two CMC concentrations – 1.3 and 1.5% w/w - each with three λ -carrageenan contents – 0.01, 0.03 and 0.05% w/w - or three concentrations of the 50:50 blend of short and long chain inulin (SC/LC inulin blend) - 7, 9 and 11% w/w -. Two more samples without inulin or λ -carrageenan, one prepared with whole milk (full-fat) and the other prepared with skimmed milk (low fat), were used as control. The amounts of sugar (6% w/w), colorant (0.052%), vanilla aroma (0.016% w/w) and the weight of rehydrated milk (80% w/w) were fixed.

2.2. Rheological measurements

Rheological measurements were carried out in a controlled stress rheometer RS1 (ThermoHaake, Karlsruhe, Germany), using parallel-plates geometry (60 mm diameter; 1mm gap). A sample temperature of $10\pm 1^{\circ}\text{C}$, selected as representative of the usual consumption temperature of dairy desserts, was kept during measurements by means of a Haake circulating water bath. Two batches of each concentration combination were prepared and each batch was measured twice, using a fresh sample for each measurement. After loading the sample, a waiting period of 10 min was used to allow the sample to recover itself and reach the desired temperature. After placing the sample between the plates carefully, the excess material was wiped off with a spatula.

2.2.1. Flow behaviour.

Sample flow was measured by recording shear stress values when shearing the samples at an increasing shear rate from 1 to 200 s⁻¹ for a period of 60 s and in reverse sequence for the same time. Experimental data of descending flow curves were fitted to Herschel-Bulkley model (eq. 1) using Rheowin Pro software (v. 3.61, Haake),

$$\sigma = \sigma_0 + K \dot{\gamma}^n \quad (\text{eq. 1})$$

where σ (Pa) is the shear stress, σ_0 (Pa) is the yield stress, K (Pasⁿ) is the consistency index, $\dot{\gamma}$ (s⁻¹) is the shear rate and n is the flow behaviour index. Shama & Sherman (1973) stated that the stimulus associated with the perception of viscosity in semisolid products could be the shear stress developed at a constant rate of 10 s⁻¹. Thus, apparent viscosity values at this shear rate (η_{10}) were calculated (eq. 2) as an index of sensory viscosity.

$$\eta_{10} = (\sigma_0 / \dot{\gamma}) + K \dot{\gamma}^{n-1} \quad (\text{eq. 2})$$

2.2.2. Viscoelastic behaviour.

Stress sweeps were made between 0.02 and 300 Pa, at a frequency of 1 Hz, in all the systems studied to determine the linear viscoelasticity zone. Frequency sweeps tests at 0.05 Pa, which is within the linear viscoelastic region, were then performed from 0.01 to 10 Hz. The oscillatory rheological parameters used to compare the viscoelastic properties of the samples were storage modulus (G'), loss modulus (G''), complex dynamic viscosity (η^*) and loss angle ($\tan \delta$) at 1 Hz. In semisolid products with viscoelastic behaviour, several authors have obtained a good correlation between the perceived thickness and the complex dynamic viscosity value at 50 rad s⁻¹ (Hill, Mitchell & Sherman, 1995). In this work, values of η^* at 8 Hz (equivalent to 50 rad s⁻¹) ($\eta^*_{8\text{Hz}}$) were determined as an index of oral thickness.

2.3. Sensory evaluation

A group of 40 panellists, with previous experience (more than three years) in evaluating sensory differences in dairy products, including dairy desserts, evaluated the intensity differences in sweetness, vanilla flavour, thickness, creaminess and smoothness between samples by paired comparison tests (ISO 5495-2005). Panellists were previously selected according to their taste sensitivity and their capacity to detect differences in intensities of the above mentioned attributes (ISO 8586-1:1993). A total of eight pairs of samples were evaluated. Each pair was composed of two samples containing the same CMC concentration. For each CMC concentration (1.3 and 1.5% CMC), four pairs of samples were evaluated. The first pair consisted of control samples (full-fat and low-fat prepared with whole milk and skimmed milk, respectively, and without fat replacer). The second and the third pairs were composed of the control full-fat system and two low-fat samples containing λ -carrageenan or SC/LC inulin blend at concentrations chosen on the strength of the rheological results. Finally, the attribute intensities of low-fat samples with λ -carrageenan and with SC/LC inulin blend were also compared.

Two pairs of samples were evaluated in each session and a total of four sessions were performed. All sessions were carried out between 11:00-13:00 in a standardised test room (ISO-8589, 2007) with separate booths. Samples (40 mL) were served at 10 ± 1 °C in white plastic vessels coded with three random digit numbers and the serving order was balanced in such a way that each sample was evaluated first an equal number of times. Panellists tasted approximately the same volume of each sample (half of a spoon) and were asked to indicate which sample, within each pair had a higher intensity of sweetness, vanilla flavour, thickness, creaminess or smoothness. Mineral water was provided to the assessors for mouth rinsing between each pair of samples.

2.4. Statistical analysis

Rheological data analysis. One-way ANOVA, considering composition as a factor, was applied for each CMC concentration. Significant differences between individual samples were determined by the Fisher's test ($\alpha=0.05$). Principal Component Analysis (PCA) was applied to the average values of flow and viscoelastic parameters. All calculations were carried out with XLSTAT-Pro software v.2007 (Adinsoft, Paris, France).

Sensory data analysis. Sensory data were processed using Compusense ® five release 4.6 (Compusense Inc., Guelph, ON, Canada). Tests were considered two-tailed and significant differences were established for $\alpha=0.05$.

3. Results and discussion

3.1. λ -carrageenan as fat replacer. Influence of composition on rheological behaviour.

Figure 1 shows the flow curves for control samples and for low-fat samples with different λ -carrageenan concentrations. All samples showed observable hysteresis loops when they were sheared during a complete cycle, indicating that sample flow was time-dependent (Figure 1). This thixotropic behaviour increased with both λ -carrageenan and CMC concentration. Full-fat samples prepared with both CMC concentrations and low-fat samples with the higher CMC and λ -carrageenan content showed an overshoot in the stress-rate curves. The maximum in the stress represents the yielding transition since the continuous network changes to a discontinuous state at this point (Mujumdar, Beris, & Metzner, 2002). Similar behaviour was observed on studying the flow properties of CMC dairy systems made with whole milk at similar CMC concentrations (Bayarri and Costell, 2009a): particles seemed to form many more connections, but the systems were more brittle as a consequence (*i.e.* a clear overshoot in their stress-rate curves). Similarly, Lizarraga, Vicin, Gonzalez, Rubiolo, & Santiago (2006) studied the flow curves of whey protein concentrate (WPC) and λ -

carrageenan aqueous mixtures and observed that increasing the WPC concentration produced a more structured system, which partially broke down with increasing shear rates and over time, as reflected by the overshoot in the shear-stress versus shear-rate profiles.

The flow curves of all the systems showed a shear thinning with yield stress behaviour. Therefore, the shear stress versus the shear-rate profiles of all the samples were consistent with the Herschel-Bulkley model. Due to the presence of an overshoot in the ascending rheograms of several samples, the experimental data of descending rheograms were fitted to the Herschel-Bulkley model. The fit was good in all cases ($0.9997 < R^2 < 0.9999$). As expected the 1.5% CMC systems gave higher values on the yield stress (σ_0), consistency index (K) and apparent viscosity at 10 s^{-1} (η_{10}) and lower ones on the flow index (n) than the equivalent samples made with 1.3% CMC (Table 1). The flow index values varied between 0.4 and 0.6, and demonstrated clear pseudoplastic behaviour (Table 1). Low-fat samples showed lower consistency and lower shear thinning than either full-fat or low-fat samples with λ -carrageenan. Results from ANOVA showed that composition effect was significant ($P < 0.05$) on all flow parameter values except for flow index values in 1.5% CMC systems ($P = 0.146$). In both CMC systems, mean values of σ_0 , K and η_{10} of low-fat samples increased with λ -carrageenan concentration (Table 1). For both CMC systems, there was no significant difference ($\alpha = 0.05$) in σ_0 , K , η_{10} and n between full-fat samples and low-fat samples with 0.03% λ -carrageenan.

With regard to the viscoelastic behaviour, all samples exhibited the viscoelastic properties usually observed for weak-gel systems, which is typical in this type of product: the elastic response predominated over the viscous one. Both dynamic moduli showed slight variation with oscillation frequency, being higher the frequency dependency of loss modulus (Figure 2). As expected, viscoelastic parameter values were higher, except $\tan \delta$, in 1.5% CMC samples than in their counterparts formulated with 1.3% CMC, which confirms previous

250 results obtained by the authors Bayarri et al. (2009ab). For comparison purposes, G' , G'' ,
251 $\tan \delta$ and η^* at 1 Hz and $\eta^*_{8\text{Hz}}$ at 8 Hz values were considered (Table 2). The elastic
252 contribution for full-fat control samples was higher than low-fat control samples, suggesting
253 a stronger gel structure. In general, all viscoelastic parameters were significantly affected by
254 the composition ($P < 0.05$), but there were no differences in G'' and $\eta^*_{8\text{Hz}}$ values ($P > 0.10$) in
255 the case of 1.5% CMC systems due to fat or λ -carrageenan concentration. Within each CMC
256 concentration, mean values of the G' , G'' and η^* (both at 1 and 8 Hz) increased and $\tan \delta$
257 decreased when λ -carrageenan was added to low-fat samples. At 1.3% CMC concentration,
258 as in the case of flow behaviour, the full-fat sample did not differ statistically ($\alpha = 0.05$) from
259 low-fat sample with 0.03% λ -carrageenan for any of the viscoelastic parameters studied,
260 while for the highest CMC concentration (1.5%), the full-fat sample did not differ ($\alpha = 0.05$)
261 from low-fat samples with both 0.01 and 0.03% λ -carrageenan.

262 Rheological properties of low-fat samples showed an increase in the consistency and
263 mechanical strength with increasing λ -carrageenan concentration. Similar results have been
264 reported previously in other systems containing milk proteins (Lizarraga et al., 2006;
265 Lagendorff et al., 2000). The interactions between carrageenans and milk proteins and their
266 influence on rheological properties have been the subject of study (Depypere, Verbeke,
267 Torres, & Dewettinck, 2009). While kappa and iota carrageenans form gels in aqueous
268 solutions, lambda is unable to do so and is used as a pure thickener. However, lambda-
269 carrageenan is able to form gels in the presence of milk. Most authors agree that carrageenan
270 associates with casein micelles through an electrostatic interaction between its negatively
271 charged sulphate groups and a positively charged region of κ -casein. In the case of κ -, and ι -
272 carrageenan, the stabilization of gel network is achieved due to crosslinking of chain
273 fragments between the micelles by double helices. For λ -carrageenan, the gelation is ensured
274 only by binding with casein micelles (Shchipunov & Chesnokov, 2003).

To study the joint variability of rheological parameters Principal Component Analysis was applied to their mean values (Figure 3). The first component accounted for 95.70% of total variability and clearly separated the samples according to CMC concentration. Samples with 1.5% of CMC, in the positive part of the first dimension, showed higher values for most of the rheological parameters (G' , G'' , η^* , $\eta_{8\text{Hz}}^*$, σ_0 , K , η_{10}) than samples with 1.3% of CMC, which were in the negative part of the first dimension. The second component, which only accounted for a low percentage of variability (3.21%), correlated well with $\tan \delta$ and with the flow index. For both CMC concentrations, low fat sample with 0.03% λ -carrageenan exhibited the same rheological behaviour as the full-fat control sample in terms of both flow and viscoelastic properties.

3.2. Inulin blend as a fat replacer. Influence of composition on rheological behaviour

Figure 4 shows the flow curves for control samples and for low-fat samples with different concentrations of SC/LC inulin blend. All samples exhibited thixotropic behaviour, which increased with both CMC and inulin concentration. As in the case of full-fat samples, low-fat samples with 1.5% CMC and inulin displayed stress overshoot in the upward rheogram. Similar behaviour was observed by Bot et al. (2004) on studying the influence of crystallisation conditions on the large deformation rheology of inulin gels. The overshoot in the stress-strain curve becomes more pronounced at higher inulin concentrations, therefore an increase in fracture stress was observed on increasing inulin concentrations. Also in this case, the fit to the Herschel-Bulkley model was good for all the samples ($0.9997 < R^2 < 0.9999$). Flow index values ranged from 0.52 to 0.58 for samples prepared with 1.3% CMC and from 0.43 to 0.47 for samples with 1.5% CMC, which is indicative of shear thinning behaviour (Table 3). The analysis of variance showed a significant effect ($P < 0.05$)

300 of composition on all flow parameters studied except for K and n in 1.5% CMC systems
 301 ($P>0.05$). In general, considering low-fat samples, σ_0 , K and η_{10} increased, and flow
 302 behaviour index decreased with inulin concentration. Within each CMC concentration, full-
 303 fat samples did not differ statistically ($\alpha=0.05$) from low-fat samples with 9% inulin for any
 304 of the flow parameters studied.

305 Concerning the viscoelastic properties of the systems, low-fat samples with inulin showed a
 306 similar mechanical spectra to that observed for low-fat samples with λ -carrageenan, *i.e.* all
 307 samples showed weak-gel behaviour (Figure 5). Storage and loss modulus values of 1.5%
 308 CMC systems were higher than in 1.3% CMC samples, which is indicative of a stronger
 309 structured matrix. With the exception of $\tan \delta$ values in 1.5% CMC systems ($P=0.142$), all
 310 viscoelastic parameters were significantly ($P<0.05$) affected by the composition of the
 311 system. Within each CMC concentration, inulin addition to low-fat samples led to higher
 312 values of G' , G'' and η^* and lower values of $\tan \delta$ (Table 4). The amount of SC/LC inulin
 313 blend required to match the viscoelastic properties of full fat samples was dependent on
 314 CMC concentration: 9% of inulin in 1.3% CMC systems and 7 or 9% in 1.5% CMC systems.

315 Principal Component Analysis was applied to mean values of rheological parameters
 316 obtained for both flow and viscoelastic behaviour (Figure 6). The first component accounted
 317 for 87.86% of total variability and clearly separated the samples according to CMC
 318 concentration. Samples with 1.5% of CMC, in the positive part of the first dimension,
 319 showed higher values for most of the rheological parameters, except for $\tan \delta$ and n , than
 320 samples with 1.3% of CMC, which were in the negative part of the first dimension. The
 321 second component, which accounted for only a small percentage of variability (8.21%), was
 322 related in its positive part with the variation in the flow index (n) and in $\tan \delta$ and in its
 323 negative part with the consistency index (K) and with apparent viscosity at 10s^{-1} (η_{10}).
 324 Mapped sample distribution with respect to the first dimension (Figure 6) showed that for

both CMC concentrations, the low-fat sample with 9% inulin blend was the one demonstrating rheological behaviour most similar to that of the whole-milk control sample. Therefore, low-fat samples with inulin were successfully formulated to produce the same rheological behaviour as full-fat samples.

3.3. λ -carrageenan and inulin blend as fat replacers. Sensory properties

According to the rheological results obtained, both fat replacers could be used in the formulation of low-fat CMC-based dairy desserts to obtain products with similar rheological behaviour to that obtained with full-fat milk. However, this does not guarantee it matches the sensorially perceived texture. This is logical if one bears in mind that during ingestion and swallowing, the thickness perceived depends not only on the shear forces in the mouth but also on the effect of saliva, mouth temperature and also, on other textural characteristics of the product. Although in many cases there is a close relationship between the values of one or various rheological parameters and the perceived thickness in semisolids foods (van Vliet, 2002), rheological information alone may not be enough to explain all the textural differences perceived particularly when products with different composition and structure are being compared (González-Tomás & Costell, 2006). Some textural attributes, creaminess, fattiness or smoothness, which strongly affect the final acceptance of semisolid dairy foods, mainly depend on the food microstructure, on some surface properties and on certain crossed interactions between texture attributes and some flavours. Moreover, besides the direct influence that the elimination or reduction of fat has on texture, it also strongly influences the mechanisms involved in flavour release and perception (Bayarri & Costell, 2009b).

In order to analyse the role fat plays in the sensory attributes of CMC-based dairy desserts, the sensory properties of full-fat and low-fat control samples were compared (Figure 7). For

350 both CMC concentrations, full-fat samples were perceived as thicker than low-fat samples,
351 which is in agreement with the rheological results obtained previously. Low-fat samples
352 were perceived as smoother while no significant differences were detected in creaminess
353 between each pair of samples with different fat content. In addition, low-fat control samples
354 were perceived as sweeter and as having greater vanilla flavour intensity than their full-fat
355 counterparts. These results are in accordance with those obtained in previous studies on
356 starch-based custards, showing that fat reduction leads to textural changes and modifies the
357 perception of their flavour (González-Tomás et al., 2007).

358 According to the rheological results obtained in the above sections, both in the samples
359 containing 1.3% CMC and those with 1.5% of CMC, by adding 0.03% of λ -carrageenan or
360 9% of the inulin blend, low fat products were obtained with similar rheological behaviour to
361 that of full-fat samples. A paired comparison test was carried out to assess the differences in
362 vanilla flavour, sweetness, thickness, smoothness and creaminess between the low-fat
363 custard dessert with 0.03% of λ -carrageenan or the low-fat custard dessert with 9% of the
364 inulin blend and the control full-fat sample with the same amount of CMC.

365 When λ -carrageenan was used as a fat replacer (Figure 8a and 8b), no significant differences
366 were found in the intensity of the texture attributes between the samples with different fat
367 content. The addition of λ -carrageenan to low-fat samples increased thickness and decreased
368 smoothness, compensating the variation detected in the texture by reducing the fat content of
369 these products. However, the substitution of fat by λ -carrageenan also influenced the flavour
370 perceived. In general, both the sweetness and the vanilla flavour of low-fat samples were
371 significantly stronger ($\alpha = 0.05$) than in the full-fat samples. This fact reflects the influence
372 of fat on flavour release and perception. For example, Lethuaut et al. (2005) studied the
373 aroma-sweetness interactions on dairy desserts with different textures and concluded that the
374 dessert with λ -carrageenan, which had the softest texture and was perceived as the sweetest,

375 was also perceived as the most highly flavoured. In this work, flavour differences may be
376 explained by rheological and textural changes, but in the present study, samples showed
377 similar rheological properties and the variations in flavour intensity may have been due to
378 other factors. It is widely known that flavour release and perception decrease as lipid levels
379 increase in the food matrix, with the exception of hydrophilic compounds showing partition
380 coefficient values near or below zero (van Ruth, King, & Giannouli, 2002; Miettinen,
381 Hyvönen, Linfoth, Taylor, & Tuorila, 2004). Bayarri, Smith, Hollowood, & Hort (2007),
382 working with model o/w emulsions with different oil contents and a composition adjusted to
383 deliver iso-release aroma *in vivo* and the same in-mouth viscosity, observed that samples
384 containing the highest oil content were perceived as significantly less sweet. This confirms
385 that fat content influences flavour in two ways: directly, it has a significant effect on the
386 release of chemical stimuli from the food matrix into the mouth and indirectly, due to its
387 influence on the product texture.

388 When the fat was replaced with the SC/LC inulin blend, its effect on texture was found to be
389 different depending on the CMC concentration. When CMC concentration was 1.3%, the
390 low-fat sample with the added inulin blend was perceived as less thick and significantly
391 smoother than the control sample while no significant difference were detected in
392 creaminess (Figure 8c). This confirmed that even when the rheological behaviour of
393 products with different fat content was alike, during consumption the orally perceived
394 texture is not always the same. A similar fact was found by Gallardo-Escamilla, Kelly, &
395 Delahunty (2007) when they observed that equiviscous fermented whey beverages, with
396 different added hydrocolloids, were perceived as having different thicknesses and by
397 Villegas, Carbonell, & Costell, (2008), who detected differences in perceived thickness
398 between equiviscous milk and soymilk vanilla beverages. In samples with 1.5% of CMC the
399 effect of adding inulin was different, being similar to that observed when λ -carrageenan was

added. In samples with this CMC concentration, there were no significant difference in thickness, smoothness and creaminess between the full-fat sample and the low-fat sample (Figure 8d). With regard to flavour, as happened when λ -carrageenan was added, low-fat samples were perceived as being significantly sweeter and having a more intense vanilla flavour.

Differences in sensory attribute intensities were also analysed between low-fat samples with either of the fat replacers, *i.e.* 0.03% λ -carrageenan and 9% inulin blend (Figure 9). For both CMC concentrations, the samples with λ -carrageenan were perceived as significantly thicker and there was a tendency to qualify their texture as less smooth and less creamy than the samples with the inulin blend, although the differences were only significant for smoothness in the samples with 1.3% CMC. Brennan & Tudorica (2008) observed that, the incorporation of native inulin at high levels (6%) to low-fat products significantly improved the perceived creaminess and mouthfeel of the product, and the resulting texture was perceived as smoother. Regarding flavour differences, samples with the inulin blend were perceived as significantly sweeter and as having greater vanilla flavour intensity than the samples with λ -carrageenan (Figure 9). Differences in sweetness and vanilla flavour can be explained by both the higher consistency perceived in samples with λ -carrageenan and the higher proportion of mono and disaccharides in short-chain inulin.

Conclusion

The results obtained showed that the two fat replacers, λ -carrageenan and SC/LC inulin blend, were successfully used to formulate low-fat products with similar texture properties to full-fat CMC semisolid dairy desserts. Nevertheless, to obtain products with different fat content but similar flavour perception, sweetener and aroma concentration should be adjusted.

425

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432 **References**

433 Abrams, S. A., Griffin, I. J., Hawthorne, K. M., Liang, L., Jun, S. K., Darlington, G., & Ellis,
434 K. J. (2005). A combination of prebiotic short- and long-chain inulin-type fructans enhances
435 calcium absorption and bone mineralization in young adolescents. *American Journal of*
436 *Clinical Nutrition*, 82, 471-476.

437 Bayarri, S., Smith, T., Hollowood, T., & Hort, J. (2007). The role of rheological behaviour
438 in flavour perception in model oil/water emulsions. *European Food Research and*
439 *Technology*, 226, 161–168.

440 Bayarri, S., & Costell, E. (2009a). Flow properties of carboxymethylcellulose dairy systems
441 with different fat content. *Journal of Food Process Engineering*, DOI: 10.1111/j.1745-
442 4530.2009.00383.x

443 Bayarri, S., & Costell, E. (2009b). Optimising the flavour of low-fat foods. In D.J. Mc
444 Clements, & E.D. Decker, *Designing functional foods: Understanding, measuring and*
445 *controlling food structure breakdown and nutrient absorption for the development of health-*
446 *promoting foods* (pp.431-447). Cambridge: Woodhead publishing & CRC Press.

447 Bayarri, S., Dolz, M., & Hernández, M.J. (2009a). Effect of carboxymethyl cellulose
 448 concentration on rheological behaviour of milk and aqueous systems. A creep and recovery
 449 study. *Journal of Applied Polymer Science*, 114, 1626–1632

450 Bayarri, S., González-Tomás, L., & Costell, E. (2009b). Viscoelastic properties of aqueous
 451 and milk systems with carboxymethyl cellulose. *Food Hydrocolloids*, 23, 441-450.

452 Bot, A., Erle, U., Vreeker, R., & Agterof, W.G.M. (2004). Influence of crystallisation
 453 conditions on the large deformation rheology of inulin gels. *Food Hydrocolloids*, 18, 574-
 454 556.

455 Brennan, C.S., & Tudorica, C.M. (2008). Carbohydrate-based fat replacers in the
 456 modification of the rheological, textural and sensory quality of yoghurt: comparative study
 457 of the utilisation of barley beta-glucan, guar gum and inulin. *International Journal of Food*
 458 *Science and Technology*, 43, 824-833.

459 Depypere, F., Verbeken, D., Torres, J.D. & Dewettinck, K. (2009). Rheological properties of
 460 dairy desserts prepared in an indirect UHT pilot plant. *Journal of Food Engineering*, 91,
 461 140-145.

462 Flamm, G., Glinsmann, W., Kritchevsky, D., Prosky, L., & Roberfroid, M. (2001). Inulin
 463 and oligofructose as dietary fiber: A review of the evidence. *Critical Reviews in Food*
 464 *Science and Nutrition*, 41, 353-362.

465 Gallardo-Escamilla, F.J., Kelly, A.L., & Delahunty, C.M. (2007). Mouthfeel and flavour of
 466 fermented whey with added hydrocolloids. *International Dairy Journal*, 17, 308-315.

467 Ghoddusi, H. B., Grandison, M. A., Grandison A. S., & Tuohy, K. M. (2007). In vitro study
 468 on gas generation and prebiotic effects of some carbohydrates and their mixtures. *Anaerobe*,
 469 13, 193-199.

470 González-Tomas, L., Costell, E. (2006). Relation between consumers' perceptions of color
 471 and texture of dairy desserts and instrumental measurements using a generalized Procrustes
 472 analysis. *Journal of Dairy Science*, 89, 4511-4519.

473 González-Tomás, L., Bayarri, S., Taylor, A.J. & Costell, E. (2007). Flavour release and
 474 perception from model dairy custards. *Food Research Internacional*, 40, 520–528.

475 González-Tomás, L., Coll-Marqués, J., & Costell, E. (2008). Viscoelasticity of inulin starch-
 476 based dairy systems. Influence of inulin average chain length. *Food Hydrocolloids*, 22,
 477 1372-1380.

478 González-Tomás, L., Bayarri, S., & Costell, E. (2009). Inulin-Enriched Dairy Desserts:
 479 Physicochemical and Sensory Aspects. *Journal of Dairy Science*, 92, 4188-4199.

480 Guinard, J.X, Zoumas-Morse, C., Mori, B., Uatoni, B., Panyam, D., & Kilara, A. (1997).
 481 Sugar and fat effects on sensory properties of ice cream. *Journal of Food Science*, 62, 1087-
 482 1094.

483 Hill, M. A., Mitchell, J. R., & Sherman, P. A. (1995). The relationship between the
 484 rheological and sensory properties of a lemon pie filling. *Journal of Texture Studies*, 26,
 485 457-470.

486 ISO (1993). Sensory analysis. General Guidance for the selection, training and monitoring of
 487 assessors. Part 1: Selected assessors. Standard nº. 8586-1. Geneva, Switzerland.

488 ISO (2005). Sensory analysis. Methodology. Paired comparison test. Standard n°. 5495:2005.
 489 Geneva, Switzerland.

490 ISO (2007). *General guidance for the design of test rooms*. Standard n°. 8589. Geneva.
 491 Switzerland.

492 Jellema, R.H., Janssen, A.M., Terpstra, M.E.J., de Wijk, R.A. & Smilde, A.K. (2005).
 493 Relating the sensory sensation 'creamy mouthfeel' in custards to rheological measurements.
 494 *Journal of Chemometrics*, 19 (3), 191-200.

495 Juskiewicz, J., & Zdunczyk, Z. (2004). Effect of cellulose, carboxymethylcellulose and
 496 inulin fed to rats as single supplements or in combinations on their caecal parameters.
 497 *Comparative Biochemistry and Physiology*, 139, 513-519.

498 Langendorff, V., Cuvelier, G., Michon, C., Launay, B., Parker, A., & De Kruif, C. G. (2000).
 499 Effects of carrageenan type on the behaviour of carrageenan/milk mixtures. *Food*
 500 *Hydrocolloids*, 14, 273–280.

501 Lethuaut, L., Brossard, C., Meynier, A., Rousseau, F., Llamas, G., Bousseau, B., & Genot, C.
 502 (2005). Sweetness and aroma perceptions in dairy desserts varying in sucrose and aroma
 503 levels and in textural agent. *International Dairy Journal*, 15, 485–493.

504 Lizarraga, M.S., Vicin, D.D., Gonzalez, R., Rubiolo, A., & Santiago, L.G. (2006).
 505 Rheological behavior of whey protein concentrate and lambda-carrageenan aqueous
 506 mixtures. *Food Hydrocolloids*, 20 (5), 740-748.

507 Michon, C., Chapuis, C., Langendorff, V., Boulenger, P., & Cuvelier, G. (2005). Structure
 508 evolution of carrageenan/milk gels: effect of shearing, carrageenan concentration and nu
 509 fraction on rheological behavior. *Food Hydrocolloids*, 19, 541–547.

510 Miettinen, S.M., Hyvönen, L., Linfoth, R.S.T., Taylor, A.J., & Tuorila, H. (2004). Temporal
511 aroma delivery from milk systems containing 0-5% added fat, observed by free choice
512 profiling, time intensity, and atmospheric pressure chemical ionization-mass spectrometry
513 techniques. *Journal of Agricultural and Food Chemistry*, 52, 8111-8118.

514 Mujumdar, A., Beris, A.N., & Metzner, A.B. (2002). Transient phenomena in thixotropic
515 systems. *Journal of Non-Newtonian Fluid Mechanics*, 102, 157-178.

516 Sandrou, D.K., Arvanitoyannis, I.S. (2000) Low fat/calorie foods: Current state and
517 perspectives. *Critical Reviews in Food Science and Nutrition*, 40, 427-447.

518 Shama, F., & Sherman, P. (1973). Identification of stimuli controlling the sensory evaluation
519 of viscosity II. Oral methods. *Journal of Texture Studies*, 4, 111-118.

520 Shchipunov, Y. A., & Chesnokov, A. (2003). Carrageenan gels in skim milk: Formation and
521 rheological properties. *Colloid Journal*, 65, 105–113.

522 Spagnuolo, P. A., Dalgleish, D. G., Goff, H. D., & Morris, E. R. (2005). Kappa–carrageenan
523 interactions in systems containing casein micelles and polysaccharide stabilizers. *Food*
524 *Hydrocolloids*, 19, 371–377.

525 Tárrega, A., Rocaful, A., & Costell, E. (2010). Effect of blends of short and long-chain
526 inulin on the rheological and sensory properties of prebiotic low-fat custards. *LWT - Food*
527 *Science and Technology*, 43, 556–562.

528 Tunland, B. C., & Meyer, D. (2002). Non digestible oligo-and polysaccharides (dietary
529 fiber): Their physiology and role in human health and food. *Comprehensive Reviews in Food*
530 *Science and Food Safety*, 1, 73–92.

531 Van Ruth, S. M., King, C., & Giannouli, P. (2002). Influence of lipid fraction, emulsifier
532 fraction, and mean particle diameter of oil-in-water emulsions on the release of 20 aroma
533 compounds. *Journal of Agricultural and Food Chemistry*, 50, 2365-2371.

534 Van Ruth, S.M., de Witte, L., & Uriarte, A.R. (2004). Volatile flavor analysis and sensory
535 evaluation of custard desserts varying in type and concentration of carboxymethyl cellulose.
536 *Journal of Agricultural and Food Chemistry*, 52 (26), 8105-8110.

537 Van Vliet, T. (2002). On the relation between texture perception and fundamental
538 mechanical parameters for liquids and time dependent solids. *Food Quality and Preference*,
539 13(4), 227–236.

540 Villegas, B., Carbonell, I., & Costell, E. (2007). Inulin milk beverages: Sensory differences
541 in thickness and creaminess using R-index analysis of the ranking data. *Journal of Sensory*
542 *Studies*, 22, 377-393.

543 Villegas, B., Carbonell, I., & Costell, E. (2008). Colour and viscosity of milk and soybean
544 vanilla beverages. Instrumental and sensory measurements. *Journal of the Science of Food*
545 *and Agriculture*, 88, 397-403.

546 Wada, T., Sugatani, J. N., Terada, E., Ohguchi, M., & Miwa, M. (2005). Physicochemical
547 characterization and biological effects of inulin enzymatically synthesized from sucrose.
548 *Journal of Agricultural and Food Chemistry*, 53, 1246-1253.

549 Warrand, J. (2006). Healthy polysaccharides. The next chapter in food products. *Food*
550 *Technology and Biotechnology*, 44, 355-370.

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Table 1. Average values (n=2) of yield stress (σ_0), consistency index (K), flow index (n) and apparent viscosity at 10 s^{-1} (η_{10}) of dairy desserts with different concentrations of CMC and λ -carrageenan.

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	Low-fat control	Low-fat - 0.01% λC^b	Low-fat - 0.03% λC	Low-fat - 0.05% λC	Full-fat control
1.3% CMC					
σ_0 (Pa)	7.3 ^a	8.1 ^a	8.9 ^a	11.8 ^b	8.2 ^a
K (Pa s ⁿ)	6.1 ^a	8.6 ^a	13.2 ^b	18.2 ^c	14.0 ^b
n	0.58 ^d	0.56 ^c	0.52 ^b	0.49 ^a	0.52 ^b
η_{10} (Pa s)	3.1 ^a	3.9 ^b	5.2 ^c	6.8 ^d	5.4 ^c
1.5% CMC					
σ_0 (Pa)	13.0 ^a	15.6 ^{ab}	18.7 ^{bc}	19.7 ^c	19.4 ^{bc}
K (Pa s ⁿ)	22.5 ^a	29.3 ^{ab}	36.7 ^{bc}	43.7 ^c	35.1 ^{bc}
n	0.47 ^a	0.45 ^a	0.43 ^a	0.42 ^a	0.43 ^a
η_{10} (Pa s)	7.9 ^a	9.7 ^b	11.7 ^{cd}	13.3 ^d	11.5 ^c

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558 ^a In each row, different superscript letters denote significant differences between samples ($\alpha=0.05$).

559 ^b λ -Carrageenan

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Table 2. Average values (n=2) of storage modulus (G'), loss modulus (G''), loss angle tangent (tanδ) and complex viscosity (η*) at 1 Hz and complex viscosity at 8 Hz (η*_{8Hz}) of dairy desserts with different concentrations of CMC and λ-carrageenan.

	Low-fat control	Low-fat - 0.01% λC ^b	Low-fat - 0.03% λC	Low-fat - 0.05% λC	Full-fat control
1.3% CMC					
G' (Pa)	99.9 ^a	133.5 ^b	189.7 ^c	233.5 ^d	173.2 ^c
G'' (Pa)	47.7 ^a	55.9 ^{ab}	60.8 ^{bc}	68.4 ^c	58.1 ^{abc}
Tan δ	0.48 ^d	0.42 ^c	0.32 ^b	0.29 ^a	0.33 ^b
η* (Pa s)	17.6 ^a	23.0 ^b	31.7 ^c	38.7 ^d	29.8 ^c
η* _{8Hz} (Pa s)	4.3 ^a	5.2 ^b	6.4 ^{cd}	7.2 ^d	6.4 ^c
1.5% CMC					
G' (Pa)	300.2 ^a	353.2 ^{ab}	391.7 ^b	488.5 ^c	378.3 ^b
G'' (Pa)	92.5 ^a	101.9 ^a	103.4 ^a	120.1 ^a	107.0 ^a
Tan δ	0.31 ^c	0.29 ^{bc}	0.26 ^{ab}	0.25 ^a	0.28 ^{abc}
η* (Pa s)	50.0 ^a	58.5 ^{ab}	64.5 ^b	80.1 ^c	62.6 ^b
η* _{8Hz} (Pa s)	9.9 ^a	10.82 ^a	11.16 ^a	13.1 ^a	10.8 ^a

^a In each row, different superscript letters denote significant differences between samples (α=0.05).

^b λ-Carrageenan

Table 3. Average values (n=2) of yield stress (σ_0), consistency index (K), flow index (n) and apparent viscosity at 10 s^{-1} (η_{10}) of dairy desserts with different concentrations of CMC and SC/LC inulin blend.

	Low-fat control	Low-fat - 7% Inulin	Low-fat - 9% Inulin	Low-fat - 11% Inulin	Full-fat control
1.3% CMC					
σ_0 (Pa)	7.3 ^a	7.3 ^a	8.4 ^a	15.4 ^b	8.2 ^a
K (Pa s ⁿ)	6.1 ^a	10.8 ^b	12.2 ^{bc}	14.9 ^d	14.0 ^{cd}
n	0.58 ^c	0.53 ^{ab}	0.53 ^{ab}	0.55 ^b	0.52 ^a
η_{10} (Pa s)	3.1 ^a	4.4 ^b	5.0 ^{bc}	6.8 ^d	5.4 ^c
1.5% CMC					
σ_0 (Pa)	13.0 ^a	14.7 ^{ab}	20.9 ^c	33.2 ^d	19.4 ^{bc}
K (Pa s ⁿ)	22.5 ^a	27.4 ^a	27.2 ^a	26.3 ^a	35.1 ^a
n	0.47 ^a	0.45 ^a	0.47 ^a	0.47 ^a	0.43 ^a
η_{10} (Pa s)	7.9 ^a	9.2 ^{ab}	10.0 ^{bc}	11.8 ^d	11.5 ^{cd}

^a In each row, different superscript letters denote significant differences between samples ($\alpha=0.05$).

Table 4. Average values (n=2) of storage modulus (G'), loss modulus (G''), loss angle tangent (tanδ) and complex viscosity (η*) at 1 Hz and complex viscosity at 8Hz (η*_{8Hz}) of dairy desserts with different concentrations of CMC and SC/LC inulin blend.

	Low-fat control	Low-fat - 7% Inulin	Low-fat - 9% Inulin	Low-fat - 11% Inulin	Full-fat control
1.3% CMC					
G' (Pa)	99.9 ^a	107.9 ^a	155.7 ^b	285.2 ^c	173.2 ^b
G'' (Pa)	47.7 ^a	55.0 ^a	54.3 ^a	92.7 ^b	58.1 ^a
Tan δ	0.48 ^b	0.51 ^b	0.35 ^a	0.32 ^a	0.33 ^a
η* (Pa s)	17.6 ^a	19.3 ^a	27.0 ^b	47.7 ^c	29.8 ^b
η* _{8Hz} (Pa s)	4.3 ^a	4.7 ^a	6.0 ^b	8.8 ^c	6.4 ^b
1.5% CMC					
G' (Pa)	300.2 ^a	338.8 ^{ab}	381.8 ^b	555.3 ^c	378.3 ^b
G'' (Pa)	92.5 ^a	95.9 ^a	105.1 ^a	143.5 ^b	107.0 ^a
Tan δ	0.31 ^a	0.28 ^a	0.28 ^a	0.26 ^a	0.28 ^a
η* (Pa s)	50.0 ^a	56.0 ^{ab}	63.0 ^b	91.3 ^c	62.6 ^b
η* _{8Hz} (Pa s)	9.9 ^a	10.0 ^a	11.5 ^a	17.6 ^b	10.8 ^a

^a In each row, different superscript letters denote significant differences between samples (α=0.05).

589 **Figure captions**

590 **Figure 1.** Flow curves of control samples (Δ = low-fat; $\diamond$ = full-fat) and low-fat samples with
 591 different λ -carrageenan concentrations ($\circ$ =0.01%; $\square$ = 0.03%; ∇ =0.05%) containing 1.3%
 592 (a) and 1.5% (b) of CMC.

593 **Figure 2.** Mechanical spectra of control samples ($\blacktriangle$ =low-fat; $\blacklozenge$ = full-fat) and low-fat
 594 samples with different λ -carrageenan concentrations ($\bullet$ =0.01%; $\blacksquare$ = 0.03%; $\blacktriangledown$ =0.05%)
 595 containing 1.3% (a) and 1.5% (b) of CMC. G' (filled symbols) and G'' (empty symbols).

596 **Figure 3.** Principal component analysis bi-plot for rheological parameters of low-fat
 597 custards with λ -carrageenan at different CMC (triangle=1.3%; square=1.5%) concentrations.
 598 Full-fat (filled symbols) and low-fat (empty symbols) control samples.

599 **Figure 4.** Flow curves of control samples (Δ = low-fat; $\diamond$ = full-fat) and low-fat samples with
 600 different SC/LC inulin blend concentrations ($\circ$ =7%; $\square$ = 9%; ∇ =11%) containing 1.3% (a)
 601 and 1.5% (b) of CMC.

602 **Figure 5.** Mechanical spectra of control samples ($\blacktriangle$ =low-fat; $\blacklozenge$ = full-fat) and low-fat
 603 samples with different SC/LC inulin blend concentrations ($\bullet$ =7%; $\blacksquare$ = 9%; $\blacktriangledown$ =11%)
 604 containing 1.3% (a) and 1.5% (b) of CMC. G' (filled symbols) and G'' (empty symbols).

605 **Figure 6.** Principal component analysis bi-plot for rheological parameters of low-fat
 606 custards with the blend of SC/LC inulin at different CMC (triangle=1.3%; square=1.5%)
 607 concentrations. Full-fat (filled symbols) and low-fat (empty symbols) control samples.

608 **Figure 7.** Sensory evaluation of the differences between full-fat ($\blacksquare$) and low-fat ($\square$)
 609 control desserts at different CMC concentrations (a=1.3%; b=1.5%). The line indicates the
 610 minimum value of response for which the difference is significant (α =0.05).

Figure 8. Sensory evaluation of the differences between the low-fat custard dessert with 0.03% of λ -carrageenan (▣) and the control full-fat sample (■) at different CMC concentrations (a=1.3%; b=1.5%) and between the low-fat custard dessert with the 9% of the blend of SC/LC inulin (■) and the control full-fat sample (■) at different CMC concentrations (c=1.3%; d=1.5%). The line indicates the minimum value of response for which the difference is significant ($\alpha=0.05$).

Figure 9. Sensory evaluation of the differences between the low-fat custard dessert with 0.03% of λ -carrageenan (▣) and with the 9% of the blend of SC/LC inulin (■) at different CMC concentrations (a=1.3%; b=1.5%). The line indicates the minimum value of response for which the difference is significant ($\alpha=0.05$).

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