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 δ and η^* at 1 Hz and η^*_{8Hz} 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 carrageenan, are of growing interest because, besides their physicochemical properties, they also have health-friendly characteristics (Warrand, 2006).

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

Inulin is a linear non-digestible polysaccharide of β-(2-1) linked fructose residues with a terminal glucose residue unit. In addition to its beneficial effects on health as a dietetic fibre and as a prebiotic ingredient (Flamm, Glinsmann, Kritchevsky, Prosky, & Roberfroid, 2001) it can be used as a low-calorie sweetener, fat substitute or texture modifier (Tungland & Meyer, 2002). These properties are linked to the polymerization degree of its chain. Long-chain inulin is more thermally stable, less soluble and more viscous than native and short-chain inulins (Wada, Sugatami, Terada, Ohguchi & Miwa, 2005) and it has been used as a fat replacer in several dairy products. Villegas, Carbonell & Costell (2007) showed that to obtain low-fat milk beverages with a similar thickness and creaminess to those perceived in whole-milk beverages, long-chain inulin must be added at a concentration above 8%. González- Tomás, Coll-Marqués & Costell (2008) observed that by adding 7.5% of long-chain inulin to low-fat starch-based custard desserts, they obtained similar viscoelastic properties to the whole-milk sample with the same starch concentration. Meanwhile, the 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 ºC for 10 min, with the help of a magnetic stirrer and a hot plate (Ared, Velp Scientifica) and stored at 4±1ºC 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±1ºC; 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±1ºC, 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),

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

where σ (Pa) is the shear stress, σ_0 (Pa) is the yield stress, K (Pas^n) 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.

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

2.2.2. Viscoelastic behaviour.

Stress sweeps were made between 0.02 and 300 Pa, at a frequency of 1Hz, 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 δ) 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}) (η^*_{8Hz}) 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 ºC 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 (α=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 α=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 hyteresis 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 δ, in 1.5% CMC samples than in their counterparts formulated with 1.3% CMC, which confirms previous results obtained by the authors Bayarri et al. (2009ab). For comparison purposes, G', G'', tan δ and η* at 1 Hz and η^*_{8Hz} at 8 Hz values were considered (Table 2). The elastic contribution for full-fat control samples was higher than low-fat control samples, suggesting a stronger gel structure. In general, all viscoelastic parameters were significantly affected by the composition ($P<0.05$), but there were no differences in G'' and η^*_{8Hz} values ($P>0.10$) in the case of 1.5% CMC systems due to fat or λ-carrageenan concentration. Within each CMC concentration, mean values of the G', G'' and η* (both at 1 and 8 Hz) increased and tan δ decreased when λ-carrageenan was added to low-fat samples. At 1.3% CMC concentration, as in the case of flow behaviour, the full-fat sample did not differ statistically ($\alpha=0.05$) from low-fat sample with 0.03% λ-carrageenan for any of the viscoelastic parameters studied, while for the highest CMC concentration (1.5%), the full-fat sample did not differ ($\alpha=0.05$) from low-fat samples with both 0.01 and 0.03% λ-carrageenan.

Rheological properties of low-fat samples showed an increase in the consistency and mechanical strength with increasing λ-carrageenan concentration. Similar results have been reported previously in other systems containing milk proteins (Lizarraga et al., 2006; Lagendorff et al., 2000). The interactions between carrageenans and milk proteins and their influence on rheological properties have been the subject of study (Depypere, Verbeken, Torres, & Dewettinck, 2009). While kappa and iota carrageenans form gels in aqueous solutions, lambda is unable to do so and is used as a pure thickener. However, lambda-carrageenan is able to form gels in the presence of milk. Most authors agree that carrageenan associates with casein micelles through an electrostatic interaction between its negatively charged sulphate groups and a positively charged region of κ-casein. In the case of κ-, and ι-carrageenan, the stabilization of gel network is achieved due to crosslinking of chain fragments between the micelles by double helices. For λ-carrageenan, the gelation is ensured 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^*, η^*_{8Hz}, 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 δ 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 ($P<0.05$)

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

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

Principal Component Analysis was applied to mean values of rheological parameters obtained for both flow and viscoelastic behaviour (Figure 6). The first component accounted for 87.86% 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, except for tan δ and n, than samples with 1.3% of CMC, which were in the negative part of the first dimension. The second component, which accounted for only a small percentage of variability (8.21%), was related in its positive part with the variation in the flow index (n) and in tan δ and in its negative part with the consistency index (K) and with apparent viscosity at $10s^{-1}$ (η_{10}). 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 both CMC concentrations, full-fat samples were perceived as thicker than low-fat samples, which is in agreement with the rheological results obtained previously. Low-fat samples were perceived as smoother while no significant differences were detected in creaminess between each pair of samples with different fat content. In addition, low-fat control samples were perceived as sweeter and as having greater vanilla flavour intensity than their full-fat counterparts. These results are in accordance with those obtained in previous studies on starch-based custards, showing that fat reduction leads to textural changes and modifies the perception of their flavour (González-Tomás et al., 2007).

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

When λ-carrageenan was used as a fat replacer (Figure 8a and 8b), no significant differences were found in the intensity of the texture attributes between the samples with different fat content. The addition of λ-carrageenan to low-fat samples increased thickness and decreased smoothness, compensating the variation detected in the texture by reducing the fat content of these products. However, the substitution of fat by λ-carrageenan also influenced the flavour perceived. In general, both the sweetness and the vanilla flavour of low-fat samples were significantly stronger ($\alpha = 0.05$) than in the full-fat samples. This fact reflects the influence of fat on flavour release and perception. For example, Lethuaut et al. (2005) studied the aroma-sweetness interactions on dairy desserts with different textures and concluded that the dessert with λ-carrageenan, which had the softest texture and was perceived as the sweetest, was also perceived as the most highly flavoured. In this work, flavour differences may be explained by rheological and textural changes, but in the present study, samples showed similar rheological properties and the variations in flavour intensity may have been due to other factors. It is widely known that flavour release and perception decrease as lipid levels increase in the food matrix, with the exception of hydrophilic compounds showing partition coefficient values near or below zero (van Ruth, King, & Giannouli, 2002; Miettinen, Hyvönen, Linforth, Taylor, & Tuorila, 2004). Bayarri, Smith, Hollowood, & Hort (2007), working with model o/w emulsions with different oil contents and a composition adjusted to deliver iso-release aroma *in vivo* and the same in-mouth viscosity, observed that samples containing the highest oil content were perceived as significantly less sweet. This confirms that fat content influences flavour in two ways: directly, it has a significant effect on the release of chemical stimuli from the food matrix into the mouth and indirectly, due to its influence on the product texture.

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

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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.

	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

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

[b] λ-Carrageenan

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 (α=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).

Figure captions

Figure 1. Flow curves of control samples (Δ= low-fat; ◊= full-fat) and low-fat samples with different λ-carrageenan concentrations (○=0.01%; □ = 0.03%; ∇=0.05%) containing 1.3% (a) and 1.5% (b) of CMC.

Figure 2. Mechanical spectra of control samples (▲=low-fat; ♦= full-fat) and low-fat samples with different λ-carrageenan concentrations (●=0.01%; ■= 0.03%; ▼=0.05%) containing 1.3% (a) and 1.5% (b) of CMC. G' (filled symbols) and G'' (empty symbols).

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

Figure 4. Flow curves of control samples (Δ= low-fat; ◊= full-fat) and low-fat samples with different SC/LC inulin blend concentrations (○=7%; □ = 9%; ∇=11%) containing 1.3% (a) and 1.5% (b) of CMC.

Figure 5. Mechanical spectra of control samples (▲=low-fat; ♦= full-fat) and low-fat samples with different SC/LC inulin blend concentrations (●=7%; ■= 9%; ▼=11%) containing 1.3% (a) and 1.5% (b) of CMC. G' (filled symbols) and G'' (empty symbols).

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

Figure 7. Sensory evaluation of the differences between full-fat (■) and low-fat (▨) control desserts at different CMC concentrations (a=1.3%; b=1.5%). The line indicates the 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 (α=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 (α=0.05).

Figure 1

Fig 1

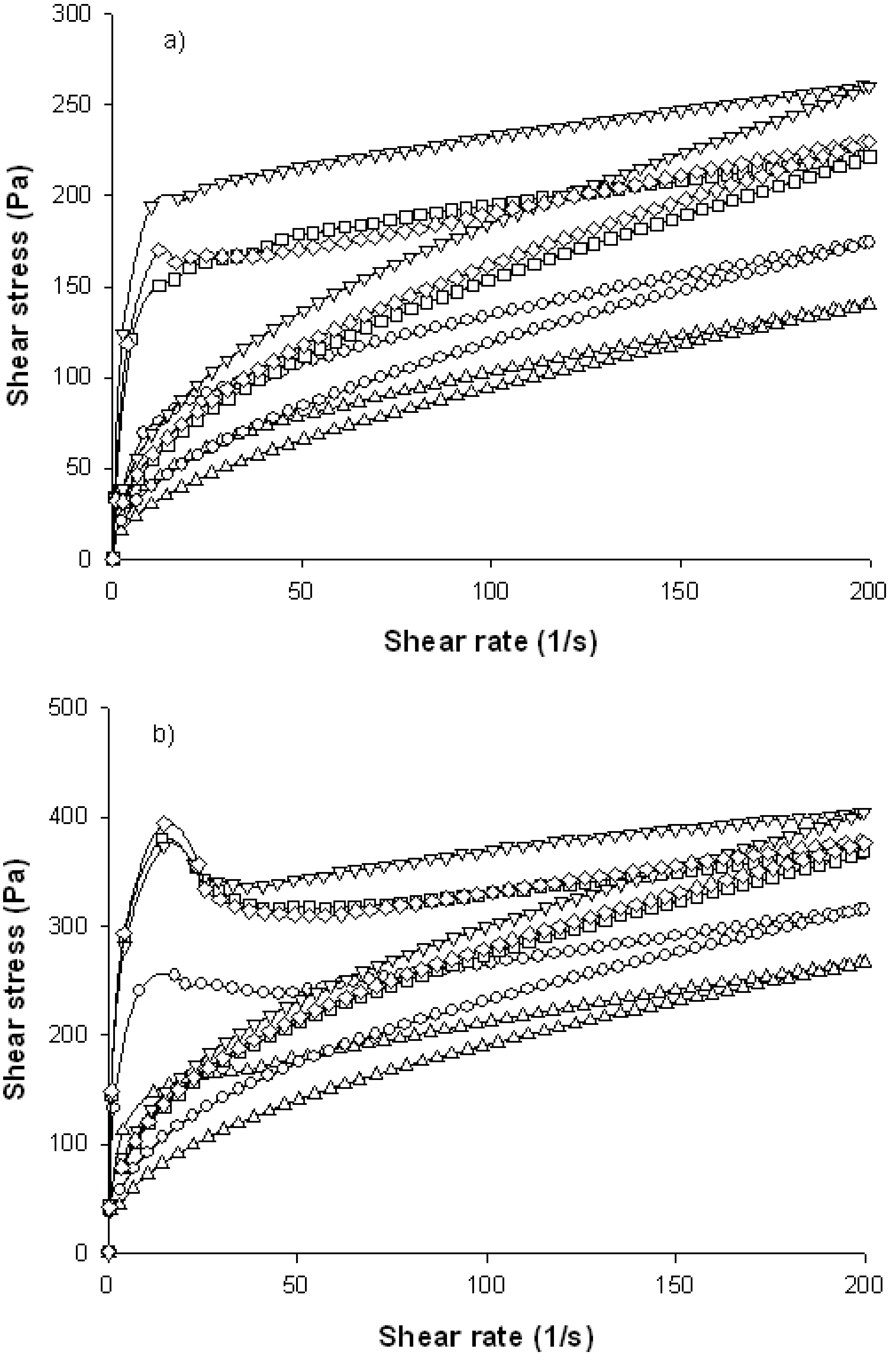

Figure 2

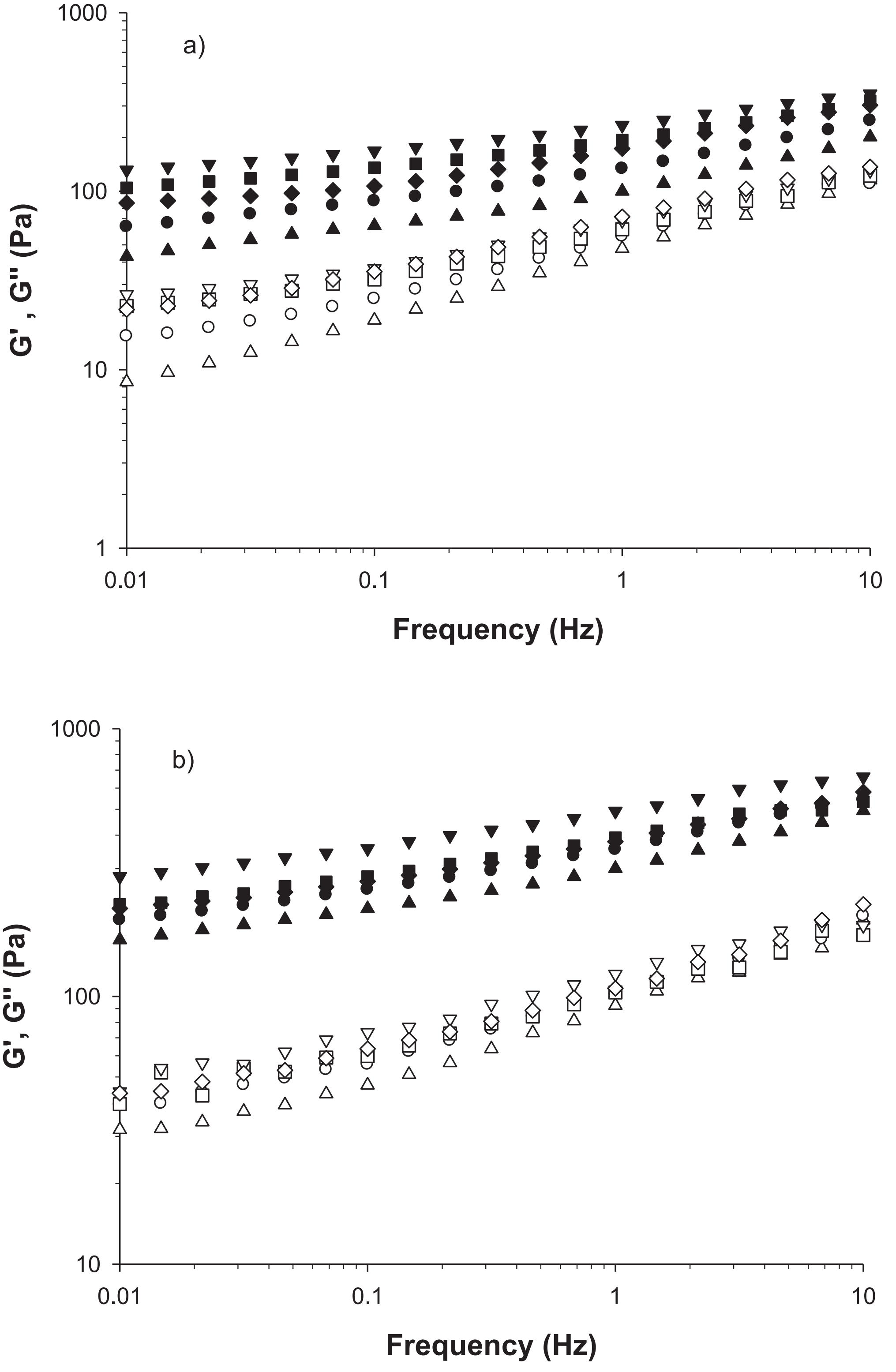

Fig. 2.

Figure 3

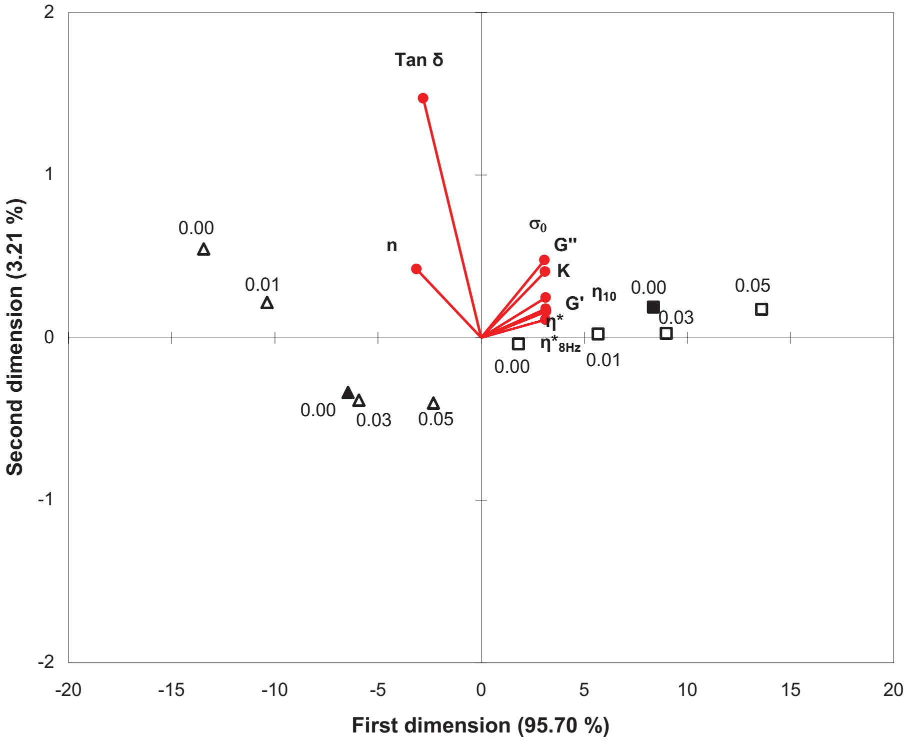

Fig. 3

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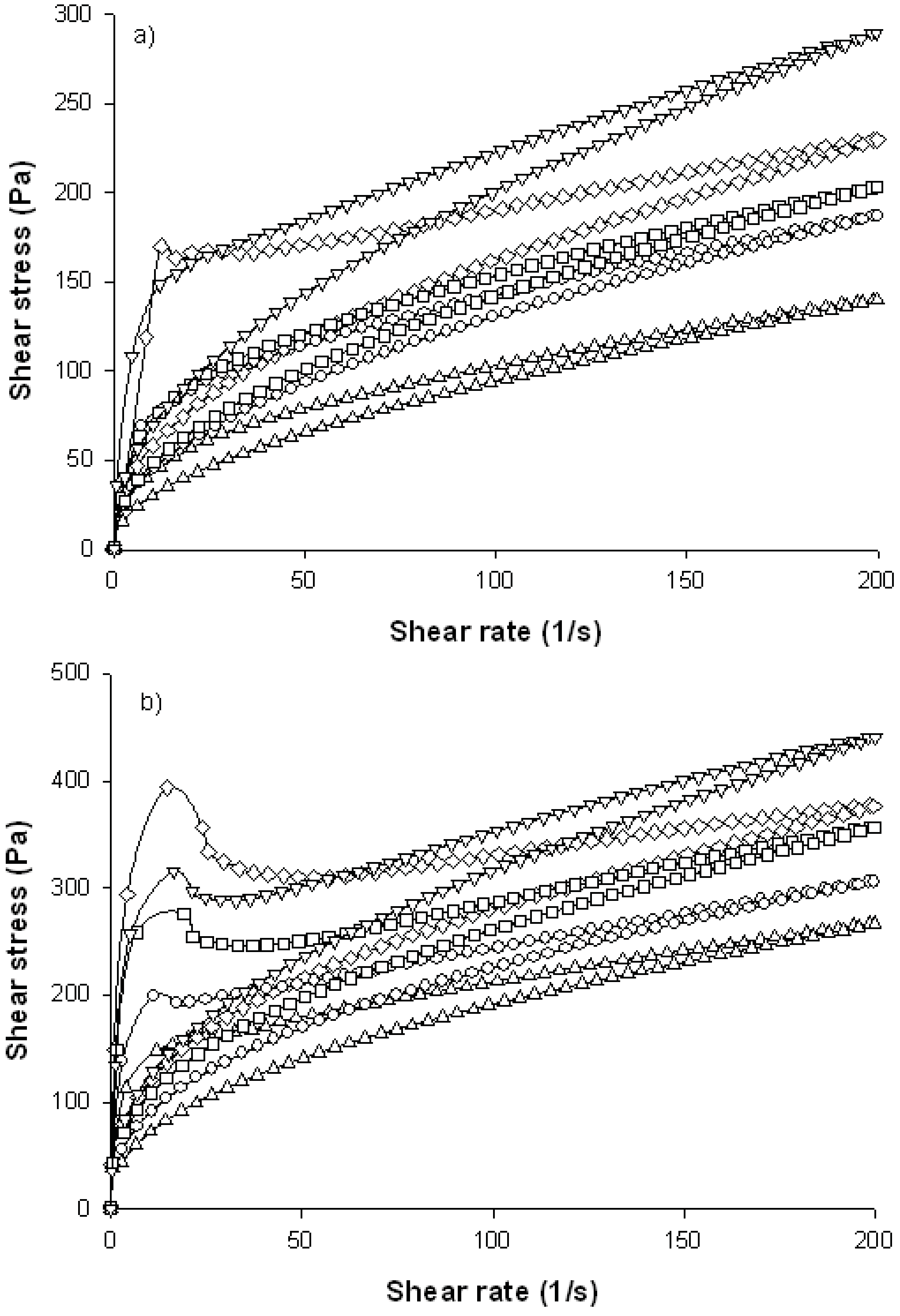

Figure 5

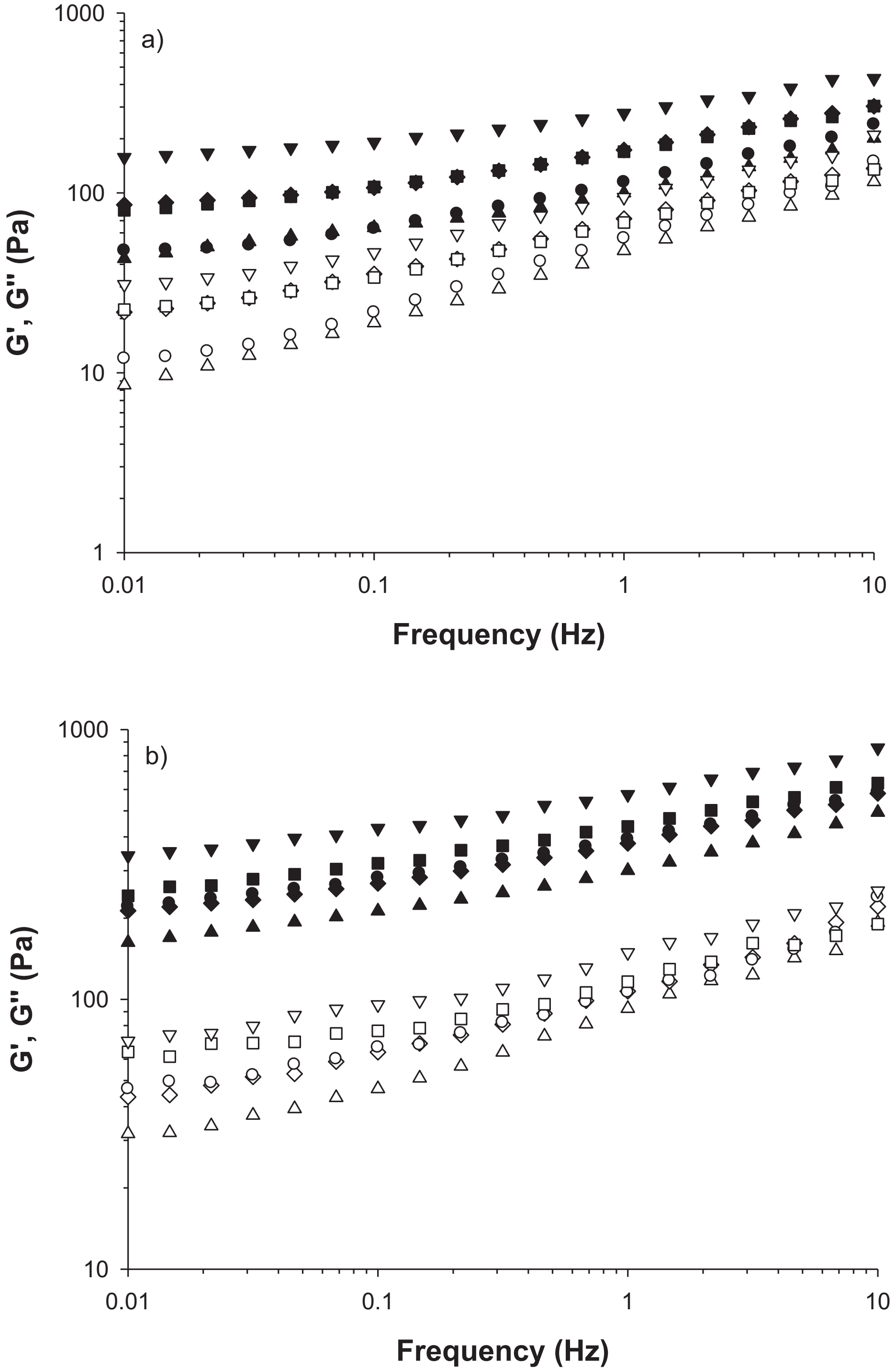

Fig. 5.

Figure 6

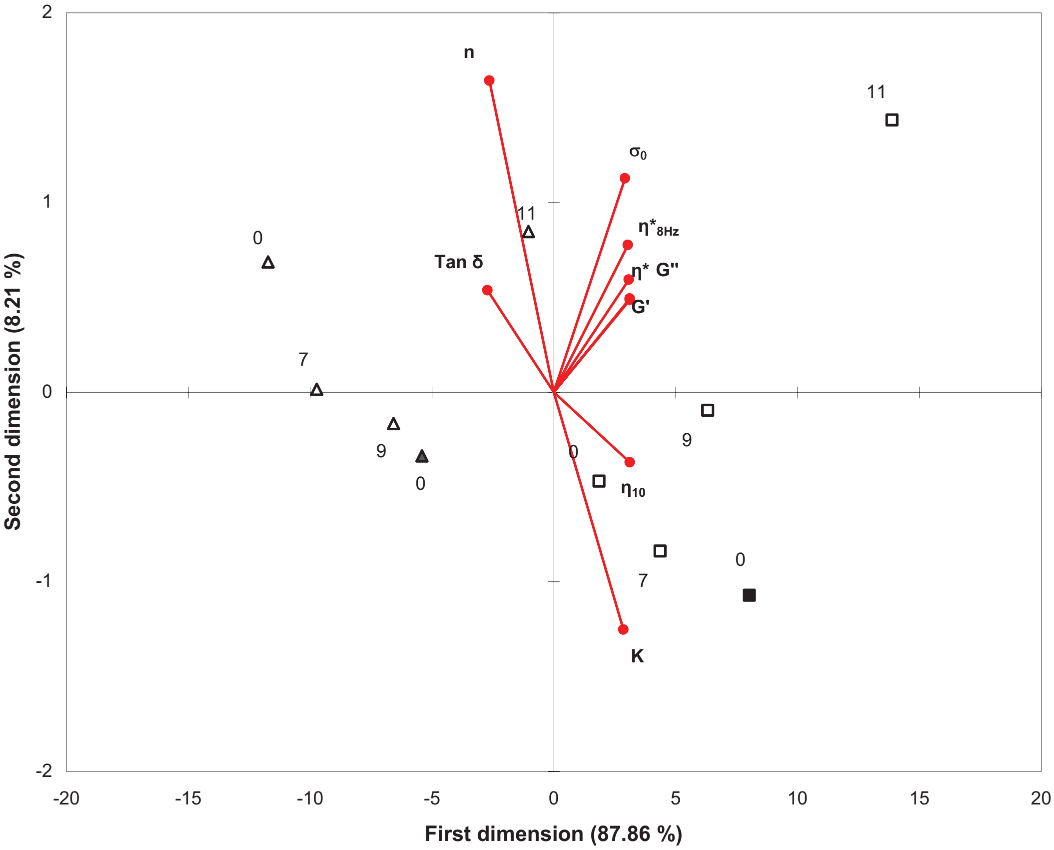

Fig. 6.

Figure 7

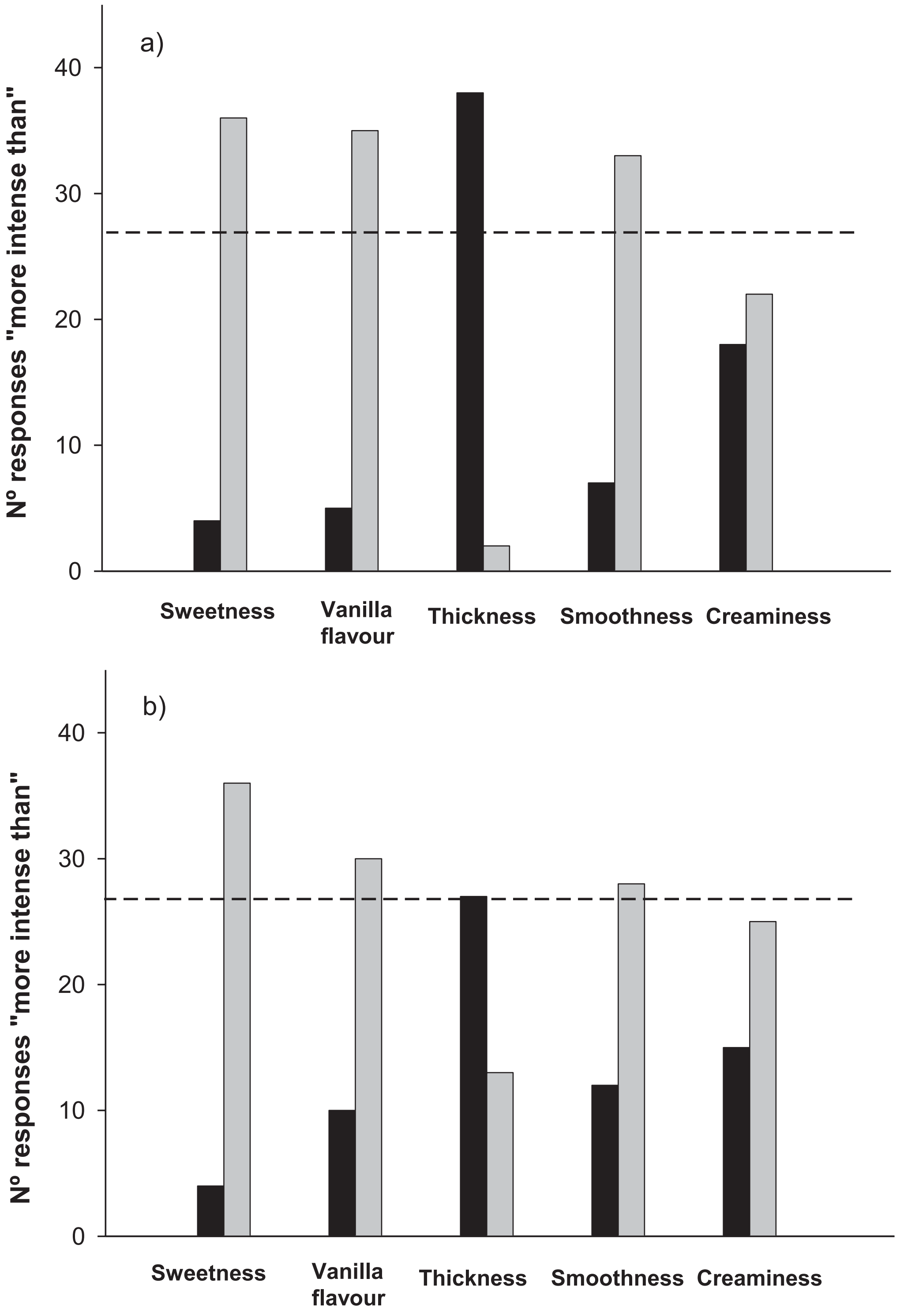

Fig. 7.

Figure 8

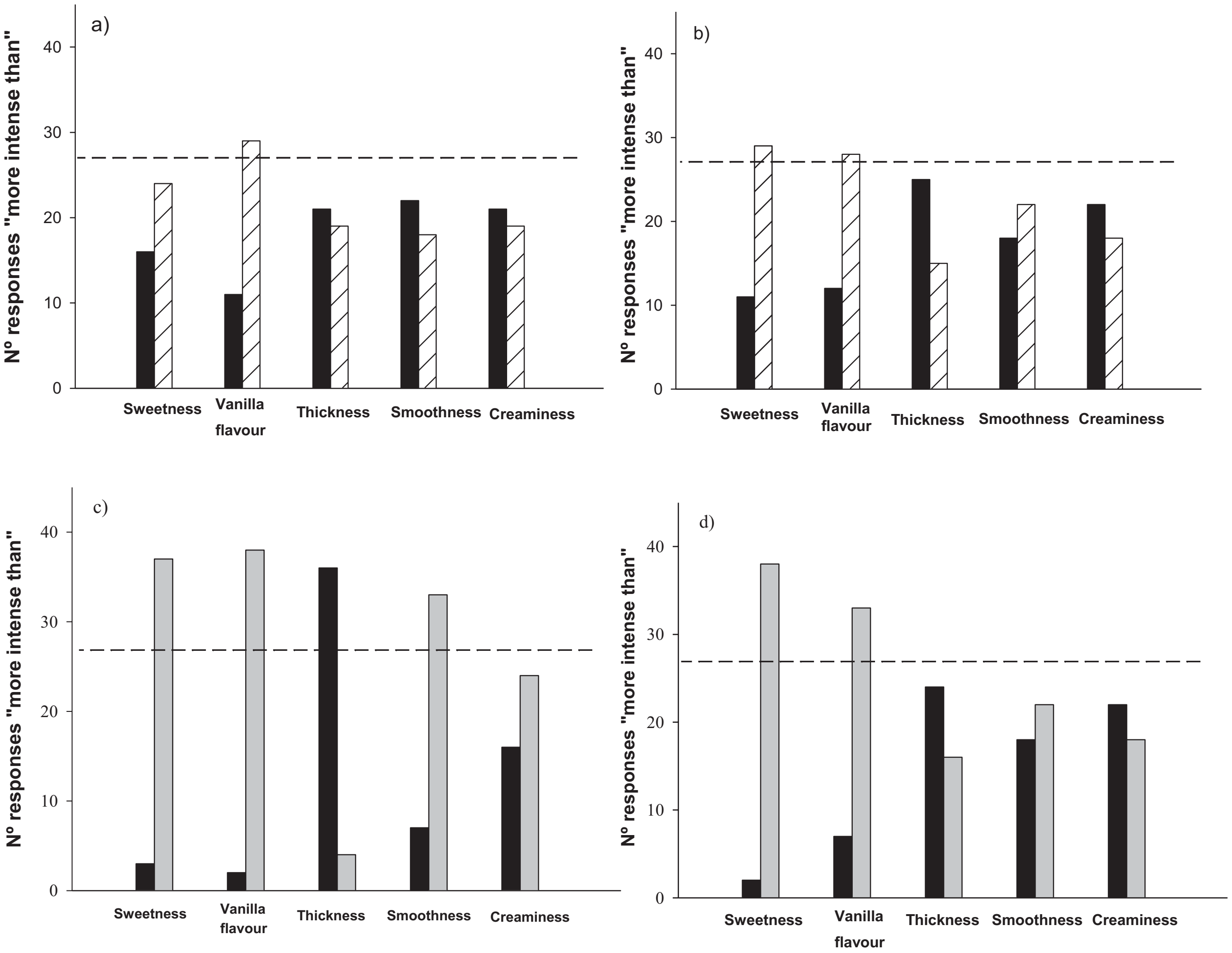

Fig. 8

Figure 9

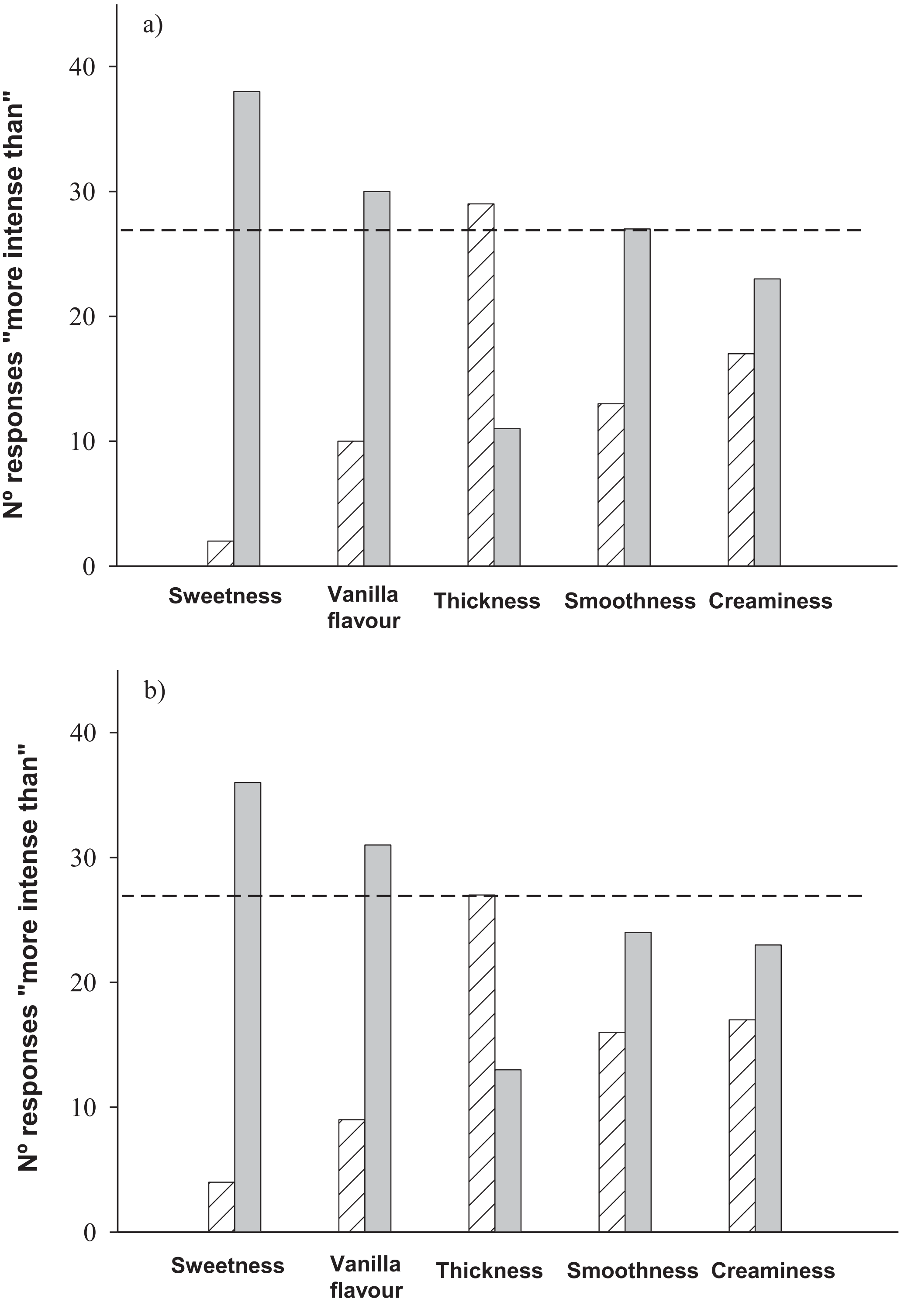

Fig. 9