Fat replacers in low-fat carboxymethyl cellulose dairy beverages: Color, rheology, and consumer perception

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ABSTRACT

Low-fat foods are an interesting option for consumers interested in health-related issues or in maintaining adequate body weight; however, fat reduction may influence consumer acceptance of the end product. This study aims to obtain information about the effectiveness of λ -carrageenan and a blend (50:50) of short- and long-chain inulin as fat replacers in dairy beverages prepared with carboxymethyl cellulose (CMC) and to determine to what extent consumers perceive instrumental color and rheological differences among samples. Results showed that both λ -carrageenan and the inulin blend could be used as fat replacers in CMC-based dairy beverages and that consumers could distinguish among samples that differed in color and rheological behavior.

Key words: fat replacer, dairy beverage, physical property, consumer

INTRODUCTION

Low-fat foods are an interesting option for consumers interested in health-related issues or in maintaining adequate BW. Furthermore, consumers look for healthy foods with satisfactory sensory characteristics and for traits similar to those of conventional products (Verbeke, 2006). The elimination or reduction of fat modifies the composition and structure of dairy foods, as well as the expected interactions among components, often giving rise to perceptible changes in color, flavor, and texture (Bayarri and Costell, 2009). These changes may influence consumer acceptance of the end product.

One of the most common strategies to compensate for fat reduction is the use of fat replacers or fat mimetics (Sandrou and Arvanitoyannis, 2000). Among fat replacers, carbohydrate-based substances, such as starch, cellulose, pectin, inulin, xanthan gum, or carrageenan, are of growing interest because they have health-friendly characteristics in addition to their phys-

icochemical properties (Warrand, 2006). In a previous study on starch-based systems (González-Tomás et al., 2009a), the addition of long-chain inulin (7.5%) gave rise to a low-fat product with the same thickness and creaminess intensity as the full-fat sample; however, it was rougher and consequently its sensory quality was negatively affected. This roughness was probably due to the presence of aggregates of long-chain inulin in the product. One way to avoid this problem is to reduce the long-chain inulin content by using a blend of short- and long-chain inulin as fat replacer, as reported in studies into the effect of short- and long-chain inulin blends on the rheological and sensory properties of low-fat, semisolid, starch-based custards (Tárrega et al., 2010). Addition of inulin blends at 7.5% to low-fat desserts did not fully emulate the rheological behavior of the full-fat custard; however, the low-fat sample with the 50:50 inulin blend was perceived to have the same creaminess and thickness as the full-fat sample. A study carried out in our laboratory (Bayarri et al., 2010) showed that low-fat, semisolid, carboxymethyl cellulose (CMC)-based dairy custards with 0.03% λ -carrageenan or with 9% of a blend of short- and long-chain inulin displayed similar rheological behavior to the full-fat control sample; that is, no differences were detected in either flow or viscoelasticity. Samples with the same rheological behavior but different fat contents were perceived as having similar thickness, creaminess, and smoothness. With respect to flavor perception, the substitution of fat by λ -carrageenan or inulin influences both perceived sweetness and flavor. These studies suggest that blends of short- and long-chain inulin or λ -carrageenan can be successfully used as fat replacers in semisolid dairy products, but no information is available for dairy beverages.

In the abovementioned studies, sensory evaluation was carried out by a group of selected panelists with previous experience on sensory analysis of dairy products and working with a previously established vocabulary to examine and describe product characteristics. Sensory evaluation of foods is usually carried out by using conventional techniques such as descriptive analysis, which requires a considerable amount of time to recruit, screen, and train assessors, who normally

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tend to generate complex and scientifically oriented terms. On the contrary, consumer sensory panels generate easily understandable vocabularies that have the disadvantages of being too personal to be interpreted by anyone except the subject, and consumers usually have difficulty in developing a vocabulary to describe the differences between samples. The repertory grid method (**RGM**) in conjunction with the free choice profile (**FCP**) is a sensory methodology developed to avoid these disadvantages, allowing researchers to obtain direct information about what sensations consumers perceive when eating food (Hersleth et al., 2003; Jaeger et al., 2005; Jahan et al., 2005; González-Tomás and Costell, 2006; Costell et al., 2010). In addition, FCP has some advantages over descriptive analysis procedures that use a consensus vocabulary: (1) FCP does not require extensive training; (2) vocabulary development is economical in terms of time and effort; and (3) the “consumer-recognizable” terms obtained are useful for marketing. A common problem when working with consumers is generating sufficient and suitable descriptors to express their sensory perceptions. The RGM seems particularly suited to developing a consumer-related vocabulary. With respect to FCP, on the one hand, it differs from conventional profiling in that each consumer develops an individual list of terms to describe the samples rather than using a common scorecard. On the other hand, it is similar in that the assessors must be able to detect differences between samples, verbally describe the perceived attributes, and quantify them (Oreskovich et al., 1991). The assessors only have to be objective, and capable of using linear scales and of using the chosen vocabulary consistently (Piggott et al., 1990). One of the advantages of RGM with FCP is that it allows one to gather information about cognitive perception directly from consumers and to identify their common perceptual dimensions (Gains and Thomson, 1990; Russell and Cox, 2003).

The objectives of this work were (1) to obtain information about the effectiveness of λ -carrageenan and a blend (50:50) of short- and long-chain inulin as fat replacers in CMC-based dairy beverages; and (2) to determine to what extent consumers perceived instrumental color and rheological differences among samples.

MATERIALS AND METHODS

Sample Preparation and Composition

Samples were prepared with CMC (Akucell AF3265 Akzo Nobel, Amersfoort, the Netherlands), sucrose, commercial whole milk powder (25% wt/wt protein, 39% wt/wt carbohydrate, 26% wt/wt fat, and 1.2% wt/wt calcium) or skim milk powder (34% wt/wt protein,

52% wt/wt carbohydrate, 1% wt/wt fat, and 1.2% wt/wt calcium; both from 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 2 types of inulin that differed in average chain length: long-chain (**LC**, ≥ 23 monomers; Frutafit TEX!) and short-chain inulin (**SC**, 7–9 monomers; Frutafit CLR), both of which were provided by Sensus (Brenntag Química, Barcelona, Spain).

Low-fat samples were prepared at 3 concentrations of CMC: 0.7, 0.9, and 1.1% (wt/wt), each with 2 λ -carrageenan contents, 0.01 and 0.03 (% wt/wt), or 3 concentrations of a 50:50 blend of short- and long-chain inulin (**SC/LC**), 7, 9, and 11% (wt/wt). The identification and composition of the samples are given in Table 1. For each CMC concentration, 2 more samples without inulin or λ -carrageenan, one with whole-milk (full-fat control: **FFC**) and the other with skim milk (low-fat control: **LFC**) were used as controls. The amounts of sugar (6% wt/wt), colorant (0.052% wt/wt), and vanilla aroma (0.016% wt/wt), and the weight of rehydrated milk (80% wt/wt) were fixed across treatments.

Whole and skim milk were prepared in advance by dissolving 13.5% (wt/wt) whole and skim 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, Usmate, Italy) and stored at $4 \pm 1^\circ\text{C}$ overnight to ensure complete hydration of the milk proteins. To prepare control samples, a dry blend of sugar with CMC was added to the rehydrated milk with the colorant and stirred (Heidolph RZR 1, Schwabach, Germany) at room temperature for 35 min; after 30 min, vanilla aroma was added. Samples were transferred to a closed flask and stored ($4 \pm 1^\circ\text{C}$; 24 h) before measurement. Low-fat samples containing λ -carrageenan were prepared in the same way, except that λ -carrageenan powder was added to the skim-rehydrated milk together with the dry blend of sugar and CMC. Long-chain inulin and short-chain inulin were mixed 50:50, and low-fat samples were prepared by dispersing skim milk powder and the corresponding inulin concentration in mineral water just before the aforementioned heat treatment.

Instrumental Measurement of Color

Color was measured in a Konica Minolta CM-3500d spectrophotometer (Konica Minolta Business Technologies Inc., Osaka, Japan). A 3.5-cm-thick layer of

Table 1. Composition of low-fat dairy beverages containing various concentrations of carboxymethyl cellulose (CMC)

Sample code	CMC (% wt/wt)	Fat replacer type	Fat replacer (% wt/wt)
1	0.7	λ -Carrageenan	0.01
2		λ -Carrageenan	0.03
3		Inulin	7
4		Inulin	9
5		Inulin	11
6	0.9	λ -Carrageenan	0.01
7		λ -Carrageenan	0.03
8		Inulin	7
9		Inulin	9
10		Inulin	11
11	1.1	λ -Carrageenan	0.01
12		λ -Carrageenan	0.03
13		Inulin	7
14		Inulin	9
15		Inulin	11

sample was contained in optical glass cells 3.8 cm high and 6 cm in diameter to measure diffused reflected light from the cell bottom using an 8-mm diaphragm aperture. Results were given using the CIELAB system for illuminant D65 and a 10° angle of vision. Registered parameters were L^* (brightness), a^* (red component), b^* (yellow component), C^* (chroma), and h^* (hue). Two batches of each composition were prepared and 2 measurements were performed on each batch.

The color difference (ΔE^*) between control samples FFC and LFC was calculated by using equation [1] (Francis and Clydesdale, 1975):

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}, \quad [1]$$

where ΔL^* , Δa^* , and Δb^* are the difference between the 2 samples in L^* , a^* , and b^* , respectively. The perception of the color difference ΔE^* varies according to the observed color and the sensitivity of the human eye. According to Bodart et al. (2008), the human eye distinguishes color difference only if ΔE^* is greater than 1 to 3. For some colors, mainly blues, ΔE^* values of 1 can be detected, but for other colors, such as red, the same ΔE^* may not be perceptible.

Rheological Measurements

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

Flow Behavior. 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 (González-Tomás et al., 2009b). Data from the upward curve of the shear cycle were fitted to the Ostwald-de Waele model (equation [2]):

$$\sigma = K \dot{\gamma}^n, \quad [2]$$

where σ (Pa) is the shear stress, $\dot{\gamma}$ (s^{-1}) is the shear rate, K ($\text{Pa}\cdot\text{s}^n$) is the consistency index, and n is the flow behavior index.

Areas under the upstream data point curve (A_{up}) and under the downstream data point curve (A_{down}) as well as the hysteresis area ($A_{up} - A_{down}$) were obtained using the RheoWin Pro software (v. 3.61, Thermo Haake). Due to the influence of the loop contour and the shear resistance of the sample on the hysteresis area, the percentage of relative hysteresis area (A_r ; equation [3]) was calculated because it allows a better comparison of the thixotropic behavior of different samples (Dolz et al., 2000):

$$A_r = \frac{A_{up} - A_{down}}{A_{up}} \times 100. \quad [3]$$

Viscoelastic Behavior. 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 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.

Sensory Evaluation: FCP. A group of 26 consumers, with an age range of 23 to 55, was recruited from staff and postgraduate students at the research center (IATA, Instituto de Agroquímica y Tecnología de Alimentos, Valencia, Spain) to take part in the FCP study. They were selected based on their being dairy-dessert consumers.

The RGM was used to generate an individual set of terms for each assessor in one session. Six samples, 2 FFC containing 0.7 and 1.1% CMC and 4 low-fat samples (sample nos. 1, 5, 11, and 15; Table 1), were selected to generate terms according to their composition. First, the consumers were briefed about the concept behind the methodology and given a procedural outline. Then, individual interviews were performed (approximately 45 min each) where 3 sets of 3 samples (30 mL each) were presented. To form the first triad, 3 samples were selected at random from the initial group of 6. The second triad was formed by randomly selecting 1 of the samples from the first triad and then combining it with 2 more samples selected from the initial group of 6. Each subject described the similarities and differences they found among samples within each triad in their own terms. This method was repeated until all 6 samples were tasted (Russell and Cox, 2003). Consumers were asked to generate terms concerning the appearance, flavor, and texture of the samples. The generated terms were listed by the interviewer on individual score sheets.

In FCP, 3 FFC samples and 6 low-fat samples chosen on the strength of the rheological results (sample nos. 1, 5, 6, 10, 11 and 15; Table 1) were scored in duplicate over 6 sessions. Each assessor evaluated 3 samples per session with its own score card that comprised the terms that he or she previously generated individually. The intensity of each attribute was scored using 9-point scales whose end terms were “not perceived” and “intense.” Samples (30 mL) were served at $10 \pm 1^\circ\text{C}$ in covered white plastic vessels coded with 3-digit random numbers. For each sample, the appearance attributes were evaluated first. Then, the assessors were asked to evaluate flavor by tasting a teaspoonful of the sample and then evaluate texture by taking a second teaspoonful. Mineral water was provided to the assessors to rinse their mouths between samples. To reduce the influence of serving order, the samples evaluated in each session

were served following a Williams’ design for 3 samples. The samples were evaluated monadically and a rest period of 30 s was imposed between consecutive samples. All sessions were carried out in a standardized test room with separate booths (ISO-8589; ISO, 2007) in morning sessions (1100 to 1300 h).

Statistical Analysis

Color and Rheological Data Analysis. To analyze the effect of fat content on color and rheological data of both FFC and LFC samples, Student’s *t*-test was used. To study the effect of adding a fat replacer to low-fat samples, a 2-way ANOVA (CMC concentration and fat replacer concentration) with interaction was applied for each fat replacer (λ -carrageenan and inulin), including low-fat control samples in the ANOVA. Significant differences between individual samples were determined by the Fisher’s test ($\alpha = 0.05$). Principal component analysis (PCA) with varimax rotation was also applied to the average values of color and rheological parameters of all samples (full-fat and low-fat samples). All calculations were carried out with XLSTAT Pro software v. 2007 (Addinsoft, Paris, France).

Sensory Data Analysis. The data from the FCP were analyzed as 18 different samples (9 duplicate samples) using the generalized Procrustes analysis (GPA) with Senstools version 3.3 (OP&P & Talcott, Utrecht, the Netherlands). To investigate the differences between subjects, as well as between samples, the Procrustes ANOVA (PANOVA) was used, determining the differences between individual and consensus configurations. Results of the PANOVA were expressed as a proportion of the total amount of variance, which was previously rescaled to 100.

RESULTS AND DISCUSSION

Influence of Fat Content on Color and Rheological Behavior

Instrumental Measurement of Color. Results showed that milk type had a significant effect on all instrumental color parameters of control samples when analyzed by Student’s *t*-test (Table 2). Within each CMC concentration, L^* , a^* , b^* and C^* decreased and h^* values increased with decreasing fat content, and a^* , b^* , and C^* increased with CMC concentration for both milk types. However, CMC addition decreased h^* values in low-fat samples, whereas no change was observed in full-fat samples. The L^* parameter was not affected by CMC addition for either type of milk. To study the total color differences between samples with different fat contents, the values of ΔE^* were calculated for each CMC concentration. The value of ΔE^* of samples with

Table 2. Mean values and standard deviations of instrumental color and rheological parameters for full-fat and low-fat control samples with different carboxymethyl cellulose (CMC) concentrations

Item	0.7% CMC		0.9% CMC		1.1% CMC		t^1
	Low-fat	Full-fat	Low-fat	Full-fat	Low-fat	Full-fat	
Color parameter ²							
L^*	60.0 ± 2.0	70.6 ± 0.3	55.4 ± 1.4	70.9 ± 0.2	59.1 ± 0.8	70.0 ± 0.9	7.9
a^*	0.7 ± 0.1	5.4 ± 0.2	1.2 ± 0.3	5.6 ± 0.1	3.0 ± 0.4	6.7 ± 1.6	14.1
b^*	21.7 ± 2.1	30.3 ± 0.3	22.0 ± 1.0	31.1 ± 0.1	27.5 ± 0.9	36.0 ± 4.5	42.8
C^*	21.8 ± 2.2	30.8 ± 0.3	22.0 ± 1.1	31.6 ± 0.1	27.7 ± 1.0	36.6 ± 4.7	45.1
h^*	88.2 ± 2.2	79.9 ± 0.2	86.8 ± 0.6	79.9 ± 0.1	83.8 ± 0.6	79.6 ± 1.2	5.3
Rheological parameter ³							
K (Pa·s ⁿ)	0.2 ± 0.03	0.8 ± 0.1	1.0 ± 0.1	5.4 ± 0.2	3.8 ± 0.4	11.2 ± 1.1	2.1
n	0.8 ± 0.01	0.7 ± 0.01	0.6 ± 0.01	0.5 ± 0.01	0.5 ± 0.01	0.4 ± 0.02	7.4
A _r (%)	3.6 ± 0.2	6.5 ± 0.7	3.6 ± 0.2	8.2 ± 0.2	3.8 ± 0.2	11.0 ± 0.4	3.8
G' (Pa)	0.7 ± 0.02	6.0 ± 0.5	6.9 ± 0.1	24.9 ± 3.7	26.6 ± 1.8	56.5 ± 0.1	2.5
G'' (Pa)	1.5 ± 0.1	5.6 ± 0.1	6.7 ± 0.2	16.9 ± 3.9	17.6 ± 1.3	28.0 ± 0.2	4.0
tan δ	2.3 ± 0.2	0.9 ± 0.1	1.0 ± 0.02	0.7 ± 0.1	0.7 ± 0.01	0.5 ± 0.01	1.6
η* (Pa·s)	0.3 ± 0.02	1.3 ± 0.1	1.5 ± 0.02	4.8 ± 0.8	5.1 ± 0.3	10.0 ± 0.1	2.7

¹*t* value ($\alpha \leq 0.1$) = 1.886.

²*L** = brightness; *a** = red component; *b** = yellow component; *C** = chroma; and *h** = hue.

³K = consistency index; *n* = flow behavior index; A_r = relative hysteresis area; G' = storage modulus; G'' = loss modulus; tan δ = loss angle; and η* = complex dynamic viscosity.

0.7, 0.9, and 1.1% CMC were 14.38, 18.44, and 14.64, respectively. These values indicated that the total color differences between samples with different fat content were noticeable to the human eye (Bodart et al., 2008).

Rheological Properties. Student's *t*-test showed that significant differences existed in the rheological parameters between samples made with different milk types, except tan δ (Table 2). In general, values for all rheological parameters were greater in full-fat samples except flow index and tan δ. All samples exhibited thixotropic and shear-thinning flow behavior. For all CMC concentrations, full-fat samples exhibited higher consistency, pseudoplasticity, and thixotropy than low-fat samples; this trend also increased with CMC concentration (Bayarri and Costell, 2010). The viscoelastic

characteristics of samples depended on both the milk type and CMC concentration. Full-fat samples showed significantly higher dynamic modulus (G' and G'') and complex dynamic viscosity (η*) values and lower tan δ values than low-fat samples, exhibiting a more structured system, probably due to the presence of fat (Abu-Jdayil et al., 2004). By increasing CMC concentration, full-fat and low-fat samples showed a reinforcement of the structure (Bayarri et al., 2009).

Influence of Fat Replacer Addition on Instrumental Color of Low-Fat Samples

Results of ANOVA showed that for each fat replacer, the concentration of both CMC and fat replacer had a

Table 3. Two-way ANOVA of instrumental color parameters in low-fat carboxymethyl cellulose (CMC)-based dairy beverages containing λ-carrageenan or inulin blend as fat replacers

Color parameter ¹	Main effects				Interaction	
	A (CMC concentration)		B (fat replacer concentration)		A × B	
	<i>F</i> -value	<i>P</i> -value	<i>F</i> -value	<i>P</i> -value	<i>F</i> -value	<i>P</i> -value
λ-carrageenan						
<i>L</i> *	9.30	<0.01	28.60	<0.01	5.48	0.02
<i>a</i> *	45.29	<0.01	18.24	<0.01	0.72	0.60
<i>b</i> *	55.46	<0.01	75.51	<0.01	1.38	0.31
<i>C</i> *	58.25	<0.01	75.20	<0.01	1.38	0.32
<i>h</i> *	27.35	<0.01	7.99	<0.01	0.67	0.63
Inulin blend						
<i>L</i> *	12.83	<0.01	14.38	<0.01	0.98	0.48
<i>a</i> *	63.25	<0.01	25.11	<0.01	1.29	0.33
<i>b</i> *	53.61	<0.01	37.43	<0.01	1.10	0.42
<i>C</i> *	54.57	<0.01	37.35	<0.01	1.12	0.41
<i>h</i> *	44.33	<0.01	15.67	<0.01	1.02	0.46

¹*L** = brightness; *a** = red component; *b** = yellow component; *C** = chroma; and *h** = hue.

Table 4. Mean values and significant differences of instrumental color parameters for low-fat carboxymethyl cellulose (CMC)-based dairy beverages with different λ -carrageenan concentrations

CMC (% wt/wt)	λ -carrageenan (% wt/wt)	Color parameter ¹				
		L^*	a^*	b^*	C^*	h^*
0.7	0	60.0 ^b	0.7 ^a	21.7 ^a	21.8 ^a	88.2 ^d
	0.01	60.5 ^b	1.6 ^{ab}	26.3 ^b	26.4 ^b	86.6 ^{bcd}
	0.03	60.7 ^{bc}	1.9 ^{bc}	27.5 ^b	27.6 ^b	86.1 ^{bc}
0.9	0	55.4 ^a	1.2 ^{ab}	22.0 ^a	22.0 ^a	86.8 ^{cd}
	0.01	60.7 ^{bc}	2.5 ^{cd}	27.9 ^b	28.0 ^b	84.8 ^{ab}
	0.03	63.4 ^d	3.2 ^{def}	30.3 ^c	30.5 ^c	84.0 ^a
1.1	0	59.1 ^b	3.0 ^{de}	27.5 ^b	27.7 ^b	83.8 ^a
	0.01	63.2 ^{cd}	3.9 ^{ef}	32.0 ^{cd}	32.3 ^{cd}	83.1 ^a
	0.03	65.4 ^d	4.1 ^f	33.0 ^d	33.2 ^d	82.9 ^a
SE ²		0.18	0.16	0.11	0.11	0.21

^{a-f}Means within a column with common superscripts did not differ significantly ($P < 0.05$).

¹ L^* = brightness; a^* = red component; b^* = yellow component; C^* = chroma; and h^* = hue.

²Standard error from ANOVA.

significant effect ($P < 0.05$) on all instrumental color parameters (Table 3). The interaction between the main effects only significantly affected L^* values when λ -carrageenan was added.

In general, for each CMC concentration, fat replacer addition to low-fat samples increased L^* , a^* , b^* , and C^* , and decreased h^* values (Tables 4 and 5). As indicated by the aforementioned interaction, the increase in L^* values due to λ -carrageenan addition depended on CMC concentration. For high levels of CMC (0.9 and 1.1%), L^* values increased significantly with λ -carrageenan addition, whereas for 0.7% CMC, the values did not change significantly. The effect of CMC concentration was similar to that observed for fat replacer content. Addition of CMC decreased h^* values and increased a^* , b^* , and C^* values in low-fat samples.

The L^* values increased with CMC concentration in the systems in which the concentration of fat replacer was higher, whereas no changes were observed at lower concentrations of CMC.

To study the joint variability of instrumental color parameters, PCA was applied to mean values obtained for 6 control samples (full-fat and low-fat) and 15 low-fat samples containing inulin or λ -carrageenan (Figure 1). The first component accounted for 55.02% of total variability and clearly separated the samples according to CMC concentration. Samples with 1.1% of CMC, in the positive part of the first dimension, showed higher a^* , b^* , and C^* values and lower h^* than samples with 0.9 and 0.7% of CMC, which were in the central and negative part of the first dimension, respectively. The second component, which accounted for 42.20% of vari-

Table 5. Mean values and significant differences of instrumental color parameters for low-fat carboxymethyl cellulose (CMC)-based dairy beverages with different inulin blend concentrations

CMC (% wt/wt)	Inulin blend ¹ (% wt/wt)	Color parameter ²				
		L^*	a^*	b^*	C^*	h^*
0.7	0	60 ^{bcd}	0.7 ^a	21.7 ^a	21.8 ^a	88.2 ^e
	7	60.4 ^{bcd}	1.5 ^{abc}	26.1 ^b	26.1 ^b	86.7 ^{de}
	9	61.1 ^{cd}	1.8 ^{bc}	26.8 ^b	26.9 ^b	86.2 ^d
	11	62.6 ^{de}	2.4 ^{cd}	28.1 ^b	28.2 ^b	85.1 ^{cd}
0.9	0	55.4 ^a	1.2 ^{ab}	22.0 ^a	22.0 ^a	86.8 ^{de}
	7	57.4 ^{ab}	1.7 ^{abc}	25.5 ^b	25.6 ^b	86.1 ^d
	9	57.4 ^{ab}	1.8 ^{bc}	25.7 ^b	25.8 ^b	86.0 ^d
	11	62.6 ^{de}	4.0 ^f	31.0 ^c	31.2 ^c	82.6 ^{ab}
1.1	0	59.1 ^b	3.0 ^{de}	27.5 ^b	27.7 ^b	83.8 ^{bc}
	7	60.9 ^{cd}	4.0 ^{ef}	31.5 ^c	31.8 ^c	82.9 ^{ab}
	9	61.4 ^{cd}	4.1 ^f	31.8 ^c	32.1 ^c	82.7 ^{ab}
	11	64.8 ^e	5.3 ^g	34.6 ^d	35.0 ^d	81.4 ^a
SE ³		0.21	0.65	0.12	0.12	0.15

^{a-g}Means within a column with common superscripts did not differ significantly ($P < 0.05$).

¹Blend (50:50) of short- and long-chain inulin.

² L^* = brightness; a^* = red component; b^* = yellow component; C^* = chroma; and h^* = hue.

³Standard error from ANOVA.

Figure 1. Principal component analysis bi-plot for color parameters of low-fat (empty symbols) and full-fat (filled symbols) dairy beverages with λ -carrageenan or inulin at different concentrations of carboxymethyl cellulose (CMC; circle = 0.7%, square = 0.9%, and triangle = 1.1%). Identification of samples is given in Table 1. FFC = full-fat control, LFC = low-fat control. Color version available in the online PDF.

ability, was related in its positive part with L^* and separated the samples according to milk type. Full-fat samples, in the positive part of the second dimension, showed higher L^* values and lower h^* values than low-fat samples. In general, adding fat replacer to low-fat

samples decreased instrumental color differences between low-fat and full-fat samples.

Agreement exists in the literature regarding the fact that full-fat products are lighter in color than low-fat products. In a previous work (González-Tomás et al.,

Table 6. Two-way ANOVA of rheological parameters in low-fat carboxymethylcellulose (CMC)-based dairy beverages containing λ -carrageenan or inulin blend as fat replacers

Rheological parameter ¹	Main effects				Interaction	
	A (CMC concentration)		B (Fat replacer concentration)		A $\times$ B	
	F-value	P-value	F-value	P-value	F-value	P-value
λ -carrageenan						
K (Pa·s ⁿ)	652.85	<0.01	786.74	<0.01	210.98	<0.01
n	311.45	<0.01	612.07	<0.01	12.70	<0.01
A _r (%)	1.28	0.32	177.62	<0.01	3.01	0.06
G' (Pa)	458.14	<0.01	142.437	<0.01	28.41	<0.01
G'' (Pa)	805.41	<0.01	134.36	<0.01	18.12	<0.01
tan δ	161.10	<0.01	93.67	<0.01	30.91	<0.01
η^* (Pa·s)	590.85	<0.01	163.04	<0.01	31.36	<0.01
Inulin blend						
K (Pa·s ⁿ)	373.58	<0.01	4.80	0.02	2.22	0.11
n	633.92	<0.01	2.36	0.12	1.40	0.29
A _r (%)	1.53	0.26	9.15	<0.01	1.14	0.40
G' (Pa)	1,839.81	<0.01	101.75	<0.01	63.23	<0.01
G'' (Pa)	1,161.71	<0.01	42.96	<0.01	20.82	<0.01
tan δ	618.99	<0.01	9.57	<0.01	4.80	0.01
η^* (Pa·s)	1,642.30	<0.01	83.46	<0.01	49.51	<0.01

¹K = consistency index; n = flow behavior index; A_r = relative hysteresis area; G' = storage modulus; G'' = loss modulus; tan δ = loss angle; and η^* = complex dynamic viscosity.

Figure 2. Rheological behavior of low-fat samples with different λ -carrageenan concentrations ($\square$ = 0%, $\diamond$ = 0.01%, and Δ = 0.03%) containing 0.9% carboxymethyl cellulose: a) upward and downward flow curves and b) mechanical spectra (filled symbols = G' , storage modulus; empty symbols = G'' , loss modulus).

2009a), milk type (whole or skim) was shown to affect color parameters of starch-based custard desserts. As in the present study, whole milk samples were the lighter-colored ones and showed lower hue values. This fact could be explained by the fact that fat content increases the amount of reflected light in milk (Phillips and Barbano, 1996). However, the effect of hydrocolloids or inulin on color parameters is not clear, although hydrocolloids have been observed to modify instrumental color in some products. Fernández et al. (2009) studied the quality of mashed potatoes and observed an increase in lightness and yellowness and a loss of greenness on adding xanthan gum or κ -carrageenan. Mittal and Barbut (1993) found that lightness (L^*) was higher in high-fat compared with low-fat raw sausage and that

CMC caused a decrease in L^* and an increase in a^* . Different results have also been obtained regarding the effect of inulin addition on color parameters, depending on the average chain length and concentration of inulin and on the product composition (Akalm et al., 2008; De Castro et al., 2008; González-Tomás et al., 2009a; Villegas et al., 2010).

Influence of Fat Replacer Addition on Rheological Properties of Low-Fat Samples

Low-fat samples with different λ -carrageenan concentrations (0, 0.01, and 0.03%) showed observable hysteresis loops when they were sheared during a complete cycle, indicating that sample flow was time-dependent. The flow curves of all the systems showed a shear thinning behavior with n values from 0.22 to 0.75. The experimental data of ascending rheograms were successfully fitted to the Ostwald-de Waele model ($0.965 < R^2 < 0.999$). The viscoelastic properties of systems ranged from fluid-like to a weak gel, depending on both the λ -carrageenan concentration and CMC concentration. As an example, Figure 2 shows the rheograms and the mechanical spectra obtained for low-fat samples with different λ -carrageenan concentrations, all of which contained 0.9% CMC.

Considering λ -carrageenan as a fat replacer, the results of the ANOVA showed that both λ -carrageenan concentration and CMC concentration, as well as their interaction, had a significant effect ($P < 0.05$) on most of the rheological parameters, except on relative hysteresis area, A_r , which was only affected by λ -carrageenan concentration (Table 6). The increase in sample consistency (K) due to λ -carrageenan addition was greater when CMC content was 1.1% than when it was 0.7% (Figure 3a). The A_r value increased with λ -carrageenan content but was not affected by CMC concentration (Figure 3b). Storage modulus, loss modulus, and complex dynamic viscosity increased with λ -carrageenan concentration, this increase being larger in general for low-fat samples with 1.1% CMC; G' values are shown (Figure 3c) as an example. Loss tangent values decreased with carrageenan concentration, especially at the lowest CMC concentration (Figure 3d). A fluid-like behavior was observed for 2 low-fat samples containing 0.7% CMC and the lowest λ -carrageenan concentrations (0 and 0.01%). The structure of samples with 0.9% CMC and without λ -carrageenan was intermediate between those of a concentrated polymer solution and a weak gel. The remaining samples exhibited weak-gel behavior.

Rheological properties of low-fat samples showed an increase in the consistency and mechanical strength on increasing λ -carrageenan concentration, probably

Figure 3. Rheological parameters values: consistency index (a), relative hysteresis area (b), storage modulus (c), and loss tangent (d) of low-fat samples with different λ -carrageenan concentrations ($\square$ = 0%, $\diamond$ = 0.01%, and Δ = 0.03%) containing 0.7, 0.9, or 1.1% carboxymethyl cellulose (CMC).

because of the ability of λ -carrageenan to form gels in the presence of milk by binding with casein micelles (Shchipunov and Chesnokov, 2003). This increase was greater at higher CMC concentrations, maybe due to a decrease in interparticle spacing because of the higher CMC concentrations (Vélez-Ruiz and Barbosa-Cánovas, 1997).

The flow curves and the mechanical spectra obtained for some of the samples containing SC/LC inulin blend as a fat substitute are shown as an example in Figure 4. As in the case of samples with λ -carrageenan, the fit to the Ostwald-de Waele model was good for all samples ($0.998 < R^2 < 0.999$) and showed a pseudoplastic and thixotropic behavior. The effect of CMC concentration was significant ($P < 0.05$) on all variables considered except A_r values. Inulin concentration also significantly affected ($P < 0.05$) all rheological parameters except

flow index values, which varied from 0.55 to 0.76 (Table 6). In general, a lower effect was observed on adding SC/LC inulin blends to low-fat samples than λ -carrageenan. In the case of the consistency index, an increase was observed only when adding the highest inulin concentration (11%) to systems containing the higher CMC levels (Figure 5a). The relative hysteresis area increased with inulin addition, although this increase was lower than that observed when carrageenan was used as fat replacer (Figure 5b). Because of the significant interaction observed between CMC concentration and inulin blend concentration on viscoelastic parameters (Table 6), systems with the higher CMC concentrations (0.9% and 1.1%) appeared to increase their G' , G'' , and η^* values with the addition of increasing amounts of inulin blend, whereas the lower ones (0.7%) did not (Figure 5c). The $\tan \delta$ values showed

Figure 4. Rheological behavior of low-fat samples different short-chain/long-chain inulin blend concentrations ($\square$ = 0%, $\diamond$ = 7%, Δ = 9%, and $\circ$ = 11%) containing 0.9% carboxymethyl cellulose: (a) upward and downward flow curves; (b) mechanical spectra (filled symbols = G' ; empty symbols = G'').

that viscoelastic behavior ranges from fluid behavior (samples with 0.7%) to weak-gel-like (samples with 1.1% CMC), with a concentrated polymer solution structure in between (samples with 0.9% CMC; Figure 5d).

Addition of inulin to low-fat dairy beverages has been reported to have different effects on rheological behavior depending on inulin type and concentration, as well as product composition. Villegas and Costell (2007) studied the effects of adding different types of inulin (short-chain, native, and long-chain) at different concentrations, on the flow behavior of milk beverages with different fat content. For low-fat milk samples with lower inulin concentrations (2, 4, and 6%), the flow was Newtonian and no significant differences in viscosity among the 3 types of inulin were observed. For the higher inulin concentration (8 and 10%) samples, the

flow was shear thinning and a sharp increase was detected in apparent viscosity of samples with long-chain inulin. Native inulin at 2 and 4% increased firmness of low-fat fermented milk (Pinheiro et al., 2009), and the addition of long-chain inulin at 5% to low-fat fermented milk significantly increased the apparent viscosity and flow time dependency; however, it did not modify the pseudoplasticity of flow nor the consistency index values (Debon et al., 2010). The observed variations in flow behavior of dairy beverages containing inulin could be explained by different factors according to previous studies: the capacity of inulin to retain water (Soukoulis et al., 2009); the interaction of inulin with milk protein, which can lead to an increase in the molar mass resulting in increased viscosity (Schaller-Povolny and Smith, 2001); and the formation of small aggregates of microcrystals that are able to retain water (González-Tomás et al., 2008).

To compare the rheological behavior of the control full-fat samples and the different low-fat samples, a PCA was applied to study the variability in both flow and viscoelastic parameters (Figure 6). The first component, which accounted for 57.45% of total variability, was related in its positive part with the variation in G' , G'' , and η^* , and in its negative part in $\tan \delta$. This component clearly separated the samples according to CMC concentration. Samples with 1.1% CMC, in the positive part of the first dimension, showed higher values for most of the rheological parameters, whereas 0.7% CMC samples fell in the opposite region, showing the highest $\tan \delta$ values. The second component accounted for 33.43% of variability and was positively correlated to A_r . This component separated low-fat samples with 0.03% λ -carrageenan that had the highest A_r values. The mapped sample distribution showed that for the highest CMC concentrations (0.9 and 1.1% CMC), the low-fat sample with 0.01% carrageenan (samples 6 and 11, respectively) or with 11% inulin blend (samples 10 and 15, respectively) were those demonstrating the most similar rheological behavior to that of the whole-milk control sample (FFC with 0.9% and 1.1% CMC), the samples with λ -carrageenan being more similar to full-fat samples in terms of rheological behavior than samples with inulin. In the case of samples with 0.7% CMC, the full-fat sample was clearly separated from all low-fat samples. For each CMC concentration, the full-fat control sample and 2 low-fat samples containing 0.01% λ -carrageenan or 11% SC/LC inulin blend were selected for sensory analysis.

Consumer Perception: FCP

Consumers generated 334 terms to describe differences among samples. These terms were subdivided

Figure 5. Rheological parameters values: consistency index (a), relative hysteresis area (b), storage modulus (c), and loss tangent (d) of low-fat samples with different short-chain/long-chain inulin blend concentrations ($\square$ = 0%, $\diamond$ = 7%, Δ = 9%, and $\circ$ = 11%) containing 0.7, 0.9, or 1.1% carboxymethyl cellulose (CMC).

into appearance (123), flavor (93), and texture (118), with individual sets ranging from 6 to 20 descriptors. In spite of the high number of terms, many assessors used identical or similar descriptors. The most frequent terms used by the consumers when describing the desserts were light or strong yellow, consistency, and liquid texture. The total amount of real variance, explained by the first 8 dimensions of the average configuration, was 71.15%. Dimensions 1 and 2 accounted for 45.0 and 16.7% of variance, respectively. Further dimensions explained a small proportion of variance (<5%); therefore, a 2-dimensional solution was finally chosen, explaining 61.7% of variance.

The assessors' plot (Figure 7) showed that consumers were randomly distributed along the first and second dimensions, indicating that they perceived all the sam-

ples in a similar way. This acceptable agreement among consumers was reflected by assessors' residual variance values, which ranged from 0.24 to 0.76. Scaling factors indicate to what extent the initial configuration of an individual has been stretched (values >1) or shrunk (values <1), to fit the average configuration. Consumers 17 and 4 had the greatest scaling factors (2.4 and 1.99, respectively), indicating that these consumers scored over a much narrower range of the scale, thus requiring the configuration to be stretched to obtain closer agreement with the other assessors; consumers 3 and 14 had the smallest scaling factors (0.70 and 0.61) and used a much wider range of the scale (Oreskovich et al., 1991).

Figure 8 shows the distribution of the total variance in the samples. Both consensus and residual variance

Figure 6. Principal component analysis bi-plot for rheological parameters of low-fat (empty symbols) and full-fat (filled symbols) dairy beverages with λ -carrageenan or inulin at different carboxymethyl cellulose (CMC) concentrations (circle = 0.7%; square = 0.9%; and triangle = 1.1%). Identification of samples is given in Table 1. FFC = full-fat control; LFC = low-fat control; K = consistency index; η^* = complex dynamic viscosity. Color version available in the online PDF.

Figure 7. Assessors' plot: first 2 principal axes obtained by free choice profile.

Figure 8. Consensus (gray) and residual variance (white) distributed over the 9 samples. Identification of samples is given in Table 1. FFC = full-fat control; CMC = carboxymethyl cellulose.

Table 7. Descriptors having correlations greater than 0.80 with the 2 dimensions of the average space generated by generalized Procrustes analysis

Dimension	Correlation	Descriptors ¹
1	+	Dense visual consistency (2), doughy consistency, thick aspect (6), creamy aspect (2), consistent appearance (8), viscous appearance (4), visual consistency (2), viscous visual texture, thick visual consistency, thick visual texture, viscous visual consistency, solid visual consistency, dense appearance, thick texture (9), creaminess, consistent texture (6), viscous texture (9), traditional custard texture, consistency (2), purée consistency, baby food consistency, heavy consistency, lumpy texture, dense texture, custard consistency, béchamel sauce texture, consistency in-mouth.
	–	Liquid appearance (7), light appearance, liquid visual consistency (4), liquid-visual texture, juice-liquid appearance, fluid appearance (2), fluid texture (3), liquid texture (14), light texture (2), milk-shake texture, fluid milk-shake texture, light consistency, vanilla milk-shake texture, liquid milk-shake texture.
2	+	Pale yellow (3), light yellow (4), dull yellow, whitish yellow, soft yellow (3), dead yellow, plastic flavor, whole-milk flavor, milky flavor, whole-milk odor.
	–	Yellow-red colored, strong yellow (2), dark yellow (3), egg yolk color, yellow-orange colored (3), orange-colored (2), artificial-yellow color, bright yellow (2), apricot color.

¹In parentheses, number of times that a descriptor had a correlation >0.80.

distribution were similar for the 2 replicates of each sample. A large amount of the total variance is explained by samples 5, 11, and full-fat control with 1.1% CMC, which should consequently be spread over the perceptual sample space. On the contrary, in samples 6 and 10, a low amount of variance was explained; they should be located close to the center of the average sample space. Residuals were very similar among samples, indicating that the consumers' evaluations of the samples agreed.

The average sample space obtained from the GPA is shown in Figure 9. The replicate reproducibility for each sample can be seen by 2 points, showing they are

proximal. Table 7 helps to interpret the dimensions of the average space, showing descriptors with correlations >0.80. Dimension 1 accounted for 45% of the consensus variance and separated the samples largely by visual consistency (thick visual consistency, thick appearance, fluid appearance, liquid appearance, liquid-visual texture) and in-mouth texture (fluid texture, liquid texture, dense texture, thick texture). This dimension split the samples into 2 groups. On the left, samples 1, 5, 6, 10, and full-fat control with 0.7% CMC were mainly described as having a liquid texture. On the right, samples 11, 15, and full-fat control with 0.9% and 1.1% CMC were perceived as having a thicker texture. It can be seen that CMC content rather than fat content differentiated samples in terms of consistency. Dimension 2 accounted for 17% of the consensus variance and was mainly related to the flavor and color attributes. On its positive side, it differentiated full-fat samples as having a milky flavor and pale yellow color, whereas on the negative side, low-fat samples (1, 5, 6, 10, 11, and 15) were evaluated as having a yellow-orange color.

CONCLUSIONS

The addition of both λ -carrageenan and an inulin blend to low-fat CMC-dairy beverages decreased instrumental differences in color and rheological traits between low-fat and full-fat samples; therefore, both could be used as fat replacers in dairy beverages. Moreover, samples with added λ -carrageenan were more similar to full-fat samples in terms of rheological behavior than samples with inulin blend, and slight instrumental differences on color and rheological parameter values were observed among them. Free choice profile results showed that samples differing in color and rheological behavior due to composition were also sensorially distinguishable by consumers.

Figure 9. Sample average space for the first 2 principal dimensions obtained by applying generalized Procrustes analysis to sensory data generated by free choice profile in duplicate. Identification of samples is given in Table 1. Empty symbols = low-fat samples; filled symbols = full-fat control (FFC) samples; concentrations of carboxymethyl cellulose: circle = 0.7%; square = 0.9%; and triangle = 1.1%.

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