Interfacial rheology and stability of food foams containing inulin

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ABSTRACT

In the present work, inulin, a prebiotic polysaccharide naturally found in species such as chicory, was added to a foam stabilized by β-lactoglobulin, at different content levels (from 0 to 10 %). The rheology of the interface seems to control the macroscopic properties of the aerated system at inulin concentrations lower than 2.5 %, but they are dominated by the thickening of the continuous phase at higher concentrations. Thus, the presence of inulin plays an important role in promoting the stabilization of the air/water interface, explained on basis of the reported thermodynamic incompatibility between β-lactoglobulin and inulin together with the polysaccharide thickening effect. Food products containing prebiotic are attractive within the food industry due to their proven health-promoting properties.

INTRODUCTION

Food foams are demanded by consumers due to their lightness and texture [1]. People are increasingly concerned about their physique and health, leading to an increased interest in low calorie foods. These precedents have prompted the use of foams for gas bubbles to strategically replace fat in the formulation [2]. Moreover, the use of polysaccharides as fat substitutes is known in the food industry due to their thickening properties [3]. Therefore, the use of polysaccharides in foam products is an attractive option to achieve lighter and healthier foods.

Inulin is a natural polysaccharide that is used as a food ingredient due to its various biological benefits (eg. anticancer, immunomodulatory) and functional and prebiotic properties [4]. Previously, the influence it exerts over the rheological and microstructural properties of emulsions and gels has been proven [5,6]. Inulin is also known to improve the stability of food foams, such as aerated desserts or ice creams (Franck 2002), although extensive interfacial research on their potential in aerated food systems has not yet been conducted.

Since inulin does not present surface activity [7], the use of an ingredient with surfactant properties is required in the foam formulation. The role of inulin in the continuous phase would be the enhancement of the protein adsorption at the interface if the behavior found in emulsions [6] is replicated in foams. As it is known that the nature of the air/water or oil/water interface influences the adsorption behavior of the protein [8], it is necessary to perform the present study to confirm the formulated hypothesis. In this sense, this contribution focuses on the interfacial and rheological characterization of foams stabilized by a typical dairy protein (β-lactoglobulin 0.25% by weight) and different inulin/β-lactoglobulin ratios (0-10% by weight). As the physical stability of food foams is of particular importance during transport and storage, it has also been studied using conductometric and optical tests.

MATERIALS AND METHODS

Materials

β-lactoglobulin was used as lyophilized powder (≥ 90%) from Sigma-Aldrich (USA), and inulin from chicory with polymerization a degree of 36 was used (I2255, Sigma-Aldrich, USA).

Sample preparation

Protein solutions were obtained through dispersion of β-lactoglobulin in water (0.5 % wt.), which was later mixed with an inulin solution at 1:1 ratio. Inulin was previously solubilized in water at different contents to eventually obtain a final protein/polysaccharide ratio in the foam continuous phase of 0, 1, 2, 4, 10, 20, 30 and 40. The pH of the continuous phases was always 7.

Characterization

Steady-state flow tests were performed in a controlled-stress rheometer (AR 2000, TA Instruments, USA) using a parallel plate geometry (diameter: 60 mm; gap; 1 mm) from 0.1 to 100 s^{-1}.

Dynamic interface pressure measurements were carried out in an automatic pendant drop tensiometer (TRACKER, IT Concept, France) [9,10]. A periodic sinusoidal interfacial compression and expansion was performed by variations in the drop volume of 10% of deformation amplitude ($\Delta A/A$) at 0.1 Hz. 5 oscillation cycles were followed by 50 cycles without any oscillation up till a steady state was reached. Interface pressure (π, $mN \cdot m^{-1}$) was monitored as the difference between the surface tension of the aqueous solution in the absence of protein (σ_o) and in the presence of protein (σ). Interfacial tests were performed at 20 ºC, in duplicate, with a reproducibility higher than 5%.

The foaming properties of the aqueous solutions with different β-lactoglobulin/inulin ratios were characterized at 20 °C through their foam stability tested in a Foamscan (IT Concept, Longessaigne, France) [11].

Foam stability was determined through the foam volume by conductimetric and optical measurements. The foam was generated by placing 20 ml of the solution at the bottom of a glass tube and then blowing nitrogen through a porous glass filter with a pore diameter of 0.2 µm. Nitrogen was blown at a flow rate of 45 cm^3/min until the foam reached a volume equal to 120 ml, being determined the foam volume with a CCD camera. Subsequently, water was drained from the foam through conductimetry by 3 pairs of electrodes located along the glass tube. Moreover, a pair of electrodes were located at the bottom of the column to measure the liquid volume not included in the foam. The foam stability was determined the half-life time ($t_{1/2}$), refered to the time required to drain half of V_{liq} (f) [12].

RESULTS

The effect of the presence of inulin on foams stabilized by a constant amount (0.25 %) of β-lactoglobulin (β-lg) was assessed employing different inulin/β-lg ratios (0, 1, 2, 4, 10, 20, 30, 40).

<u>Flow tests of aqueous phase</u>

When performing rotational flow tests on aqueous solutions containing different inulin/β-lg ratios, a Newtonian behaviour was detected at ratios lower than 4, tending onto a Non-Newtonian flow response, with a slight shear-thinning behaviour (flow index lower than the unity) at higher inulin/β-lg ratios (10-40). Figure 1 shows the evolution of η_{10}, viscosity obtained at a shear rate of 10 s^{-1}, with the protein/polysaccharide ratio. The thickening role played by inulin in the solution was clear, as an overall tendency onto higher η_{10} values was obtained as the polysaccharide concentration was increased. This is in agreement with the fact that polysaccharides are common thickening and gelling ingredients in several food products [13].

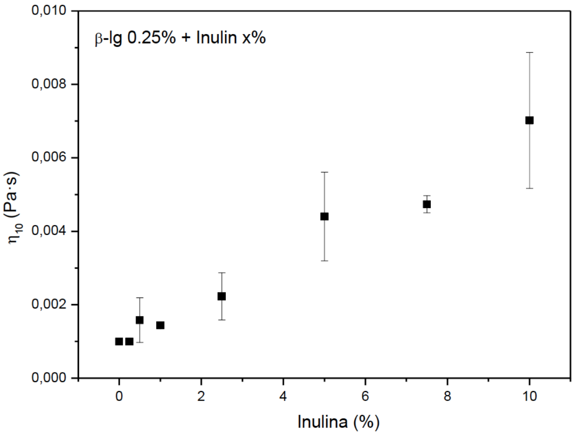

Figure 1. Viscosity at 10 s^{-1} and 25 ºC of the aqueous phases of foams studied

Surface pressure at the air/water interface

Figure 2 shows the evolution of the surface pressure, π, with time, t, as protein was adsorbed in the air/water interface, as inulin is known for not possessing any superficial activity. The effect of the inulin content on the β-lactoglobulin adsorption can be clearly observed for different inulin contents (Inulin/β-lg: 0, 10, 30, 40).

Inulin exerted a positive effect on the adsorption of the protein, although it was dependent on the polysaccharide content. So, protein adsorption was unaffected by the presence of inulin at ratios lower than 10 (data not shown), obtaining a surface pressure profile identical to that of the solution not containing inulin (Inulin/β-lg: 0); however, at higher inulin concentrations (Inulin/β-lg: 10, 30) an important increase of π values was observed, which would be associated to a greater protein surface activity. It is worth mentioning that π values decreased when further increasing inulin content, eventually reaching a point at Inulin/β-lg equal to 40 when π values were close to that obtained for β-lactoglobulin alone.

The surface dilatational modulus, E, as a function of adsorption time, t, for different inulin contents (Inulin/β-lg: 0, 1, 2, 4 10, 20, 30, 40) is shown in Figure 3.

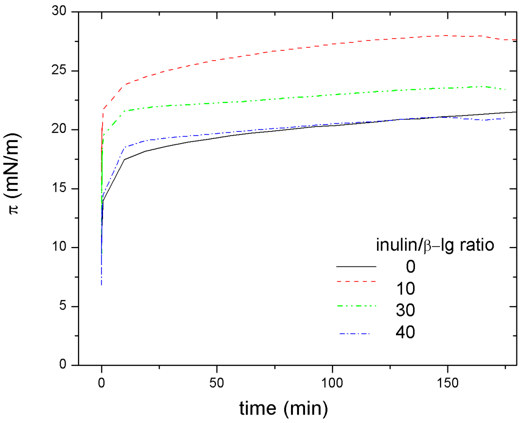

Figure 2. Evolution of the surface pressure with time for different inulin/β-lactoglobulin ratios (0, 10, 30, 40) at A/W interface.

Generally, the increase of inulin content lead to a gradual reduction in E values, highlighting a poorer elastic character probably due to a weakening of the protein network. In addition to this, the surface would be covered by a smaller amount of protein molecules, especially at higher inulin contents, because of the thickening of the aqueous phase that inhibits the protein mobility onto the air/water interface. This could explain the remarkable drop in E observed at the higher inulin contents. Moreover, as inulin content increased, E did not reach a steady value at long times during the tests performed, which may be related to the commented weaker character of the surface at higher inulin contents.

These interfacial results match those previously obtained for oil in water emulsion systems stabilized by the same polysaccharide/protein system [6].

Consequently, a limited thermodynamic compatibility between inulin and β-lg might be deduced, resulting in an accelerated protein diffusion when Inulin/β-lg ratio was 10, which could be explained by a mutual exclusion between the domains formed by β-lg and inulin. That exclusion would stimulate the protein adsorption due to osmotic forces, which would explained the higher surface pressure [6,14]. At greater inulin contents, the commented thickening effect of inulin (Fig. 1) would be more important than the protein-polysaccharide incompatibility, resulting in a decrease in the diffusion rate.

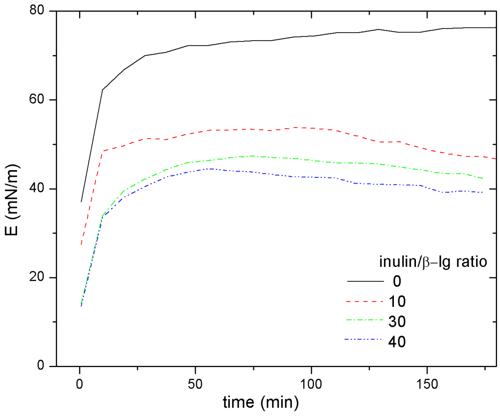

Figure 3 Dilatational elastic modulus evolution for different inulin/β-lactoglobulin ratios (0, 10, 30, 40) at A/W interface.

Foam stability

Table 1 displays the average lifetime ($t_{1/2}$) for foams stabilized by a constant amount (0.25 %) of β-lactoglobulin (β-lg) at different inulin/β-lg ratios (0, 1, 2, 4, 10, 20, 30, 40). This parameter permits the study of the foam stability, as $t_{1/2}$ represents the time needed to drain half of the volume of the aqueous phase incorporated in the foam.

When observing these values, it may be concluded that this time is similar to that estimated for the reference system containing only β-lactoglobulin at inulin/ β-lg ratios of 1 or 2. However, a decrease in $t_{1/2}$ was estimated at higher ratios, increasing again from a protein/polysaccharide ratio of 20. The observed evolution should be correlated to the important role exerted by the interfacial properties at inulin/ β-lg ratios below 20, while the properties of the thickened solution seems to rule the behaviour at higher inulin contents.

Table 1. Average lifetime ($t_{1/2}$) for inulin/β-lactoglobulin foams at different ratios

inulin/β-lg ratio	$t_{1/2}$ (s)
0	166 ± 6
1	158 ± 6
2	158 ± 12
4	93 ± 4
10	79 ± 16
20	150 ± 10
30	218 ± 14
40	230 ± 29

CONCLUSIONS

Despite not possessing an important surface activity, inulin is able to modify the interfacial properties of β–lactoglobulin. Therefore, an inulin-β–lactoglobulin ratio of 10 % was needed to increase significantly the surface pressure at the air/water interface. Nevertheless, higher inulin contents also resulted in an important increase in the viscosity of the aqueous phase, which contributed to lowering the adsorption kinetics. Thus, higher polysaccharide concentrations made interfacial properties lose their influence in favour of the properties of the bulk phase (i.e. higher viscosity). Consequently, inulin-β–lactoglobulin ratios higher than 20 resulted in more stable foams due to this thickening effect.

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