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Aerated whey protein gels as new food matrices: Effect of thermal treatment over microstructure and textural properties

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ABSTRACT

Aerated gels (AG) contain both bubbles and entrapped water in their structure, thus offering ample versatility in product development. The objective of this study was to evaluate the effect of thermal treatment of whey protein isolate (WPI) dispersions over the microstructure and textural properties of AG fabricated with these dispersions. WPI dispersions (9% w/w) with NaCl (0.4% w/w) at three pH's (6.50, 6.75 and 7.00) were prepared. Dispersions were subjected to thermal treatment at three temperatures (70, 75 and 80 °C) at different times depending on the pH. After thermal treatment, dispersions were aerated by mechanical agitation at 2000 rpm for 3 min. Finally, aerated dispersions were cooled at 10 °C for 24 h to set the AG structure. AG were characterized in terms of their gas hold-up capacity, microstructure (bubble sizes) and textural properties. Thermal treatment temperature influenced the gas hold-up and mean diameter (D_M) of air bubbles in the AG, both decreasing with an increase in temperature. Maximum gas hold-up was about 70% and D_M were in the range of 530–700 µm. The increase in apparent viscosity of thermally treated dispersions produced lower air incorporation in AG structure and smaller bubble sizes. Compression stress at break decreased with an increase in the thermal treatment temperature. Control of thermal treatment conditions for WPI dispersions allows to fabricate AG with different microstructural and textural properties which can be used as innovative food matrices for obesity control or delivery of bioactives.

1. Introduction

The foods in a modern shopping basket increasingly feature a novel, but often overlooked ingredient: bubbles. Aerated foods gain importance as manufacturers seek to exploit the novelty and versatility of bubbles as food ingredients. However, bubbles in food have been present for centuries in products such as beer, bread and ice cream. Bubbles are desirable elements in gastronomy creations. Mousses and soufflés, recognized as emblematic forms in culinary art, are classic examples in which the incorporation and retention of bubbles is a critical factor in the success of the dish. Besides, modern innovative cooks exploit bubbles in their creations (Zúñiga and Aguilera, 2008).

Air bubbles are structural elements in solids, semi-solids and liquid foods. The mere incorporation of air in a food product change their physical and sensory properties, which depend on the structure formed during processing, in this regard a scientific understanding of structure formation in aerated food is needed with the aim of designing products with tailored physical and sensory properties (Zúñiga and Aguilera, 2008). The final objective of structuring foods is to obtain structure–property relationships, in other words, the underlying connection between the structure and how the product behaves (Aguilera and Lillford, 2007).

The positive benefits of aerated foods primarily relate to texture. Fluid products such as whipped cream and mousses obtain smoothness and novelty, while solid products such as breakfast cereals and snacks become light and crispy. An aerated structure may facilitate mastication, enzyme accessibility to substrates and enhance flavor delivery (Zúñiga and Aguilera, 2008). Introducing a gas phase into a food matrix not only affects its texture and firmness making the product softer, but also changes the appearance, color and mouth-feel (Campbell and Mougeot, 1999). Thus, the presence of bubbles in gel-based food products may result in unique properties conferred by the additional gaseous phase and the increased internal surface area (Nussinovitch et al., 1992).

In recent years, new aerated foods appearing in the market are perceived as lighter in terms of calories, thus satisfying urgent consumer needs. An important benefit of air inclusion, or other gases, in foods is the reduction in the “caloric density”, understanding

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caloric density as the amount of calories per unit of volume. Dispersed air in foods reduces the energy consumed per unit of volume making portions less caloric-dense, in line with the suggestions of food psychologists who advocate for constant volume but fewer calories in rations (Osterholt et al., 2007; Rolls et al., 2000). These studies showed that volume, independent of weight, can have an effect on food and energy intake. In fact, Osterholt et al. (2007) demonstrated that, within limits, people eat by volume. In this study, subjects consumed a greater volume but less weight and energy of the more-aerated snack compared to the less-aerated snack; however, no differences were found in terms of fullness after consumption. Rolls et al. (2000) showed that increasing the volume of a food by incorporating air can affect satiety, thus decreasing the energy intake at the subsequent meal. In agreement with these results, higher ratings of fullness (satiety) were found after consumption of a high-volume food compared with the same food at lower volume (Bell et al., 2003). Thus, aerated foods may provide a sense of fullness higher or comparable to the non-aerated food, but giving fewer calories. In addition, it was demonstrated that the inclusion of air bubbles may be an alternative for the reduction of sodium chloride or sucrose in food products (Goh et al., 2010). In this work, the reduction of total sugar or salt (by volume) was proportional to the incorporation of bubbles, thus the concentration of sugar or salt in the continuous gel phase was the same for non-aerated or aerated gel, not affecting the perception of sweetness or saltiness. In this way, air incorporation would decrease caloric density in solid foods making people feel as satisfied as they eat a normal food. A strategy in food design may then be to maintain the taste perception of demanded energy-dense foods while imperceptibly adding air as small bubbles and/or immobilizing water in the food matrix, thus lowering their caloric content per portion.

There is increased evidence that the quantity, composition and microstructure of the food ingested affect health (Norton et al., 2007; Zúñiga and Troncoso, 2012). Besides, the physical form of the food may profoundly alter the sensation of fullness and satiety. In solid foods, the microstructure has a major influence on the sensation of satiety by slowing down the rate of breakdown in the gastrointestinal tract. It is believed that a slower breakdown in the stomach can lead to a more lasting sensation of satiety (Marciani et al., 2001; Norton et al., 2006). Enhancing satiation may restrict the daily food intake and the desire of overeating, therefore, contributing to control of body weight. In this sense, tailoring the continuous phase of AG (by changing polymer concentration) could increase the initial sense of fullness, but the effect of an aerated structure on the rate of breakdown in the gastrointestinal tract needs to be determined. Designed AG with tailored texture and low caloric density may help in developing new dietetic foods for the treatment of obesity.

Most foods are structurally complex and their structure determines its physical, sensory and nutritional properties. Entrapping abundant amounts air in gel matrices may be one alternative to design products that promote satiety with reduced caloric density (Zúñiga and Aguilera, 2008, 2009; Zúñiga et al., 2011). In this sense, protein gelation could be a mechanism to "entrap" bubbles in a solid matrix that contain high amounts of water. Tomczyńska-Mleko (2013a) developed a novel method to induce simultaneous gelation and aeration of pre-heated WPI dispersions, gelation was induced by ions at room temperature (similar to cold-gelation) and the structure was able to retain air bubbles. The same author used "reversibility" of the gelation process to production of AG. Weak non-covalent interactions can be broken up and reformed after removing the shearing force used at the aeration (Tomczyńska-Mleko, 2013b). Recently, the same group employed whey protein AG as floating matrices for the controlled release of minerals in simulated gastric conditions (Tomczyńska-Mleko and Mleko, 2014a). From the above discussion, the objective of this work was to study the effect of thermal treatment and pH of WPI dispersions on the structural and textural characteristics of AG made from WPI.

2. Materials and methods

2.1. Raw materials

Whey protein isolate (WPI) (BiPro, Davisco Foods International, USA) was used as gelling material. WPI is mainly composed of three proteins: β-lactoglobulin, α-lactoalbumin and bovine serum albumin, but their functional properties are result of their β-lactoglobulin content. Proximate analysis of WPI was provided by manufacturer: 4.6 ± 0.3 of moisture content (% wb), 97.6 ± 0.3 of protein content (% db), <0.5 of fat content (% wb), 2.0 ± 0.2 of ash content (% wb), and 0.4 ± 0.2 of lactose content (% wb). The pH of the native WPI dispersion was about 6.8.

2.2. Methods

2.2.1. Formation of WPI dispersions

Dispersions of WPI (9% w/w) and NaCl (0.4% w/w) in distilled water were prepared by slow stirring (200 rpm) at 25 °C for 2 h, avoiding foam formation. The pH of the dispersions (6.50, 6.75 and 7.00) was carefully adjusted with 1 N HCl or NaOH solutions (Sigma–Aldrich Corp., St. Louis, Mo, U.S.A.). In previous papers (Zúñiga et al., 2010, 2011), it was demonstrated that thermally-induced β-lactoglobulin aggregates produced at this narrow pH range had very different physicochemical properties, which could influence the foaming properties of the protein. The WPI dispersions were left at 5 °C for at least 12 h to allow complete hydration of the protein.

2.2.2. Thermal treatment of WPI dispersions

Samples (7 mL) were heated in test tubes (inner diameter: 10 mm; length: 120 mm) in order to induce denaturation of the WPI dispersions. The tubes were immersed in a water bath (Memmert, model Basic WNB, Germany) at a constant temperature of 70, 75 or 80 °C (the time to reach constant temperature inside the tubes was about 45 s). The time of thermal treatments (Table 1) was chosen based on previous experiments following the methodology of Kerstens et al. (2006). Briefly, the tubes were taken out for observation at regular intervals, and the gel point was defined empirically as the time at which a tube could be turned upside-down without observable downwards flow of its contents, indicating the formation of a self-supporting gel. Times before dispersions became a gel were chosen for each experimental condition. After the heat treatment, samples were cooled in ice

Table 1
Combination of pH and thermal treatment conditions for the denaturation of WPI dispersions.

Experimental run	pH of dispersion	Thermal treatment temperature (°C)	Thermal treatment time (min)
1	6.50	70	31
2	6.75	70	24
3	7.00	70	18
4	6.50	75	10
5	6.75	75	9
6	7.00	75	8
7	6.50	80	3.5
8	6.75	80	3.5
9	7.00	80	3.5