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**Effect of blends of short and long-chain inulin on the rheological and sensory
properties of prebiotic low-fat custards**

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Abstract

Long-chain inulin (TEX) and short-chain inulin (CLR) combined in different proportions (25:75, 50:50, and 75:25) were added (7.5 g/100g) to low-fat custards and their rheological and sensory properties were studied. The effect of the inulin blends on the rheological properties depended on the presence of lambda carrageenan (0.01g/100g). Slight variations were observed when inulin blends were added to custards without lambda carrageenan whereas in samples with carrageenan, there was an important increase in thixotropy, consistency and elasticity. In both cases (samples with and without carrageenan) the differences perceived by assessors indicated that the blends 50:50 and 25:75 TEX:CLR were those affording greater thickness, sweetness and vanilla flavour intensity to the custards. Addition of inulin blends to low-fat samples did not manage to fully emulate the rheological behaviour of full-fat custard. However, the low-fat sample with the inulin blend 50:50 TEX:CLR added was perceived to have the same creaminess and thickness as the full-fat sample. The use of this blend combined with carrageenan gave thicker, creamier custard, which was preferred over the full-fat custard.

Keywords: oligofructose, long chain inulin, carrageenan, custard, rheology, sensory

1   **1. Introduction**

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3   Inulin and oligofructose are non-digestible fructans of interest in human nutrition
4   due to their prebiotic effect, i.e. specific stimulation of growth and/or activity of
5   colonic bacteria that benefit the host, as well as inhibiting the growth of pathogens
6   and harmful microorganisms (Roberfroid, 2007). Native inulin contains molecules
7   of different polymerization degree (from 2 to 60) and commercial products
8   containing only short-chain inulin (oligofructose) (2-7 units) or long-chain inulin
9   (22-25 units) are obtained from native inulin industrially. The prebiotic effects of
10   inulin depend both on the composition of the intestinal flora in each individual and
11   also on the degree of polymerization of fructose-chains (Biedrzycka, & Bielecka,
12   2004; Coudray, Tressol, Gueux, & Rayssiguier, 2003) showed that low-chain
13   fructans act more intensively in the proximal colon and inulin in more distal colonic
14   regions and suggested that the use of mixtures of oligofructose and inulin could
15   prolong effectiveness in the bowel. Stewart, Timm, & Slavin, 2008 studied the *in*
16   *vitro* fermentation of inulin samples with different polymerization degrees,
17   confirming that chain length affects fermentability, with short chains fermenting
18   rapidly and long chains fermenting steadily. They also showed that a mixture of
19   long-chain and short-chain inulin produced significantly more short-chain fatty acids
20   (SCFA) and acetate. Accordingly, blends of inulin with different chain length could
21   maximize fermentative and prebiotic characteristics of inulin.

22   Chain length also affects certain properties of inulin and different technological
23   properties and applications correspond to different inulin types. Short-chain inulin or
24   oligofructose is much more soluble and sweeter than native inulin, with a sweetness
25   profile similar to that of sucrose, and a low caloric content (1–2 kcal/g) but with a

1 lower sweetening power (30–35%) (Franck, 2002). It can be useful to partially
2 replace sucrose in a formulation (De Castro, Cunha, Barreto, Amboni, & Prudencio,
3 2009; Villegas, Tarrega, Carbonell, & Costell, 2009) or to replace it totally when
4 combined with other non-caloric sweeteners. Long-chain inulin, with a high degree
5 of polymerization (22–25), is more thermally stable, less soluble and more viscous
6 than the native one (Wada, Sugatani, Terada, Ohguchi, & Miwa, 2005) and has been
7 used as a fat substitute in different dairy products (El-Nagar, Clowes, Tudoric, Kuri,
8 & Brennan, 2002; Kip, Meyer, & Jellema, 2006, Tarrega, & Costell, 2006b;
9 Paseephol, Small, & Sherkat, 2008. Gonzalez-Tomas, Coll-Marques, & Costell
10 (2008) observed that long-chain inulin, used as fat replacer in skimmed-milk starch-
11 based dairy desserts, must be added at over 7 g/100g of product to obtain similar
12 rheological properties to whole-milk samples with the same starch concentration.

13 A study carried out in our laboratory (González-Tomás L, Bayarri , & Costell E,
14 2009) investigated how adding different types of inulin (oligofructose, native and
15 long chain), at a concentration of 7.5 g/100g of custard, affected sensory properties.
16 The addition of short-chain inulin enhanced flavour and sweetness of low-fat
17 samples although it did not significantly increase creaminess or consistency.
18 Meanwhile, the addition of long-chain inulin improved creaminess and consistency
19 of low-fat custards, mimicking those of full-fat custard, but also reduced smoothness
20 and increased the sensation of roughness. The latter effect is probably due to the
21 presence of small crystals or crystal aggregates of long-chain inulin in the product.
22 As the crystallization process of inulin depended on both the size of the inulin chains
23 and the initial inulin concentration (Bot, Erle, Vreeker, & Agterof, 2004) reducing
24 long-chain inulin concentration can decrease the formation of inulin crystals.

1 There is no information available on the effects of mixtures of short and long-chain
2 inulin on the physical and sensory properties of custard desserts; however, one could
3 expect them to reflect the combination of the effects of both inulin types. The
4 amount of long-chain inulin needed to formulate prebiotic custard could be reduced
5 by using inulin blends. This would have the nutritional advantage of inulin although
6 lowering long-chain inulin concentration is also expected to reduce its fat replacing
7 capacity.

8 This study aimed to assess to what extent the physicochemical and sensory properties
9 of prebiotic low-fat custards are affected by adding different blends of two inulins
10 with different average chain length (short and long) and of combining these with λ -
11 carrageenan. Special attention was paid to whether or not inulin blends and
12 carrageenan addition to low-fat custard could emulate the consistency and creaminess
13 of full-fat custard.

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15 **2. Material and methods**

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17 *2.1. Sample composition and preparation*

18 The following ingredients were used: hydroxypropylated tapioca di-starch phosphate
19 (C* Creamtex 75720; Cerestar Ibérica, Spain), two types of inulin: short-chain inulin
20 (2-10 monomers, Frutafit® CLR) and inulin of long chain length (≥ 23 monomers,
21 Frutafit® TEX!) from Sensus (Brenntag Química, Spain), lambda-carrageenan
22 (Satiagum™ ADC 25; Degussa Texturant Systems, Spain), colorant (Vegex NC 2c;
23 CHR Hansen S.A., Spain), vanilla aroma (37548A; Lucta S.A., Spain), skim and
24 whole-milk powders (Central Lechera Asturiana, Spain), mineral water (Font Vella,

Spain) and commercial sucrose. Starch moisture content was determined with a LJ16 moisture analyzer (Mettler Toledo GmbH, Greifensee, Switzerland). Three blends of long-chain inulin (TEX) and short-chain inulin (CLR) that differed in the TEX:CLR ratio (25:75, 50:50 and 75:25), were added to the samples at a concentration of 7.5 g/100g of custard. Two sets of samples were prepared either with or without lambda carrageenan (0.01 g/100g). All samples included fixed amounts of starch (3.75 g/100g), skimmed milk (80 g/100g), sucrose (6 g/100g), colorant (0.052 g/100g) and vanilla aroma (0.016 g/100g). A sample with whole milk and one with skimmed milk were prepared without inulin and without carrageenan as control full-fat and low-fat samples, respectively. Both skim milk (0.14 g fat /100g) and whole milk (3.5 g fat/100g) were prepared 24h in advance by dissolving milk powder (13.5 g/100g) in mineral water and storing under refrigeration ($4 \pm 1^\circ\text{C}$). Samples were prepared in batches of 800g. All ingredients were weighed in a flask and mixed under magnetic stirring for 10 min. The flask was placed in a water bath at $97 \pm 1^\circ\text{C}$ and stirred constantly with a propeller stirrer. After 10 min the product temperature reached $85 \pm 1^\circ\text{C}$ and heating was maintained at this temperature for 15 min. After the heating process, the evaporated water was replaced gravimetrically. The sample was cooled in a water bath at 20°C until it reached temperatures of about 40°C and then the aroma was added. The sample was homogenized, transferred to a closed flask and stored under refrigeration ($4 \pm 1^\circ\text{C}$) for 48 h.

2.2. Rheological measurements

All rheological measurements were carried out in a controlled stress rheometer (RheoStress 1, Karlsruhe, Germany), monitored by a Rheowin Projob Manager,

1 using a parallel-plates sensor system (6 cm diameter and 1mm gap). During
2 measurements temperature was kept constant at $10 \pm 1^\circ\text{C}$ using a Phoenix P1
3 Circulator device (Thermo Haake). Two batches of each composition were prepared
4 and at least one measurement was performed on each batch.

5 Flow behaviour was measured by recording shear stress values when shearing the
6 samples at linearly increasing shear rates from 1 to 200 s^{-1} through 60 s and down in
7 reverse sequence for the same time (Tarrega, Duran, & Costell, 2004). To quantify
8 the time dependence of the flow, the thixotropic area was calculated. Data from the
9 ascending flow curve were fitted to the Ostwald-de Waele model ($\sigma = K \dot{\gamma}^n$) where
10 $K (\text{Pa.s}^n)$ is the consistency index and n is the flow index. These calculations were
11 performed using the Rheowin Pro software (version 2.93, Haake).

12 Viscoelastic properties were measured using small amplitude oscillatory shear tests.
13 First, to determine the linear viscoelastic region, stress sweeps were run at 1 Hz.
14 After that, the frequency sweeps were performed over the range $f = 0.01\text{-}10 \text{ Hz}$ and
15 the values of the storage modulus (G'), the loss modulus (G''), the loss tangent
16 angle ($\tan \delta$) and the complex viscosity (η^*), as a function of frequency, were
17 calculated using the Rheowin Pro software (version 2.93, Haake) (Tarrega, Duran, &
18 Costell, 2005).

19

20 2.3. Sensory evaluation

21

22 All sensory tests were carried out in the morning in a standardised test room (ISO,
23 2007). Samples (30 ml) were served in white plastic cups coded with three digits
24 random numbers. Mineral water was provided for mouth-rinsing. Data acquisition
25 was performed using Compusense Five v.4.6 software (Compusense Inc. Guelph,

1 Canada). Sensory tests were carried out by a group of 42-44 assessors, with previous
2 experience on sensory analysis of dairy products, and selected according to their
3 taste sensitivity and their capacity to detect differences in intensities of the
4 considered attributes (ISO, 1993).

5 *Ranking tests.* Ranking tests (ISO, 2006) were used to study the effects of adding
6 inulin blends, and their combination with carrageenan, on the sensory properties of
7 two different sets of four samples of low-fat dairy desserts. For each set of samples,
8 assessors were asked to rank the four low-fat samples according to thickness,
9 creaminess, sweetness and vanilla flavour intensity and also according to preference.
10 The first set included the three samples containing the different inulin blends (25:75,
11 50:50 and 75:25, TEX:CLR) and the control low-fat sample (without inulin and
12 without carrageenan). The second set included the three samples containing lambda
13 carrageenan (0.01g/100g) and each of the inulin blends (25:75, 50:50 and 75:25,
14 TEX:CLR) and the control low-fat sample (without inulin and without carrageenan).

15 *Paired comparison tests.* The effect of replacing fat with inulin and carrageenan on
16 sensory characteristics was evaluated by comparing three selected formulations of
17 low-fat dairy dessert with the control full-fat dairy dessert. Paired comparison tests
18 (ISO, 2005) were performed to evaluate the differences in thickness, creaminess,
19 sweetness, vanilla flavour and preference. In order to reduce the possible effect of
20 the serving order, an equal number of assessors received a different sample first for
21 each pair.

22

23 2.4. Data analysis

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1 Two-way analysis of variance (ANOVA) with interaction was performed on the
2 rheological parameters to study the effects of both inulin blend and lambda
3 carrageenan addition. Principal Component Analysis (PCA) was applied to the
4 correlation matrix of the average values of the rheological parameters obtained for
5 low-fat samples and the control full-fat sample. Both analyses were performed using
6 the XLSTAT-Pro Version 2007 (Addinsoft, Paris, France).

7 Friedman Analysis of Variance was applied to the sensory data obtained in the
8 ranking tests, and significance of differences between samples were determined by
9 the Fisher test ($\alpha = 0.05$), as modified for non-parametric data (Meilgaard, Civille, &
10 Carr, 1999). Paired comparisons tests were considered two-tailed and significant
11 differences were established for $\alpha=0.05$. Sensory data analysis was performed using
12 Compusense® five release 4.6 software (Compusense Inc., Guelph, Ontario,
13 Canada).

14

15 **3. Results and Discussion**

16

17 *3.1. Effect of the addition of inulin blends and carrageenan on the rheological*
18 *properties of low-fat desserts.*

19

20 *Flow behaviour.* Flow curves were obtained for custard samples and all of them
21 exhibited shear thinning and time-dependent flow behaviour which is in accordance
22 with previous studies (Tarrega et al., 2004; Doublier, & Durand, 2008). The flow
23 curves obtained for some of the samples are shown as an example in Figure 1.
24 Differences in the magnitude of the hysteresis loop were observed indicating
25 different degrees of time dependency in the samples flow. To quantify it, thixotropic

1 area values were calculated (Table1). The ANOVA showed a significant interaction
 2 between both carrageenan and inulin effects ($F_{\text{int}}=26.96$, $p<0.001$) indicating that the
 3 effect of the different inulin blends on thixotropy depended on the presence of
 4 carrageenan. In samples without carrageenan the thixotropic area did not
 5 significantly vary when any of the mixtures were added, while for the samples with
 6 carrageenan (0.01 g/100g), adding the inulin blends gave rise to an increase in the
 7 value of the thixotropic area, which was similar for all three blend types.

8 Experimental data of the upward flow curve were fitted to Ostwald de Waele model
 9 ($0.973 \leq R^2 \leq 0.999$). The flow of all samples was clearly pseudoplastic, showing
 10 flow indices (n) in the range between 0.24 and 0.47 (Table 1). The consistency index
 11 value (K) ranged from 6.3 Pa.s ^{n} for the low-fat control sample (without carrageenan
 12 and without inulin) to 30.1 Pa.s ^{n} for the sample with carrageenan and the inulin
 13 blend 25:75 TEX:CLR. ANOVA results showed that the inulin-carrageenan
 14 interaction was significant for K values ($F_{\text{int}}=15.73$, $p=0.001$) and for n values
 15 ($F_{\text{int}}=13.00$, $p=0.002$). For samples without carrageenan, the increase in consistency
 16 and pseudoplasticity depended on the type of inulin blend. The increase in
 17 consistency was only significant for the sample with the highest amount of long-
 18 chain inulin (75:25 TEX:CLR) while pseudoplasticity increased (n values
 19 decreased) according the amount of long-chain inulin in the blend (Table 1). For
 20 samples with carrageenan, inulin addition caused a significant increase in both
 21 consistency and pseudoplasticity values with no differences among the three inulin
 22 blends.

23

24 *Viscoelastic properties.* Mechanical spectra were obtained or each of the studied
 25 samples. Figure 2 shows, for example, those obtained for some samples. In general,

1 mechanical spectra were typical of weak gels with G' values above those of G'' with
2 both being quite frequency-dependent. The sample having the weakest structure was
3 made with skimmed milk which gave a spectrum with low G' and G'' values while
4 the samples with carrageenan (0.01g / 100g of Custard) gave mechanical spectra
5 with higher G' and G'' values and were less frequency-dependent, indicating a
6 stronger gel structure. To compare the viscoelastic properties of skimmed-milk
7 samples, the values of the parameters G' , G'' and $\tan \delta$ at 1 Hz were considered. For
8 the storage modulus G' , ANOVA revealed a significant interaction between inulin
9 and carrageenan ($F_{\text{int}}=5.83$, $p=0.021$). Inulin addition caused a significant increase in
10 G' values for samples containing carrageenan, the increase being higher for blends
11 with a higher proportion of short-chain inulin (25:75 TEX:CLR). In the samples
12 without carrageenan no significant differences in G' values were observed among
13 samples (Table 2). Loss modulus values were only significantly affected by the
14 presence of carrageenan ($F=90.7$, $p<0.001$) but the effect of inulin addition was not
15 significant ($F=2.07$, $p=0.18$). The values of $\tan \delta$ decreased with inulin addition
16 ($F=10.54$, $p=0.004$) with no significant differences among the three inulin blends
17 (Table 2).

18 Rheological results show that for both flow behaviour and visco-elasticity the effect
19 of mixtures of short-chain and long-chain inulin depended on the presence of
20 carrageenan in the sample. In the absence of carrageenans, the addition of inulin
21 blends hardly affected values of most rheological parameters of the samples except
22 those recorded for the flow-index and $\tan \delta$, which decreased. Previous studies have
23 found that the addition of short-chain inulin and especially long-chain inulin at a
24 concentration of 6 and 7.5g/100g to custard desserts can significantly change their
25 rheological behaviour by increasing the consistency, viscosity and elasticity of

1 systems (Tarrega et al., 2006b; Gonzalez-Tomas et al., 2008; González-Tomás,
2 Bayarri, Coll-Marqués, & Costell, 2009). Soluble short-chain inulin behaves as a co-
3 solute which can bind water molecules, thus increasing the viscosity of the
4 continuous phase of the system. Long-chain inulin is less soluble and at high
5 concentrations they can interact with each other forming small aggregates, which
6 occlude a great amount of water. However for lower concentrations of inulin (2.5
7 and 5 g/100g of custard (Gonzalez-Tomas et al., 2008) the effect was found not to
8 be significant

9 In the present study, the very low effect observed on adding blends of the two types
10 of inulin could be explained by the fact that in no case did the concentration of each
11 inulin type become sufficient to cause the effect observed when added separately at
12 a concentration of 7.5 g/100g of custard.

13 In samples containing carrageenans, the addition of the inulin blends generally led to
14 a significant increase in the thixotropic area, in consistency and in elasticity, which
15 in the latter case was greater for the mixture with a higher proportion of short-chain
16 inulin. The extent of the effect of low carrageenan concentrations on the behaviour
17 of this type of product can change greatly by varying the concentration of one of the
18 components (Syrbe, Bauer, & Klostermeyer, 1998; Tarrega, & Costell, 2006a). The
19 important effect of adding inulin is probably due to an increase in the effective
20 concentration of carrageenan able to generate the network in the continuous phase.

21 The same effect has been observed when adding short and long-chain inulin to milk
22 beverages (Villegas, & Costell, 2007). Adding inulin concentrations of 2 to 6
23 g/100g of beverage, hardly affected sample viscosity; however, when *kappa*-
24 carrageenan was also present viscosity increased significantly. In these samples (2-
25 6g inulin / 100g of beverage), the increase in viscosity was higher for short-chain

1 inulin than for long-chain inulin which is in accordance with the more elastic trait
2 observed in our case for the custard containing the blend with highest amount of
3 short-chain inulin. That can be due to the fact that although both types of inulin
4 retain water, in the case of long chain inulin, the aggregates may disrupt the
5 carrageenan-casein network and in the case of short chain inulin, it remains
6 solubilised and does not affect the network.

7

8 *3.2. Effect of adding inulin blends and carrageenan on sensory properties of low-fat* 9 *desserts*

10

11 First, the effects of adding different inulin blends on the sensory properties of low-
12 fat custards were studied. Friedman analysis of ranking data showed that assessors
13 perceived significant differences in the intensity of sweetness, vanilla flavour,
14 thickness and preference among samples (F values were 51.5, 15.0, 20.2 and 11.5,
15 respectively; theoretical F value being 7.81 for $\alpha=0.05$). In general, inulin addition
16 increased both sweetness and vanilla intensity, with this effect being more
17 remarkable in the case of samples with higher amounts of short-chain inulin (25:75
18 y 50:50 TEX:CLR) (Figure 3). These two samples also proved significantly thicker
19 than low-fat control sample and, although the effect of inulin on creaminess was not
20 significant ($F=7.3$ $p=0.064$), the trend was that these two samples were also
21 perceived as creamier. In terms of preference, no significant differences were
22 observed among the three samples containing inulin; however, they were preferred
23 to the control sample. Secondly, the effects of adding carrageenans and inulin blends
24 together on the sensory properties of low-fat custard were studied. In this case, the
25 samples revealed significant differences in all attributes evaluated (F values were

1 33.1, 14.0, 39.9, 47.2 and 10.4 for sweetness, vanilla flavour, creaminess, thickness
2 and preference respectively; theoretical F value being 7.81 for $p=0.05$). The joint
3 addition of carrageenans and inulin led to an increase in sweetness, vanilla flavour,
4 creaminess and consistency, which was greatest in samples containing inulin blends
5 25:75 and 50: 50 TEX:CLR (Figure 4). Likewise, these two samples were clearly
6 preferred to the control sample and the sample with the highest proportion of inulin
7 TEX.

8 Both in the case of adding inulin alone and adding inulin combined with
9 carrageenans, the sensory properties of the custard varied with the inulin blend
10 employed. In both cases and according to the differences perceived by assessors, the
11 blend with the same amount of the two inulins (50:50 TEX:CLR) and the blend
12 with a higher proportion of short-chain inulin (25:75 TEX:CLR) were those that
13 provided additional thickness, sweetness and vanilla flavour intensity to the vanilla
14 custard, while the effect was clearly lower or no significant for the mixture
15 containing a higher proportion of long-chain inulin.

16

17 *3.3. Inulin and carrageenan as fat replacers in custards*

18

19 As stated previously, one of the most interesting technological characteristics of
20 inulin and oligofructose is their ability to act as a fat replacer in dairy products
21 (Franck, 2002; Guven, Yasar, Karaca, & Hayaloglu, 2005; Koca, & Metin, 2004;
22 Schaller-Povolny, & Smith, 1999). In order to compare the rheological properties of
23 the different low-fat samples studied in this work with those of the control full-fat
24 sample, the variability in all rheological parameters was studied by a PCA test. The
25 first two components (PC1 and PC2) accounted for 97.4% of the total variability

1 (Figure 5). PC1, accounting for 90.2 % of the total variability, was positively
2 correlated with thixotropic area, consistency index (K) and the elastic modulus (G').
3 PC2 accounted for 7.2 % of the variability and was mainly associated with two
4 parameters: $\tan \delta$ and flow index (n). The low-fat control sample fell within in the
5 upper left-hand quadrant, showing the lowest values for thixotropic area, K and G'
6 and the highest n and $\tan \delta$ values. The full-fat control sample fell in the opposite
7 side (lower right-hand quadrant) indicating that the differences between the low-fat
8 control and the full-fat control samples affected parameters associated with the two
9 components. Fat presence caused an increase in values of thixotropic area, K and G'
10 but also decreased the values of parameters n and $\tan \delta$. In order to imitate the
11 rheological properties of fat, a fat replacer should have the same effects on the low-
12 fat sample.

13 Position of samples containing inulin indicated that inulin addition mainly led to a
14 decrease in $\tan \delta$ and n values which approximated those of the full-fat sample in the
15 PC plot but which was not enough to fully imitate its rheological behaviour. This is
16 in agreement with that observed by (Gonzalez-Tomas et al., 2008) when comparing
17 rheological behaviour of a full-fat dessert and low-fat desserts with different inulin
18 concentrations. The long-chain inulin used as fat replacer requires inulin addition at
19 concentrations over 7 g/100g of custard and in the present study all the samples
20 contained long-chain inulin at below 7 g/100g. The sample with added carrageenan
21 appeared displaced to the right side with respect to the control low fat sample
22 indicating that the main effect of carrageenan was an increase in consistency,
23 thixotropy and elasticity. Finally, the joint addition of inulin blends and carrageenan
24 caused both types of effect but to a greater extent than fat did. Samples containing a

1 combination of carrageenan and inulin blends fell in the right-hand side, having
2 greater consistency, thixotropy and elasticity than the full-fat sample.

3 Three low-fat samples were selected: i) the sample with inulin blend 50:50 TEX:
4 CLR added, ii) the sample with added carrageenan and iii) the sample containing
5 both ingredients, in order to compare their sensory properties with those of the full-
6 fat control custard. The low-fat sample with the blend 50:50 TEX:CLR was selected
7 as the nutritional advantages described in the literature for the inulin blends mainly
8 refer to this blend ratio (Ghoddusi, Grandison, Grandison, & Tuohy, 2007; Abrams
9 et al., 2005). This low-fat custard enriched with inulin was sweeter, with more
10 vanilla flavour and no significant differences ($p=0.05$) in creaminess, thickness or
11 preference when compared with the full-fat control custard (Figure 6). The sample
12 containing carrageenan also had stronger flavour intensity and no differences in
13 consistency and preference compared to the whole-milk sample; however, it was not
14 as creamy (Figure 7). Finally the low-fat custard with the blend 50:50 TEX:CLR
15 added together with carrageenan proved sweeter, with more vanilla flavour, thicker,
16 creamier and preferred more than the full-fat custard (Figure 8). In general the three
17 low-fat samples were perceived to have significantly ($p=0.05$) more flavour and
18 greater sweetness intensity than the full-fat control samples, indicating that flavour
19 intensity was affected not only by inulin addition (Tarrega et al., 2006b) but also by
20 fat-content reduction (Gonzalez-Tomas, Bayarri, Taylor, & Costell, 2007).

21 From the nutritional viewpoint, the mixture of short and long-chain inulin 50:50
22 affords some extra advantages in addition to improving prebiotic effectiveness.
23 Abrams et al., (2005) demonstrated that a daily intake of 8 g of this inulin blend
24 enhances calcium absorption and bone mineralization in pubertal adolescents and
25 according to Ghoddusi et al., (2007), a mixture of oligofructose and inulin 50:50

1 could prove effective in reducing the amount of gas produced while increasing or
2 maintaining their ability to support beneficial bacteria in the colon. Regarding the
3 technological properties, the mixture 50:50 long and short-chain inulin was found
4 the most appropriate to formulate a new *petit suisse* cheese with prebiotic and
5 probiotic properties because this combination improved both probiotic viable count
6 and acceptability most (Cardarelli, Buriti, Castro, & Saad, 2008). In the present
7 study adding this inulin blend (50:50, TEX:CLR) to low-fat custard proved
8 insufficient to completely emulate the rheological behaviour of full-fat custard,
9 while when combined with lambda carrageenan it exceeded the full-fat effect.
10 However, the sensorial results indicated that custard enriched with TEX:CLR inulin
11 blend 50:50 showed no significant differences in viscosity, creaminess and
12 acceptability with the full-fat custard and when this inulin blend was used combined
13 with carrageenan at 0.01 g/100g of product the custard was more viscous, creamier
14 and preferred over the whole-milk custard.

15

16 **4. Conclusions**

17

18 This study has shown that the effect of adding inulin blends (7.5 g/100g custard) on
19 the rheological properties of custard depends on the presence of carrageenan and
20 that only slight differences were observed among inulin blends. Sensory properties
21 did vary among the different inulin blends and in both cases (custards with and
22 without carrageenan) the 25:50 and 50:50 TEX:CLR inulin blends enhanced
23 product flavour intensity and thickness. The use of the 50:50 TEX:CLR blend,
24 which affords certain nutritional advantages, can also act as fat replacer. The results
25 of this study are of great interest in the development of prebiotic products which

1 maximize nutritional benefits and sensory characteristics to meet consumer
2 demands.

3

4

5 **Acknowledgments**

6

7 To MICINN of Spain for financial support (Project AGL 2007-63444). To CHR
8 Hansen S.A., Lucta S.A., Brentag Química, Degussa Texturant Systems and Central
9 Lechera Asturiana for providing free samples of the ingredients.

10

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7 **FIGURE CAPTIONS**

10 Figure 1. Flow curves obtained for low fat custards. Control low fat sample (○) and
11 samples enriched with the inulin blend 75:25 TEX:CLR (7.5 g/100g) (■), with
12 lambda carrageenan (0.01 g/100g) (▲) and with the combination of both
13 ingredients(◇).

15 Figure 2. Mechanical spectra obtained for low fat custards. Control low fat sample
16 (○) and samples enriched with the inulin blend 75:25 TEX:CLR (7.5 g/100g) (□),
17 with lambda carrageenan (0.01 g/100g) (△) and with the combination of both
18 ingredients (◇).

20 Figure 3. Sensory evaluation of differences among the control low fat custard (▒)
21 and custards with different blends of TEX and CLR inulin: 25:75 (⋮), 50:50 (▤)
22 and 75:25 (▢). Different letters on top of bars means significant differences ($p=0.05$).

24 Figure 4. Sensory evaluation of differences among the control low fat custard (▒)
25 and custards containing carrageenan combined with different blends of TEX and CLR
26 inulin: 25:75 (⋮), 50:50 (▤) and 75:25 (▢). Different letters on top of bars
27 means significant differences ($p=0.05$).

29 Figure 5. Principal component analysis plot for rheological parameters of low fat
30 custards enriched with blend of TEX:CLR inulin and elaborated without (○) or with
31 lambda carrageenan (●). Control full fat sample (FF, ▲).

33 Figure 6. Sensory evaluation of the differences between the low fat custard with the
34 blend of inulin TEX:CLR 50:50 (▢) and the control full fat custard (■). The
35 line indicates the minimum value of responses for which the difference is significant
36 ($p=0.05$).

38 Figure 7. Sensory evaluation of the differences between the low fat custard with
39 carrageenan (▢) and the control full fat custard (■). The line indicates the
40 minimum value of responses for which the difference is significant ($p=0.05$).

42 Figure 8. Sensory evaluation of the differences between the low fat custard
43 containing carrageenan and the blend of inulin TEX:CLR 50:50 (▢) and the

- 1 control full fat custard (■). The line indicates the minimum value of response for
- 2 which the difference is significant ($p=0.05$).
- 3
- 4

Table 1. Flow behaviour parameters for dairy desserts. Thixotropic Area (A), consistency index (K) and flow index (n) values.^{1,2,3}

Carrageenan %	Inulin %	TEX:CLR Ratio	A (Pa)	K (Pa.s ⁿ)	n
0	0	-	814 ^a	6.3 ^a	0.47 ^e
	7.5	25:75	797 ^a	7.2 ^{ab}	0.43 ^d
	7.5	50:50	933 ^a	7.5 ^{ab}	0.41 ^{cd}
	7.5	75:25	1200 ^a	11.6 ^b	0.33 ^b
0.01	0	-	1660 ^b	11.1 ^b	0.39 ^c
	7.5	25:75	3840 ^c	30.1 ^c	0.24 ^a
	7.5	50:50	3440 ^c	27.1 ^c	0.25 ^a
	7.5	75:25	3550 ^c	29.5 ^c	0.25 ^a

¹ K and n values were obtained from Ostwald de Waele fit of flow curves ($0.973 \leq R^2 \leq 0.999$)

² For each column, different letter superscripts means significant differences ($\alpha=0.05$).

³ Values for full fat control sample: Area= 3025 ± 63 Pa, K =18.6 ± 0.1 Pa.sⁿ, n=0.29 ± 0.002

Table 2. Storage modulus (G'), loss modulus (G''), loss angle tangent ($\tan \delta$) and complex viscosity (η^*) values at 1 Hz for dairy desserts.^{1,2,3}

Carrageenan %	Inulin %	TEX:CLR Ratio	G' (Pa)	G'' (Pa)	η^* (Pa.s ⁿ)	$\tan \delta$
0	0	-	14.8 ^a	10.8 ^a	2.9 ^a	0.73 ^d
	7.5	25:75	20.3 ^a	11.2 ^a	3.7 ^a	0.58 ^{bc}
	7.5	50:50	20.0 ^a	10.0 ^a	3.6 ^a	0.51 ^{bc}
	7.5	75:25	21.8 ^a	10.8 ^a	3.9 ^a	0.50 ^{bc}
0.01	0	-	24.2 ^a	15.5 ^b	4.6 ^a	0.64 ^{cd}
	7.5	25:75	54.9 ^c	20.2 ^c	9.3 ^b	0.37 ^a
	7.5	50:50	47.9 ^{bc}	17.8 ^{bc}	8.1 ^b	0.37 ^a
	7.5	75:25	43.9 ^b	18.4 ^{bc}	7.5 ^b	0.44 ^{ab}

¹ For each column, different letter superscripts means significant differences ($\alpha=0.05$).

² Values for full fat control sample: $G' = 30.1 \pm 1.5$ Pa, $G'' = 12.7 \pm 0.6$ Pa, $\eta^* = 5.2 \pm 0.3$ Pa, $\tan \delta = 0.42 \pm 0.001$

Figure1

Figure 1.

Figure 2

Figure 2.

Figure 3.

Figure 4.

Figure 5

Figure 6.

Figure 7.

Figure 8.