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Hydrocolloids for enhancing satiety: Relating oral digestion to rheology, structure and sensory perception

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ABSTRACT

Satiety expectations can be closely related to the structural changes that take place in the mouth. An important role of hydrocolloids is to impart viscosity, which has a key effect on the feelings of richness, mouthcoating and fullness. In this study, native and modified corn starch, λ-carrageenan and guar gum were used to formulate milkshakes. Expected satiety was rated (106 consumers) and the perception of various attributes was studied. The rheological properties of the milkshakes without and with added saliva were analysed and observed with a light microscope during *in vitro* oral digestion.

Disintegration of the swollen starch granules by saliva was observed mainly in the modified starch sample. The structure of the milkshakes prepared with λ-carrageenan and guar gum was preserved better. It could be hypothesized that the starch would provide lower expected satiety due to the extensive in-mouth disintegration. However, the sensory analysis showed that the modified starch milkshakes obtained the highest expected satiety scores, with consumers finding them homogeneous, thick in the mouth and very creamy. These results suggested that consumers related satiety more with the thick and creamy characteristics at the very start of the consumption than with the loss of structure in mouth. Sensory properties affect the assessment of the satiating capacity, especially texture, which is directly related to the orosensory exposure and, therefore, to the feeling of fullness that the milkshakes elicit. The present study casts light on the factors affecting in-mouth perception of different hydrocolloids used to design foods with enhanced satiety.

1. Introduction

Nowadays, opportunities to consume energy-dense, unhealthy snacks are encouraged by the obesogenic environment that has developed in the western world, particularly among adolescents (Fiszman & Varela, 2013). One of the main trends in weight management is to develop foods and beverages that provide satiety or hunger satisfaction (Tecklenburg, 2009). A wide range of ingredients is available for the creation of satiety-related products. Hydrocolloids have been studied for over 30 years as a means to provide satiety and blunt glucose absorption (Kay & Stitt, 1978; Wilmshurst & Crawley, 1980; Wong, 1974).

Hydrocolloids provide viscosity and play a role in developing foods with high satiating capacity. An enormous number of studies have assessed the satiating capacity of a long list of soluble gums that are viscous in solution. The effect on the feeling of satiety of most of this type of compounds which impart viscosity to their solutions is caused by mechanisms which are related with slowing down enzyme action efficacy and/or with gastric antrum distension (as they absorb large quantities of liquid) and/or delaying gastric emptying, which, in turn, may increase or prolong the satiety signals from the stomach (Fiszman & Varela, 2013). Based on availability to impart viscosity, almost any gum could act as a potential satiety-enhancing agent. From a compositional point of view there are basically two types of gums, with some variation within each type: neutral hydrocolloids, including guar, locust bean gum and konjac, which simply hydrate to a fully extended form, creating viscosity through polymer entanglement, and charged hydrocolloids such as alginate, pectin, carrageenan and gellan gum, which also develop maximum viscosity with full hydration in water but may also develop additional viscosity through association with mono- and divalent ions and, in some cases, hydrogen ions

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(Aimutis et al., 2007; Boers, Strom, & Wiseman, 2008; Wolf, Blidner, Garleb, Laie, & Schenz, 2007). If these hydrocolloids are dispersed in a milk beverage, some calcium ions released from the milk micelles can help them to form gels during acidification in the stomach. The meals formulated with this type of hydrocolloid form lumps in the stomach, producing large volumes. Although gastric emptying is similar, the sense of fullness for the same gastric volume is significantly greater than for meals without any hydrocolloid (Fiszman & Varela, 2013; Hoad et al., 2004).

Perceived satiety is limited in the case of foods that can be consumed quickly and with little effort, such as liquid or semiliquid foods (Hogenkamp & Schiöth, 2013). It has been suggested that greater an increased length or intensity of orosensory exposure (i.e. food present in the oral cavity) would contribute to the development of satiety and further control of the energy intake (McCrickerd et al., 2012). Oral exposure is affected by the characteristics of a food (Hutchings et al., 2009; de Wijk, Zijlstra, Mars, de Graaf, & Prinz, 2008) and viscosity is one important attribute to take into account (Viskaal-van Dongen, Kok, & de Graaf, 2011). Related properties such as the perception of mouthcoating or creaminess that some hydrocolloids impart during consumption could be interesting and worth researching. Other factors that determine orosensory exposure include bite size, oral processing time and chewing frequency (Bolhuis, Lakemond, de Wijk, Luning, & de Graaf, 2011; Zijlstra, de Wijk, Mars, Stafleu, & de Graaf, 2009). Hogenkamp, Brunstrom, Stafleu, Mars, and de Graaf (2012) observed that an increase in the perceived thickness of several dairy products resulted in a consistent increase in the expected satiating capacity of the foods.

Consequently, expectations about the satiety effects of a specific food are based, among others, on its texture attributes (Hogenkamp, Mars, Stafleu, & de Graaf, 2012; Sørensen, Møller, Flint, Martens, & Raben, 2003). In this sense hydrocolloids, including starches, offer a complete field of possibilities for arousing these sensations. Attributes such as sliminess or creaminess are important in selecting one hydrocolloid rather than another for thickening a liquid or semisolid food to provide good satiating capacity. However, almost no attention has been paid to relating the distinctive oral sensations communicated by hydrocolloids with their potential to elicit expectations of satiety.

Based on the foregoing, the authors of the present study hypothesized that the oral digestion (as in the case of starches) and oral processing of different hydrocolloids could play a critical role in the sensations related to perceptions of expected satiety (Morell, Hernando, & Fiszman, 2014).

The aim of the present work was to analyse the effect of adding different hydrocolloids imparting similar initial viscosities during pouring or handling to milkshakes on the expected satiety they elicited in consumers. Rheological and microstructural studies before and after an *in vitro* oral digestion were performed and analysed in relation with oral perceptions. Additionally, sensory and non-sensory attributes of the milkshakes were evaluated with a "check-all-that-apply" consumer study.

2. Materials and methods

2.1. Milkshake ingredients

The ingredients used in the preparation of the milkshakes were powdered skimmed milk (kindly supplied by Central Lechera Asturiana, Asturias, Spain), native corn starch (C Gel 03401), hydroxypropyl distarch phosphate (C PolarTex 06748) and guar gum (Viscogum MP41230) (all three from Cargill, Inc., Minneapolis, Minn., U.S.A.), λ-carrageenan (Secolacta BR, from Hispanagar S.A. Burgos, Spain), aspartame and acesulfame K (both from EPSA Aditivos Alimentarios, Valencia, Spain), cochineal carmine (Roha Europe S.L.U., Valencia, Spain), strawberry flavour (Firmenich S.A., Barcelona, Spain) and distilled water.

2.2. Artificial saliva

Artificial saliva was prepared according to the method described by Mishellany-Dutour et al. (2011), with some modifications. All the reagents were of analytical grade. The components were sodium bicarbonate (5.208 g/L), potassium phosphate dibasic trihydrate (1.369 g/L), sodium chloride (0.877 g/L), potassium chloride (0.477 g/L), calcium chloride dehydrate (0.441 g/L), mucin from porcine stomach type II (PGM) (Sigma, M2378) (2.16 g/L), α-amylase type VI-B from porcine pancreas (Sigma, A3176) (8.70 g/L (200.000 units)) and HPLC grade doubly-distilled water. To perform the *in vitro* oral digestion, the ratio of saliva to sample was 1:4 (Sanz & Luyten, 2006).

2.3. Sample preparation

Four milkshakes consisting of 100 mL water, 10 g powdered skimmed milk, 0.0175 g aspartame, 0.0075 g acesulfame K, 0.001 g cochineal carmine and 0.1 mL strawberry flavour were each formulated with a different hydrocolloid.

The quantity of hydrocolloid was selected through a preliminary study to obtain similar viscosities. The criterion used in this step was to have similar values of apparent viscosity at a low shear rates typical of sensory viscosity assessed during tilting the container upon pouring the milkshake in a glass (Elijalde & Kokini, 1992). The apparent viscosity of the milkshakes was measured using a viscometer (Haake Viscotester 6 R Plus, Thermo Scientific, Walthman, Mass., U.S.A.), equipped with spindle 2, at 6 rpm at a temperature of 10 °C. Measurements were performed in triplicate. The final amounts selected for each hydrocolloid were 4.56 g of native corn starch (sample NS), 4.56 g of modified waxy corn starch (sample MS), 0.665 g of guar gum (sample *GG*) and 0.215 g of λ-carrageenan (sample λ-C). Since the only difference between the samples was the variation in the hydrocolloid concentration, the samples may be considered almost equicaloric.

Powdered skimmed milk, distilled water and the corresponding hydrocolloid were placed in a cooking device (Thermomix TM 31, Wuppertal, Germany). The milkshakes were heated to 70 °C for 5 min at 1250 rpm (Hoad et al., 2004). The sweeteners, colouring and strawberry flavour were added after cooling at ambient temperature. The samples were placed in glass beakers (250 mL), covered with plastic film, and stored at 4–5 °C for 24 h before performing the tests.

2.4. Rheological measurements

Measurements were made in a controlled stress rheometer RS1 (Thermo Haake, Karlsruhe, Germany), using a parallel plates geometry of a 6-cm diameter and 1-mm gap, and monitored by a RheoWin software package (version 2.93, Haake). During the measurements with a Phoenix P1 Circulator device (Thermo Haake), the temperature was kept at 10 ± 1 °C, selected as representative of the usual consumption temperature of milkshakes. Measurements were made of each formulation with and without the saliva treatment (*in vitro* oral digestion). All the samples were allowed to rest for 5 min before each measurement in the rheometer cell. For the *in vitro* oral digestion, a saliva:sample ratio of 1:4 was used (Sanz & Luyten, 2006). All the measurements were made in triplicate.

2.4.1. Flow behaviour

Sample flow was measured by recording the shear stress values when shearing the samples with a linearly increasing shear rate