How hydrocolloids affect the temporal oral perception of ice cream

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A B S T R A C T

In-mouth texture largely determines the acceptability of ice cream, making it a key quality factor. Its perception involves movements of the tongue and other oral structures while the product melts and becomes a smooth, creamy viscous liquid as its temperature increases. Time is therefore an important issue in the sensory perception of ice cream, but has barely been considered in ice cream evaluation. In the present work, six ice cream samples with very different textures, formulated with milk, cream, egg, and hydrocolloids, were analysed by the Temporal Dominance of Sensations (TDS) method. Iciness, coldness, creaminess, roughness, gumminess, and mouth coating were assessed. Hydrocolloids (and cream or egg to a lesser extent) modulated the temporal perception of ice cream attributes, reducing the first impact of sensations such as iciness and coldness. They also favoured an early perception of creaminess. Dynamic perception techniques combined with consumer sensory description by CATA (Check-all-that-apply) and liking scoring techniques gave a better understanding of which attributes drive consumer liking in relation to ice cream consumption.

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1. Introduction

The term “ice cream” in its broadest sense covers a wide range of different types of frozen dessert that are normally eaten in the frozen state. On a macroscope, the ice cream texture perceived is determined by the microscopic features of the structure. In turn, microstructure is determined by complex molecular interactions. The ingredients used in ice cream can be classified into major ingredients, present in significant quantities, and minor ingredients such as emulsifiers, stabilizers, colours and flavours, present in amounts of less than about 1% by weight. Although ice cream formulations have varied widely depending on the manufacturing process, basically they are composed of cream, egg, sugar, and milk. Each ingredient has a purpose in the product (Clarke, 2004).

Cream (fat content about 30–40%) actually comprises both fat and non-fat portions, which provide very different technofunctional properties. The proteins in the cream contribute to the development of the ice cream’s structure, including its emulsification, whipping, and water holding capacity (Goff, 1997). The emulsification properties of the proteins in the mix arise from their adsorption to fat globules during homogenization, their whipping properties contribute to the formation of the initial air bubbles and their water holding capacity leads to enhanced viscosity, which imparts a beneficial body to the ice cream, increases the meltdown time and contributes to reduced iciness. As regards the fat, its partial coalescence contributes to the formation of a fat network which is essential to give the ice cream its creaminess and melting resistance, as well as being important for the stability of the air bubbles (Zhang & Goff, 2005). In addition, fat provides texture, palatability, creaminess, flavour and lubrication in the mouth (Aime, Arnfield, Malcolmson, & Ryland, 2001; Akalin & Erisir, 2008; Bolliger, Goff, & Tharp, 2000; Granger, Leger, Bary, Langendorf, & Cansell, 2005).

Egg yolks have high nutritional value and multifunctional properties. They contain several components with emulsifying properties (notably about 9% lecithin). In ice cream manufacture they are used in different forms, such as pasteurized fresh egg yolk, frozen sugared pasteurized egg yolk or dehydrated egg yolk. The use of egg yolk solids is around 0.5–3% (Clarke, 2004). According to Herald, Aramouri, and Abu-Ghoush (2008) the beneficial effects of egg yolk are, among others, firmer ice cream, increased whipping rate, less change in overrun percentage while unloading a batch freezer, improved appearance while the ice cream is melting and slightly improved texture. The use of egg yolk in traditional ice cream formulations has given way in modern formulations to specific ingredients that deliver much greater functionality at a lower cost. In ice cream, egg yolk affects viscosity, texture and sensory properties (Alfaifi & Stathopoulos, 2010).
Sugars (about 12–17% of total volume of the mix) are used in all types of ice cream. They have two principal functions in this product: to confer sweetness and to control the total ice content or ice phase volume, and hence the softness of the ice cream, by depressing the freezing point. Sugars also influence the viscosity of the mix (Ablett, Clarke, Izzard, & Martin, 2002; Goff, 2002; Muse & Hartel, 2004).

Hydrocolloids affect ice cream texture through different mechanisms, which include controlling ice crystal formation or growth during processing; controlling recrystallization phenomena during storage; increasing viscosity and water retention, preventing separation of the ice cream mix (an oil in water emulsion); and producing charged films at the interfaces (in the case of charged hydrocolloids) so the individual particles or droplets tend to repel each other, avoiding coalescence (Helgerud, Gåserød, Fjæreide, Andersen, & Larsen, 2010). The latter mechanisms preserve the structure by slowing down melting at consumption stage (Goff, 2002). Hydrocolloids are used in ice cream production at concentrations of 0.2–0.5%.

The in-mouth texture of the ice cream largely determines the quality and acceptability of the product, making it a key quality factor. Appreciation of the ice cream starts in visual mode as it is being served but its definitive evaluation takes place in the mouth, using tongue movements and the involvement of other oral structures while the product melts as its temperature increases. It is generally accepted that for a good ice cream texture the compounds have to interact in a balanced way, providing a uniform structure that is reflected in a soft, light, creamy ice cream. The perception of an ice cream (an ice-cold sensation) has a negative impact on consumers (El-Nagar, Clowes, Tudorica, Kuri, & Brennan, 2002). A number of papers deal with sensory evaluation of ice cream. Normally they describe changes in the sensory attributes with reference, as in fat replacement (Aime et al., 2001; Ayalon, Seggin, & Guzel-Seydim, 2005; Liou, 2002), protein replacement (Alvarez, Wolters, Vodovotz, & Ji, 2005), sucrose replacement (Akin, Sezgin, & Guzel-Seydim, 2005; Liou & Grun, 2007), protein-sugar-replacement (Alfaiati & Stathopoulos, 2010; Herold et al., 2008), adding several stabilizers (Gruver, Karaca, & Karar, 2003; Trindade, Balieiro, Dias, Sanino, & Boschini, 2007), different flours or fibre (Dervisoglu, 2006; Dervisoglu & Yazici, 2006), or inulin (El-Nagar et al., 2002; Schaller-Povoiny & Smith, 1999), or using cultured milk (Cruz, Antunes, Sousa, Faria, & Saad, 2009; Homayouni, Azizi, Ehsani, Yarmand, & Razavi, 2008; Soukoulis, Lyroni, & Tzia, 2010).

However, the impact of sensations over the consumption time has been investigated less despite being very important for the appreciation of ice cream, where the texture changes from a cold solid to a creamy, melting/melted liquid. For instance, the Time Intensity method has been used to show how the dynamics of flavour intensity in ice cream are affected by changes in fat level and in the type of flavourings (Chung, Heymann, & Grun, 2003; Frøst, Heymann, Bredie, Dijkstra, & Martens, 2005). In recent years, the Temporal Dominance of Sensations (TDS) method has been used to study the appearance and evolution over time of different sensory attributes in the mouth during ingestion. With this sensory method the assessors can evaluate what sensation is dominant at each moment of consumption (Labbe, Schlicht, Pineau, Gilbert, & Martin, 2009; Pineau et al., 2012) throughout a consumption sequence at one session (Foster et al., 2011). In turn, the TDS responses can be linked to acceptance, using the temporal data to gain a better understanding of consumer response. Experimentally, this method consists in showing the entire set of attributes to the assessors on the computer screen. During the test, the assessor has to decide what the dominant sensory perception is and select and score the corresponding attribute. If the assessors think that the attribute has changed they have to identify and score the new perception (Pineau et al., 2009).

This technique has been applied increasingly in the last five years to a number of foods and wines, to liquid dairy products and to some solid products such as wheat flakes (Lenfant, Loret, Pineau, Hartmann, & Martin, 2009) or fish fingers (Albert, Salvador, Schlicht, & Fiszman, 2012).

The objective of this work was to study the effect of different formulations, varying the proportion of stabilizing components (cream, egg yolk and a hydrocolloid mix) on the temporal sensory properties of the ice cream. The relationships of some characteristics of the mix and of the ice creams with consumer liking were also investigated.

2. Materials and methods

2.1. Ice cream preparation

Six ice cream formulations were prepared. All the ingredients were bought at a local supermarket. The ingredients were: 36% (w/w) skimmed milk (9.1% non-fat total solids) (M), 36% (w/w) cream (6.1% non-fat total solids, 33% fat) (C), 13.5% (w/w) sugar, 14% (w/w) pasteurized egg yolk (16.2% non-fat total solids) (E) and 0.5% (w/w) of a commercial mix of hydrocolloids (H) suitable for ice cream stabilization (Lygomme™ FM 1005, kindly provided by Brenntag Iberica, composed of guar gum, dextrose and carrageenan). Different combinations and amounts of these ingredients were selected to obtain ice cream samples with very different properties and sensory profiles. In one formulation, the cream, egg yolk and hydrocolloids were replaced with milk (Table 1).

The ingredients were dispersed in water at 60 °C using a mixer, pasteurized at 70 °C for 30 min and then cooled to 4 °C. The ice cream mixes were frozen in batches of 1000 g of mix in a home-style ice cream maker (Cuisinart, East Windsor) for 20 min (the initial temperature of the canister was −27 °C). The ice cream samples were placed in 100-mL foam plastic cups, carefully levelled off with a spatula and covered with the lid. They were kept at −17 °C for 24 h before sensory and physicochemical analysis.

2.2. Ice cream mix properties

2.2.1. Ice cream mix flow behaviour

The flow properties of the pre-freezing mixes (stored at 4 °C for 24 h) were measured with a rheometer G2 AR (TA Instruments, Crawley, England), employing a plate geometry of 60 mm diameter with a 1 mm gap and a 0.01–200 s−1 shear rate for 2 min at 25 °C. Two replicates were performed for each sample, using formulations prepared on different days. The shear stress and apparent viscosity values of the samples as a function of shear rate were determined. The data were fitted to the Ostwald (power law) model (Eq. (1)):

$$\eta_s = ky^n$$

(1)

Were ηs is the apparent viscosity (Pa s), k is the consistency index (Pa s^n), γ is the shear rate (s^-1) and n (dimensionless) is the flow

<table>
<thead>
<tr>
<th>Sample</th>
<th>M (% w/w)</th>
<th>C (% w/w)</th>
<th>E (% w/w)</th>
<th>H (% w/w)</th>
<th>S (% w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>36</td>
<td>36</td>
<td>14</td>
<td>0.5</td>
<td>13.5</td>
</tr>
<tr>
<td>MECH</td>
<td>72</td>
<td>14</td>
<td>0.5</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>MCE</td>
<td>36.5</td>
<td>36</td>
<td>14</td>
<td>0.5</td>
<td>13.5</td>
</tr>
<tr>
<td>MCH</td>
<td>50</td>
<td>36</td>
<td>0</td>
<td>0.5</td>
<td>13.5</td>
</tr>
<tr>
<td>MH</td>
<td>86.5</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>13.5</td>
</tr>
<tr>
<td>M</td>
<td>86.5</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>13.5</td>
</tr>
</tbody>
</table>
behaviour index. The consistency index \( k \) and flow index \( n \) were calculated for each formulation.

### 2.2.2. Ice cream instrumental texture

#### 2.2.2.1. Penetration test

A strict routine was followed to control the temperature of the sample during the penetration test: each sample container was taken out of the freezer \((-27 ± 1 \, ^\circ C)\) and tested at room temperature \((25 ± 1 \, ^\circ C)\) exactly 10 min afterwards. One measurement was made of each individual sample. The ice cream hardness was determined with a TA.XT plus texture analyser (Stable Microsystems, Godalming, United Kingdom). The samples were penetrated to a depth of 20 mm with a 13-mm diameter cylindrical probe. For each sample, the force-deformation curves gave the maximum force \( N \) as a measure of hardness, the initial slope \((N \, s^{-1})\) of the penetration curve as a measure of firmness and the penetration work \( N \, s \) (area under the curve) as a measure of resistance to penetration. Two replications were performed with samples prepared on different days, each with five determinations per sample.

### 2.3. Sensory evaluation

#### 2.3.1. Temporal Dominance of Sensations

##### 2.3.1.1. Selection of terms and panel instruction and training

Fourteen assessors participated in this study. The assessors had previous experience in sensory descriptive analysis but were not trained specifically in the description of ice-cream. Four 1-hour preliminary sessions were conducted in order to explain the TDS technique and the notion of temporality of sensations and to give the assessors the chance to test the data collection software and familiarize themselves with it. In the first session the subjects described three very different ice cream samples \((M, MC, and ME)\) and generated a list of terms, mainly focussing on in-mouth sensations during the melting period. In the second session, the most frequently cited attributes were selected and their definitions and the protocol for measuring them were developed (Table 2).

During the third and fourth sessions the panelists learned to understand the dominance and sequence concepts and participated in a simulated TDS session with several samples of ice cream in order to solve questions and become familiar with the computer and the methodology.

##### 2.3.1.2. Formal assessment

The TDS evaluation took place over three sessions held on three different days to conduct three replications. The samples were provided in a sequential monadic series according to a balanced random design (Williams, 2012). The six samples \((M, MH, MEH, MCH, MCE, and MECH)\) each showed the six attributes to be evaluated and an 10 cm-unstructured scale ranging from “weak” to “strong” for each attribute. After being given the spoonful of ice cream, the assessors were asked to click the start button when they placed the sample in their mouths and then indicate which attribute they considered dominant at each moment during oral processing. The evaluation ended when the assessors no longer perceived sensations (after swallowing, when no perception of after-sensations remained) and clicked the stop button.

The data were collected with Fizz Software version 2.45 (Biosystems, Counternon, France).

#### 2.3.2. Consumer tests

Eighty-five untrained consumers aged between 23 and 68 years were recruited, 30% of them male. They were all vanilla ice-cream acceptors and consumers. The evaluation was performed in a standardized room equipped with individual booths (ISO, 1988). The six samples \((M, MH, MEH, MCH, MCE, and MECH)\) were coded with 3-digit numbers and were assessed in a sequential monadic series according to a balanced random design (Williams’ design) (Wakeling & MacFie, 1995). They were served in individual plastic containers \((50 ml capacity)\) with a small plastic spoon. The consumers performed two tests: they rated overall liking and liking for some attributes and then answered a CATA (check-all-that-applies) question. Data collection was performed with Compusense® 5.0 software (Compusense Inc., Guelph, Canada).

##### 2.3.2.1. Liking test

The consumers tasted the samples and rated their overall liking and liking for appearance, texture and flavour on 9-point box-scales labelled from 1 = dislike extremely to 9 = like extremely.

##### 2.3.2.2. Check-all-that-apply (CATA) questionnaire

Check-all-that-apply (CATA) is a consumer-friendly method (Adams, Williams, Lancaster, & Foley, 2007) that is increasingly being used to capture consumer perceptions of food products. This method, in which a product is described by selecting appropriate words from a given list, is a simple and valid approach to gathering information about sensory (and non-sensory) perception. Consumer-elicited CATA profiles have shown good agreement with traditional panel-developed sensory profiles, suggesting that CATA could be a valuable alternative for understanding perceptions of a product’s sensory attributes, with the added advantage of obtaining direct consumer feedback (Ares, Deliza, Barrero, Gimenez, & Gambaro, 2010; Dooley, Lee, & Meullenet, 2010; Varela & Ares, 2012).

In this study, the consumers described the samples by selecting appropriate attributes from a given list. The 26 attributes presented were selected from the available literature and from initial tastings by the researchers and the sensory descriptive panel used in the TDS evaluation. The instruction given to the participants was: “Please check all the answers that apply to the vanilla ice cream you have tasted”. The attributes included were: rough surface, creamy appearance, white colour, yellow colour, crystalized, sweet, double cream flavour, egg flavour, vanilla flavour, milk flavour, soft, hard, smooth, creamy texture, coarse texture, gummy, elastic, cold, melting easily, melting slowly, fatty, aerated, dense, easy to spoon,

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**Table 2**

Attributes generated by the trained panel and their definitions.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iciness</td>
<td>Perception of cold produced by large ice crystals</td>
</tr>
<tr>
<td>Coldness</td>
<td>Impact of cold after placing the sample on the tongue</td>
</tr>
<tr>
<td>Roughness</td>
<td>Coarse sensation due to detectable ice particles that melt in the mouth. The opposite of smoothness</td>
</tr>
<tr>
<td>Creaminess</td>
<td>The sample has a homogenous soft texture</td>
</tr>
<tr>
<td>Gumminess</td>
<td>Perception of gummy, chewable texture</td>
</tr>
<tr>
<td>Mouth coating</td>
<td>Amount of product that remains covering the mouth after swallowing</td>
</tr>
</tbody>
</table>
fatty residual sensation and residual flavour. The attributes were randomized between products and across consumers.

2.4. Data analysis

For the TDS data analysis, the attribute chosen as dominant and the times when the dominance started and stopped were collected for each panelist run. As the duration of the period up to complete swallowing differed from one subject to another and the sensory perception time scales differ as a result, the data were normalized by adjusting them according to the individual duration of each subject’s test (Albert et al., 2012). Finally, to build the TDS curves, the period when a sensation was dominant for a product at panel level (dominance rate) was computed at each point of time (Lenfant et al., 2009).

When the TDS curves were plotted, two additional lines were drawn for the chance and significance levels. The chance level refers to the dominance rate that an attribute could obtain by chance.

Analysis of variance (one-way ANOVA) was applied to the consumer liking scores and the instrumental texture analysis results. Least significant differences were calculated by Fisher’s LSD test ($p < 0.05$).

The CATA results were analysed by Multiple Factor Analysis (MFA) of the frequency counts of the attributes in order to obtain a two-dimensional representation of the samples and attributes. The overall liking data were used as illustrative data in the MFA analysis.

All the statistical analyses were performed with XLStat 2009 software (Addinsoft, Paris, France).

3. Results and discussion

3.1. Influence of formulation on ice cream mix flow behaviour

Table 3 shows the flow parameter values for the different ice cream mixes before freezing. All the samples presented shear-thinning, non-Newtonian pseudoplastic behaviour in the shear rate range studied, fitting the power-law equation (Eq. (1)) fairly well ($r > 0.98$). The consistency index ($k$) was significantly ($p < 0.05$) higher for the MECH formulation, followed by the MCH, MEH and MH in decreasing order. All the formulations containing the hydrocolloid stabilizer clearly presented higher values of $k$ than those without the stabilizer, following a decreasing order according to the complexity of the rest of the formulation (egg plus cream, cream, egg, or only milk), which was an expected result. Adding hydrocolloids that bind water and form a gel-like network in addition to the other components of the mix would obviously modify its rheology (El-Nagar et al., 2002). Adding carrageenan to ice cream mixes has led to the reinforcement of pseudoplasticity, possibly caused by gelation phenomena (Souloulis, Chandrinos, & Tzia, 2008). Thaiudom and Goff (2003) reported that the presence of carrageenan in protein/poly saccharide model solutions led to more heterogeneous distribution of casein micelles as an effect of k-carrageenan/casein complexes being formed.

For their part, both cream (C) and egg yolk (E) contribute fat globules to the mixes when present, so a decrease in mix viscosity with increasing shear rate would be partly due to the decreasing size of the fat agglomerates during shearing, consequently reducing the viscosity of the mix (Nazaruddin, Syliza, & Van-Roennan, 2008; Rossa, de Sá, Burin, & Bordignon-Luiz, 2011). Mix viscosity has been found to be highly correlated with a decreasing melting rate and increased shape retention (Alvarez et al., 2005; Li, Marshall, Heymann, & Fernando, 1997), both of which are positive for ice cream quality. The MCE and M formulations presented very low consistency index values, while that for MH was obviously higher.

For a pseudoplastic solution, the flow index $n$ values are an indication of the departure from Newtonian behaviour. The flow index values proved significantly ($p < 0.05$) lower for samples MECH, MEH, MCH and MH, those containing hydrocolloids in their formulation, with no significant differences between them (Table 3). MCE and M showed higher values of $n$, corresponding to a more Newtonian, fluid-like behaviour. The presence of polysaccharide hydrocolloids reinforces the pseudoplastic characteristic of the mix. The mix with hydrocolloids, cream and egg yolk resulted in a complex colloidal system, the furthest from a Newtonian-like flow.

3.2. Ice cream instrumental texture

In the ice cream penetration test, the M and MH samples presented significantly ($p < 0.05$) higher maximum force, penetration work and penetration slope values than the rest of the formulation (Table 3), denoting a harder, firmer system with greater resistance to penetration. They also had the highest water content in the mix, and consequently more ice and ice network formation and accretion, which gave a hard texture. Indeed, in these two samples a rough surface with large ice crystals could be seen with the naked eye. According to Souloulis et al. (2008), instrumental hardness may be used as a measure of ice crystal growth: the number and size of ice crystals formed from the available water during freezing influences ice crystal formation and growth during storage. Samples M and MH lacked sufficient stabilization against ice crystal growth, so became very hard.

The order of the rest of the samples was MECH, MCE, MEH and MCH (these last two samples presented the lowest penetration parameter values, with no significant differences between them). Apart from the size of the ice crystals, the hardness of the ice cream can be affected by a number of other factors such as overrun, the extent of fat destabilization, and ice phase volume (Muse & Hartel, 2004). Samples M and MH are very low-fat systems with considerable available water and not enough stabilizing components to limit the appearance of large ice crystals. In the samples that contained cream and egg, these contributed fat and some stabilization of the fat-water emulsion while the hydrocolloids retained free water, reducing the growth of ice crystals (Flores & Goff, 1999; Sakurai, Kokubo, Hakamata, & Yoshida, 1996).

Table 3

<table>
<thead>
<tr>
<th>Sample</th>
<th>Flow behaviour</th>
<th>Penetration test</th>
<th>Curve slope (N/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consistency index $k$ (Pa s$^n$)</td>
<td>Flow behaviour index $n$</td>
<td>Hardness (N)</td>
</tr>
<tr>
<td>MECH</td>
<td>2.181 (0.012)</td>
<td>0.562 (0.002)</td>
<td>66.4 (1.3)</td>
</tr>
<tr>
<td>MEH</td>
<td>0.972 (0.007)</td>
<td>0.561 (0.001)</td>
<td>38.6 (8.1)</td>
</tr>
<tr>
<td>MCE</td>
<td>0.041 (0.002)</td>
<td>0.792 (0.011)</td>
<td>54.6 (1.1)</td>
</tr>
<tr>
<td>MCH</td>
<td>1.274 (0.032)</td>
<td>0.553 (0.004)</td>
<td>25.6 (8.3)</td>
</tr>
<tr>
<td>MH</td>
<td>0.531 (0.001)</td>
<td>0.582 (0.001)</td>
<td>111.5 (8.1)</td>
</tr>
<tr>
<td>M</td>
<td>0.008 (0.001)</td>
<td>0.873 (0.001)</td>
<td>92.0 (1.4)</td>
</tr>
</tbody>
</table>

$^a$Means with the same letter in the same column are not significantly different ($p < 0.05$).

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3.3. Sensory tests

3.3.1. Dynamic sensory profile with semi-trained assessors — TDS curves

Fig. 1(a–f) shows the TDS graphs for the six ice creams formulated. Each curve represents the attributes chosen as dominant at each moment during the evaluation.

3.3.1.1. Sensations of iciness, coldness and roughness. These three sensations are related to the presence of large ice crystals. The strong direct relationship between ice crystal size and development of a coarse and/or icy texture is well known (Regand & Goff, 2006). In contrast, when the structure of the ice cream is well stabilized the ice crystals remain small. Since finer structures, in general, produce sensory properties such as creaminess and smoothness, coldness has less impact in these samples. In the present study, iciness was included as a different attribute from coldness since the panel was able to distinguish between them (Table 2). Sample M showed a shorter but higher dominance rate for iciness than MH, MCE, and MEH, for which the dominance rate was smaller but still significant. Sample M and MH presented the highest values of instrumental maximum force, penetration work and penetration slope values (Table 3), which could be attributed to the presence of large ice crystals, and these, in turn, would produce this first impact of in-mouth iciness. Samples MCH and MECH showed no significant dominance rate for iciness.
Coldness was the second sensation that the panellists marked. It began to be significant for all the samples at nearly 25% of the consumption time, presenting the highest values of dominance rate for sample M (which also presented the highest iciness), and its values remained significant up to the end of the consumption time. No noticeable differences among dominance rates for coldness were found for the rest of the samples.

3.3.1.2. Sensation of creaminess. Creaminess is a difficult term to describe when applied to a food. Various authors recognize that the perception of creaminess involves a number of factors. Obviously, many of them are associated with texture, but others have to do with flavour (particularly vanilla, sweetness and fat-related flavours) or pleasantness (Anttinen, Ares, Salvador, Varela, & Fiszman, 2011). In the case of ice cream, creaminess is primarily associated with a high fat content and is usually described as the perception of a somewhat soft mass that melts gently without detectable particles appearing in the mouth.

The creaminess dominance rate was significant for all samples. This attribute appeared first for sample MECH, followed by MCH, MCE, MEH, and MH (Fig. 1a–f). The three samples containing cream were the first to be perceived as creamy. The sensation first appeared as dominant in the two samples containing hydrocolloids (25% and 36% of the consumption time respectively), which were those with the highest pre-freezing consistency index values, followed by MCE (48% of the time), and lasted almost up to the end of consumption.

The widely different functional properties of crystalline and liquid fat are the key feature determining ice cream quality. Partially crystalline emulsion droplets aggregate readily during ice cream processing to form increasingly large fat networks that extend throughout the aerated emulsion. This process, known as partial coalescence, builds up the microstructure (Méndez-Velasco & Goff, 2011), which in turn increases the perceived creaminess of oil-in-water emulsions (Akhtar, Murray, & Dickinson, 2006).

Even the M and MH samples were perceived as creamy after a longer consumption time. The reason could be that once these samples had melted in the mouth they became more or less smooth liquids that the panelists described as creamy. For sample M, however, creaminess appeared just barely over the significance level for a very short period of time and coldness was dominant over creaminess during the whole food processing period, so creaminess can be considered insignificant for this sample.

3.3.1.3. Gumminess. This sensation, associated with the perception of a fairly cohesive substance that could almost be chewed, appeared with a significant dominance rate for sample MECH at 60% of the consumption time. In the other samples it made its appearance later (after around 75% of the time), with low dominance rates that were not significant (samples MCH and MCE) or were below the chance level (sample M) (Fig. 1a–f). The excessive cohesiveness of the MECH sample was attributed to over-stabilization of the formulation, which contained not only egg and cream but also the hydrocolloids. This mix was the one with the highest pre-freezing consistency index. Guar gum has been reported to be an agent that constrains wateriness and increases the perception of ice creams as gummy and greasy (Soukoulis et al., 2010).

3.3.1.4. Mouth coating. All the samples showed some significant dominance of mouth coating during the last period of consumption. The exception was M, the only sample to present dominance of the sensation of coldness even at the end of the consumption period. This could be because after swallowing (with almost no ice cream left in the mouth) the panellists centred their attention on the mouth coating attribute alone, and because all the samples with some sort of stabilizer (egg, cream, hydrocolloid) ended up as a viscous liquid that imparted a perception of mouth coating. The sample with the highest dominance rate for mouth coating was MECH, followed by MCH, MEH, MCE, MH and M. In other words, the samples containing the hydrocolloids and/or cream were the ones with the greatest dominance rates for the mouth coating attribute, in agreement with the instrumentally measured consistency index (k).

3.3.2. Consumer tests

3.3.2.1. Liking test. The consumer liking test (Table 4) showed that the MEC sample obtained the significantly highest overall liking score (p < 0.05), followed by samples MECH and MCH. The least-liked samples were MEH, MH and M, which all obtained values below 5, meaning that they were rejected by the consumers. The measurements of liking for some specific attributes (appearance, texture, flavour) help in understanding this rejection, as they all received quite low scores, particularly in texture, where samples MH and M performed very poorly. This can be linked to the dynamic profiles obtained through TDS by the semi-trained panel, where the samples the consumers liked least had very distinct dynamic properties. M and MH were perceived as less creamy in mouth, and creaminess is a determining factor for hedonic responses in this product category. Also, sample M in particular was perceived as having iciness, coldness and roughness as the dominant sensations, with coldness lasting until the end of the consumption process, in line with its low texture and overall appreciation liking scores. The products containing cream (MCH, MCE and MECH) were the best liked, also in agreement with their dynamic profiles (TDS assessment). They were the first to be perceived as creamy (linked to consumer acceptance). In samples MCH and MECH in particular, iciness (a negative perception in this category) was not dominant at any point in the consumption process. MCE and MCEH did not present major differences in liking, but there was a trend of lower liking scores for MCEH, significant for flavour liking, which could be linked to excessive gumminess, attributable to the over-stabilization of the complete formulation, and to its having less flavour.

3.3.2.2. CATA question. MFA analysis of CATA questions makes it possible to work with different groups of variables, like appearance, texture and flavour, to obtain a concise representation that considers all the information together, linking it to sample positioning. In the present case, the three first factors of the MFA explained 43.5%, 23.7% and 16.5% of the variability of the data. The purpose of this test was to gain a better understanding of which sensory descriptors defined the samples and were responsible for the hedonic response of consumers. For this reason, overall liking was plotted as a supplementary variable in the MFA. Overall liking was better explained in the perceptual space defined by factors 1 and 3 (Figs. 2 and 3). It was highly correlated to vanilla, milk and double coating attribute alone, and because all the samples with some sort of stabilizer (egg, cream, hydrocolloid) ended up as a viscous liquid that imparted a perception of mouth coating. The sample with the highest dominance rate for mouth coating was MECH, followed by MCH, MEH, MCE, MH and M. In other words, the samples containing the hydrocolloids and/or cream were the ones with the greatest dominance rates for the mouth coating attribute, in agreement with the instrumentally measured consistency index (k).

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Mean liking scores for the different ice cream formulations on a 9-point hedonic scale.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>Overall liking</td>
</tr>
<tr>
<td>M</td>
<td>3.5 d (1.9)</td>
</tr>
<tr>
<td>MH</td>
<td>3.6 d (1.8)</td>
</tr>
<tr>
<td>MCH</td>
<td>5.2 b (2.0)</td>
</tr>
<tr>
<td>MEH</td>
<td>4.3 c (2.0)</td>
</tr>
<tr>
<td>MCE</td>
<td>5.8 a (1.8)</td>
</tr>
<tr>
<td>MECH</td>
<td>5.2 ab (1.9)</td>
</tr>
</tbody>
</table>

* Means with the same letter in the same column are not significantly different (p < 0.05). Figures in brackets are standard deviations.
creamy flavours, smoothness, melting slowly and creamy texture, and negatively correlated to coarse texture, residual flavour, cold, crystallized, and rough surface. Also, when looking at the first two factors of the MFA (plot not shown), easy to spoon came up as highly correlated to liking and hard as opposed to it. Samples MEH, MCE and MCH appeared in the upper left quadrant in the space defined by factors 1 and 3, linked to the attributes which were positively related to overall liking.

In terms of a more detailed description of the samples, MECH was associated with the attributes dense, gummy, elastic, and melts slowly, reflecting an over-stabilized ice cream and in line with the dominant gumminess perceived by the semi-trained panel in the TDS evaluation. MCH and MEH were closely associated with cream flavour, milk flavour, and vanilla flavour, reflecting good flavour release for these samples, whereas when added to both cream and egg, in the MECH sample, the hydrocolloid stabilizer probably had a masking effect.

The role of hydrocolloids in flavour release presents conflicting results, as some authors have reported increased flavour perception when hydrocolloids were present (Souloulis et al., 2008) while others (Morris, 1995) have reported that their addition may lead to flavour suppression. Ice creams are very complex systems and the role of the hydrocolloids cannot be analysed easily, since many factors are in play (type of hydrocolloid, concentration, relative concentration in relation to other stabilizing components, type of ice cream preparation, aeration, fat content, etc.).

The present paper examines the perception of six ice cream formulations with very different characteristics. The intention is not to recommend the use of one or another component but to compare the relative dynamic perceptions in the mouth and their potential relation to liking.

The three samples containing cream (MCH, MCE and MECH) were the best liked. They were perceived as creamy in appearance and texture and low in attributes with negative associations like crystallized, rough surface, coarse texture, cold and residual flavour. It seems that the cream content is related to high acceptability, as both texture and flavour were important for the overall liking assessment. Not only the creamy flavour but also that of vanilla are generally associated with cream content. Creamy and fatty attributes may interact with sweet, vanilla and other flavour perceptions and a creamy texture might enhance flavour perception. De Wijk, Rasing, and Wilkinson (2003) reported such interactions in vanilla custards, where the addition of flavourings interacted with
the perception of texture, so it is possible that this might also happen in ice-cream assessment. Samples MEH and MH were intermediate in the intensity of desirable (and undesirable) textural parameters and had low intensities of the flavour-related attributes, probably because of both the absence of cream and the presence of the hydrocolloids, as discussed above. These characteristics were in line with the TDS assessment, as even if the samples presented some dominant perception of creaminess at a certain point in their oral processing, ice, coldness and roughness were dominant at the beginning of the consumption time. Sample M was particularly high in all the negative textural attributes related to sample rejection (coarse texture, residual flavour, cold, crystallized and rough surface), and when observing the perceptual space defined by factors 1 and 2 it was also perceived as quite hard.

4. Conclusions

Dynamic perception techniques made it possible to show how different attributes are perceived at different times during ice cream consumption and how they are modulated by the presence of hydrocolloids, cream and egg. Also, the combination of dynamic sensory data with consumer sensory description gave a better understanding of which attributes drive consumer liking in relation to ice cream consumption.

Iceyness and coldness were the most perceivable attributes at the start of consumption for all the ice cream formulations, but more so for the less stabilized samples (M and MH). This first impact, especially negative in the case of iciness, can be reduced by using hydrocolloids. Mouth coating appeared later in the consumption time, probably because it is associated more with a post-consumption attribute.

Creaminess presented the highest dominance rate in the MCE ice cream sample. However, the first samples to elicit the sensation of creaminess were MCH and MECH (which contained both hydrocolloids and cream) and it lasted as long as in other samples. This could be considered an advantage, making it possible to formulate ice creams with an early perception of creaminess. These three samples were the most liked, as demonstrated by the consumer test, showing the strong relation between creaminess and the perception of high quality.

Knowledge of the dynamic perception of ice cream attributes can help to improve the use of hydrocolloids in ice cream stabilization. Some attributes that are negatively related to ice cream quality, like iciness, appear very early during consumption, and an appropriate use of hydrocolloids may retard or even eliminate this sensation. In the same way, using hydrocolloids to reinforce creaminess may prolong its perception, which is highly associated with a good quality ice cream.

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