NEW HYDROCOLLOID-BASED EMULSIONS FOR REPLACING FAT IN PANNA COTTAS: A STRUCTURAL AND SENSORY STUDY

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ABSTRACT

BACKGROUND: Dairy desserts are popular traditional products but because of their high calorie or fat content, they can be unsuitable for people who have certain dietary requirements. The aim of this study was to design panna cottas with similar organoleptic and textural properties to the traditional ones but with a lower fat content, by replacing part of the cream with new emulsions prepared with hydrocolloids (cellulose ethers), namely methylcellulose (MC) and hydroxypropyl methylcellulose (HPMC).

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RESULTS: Incorporating the MC and HPMC emulsions modified the textural properties (firmness and stiffness) of the panna cottas. Regarding the sensory results, the panna cottas prepared with the MC and HPMC emulsions were considered lumpy and soft, respectively.

CONCLUSIONS: Considering the results as a whole, the cellulose type and the amount of cream are factors to take into account. Although the texture and taste of the control panna cotta are better than those of the panna cottas prepared with the MC and HPMC emulsions, it is possible to replace 75% of the cream in traditional panna cottas with HPMC emulsions and obtain good consumer acceptance and purchase intention. The panna cottas with 75% substitution by HPMC emulsion were described as creamy, with smooth appearance and moist mouth feel.

Keywords: dairy dessert; reduced fat; cellulose ether emulsion; texture; microstructure; sensory properties

INTRODUCTION

In recent years, extensive scientific evidence has emerged which indicates that dietary patterns have specific health or disease outcomes.[1] However, the public often prefers particular foods, sometimes of a markedly traditional character, even though their composition is inadvisable. In this regard, reformulating traditional products by replacing unhealthy ingredients with others that have similar technological functions and retain the sensory characteristics of these foods is a promising alternative for producing healthier products.[1] Achieving such changes in composition without altering their organoleptic properties and overall acceptability to consumers requires a very great and highly complex research effort.[2–4] Designing healthier foods gives rise to new opportunities and challenges for the food industry, which, in today's competitive market, needs to pursue growth through constant innovation in products that consumers find attractive.[5,6]

Dairy desserts are popular traditional products in Europe. As well as their sensory properties, their being easy to consume and easily swallowed makes them particularly suitable and convenient foods for the population in general. Nevertheless, some of them may be unsuitable for those with particular dietary requirements, owing to their high calorie and fat contents. Panna cotta (Italian for 'cooked cream') is a typical dessert from the Piedmont region of Italy that is largely composed of cream, sugar and gelatine, so as well as being high in calories, it also has a high saturated fat content. Saturated fat is associated with the appearance of numerous disorders such as obesity, cancer, cholesterol and coronary diseases.[7] The quantity and type of fat in the composition of a food have become a subject of concern for many consumers who want to maintain healthy habits.[8,9] Reducing the fat content of a food alters its composition and structure, giving rise to perceptible changes in colour, flavour and texture[10] that influence its sensory acceptability. To compensate for this effect, different types of fat replacers that have similar physical, chemical and sensory properties to those of fats but add few or no calories are habitually used.[11] The choice of these replacements depends on the composition and characteristics of each food.[12–14] Fat replacers are classified into three basic types according to their chemical composition: carbohydrate-based, protein-based or fat-based.[11,15]

Fats in foods can be replaced by emulsions.[16] In the present study, to reduce the amount of fat, new emulsions were designed based on cream, water and two types of hydrocolloid: a methylcellulose (MC) and a hydroxypropyl methylcellulose (HPMC). MC and HPMC are hydrocolloids which are obtained from cellulose through chemical derivatization.[7] These cellulose ethers produce gel networks that can modify the texture, increase the viscosity and contribute dietary fibre.[17] Additionally, they have been used to replace saturated fats as stabilisers of oil-water emulsions, since cellulose ethers adsorb to the emulsion interface.[18,19] Some studies have shown that when the fat phase is dispersed in an aqueous medium, the same organoleptic result can be achieved with less initial fat[11] and, irrespective of the energy content of the emulsion, the fat droplet size falls and the sensation of creaminess increases, leading to increased satiation.[20,21]

The aim of this study was to design panna cottas with similar organoleptic and textural properties to those of the traditional product but with lower fat and calorie contents, by replacing the cream with new emulsions based on cellulose ethers (MC and HPMC). To this end, it examined the effects of substituting the emulsions for different proportions of the cream on the texture, microstructure (using light microscopy and confocal laser scanning microscopy) and sensory properties of the panna cottas.

EXPERIMENTAL

Emulsion preparation

The emulsions were prepared with two different cellulose ethers with thermo-gelling ability (METHOCEL™ MX and F4M, both supplied by The Dow Chemical Co.). MX is a methylcellulose (MC) and F4M is a hydroxypropyl methylcellulose (HPMC). Their viscosity was 50000 and 4000 mPa s, respectively (in a 20 g kg^{-1} aqueous solution at 20 ºC, measured by The Dow Chemical Company following reference methods ASTM D1347 and ASTM D2363).

The ingredients of the emulsions were liquid cream (500 g kg^{-1}) with 350 g kg^{-1} of fat (Pascual, Calidad Pascual S.A.U., Burgos, Spain), drinking water (490 g kg^{-1}) (Bezoya, Calidad Pascual S.A.U., Burgos, Spain) and the different cellulose ethers (10 g kg^{-1}). The emulsions were prepared according to Sanz *et al.*[22] with some modifications. Briefly, the cellulose ethers were dispersed in previously warmed cream (microwaved at 500 W for 30 s) using a Heidolph stirrer (Heidolph RZR 1, Schwabach, Germany) at 120 g for 5 min. The mixture was then hydrated by gradually adding the water at 1ºC while stirring with a homogenizer (Ultraturrax T18, IKA, Staufen, Germany) at 3390 g for 30 s and subsequently at 7458 g for 60 s.

Panna cotta preparation

A control panna cotta was prepared with reconstituted skim milk powder (Central Lechera Asturiana, Corporación Alimentaria Peñasanta S.A., Siero, Spain) in drinking water, liquid cream with 350 g kg^{-1} of fat, κ-carrageenan (SatiagelTM ME5, Cargill France SAS, Saint-Germain-en-Laye, France), sodium alginate (MANUCOL DMF, FMC Biopolymer, Philadelphia, United

States) and liquid sweetener (Consum, Krüger GmbH & Co. KG., Bergisch Gladbach, Germany) (Table 1). Four different panna cottas (P75M, P100M, P75H and P100H) were prepared by replacing 75% or 100% of the liquid cream in the control panna cotta formulation with the MC emulsion (P75M or P100M) or the HPMC emulsion (P75H or P100H). Because the emulsions were also prepared with cream, the final cream content was 465.3 g kg^{-1} in panna cottas P75M and P75H and 372.3 g kg^{-1} in panna cottas P100M and P100H (Table 1). Therefore, the cream content reduction compared to the control panna cotta was 37.5% and 50%, respectively.

The panna cottas were prepared according to Borreani *et al.*[23], then placed in silicone moulds (truncated cone; base circle: 6.3 cm, height: 3.7 cm, top circle: 4.5 cm) and cooled to ambient temperature. The samples were stored at 4-5 ºC in a refrigerator until they were analysed.

Texture analysis

A penetration test was performed according to Borreani *et al.*[23] with a penetration distance of 15 mm. The firmness of the panna cotta was defined as the maximum force measured during sample penetration[24] expressed in N and the stiffness (N/s) as the slope of the curve before the rupture point. The texture analysis was performed in triplicate.

Microstructure analysis

An aliquot of both the MC and HPMC emulsions and a slim section of each panna cotta sample were placed on glass slides and observed at 60x magnification according to Borreani *et al.*[25] for light microscopy (LM) and according to Borreani *et al.*[23] for confocal laser scanning microscopy (CLSM).

Sensory analysis

The sensory analysis was carried out with 117 consumers (54.9% women and 45.1% men) recruited among the employees and students of the University. The samples (control, P75M, P100M, P75H and P100H) were analysed in a sensory laboratory equipped with individual booths.[26] Each consumer tasted the four reformulated panna cottas and the control sample, presented monadically at a single session following a balanced complete block experimental design. The samples were served in small plastic cups coded with random three-digit numbers. The samples were served at room temperature in random order. Water was supplied to clean the consumers' mouths between each sample.

Acceptability test

The consumer acceptance test was performed using a nine-point hedonic scale (1 = dislike extremely to 9 = like extremely). For each panna cotta, the consumers scored their degrees of liking in the following order: "appearance", "aroma", "texture", "taste" and "overall acceptability". The consumers also rated their probability of purchasing each sample on a five-point hedonic scale ranging from 1 = "I would definitely not buy it" to 5 = "I would definitely buy it".

CATA question

For each sample, the participants answered a CATA (Check All That Apply) question featuring 22 attributes: *lumpy appearance, smooth appearance, thick appearance, odd flavour, pleasant flavour, sweet flavour, cream flavour, tasteless, aftertaste, lumpy in mouth, soft in mouth, thick in mouth, dry mouth feel, moist mouth feel, mouth coating, creamy, gummy, nutritious, satiating, healthy, low in calories, high in calories*. The terms had been previously selected on the basis of the available literature about similar products. The following instruction was given to participants: “Check all the characteristics you consider represent this sample”.

Statistical analysis

All the data analyses were performed with XLSTAT statistical software (Addinsoft, NY, USA).

Texture and acceptability tests

One way ANOVA was applied to study the differences between formulations in the texture and consumer acceptance tests. The least significant differences were calculated by Tukey’s test ($P < 0.05$).

CATA question

Firstly, the frequency of use of each CATA term was determined by counting the number of consumers that selected that term to describe each sample. Cochran’s Q test[27] was carried out to identify the significant differences between the samples for each of the sensory terms. The variability in frequencies of attribute selection which were significant according to Cocharan's test was analysed with a correspondence analysis (CA). Finally, in order to assess the relationship between the CATA question responses and the panna cotta acceptability scores, a multiple factor analysis (MFA) was performed on the frequencies of mention in the CATA question.

RESULTS AND DISCUSSION

Texture analysis

The firmness values of the different panna cottas analysed in this study ranged from 0.765 N (P100H) to 1.172 N (P100M) (Table 2). The control sample was significantly different ($P < 0.05$) to the other panna cottas, with a firmness value that lay between those of the samples prepared with the MC emulsion and with the HPMC emulsion. The panna cottas prepared with the MC emulsion (P75M and P100M) presented the greatest firmness, with no significant differences between them ($P > 0.05$). Conversely, those prepared with the HPMC emulsion were the least firm, with the P100H panna cotta presenting significantly ($P < 0.05$) the lowest firmness value (0.765 N). Although using cellulose ethers can contribute viscosity to some systems,[19,28] in the present case it was found that replacing cream with the HPMC emulsion decreased the firmness values of samples P75H and P100H compared to those of the control. This could be due to the lowest consistency of the HPMC emulsion than that of the cream used in the control panna cotta. Consequently, the panna cottas prepared with the

HPMC emulsion presented lesser consistency than the control panna cotta and therefore, the higher percentage of HPMC emulsion used, the lower firmness values were obtained. In contrast, the MC emulsion gave the P75M and P100M samples higher firmness values than both the HPMC emulsion samples and the control panna cotta. This is probably due to the fact that the gel strength of aqueous MC and HPMC solutions is strongly dependent on their concentration and methoxyl content.[29] Indeed, when oil-in-water emulsions were prepared with MC and HPMC by Sanz *et al.*[22] and Sanz *et al.*[30], those with MC developed a stronger consistency than when HPMC was used. This could explain why the MC panna cottas (P75M and P100M) were firmer than those prepared with the HPMC emulsion (P75H and P100H). It is well known that self-assembly of cellulose ethers is driven by hydrophobic interactions between the hydrophobic substituents (methyl groups).[31] The higher the methyl substitution, the stronger the hydrophobic interactions, so stronger consistencies are obtained. Therefore, in the case of HPMC, the lower methyl group content and the presence of the more polar and larger hydroxypropyl groups that inhibit intermolecular association leads to the formation of a weaker consistency system than with MC.[32,33] In short, the firmness of the panna cottas appeared to depend on the type of emulsion, and therefore on the type of cellulose employed in the formulation, but in the case of the panna cottas prepared with the HPMC emulsion it also depended on the percentage of cream replaced (75% or 100%).

As regards the stiffness values of the different panna cottas investigated in this study, they varied between 1.446 N/s (P100H) and 2.297 N/s (control), with significant differences ($P < 0.05$) among all the formulations. The stiffest sample was the control panna cotta. The panna cottas prepared with the MC emulsion were significantly stiffer ($P < 0.05$) than those prepared with the HPMC emulsion, at both replacement levels (75% and 100%). Consequently, it would seem that the stiffness values, like the firmness values, depend on the type of emulsion used and, consequently, on the type of cellulose used. Indeed, it has been reported that the stiffness depends on the level of methoxyl and hydroxypropyl substitution, where an increase in hydroxypropyl substitution diminishes the stiffness of the resulting gel.[34] Regarding the cream content, the control panna cotta had the highest cream content and exhibited the highest stiffness value, as mentioned above. Moreover, the panna cottas prepared with replacement of 75% of the cream by the MC emulsion (P75M), which had a higher cream content than the panna cottas with 100% cream replacement (P100M), exhibited stiffness values that were significantly ($P < 0.05$) higher than the latter (P100M) and approached those of the control panna cotta. This was also observed in the panna cottas prepared with the HPMC emulsion, where P75H exhibited significantly ($P < 0.05$) higher stiffness values than P100H. Consequently, the proportion of cream replaced by the MC or HPMC emulsion appeared to have a directly proportional influence on the stiffness of the panna cottas. The higher the cream content, the greater the stiffness. In short, the stiffness of the panna cottas seemed to depend both on the type of emulsion employed (MC or HPMC) – and consequently on the type of cellulose employed – and on the percentage of cream that was replaced.

Microstructure analysis

In Figure 1, the structure of the MC and HPMC emulsions that replace part or all of the cream in the original panna cotta formulation employed in the control can be observed in Figures 1A and 1B and Figures 1C and 1D, respectively. In the LM images (Figs. 1A and 1C) the protein and the carbohydrates in the emulsions are stained purple and the fat is unstained, while in the CLSM images (Figs. 1B and 1D) the protein and the carbohydrates are stained red and the fat is stained green. In the MC emulsion (Figs. 1A and 1B) the fat can be seen both as fat globules of different sizes very close to each other, forming a dense network, and as large, dense clusters (pointed to by the white arrows), possibly due to flocculation and/or coalescence among some of them. In contrast, although flocculation and/or coalescence can also be seen in the HPMC emulsion (Figs. 1C and 1D), the fat seems to be distributed in a more dispersed and homogeneous way throughout the sample and to form smaller clusters. These results were in accordance with Sanz *et al.*[22], who observed that the fat globule size was larger in emulsions with MC than in emulsions with HPMC, when both emulsions were made with vegetable oil, and that the MC emulsion presented fat globule coalescence and a gel texture. Consequently, the more compact structural appearance of the MC emulsions compared to the HPMC emulsions could be related to the textural findings, as the samples prepared with these emulsions presented higher and lower firmness values, respectively.

Figure 2 shows the LM (Figs. 2 A-E) and CLSM (Figs. 2 F-J) images of the different panna cottas examined in this study. The fat of the control sample (Figs. 2A and 2F) can be seen both as small globules and as clusters of different sizes dispersed through the protein network, which is stained red (Fig.

2F). The higher fat content probably favoured coalescence formation in the control sample, giving rise to large clusters of fat. As in the control panna cotta, in sample P75M (Figs. 2B and 2G) the fat was also found to be surrounded by the protein network (stained purple in Fig. 2B and red in Fig. 2G). The fat also seemed to present a similar appearance to that observed in the MC emulsion. In other words, it formed large, compact, dense clusters as well as globules of different sizes. The appearance of the P100M panna cotta (Figs. 2C and 2H) was similar to that of P75M. However, it seemed to have a lighter, less compact/dense structure, probably because the fat clusters were smaller and more dispersed. This agrees with the texture analysis results, which found that the higher the fat content, the greater the stiffness value. Of the two panna cottas formulated with MC, P75M was the more similar in appearance to the control. It was also the one with the closest firmness and stiffness values to those of the control. In the P75H (Figs. 2D and 2I) and P100H (Figs. 2E and 2J) panna cottas, as in the MC ones, a homogeneously distributed protein network surrounded the fat. Sample P75H (Figs. 2D and 2I) appeared not to retain the structure of the HPMC emulsion, since homogeneously distributed fat globules were not observed and there were mainly large fat clusters (Fig. 2I). As the HPMC emulsion had a lower consistency from the start than the MC emulsion, it could be that the conditions in which the samples were prepared affected it more than they did the MC emulsion. Nevertheless, P100H did appear to maintain the structure observed in the HPMC emulsion, possibly because it contained a higher proportion of the emulsion than the P75H panna cotta.

In general, the panna cottas prepared with the HPMC emulsion (P75H and P100H) appeared to present smaller fat globules and less flocculation and/or coalescence, giving them a lighter structure than those prepared with the MC emulsion (P75M and P100M). This agrees with the texture findings, as the panna cottas prepared with the HPMC emulsion had lower firmness and stiffness values than those prepared with the MC emulsion.

Sensory analysis

Acceptability study

Table 3 shows the results of the consumer acceptability test for the different panna cottas. The attributes assessed in this test were appearance, aroma, texture, taste and overall acceptability. Although no significant differences between the samples were found for appearance and aroma ($P > 0.05$), a slight decrease in aroma was observed between the control panna cotta and those containing the MC and HPMC emulsions, as well as between the panna cottas with 75% and 100% cream replacement. This could be due to the decrease in fat content. Fewer of the lipophilic compounds that influence flavour release and perception were present in panna cottas prepared with fat replacement than in the control panna cottas.

As regards the acceptability of the panna cotta textures, the control and P75H were rated the best, with no significant differences between them ($P > 0.05$). Nor were significant differences ($P > 0.05$) found between P75H, P75M and P100H. Although the firmness values of the panna cottas prepared with the MC emulsion were closer to those of the control sample (Table 2), the consumers rated the texture of the panna cottas prepared with the HPMC emulsion more highly. This could be due to the lighter structure of the panna cottas prepared with the HPMC emulsion, where the fat was distributed in a more homogeneous way throughout the sample than the panna cottas prepared with the MC emulsion, as seen in microstructure results (Fig. 2). Consequently, the HPMC emulsion gave rise to a soft texture in the panna cottas (see the next section, *Differences between samples described by the CATA questionnaire,* where the attributes "soft in mouth", "creamy" and "moist mouth feel" were more often mentioned for panna cottas prepared with the HPMC emulsion). Moreover, the consumers rated the softer texture of the P75H and P100H panna cottas more highly (Table 3).

With regard to taste, the control sample was rated most highly, by a significant difference ($P < 0.05$) compared to all the other panna cottas. The following panna cottas in the taste rankings were P75M, P75H and P100H. In the same way as for texture, P100M scored lowest, although there was no significant difference ($P > 0.05$) between this sample and P100H. It would appear that the acceptability of the taste was in line with the differences in cream content. Samples with a higher percentage of cream (P75M and P75H) obtained better results than those with a lower percentage of cream (P100M and P100H), and the control panna cotta (which had the highest cream content) obtained the highest score. Lastly, as regards the overall acceptability of the panna cottas, the scores followed the same trend as for taste. In other words, the most acceptable sample was the control panna cotta, followed by samples P75H and P75M. Consequently, according to these findings it may be concluded that taste and texture are the attributes that seem to have determined the overall acceptability of the panna cottas, and that these depended to a certain extent on the cream content and the type of emulsion employed. The higher the cream content – and therefore the lower the cellulose emulsion content – the higher the overall acceptability (better texture and taste). In accordance with these results, Arancibia *et al.*[35] reported that adding food thickeners is believed to increase texture and decrease aroma and taste intensity, although these effects seem to be dependent on thickener type.

As regards the likelihood of purchasing the panna cottas, over half the consumers (54.9%) would buy the control. Of the panna cottas formulated with the emulsions, the 75% replacement samples achieved a purchase intention of nearly 30% (29.4% of the consumers would buy P75H and 26.8% would buy P75M). The panna cottas with the lowest purchase likelihood rates were P100H and P100M, at 17.7% and 15.0% respectively. These results could indicate a direct relationship between the quantity of cream and the purchase likelihood, as the lower the cream content of the panna cotta formulation, the lower the likelihood of purchase. They agree with the overall acceptability rating and texture analysis, where P100M scored lowest and presented the highest firmness.

Differences between samples described by the CATA questionnaire

Cochran's non-parametric test found significant differences in 14 of the 22 CATA attributes used to describe the samples (Table 4). This demonstrates that differences in the consumers' sensory perception of the panna cottas could be detected with the CATA questionnaire.

Figure 3 shows the diagram resulting from a correspondence analysis (CA) of these 14 attributes. The first two dimensions of the CA graph explained

95.5% of all the variability in the data: 71.2% corresponded to the first dimension and 24.3% to the second dimension. It will be seen that terms such as pleasant flavour and creamy, which were associated with the control sample and with P75H, appeared on the positive side of the X axis. P75M, P100M and P100H, associated with negative terms such as lumpy appearance, tasteless and mouth coating, appeared on the negative side of the X axis. Moreover, the attributes can roughly be divided into five groups. The first group consisted of positive taste attributes and it is where the control panna cotta was located. Opposite the “positive taste” group, the “negative taste” group consisted of negative taste attributes such as “tasteless” and “odd flavour”, as well as negative in-mouth attributes (“gummy” and “dry mouth feel”), and is where the panna cottas P75M and P100M were placed close together. The “soft” group consisted of attributes related to soft texture and sensations (“creamy”, “moist mouth feel” and “smooth appearance”) and contained the P75H panna cotta, which exhibited low firmness and stiffness values (Table 2). Opposite the “soft” group was the “lumpy” group, where the P75M and P100M panna cottas were also found close to each other. The negatives attributes found in the “negative taste” and “lumpy” groups for these samples (P75M and P100M) were related with the presence of the MC emulsion, which provided high firmness and stiffness values and a worse taste to the panna cottas than the HPMC emulsion. The last group only consisted of the “mouth coating” attribute, where the P100H panna cotta was located. To summarize, the attributes of the panna cottas seemed to be organized along two “sensory dimensions”, as de Wijk *et al.*[36] also observed in custard desserts.

To gain a better understanding of which sensory characteristics were most highly related to the overall acceptability of the samples, multi-factor analysis (MFA) was used to examine a combination of frequency of mention of the significant attributes in the CATA questionnaire (Table 4) and the overall acceptability test results (Table 3). Figure 4 shows the results of this analysis (A: attributes; B: samples). The first two dimensions of the MFA explained 93.83% of all the variability in the results: 64.44% corresponded to the first dimension and 29.39% to the second dimension. In Figure 4A it will be seen that the overall acceptability was related to soft in the mouth, cream flavour, pleasant flavour and sweet flavour, so it would appear that flavour was the main attribute that decided overall acceptability, together with texture, although to a lesser extent. Indeed, it may be seen that the control, which was closely related to the positive flavour attributes, was the sample that obtained the highest overall acceptability score. Additionally, the frequency of mention of “creamy” (Table 4) was very high for the control sample, which will certainly also have influenced its overall acceptability. Nevertheless, sample P75H, related to moist mouth feel, smooth appearance and creamy, which refer to its texture, was also relatively close to the concept of overall acceptability (Fig. 4A). This confirms that texture attributes also influenced the overall acceptability of the samples, although to a lesser extent than flavour. In fact, like the control sample, P75H also obtained high frequencies for mentions of cream flavour and creamy (Table 4). The two samples prepared with the MC emulsion (P75M and P100M), which presented high firmness and stiffness values, were related to the negative texture attributes of gummy, lumpy in mouth and lumpy appearance, as may be seen in Figure 3. For this reason, these samples scored worst in the acceptability test and were negatively correlated to the concept of overall acceptability (Fig. 4). Finally, sample P100H was related to mouth coating and was also placed at a distance from overall acceptability.

This analysis confirms that of the samples prepared with cellulose emulsions, the P75H panna cotta was the most acceptable to consumers. This could be because it scored higher on flavour- and texture-related attributes than the other samples formulated with emulsions and consequently presented similar attributes to those described for the control sample.

CONCLUSIONS

There seems to be a direct relationship between the structure of the emulsions (MC and HPMC) and the texture values of the panna cottas. The MC emulsion, which has a compact/dense microstructure, gives greater firmness and stiffness to the panna cottas made with it, which were also described as lumpy. The HPMC emulsion gives a lighter structure and consequently less firmness and stiffness to the panna cottas made with it, which were described sensorially as being soft and smooth.

In the sensory study of the panna cottas, the most acceptable percentage of fat substitution was 75%. Specifically, the panna cotta with 75% of the cream replaced by the HPMC emulsion was rated the best by the consumers and presented similar attributes to those of the control sample. Consequently, although the texture and taste of the control panna cotta are better than those of the panna cotta prepared with 75% of cream substitution by HPMC emulsion, this emulsion could be used as a cream replacer to reduce the fat and calorie contents of a traditional panna cotta, with good consumer acceptability and purchase intention. In fact, the panna cottas with 75% substitution by HPMC emulsion were described as creamy, with smooth appearance and moist mouth feel.

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REFERENCES

1. Nehir El S and Simsek S, Food technological applications for optimal nutrition: An overview of opportunities for the food industry. *Compr Rev Food Sci Food Saf* **11**: 2–12 (2012).
2. Urala N and Lähteenmäki L, Attitudes behind consumers' willingness to use functional foods. *Food Qual Prefer* **15**: 793–803 (2004).
3. Verbeke W, Functional foods: Consumer willingness to compromise on taste for health? *Food Qual Prefer* **17**: 126–131 (2006).
4. Su HP, Lien CP, Lee TA and Ho JH, Development of low-fat mayonnaise containing polysaccharide gums as functional ingredients. *J Sci Food Agric* **90**: 806–812 (2010).

5. Costa AIA and Jongen WMF, New insights into consumer-led food product development. *Trends Food Sci Technol* **17**: 457–465 (2006).

6. Stewart-Knox B and Mitchell P, What separates the winners from the losers in new food product development? *Trends Food Sci Technol* **14**: 58–64 (2003).

7. Akoh CC, Fat replacers. *Food Technol* **52**: 47–53 (1998).

8. Sudha ML, Srivastava AK, Vetrimani R and Leelavathi K, Fat replacement in soft dough biscuits: Its implications on dough rheology and biscuit quality. *J Food Eng* **80**: 922–930 (2007).

9. Zoulias EI, Oreopoulou V and Tzia C, Textural properties of low-fat cookies containing carbohydrate- or protein-based fat replacers. *J Food Eng* **55**: 337–342 (2002).

10. Guinard JX and Marty C, Acceptability of fat-modified foods to children, adolescents and their parents: Effect of sensory properties, nutritional information and price. *Food Qual Prefer* **8**: 223–231 (1997).

11. ADA, Position of the American Dietetic Association: Fat replacers. *J Am Diet Assoc* **105**: 266–275 (2005).

12. Sandrou DK and Arvanitoyannis IS, Low-fat/calorie foods: Current state and perspectives. *Crit Rev Food Sci Nutr* **40**: 427–447 (2000).

13. Bayarri S, Chuliá I and Costell E, Comparing λ-carrageenan and an inulin blend as fat replacers in carboxymethyl cellulose dairy desserts. Rheological and sensory aspects. *Food Hydrocoll* **24**: 578–587 (2010).

14. Cadena RS, Cruz AG, Faria JAF and Bolini HMA, Reduced fat and sugar vanilla ice creams : Sensory profiling and external preference mapping. *J Dairy Sci* **95**: 4842–4850 (2012).

15. Oreopoulou V, Fat replacers. in *Bakery Products: Science and Technology,* ed. by Hui YH. Blackwell Publishing, Ames, Iowa, USA, p. 193–210 (2006).

16. Tarancón P, Fiszman SM, Salvador A and Tárrega A, Formulating biscuits with healthier fats. Consumer profiling of textural and flavour sensations during consumption. *Food Res Int* **53**: 134–140 (2013).

17. Dickinson E, Hydrocolloids as emulsifiers and emulsion stabilizers. *Food Hydrocoll* **23**: 1473–1482 (2009).

18. Sanz T, Salvador A, Fiszman S and Laguna L, Fabricación y aplicación de emulsión sustituta de grasa. Spain Patent ES2408690 (2011).

19. Tárrega A, Martínez M, Vélez- Ruiz JF and Fiszman S, Hydrocolloids as a tool for modulating the expected satiety of milk-based snacks. *Food Hydrocoll* **39**: 51–57 (2014).

20. Lett AM, Norton JE and Yeomans MR, Emulsion oil droplet size significantly affects satiety : A pre-ingestive approach. *Appetite* **96**: 18–24 (2016).

21. Lett AM, Yeomans MR, Norton IT and Norton JE, Enhancing expected food intake behaviour, hedonics and sensory characteristics of oil-in-water emulsion systems through microstructural properties, oil droplet size and flavour. *Food Qual Prefer* **47**: 148–155 (2016).

22. Sanz T, Falomir M and Salvador A, Reversible thermal behaviour of vegetable oil cellulose ether emulsions as fat replacers. Influence of glycerol. *Food Hydrocoll* **46**: 19–27 (2015).

23. Borreani J, Llorca E, Quiles A and Hernando I, Designing dairy desserts for weight management: Structure, physical properties and *in vitro* gastric

digestion. *Food Chem* **220**: 137–144 (2017).

24. Salvador A and Fiszman SM, Textural and sensory characteristics of whole and skimmed flavored set-type yogurt during long storage. *J Dairy Sci* **87**: 4033–4041 (2004).
25. Borreani J, Llorca E, Larrea V and Hernando I, Adding neutral or anionic hydrocolloids to dairy proteins under *in vitro* gastric digestion conditions. *Food Hydrocoll* **57**: 169–77 (2016).
26. ISO, Sensory analysis-General guidance for the design of test rooms. ISO Standard 8589. International Organization for Standarization, Geneva, Switzerland, p. 9–11 (2007).
27. Manoukian EB, *Mathematical Nonparametric Statistics*. Gordon and Breach Science Publishers, Inc., Newark, NJ, USA, (1986).
28. Arboleya J and Wilde P, Competitive adsorption of proteins with methylcellulose and hydroxypropyl methylcellulose. *Food Hydrocoll* **19**: 485–491 (2005).
29. Sarkar N, Kinetics of thermal gelation of methylcellulose and hydroxypropylmethylcellulose in aqueous solutions. *Carbohydr Polym* **26**: 195–203 (1995).
30. Sanz T, Laguna L and Salvador A, Biscuit dough structural changes during heating: Influence of shortening and cellulose ether emulsions. *LWT - Food Sci Technol* **62**: 962–969 (2015).
31. Pizones Ruiz-Henestrosa VM, Bellesi FA, Camino NA and Pilosof AMR, The impact of HPMC structure in the modulation of *in vitro* lipolysis: The role of bile salts. *Food Hydrocoll* **62**: 251–261 (2017).
32. Torcello-Gómez A and Foster TJ, Interactions between cellulose ethers

and a bile salt in the control of lipid digestion of lipid-based systems. *Carbohydr Polym* **113**: 53–61 (2014).

33. Torcello-Gómez A, Fernández Fraguas C, Ridout MJ, Woodward NC, Wilde PJ and Foster TJ, Effect of substituent pattern and molecular weight of cellulose ethers on interactions with different bile salts. *Food Funct* **6**: 730–739 (2015).

34. Primo-Martín C, Sanz T, Steringa DW, Salvador A, Fiszman SM and van Vliet T, Performance of cellulose derivatives in deep-fried battered snacks: Oil barrier and crispy properties. *Food Hydrocoll* **24**: 702–708 (2010).

35. Arancibia C, Castro C, Jublot L, Costell E and Bayarri S, Colour, rheology, flavour release and sensory perception of dairy desserts. Influence of thickener and fat content. *LWT - Food Sci Technol* **62**: 408–416 (2015).

36. de Wijk RA, van Gemert LJ, Terpstra MEJ and Wilkinson CL, Texture of semi-solids; sensory and instrumental measurements on vanilla custard desserts. *Food Qual Prefer* **14**: 305–317 (2003).

Figure captions

Figure 1. Light microscopy (A, C) and confocal laser scanning microscopy (B, D) images of the MC (A, B) and HPMC (C, D) emulsions. Arrow: fat. Toluidine blue stained proteins and carbohydrates in *purple*, Nile Red stained fat in *green* and Rhodamine B stained proteins and carbohydrate in *red*. Magnification 60x.

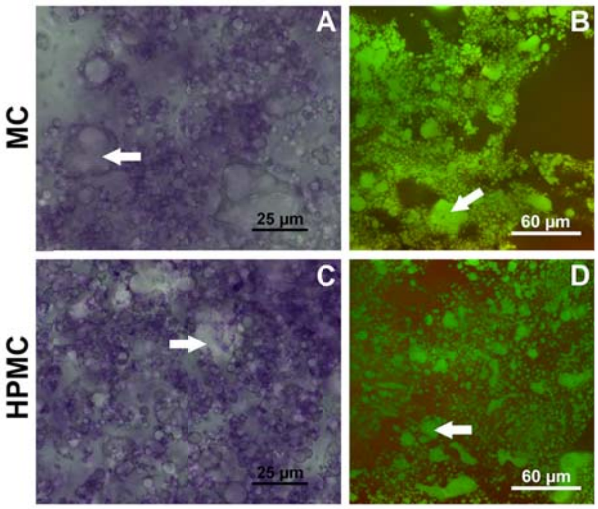


Figure 2. Light microscopy (A - E) and confocal laser scanning microscopy (F - J) images of the five panna cottas. P75M and P100M: respectively 75% and 100% of cream replaced by MC emulsion. P75H and P100H: respectively 75% and 100% of cream replaced by HPMC emulsion. Toluidine blue stained proteins and carbohydrates in *purple*, Nile Red stained fat in *green* and Rhodamine B stained proteins and carbohydrates in *red*. Magnification 60x.

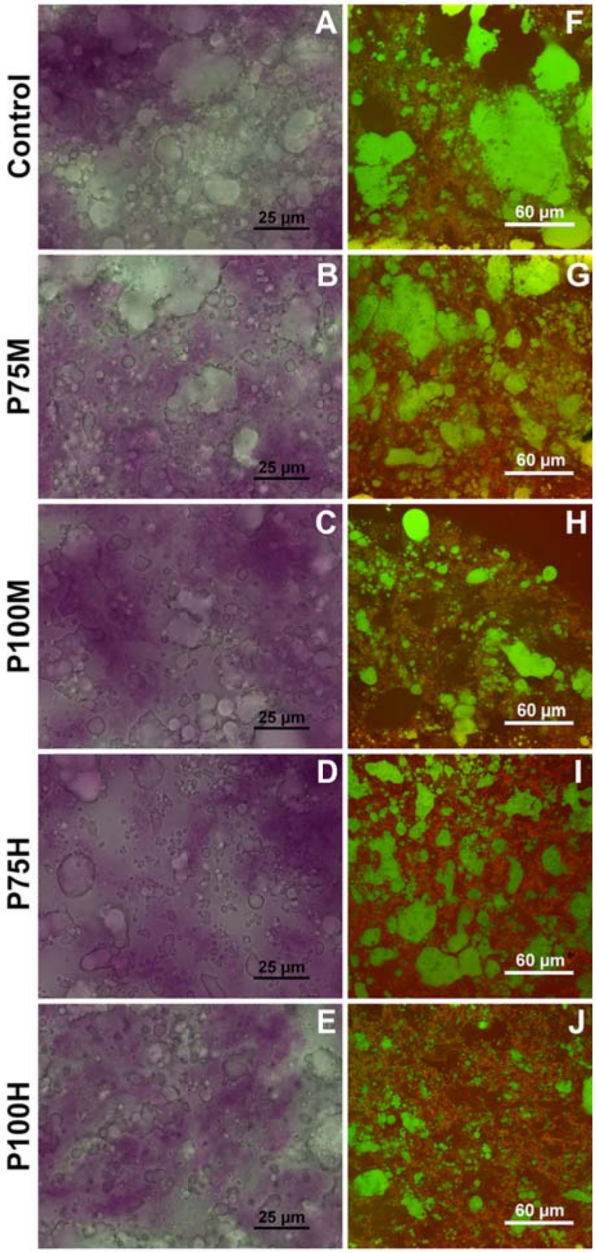


Figure 3. Correspondence analysis of the check-all-that-apply (CATA) questions. P75M and P100M: respectively 75% and 100% of cream replaced by MC emulsion. P75H and P100H: respectively 75% and 100% of cream replaced by HPMC emulsion.

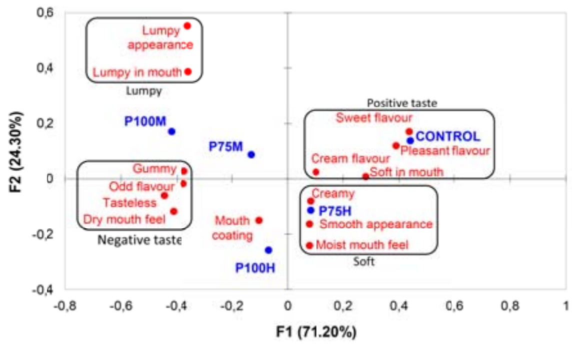
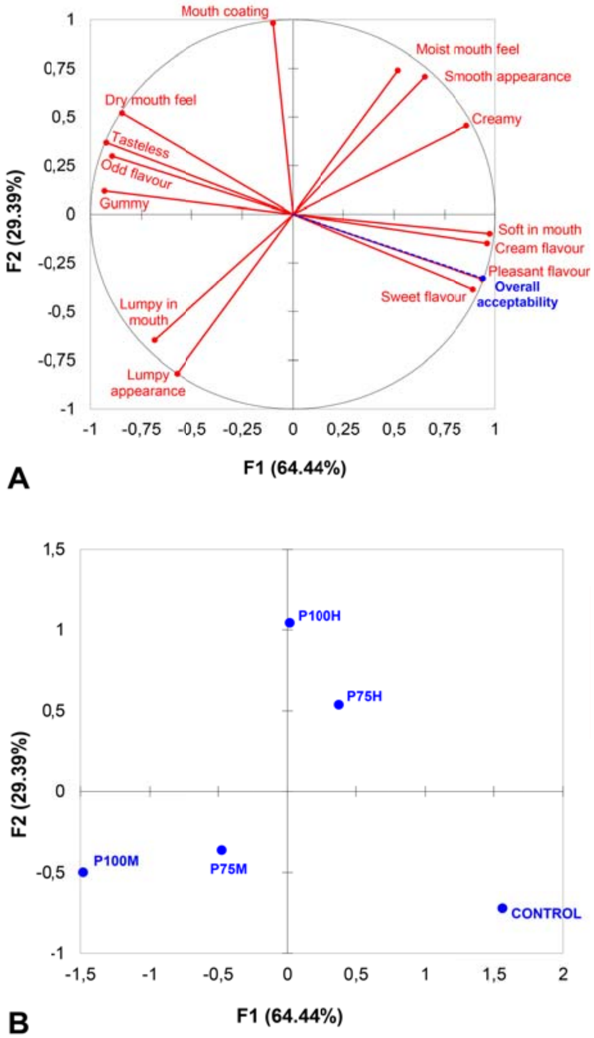


Figure 4. A) Attribute map from the check-all-that-apply (CATA) questionnaire, and **B)** Representation of the five panna cottas in the first two dimensions of the multiple factor analysis (MFA) of the CATA counts. P75M and P100M: respectively 75% and 100% of cream replaced by MC emulsion. P75H and P100H: respectively 75% and 100% of cream replaced by HPMC emulsion.



Tables

Table 1. Panna cotta formulations (g kg^{-1}) with new emulsions as fat replacers.

Ingredients (g kg^{-1} panna cotta)	Panna cottas				
	Control	**P75M**	**P100M**	**P75H**	**P100H**
Skimmed milk powder	41.4	41.4	41.4	41.4	41.4
Water	206.8	206.8	206.8	206.8	206.8
κ-carrageenan	3.3	3.3	3.3	3.3	3.3

Sodium alginate	2.5	2.5	2.5	2.5	2.5
Sweetener	1.6	1.6	1.6	1.6	1.6
Cream	744.5	186.1	-	186.1	-
MC emulsion	-	558.4	744.5	-	-
HPMC emulsion	-	-	-	558.4	744.5
Total cream content	***744.5***	***465.3***	***372.3***	***465.3***	***372.3***
Fat content	***261.0***	***163.2***	***130.7***	***163.2***	***130.7***

MC: methylcellulose. HPMC: hydroxypropyl methylcellulose. P75M and P100M: respectively 75% and 100% of cream replaced by MC emulsion. P75H and P100H: respectively 75% and 100% of cream replaced by HPMC emulsion.

Table 2. Influence of cream substitution percentage and cellulose ether type on the texture of the panna cottas.

Sample	Firmness (N)	Stiffness (N/s)
Control	1.078 ± 0.042 ^{B}	2.297 ± 0.072 ^{A}
P75M	1.167 ± 0.027 ^{A}	2.127 ± 0.081 ^{B}
P100M	1.172 ± 0.032 ^{A}	2.033 ± 0.115 ^{C}
P75H	0.801 ± 0.027 ^{C}	1.678 ± 0.100 ^{D}
P100H	0.765 ± 0.022 ^{D}	1.446 ± 0.074 ^{E}

Mean values ± standard deviations (n = 15). Values with different letters within the same column are significantly different ($P < 0.05$) according to the HSD multiple range test.
P75M and P100M: respectively 75% and 100% of cream replaced by MC emulsion. P75H and P100H: respectively 75% and 100% of cream replaced by HPMC emulsion.

Table 3. Liking for appearance, flavour, texture and taste and overall acceptability scores of the five panna cottas.

Sample	Appearance	Aroma	Texture	Taste	Overall acceptability

Control	6.75 ± 1.56 ^{A}	5.63 ± 1.60 ^{A}	7.10 ± 1.43 ^{A}	6.99 ± 1.93 ^{A}	6.85 ± 1.65 ^{A}
P75M	6.24 ± 1.69 ^{A}	5.61 ± 1.64 ^{A}	5.86 ± 2.15 ^{BC}	5.35 ± 2.27 ^{B}	5.62 ± 1.96 ^{BC}
P100M	6.22 ± 1.47 ^{A}	5.31 ± 1.36 ^{A}	5.48 ± 2.06 ^{C}	4.42 ± 2.10 ^{C}	5.19 ± 1.80 ^{C}
P75H	6.56 ± 1.58 ^{A}	5.58 ± 1.50 ^{A}	6.43 ± 1.87 ^{AB}	5.64 ±2.04 ^{B}	5.94 ± 1.84 ^{B}
P100H	6.44 ± 1.59 ^{A}	5.42 ± 1.56 ^{A}	5.90 ± 2.22 ^{BC}	5.05 ± 1.94 ^{BC}	5.47 ± 1.72 ^{BC}

Mean values ± standard deviations (n = 117). Values with different letters within the same column are significantly different ($P < 0.05$), according to the HSD multiple range test.

P75M and P100M: respectively 75% and 100% of cream replaced by MC emulsion. P75H and P100H: respectively 75% and 100% of cream replaced by HPMC emulsion.

Table 4. Frequency of mention of CATA terms and p-value of Cochran's Q test for differences between the five panna cotta formulations.

Attributes	p-value (Cochran test)	Frequency of mention				
		Control	**P75M**	**P100M**	**P75H**	**P100H**
Thick appearance	0.057*	30	34	37	26	20
Mouth coating	0.011	27	34	31	42	45
Satiating	0.642*	33	31	26	30	27
High in calories	0.168*	28	37	27	27	32
Low in calories	0.521*	7	8	11	5	9
Nutritious	0.420*	8	11	9	8	13
Healthy	0.498*	7	3	7	7	7
Aftertaste	0.650*	12	17	18	16	17
Pleasant flavour	<0.0001	57	25	15	34	22
Odd flavour	0.003	7	20	26	22	19
Tasteless	<0.0001	10	35	48	30	42
Cream flavour	0.000	70	53	40	53	54
Sweet flavour	<0.0001	49	18	13	30	14
Moist mouth feel	0.036	14	7	9	15	19
Dry mouth feel	0.001	5	16	23	17	22

Gummy	0.038	8	18	21	11	18
Thick in mouth	0.069*	19	27	24	14	15
Creamy	<0.0001	64	54	37	64	63
Soft in mouth	<0.0001	65	31	22	40	41
Lumpy in mouth	0.002	10	13	22	10	5
Smooth appearance	0.002	35	26	22	44	40
Lumpy appearance	<0.0001	15	22	28	7	4

*Attributes that do not present significant differences according to the Cochran test (n = 117).

P75M and P100M: respectively 75% and 100% of cream replaced by MC emulsion. P75H and P100H: respectively 75% and 100% of cream replaced by HPMC emulsion.