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Fibrillization of whey proteins improves foaming capacity and foam stability at low protein concentrations

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ABSTRACT

The foaming properties of fibrillar whey proteins were compared with those of native or denatured whey proteins and also with egg white protein. Whey protein foaming capacity and stability were related to protein concentration, pH, time of whipping, pressure and heating treatments. Foams produced from fibrils showed significant improvement in foaming capacity and stability when compared with non-fibrillar whey proteins. Dynamic high shear (microfluidization) or moderate shear (Ultra-Turrax mixing) of fibrillar protein dispersions did not significantly affect their subsequent foaming properties. Furthermore, foams prepared with fibrillar whey protein (⩽3% protein) had comparable capacity and stability to that from egg white protein, which is the traditional foaming ingredient in food industry. Results suggest that fibrillized whey proteins are highly effective foaming agents even at relatively low protein concentrations (1–3% w/w).

1. Introduction

Whey protein isolate (WPI) and egg white protein (EWP) are often used as foaming agents in the food industry in the manufacture of meringues, cake, whipped toppings and leavened bakery products (Campbell and Mougeot, 1999; Damodaran, 1996, 1997; Davis and Foegeding, 2007; Kuropatwa et al., 2009; Linden and Lorient, 1999; Nicorescu et al., 2009a,b; Vaclavik and Christian, 2008; van der Plancken et al., 2007).

Previous studies have shown that WPI or EWP can improve and maintain the quality (texture, volume) of "foamed" food, in particular foaming capacity and stability (Davis and Foegeding, 2004; Doi and Kitabake, 1997; Kuropatwa et al., 2009; Vaclavik and Christian, 2008). The foaming properties of WPI are influenced by protein concentration, pH, high pressure, thermal treatment, foam procedure, by their nature and behavior at interfaces (denaturation, protein–protein interactions) and by their interactions with other food ingredients (Bouaouina et al., 2006; Croguennec et al., 2007; Damodaran, 1996, 2005; Ibanoglu and Karatas, 2001; Linden and Lorient, 1999; Pittia et al., 1996; Schmitt et al., 2007; Vaclavik and Christian, 2008; Zhu and Damodaran, 1994).

The stability of foams is affected by numerous factors such as the protein adsorption from solution at the liquid/gas interface, the surface rheological properties, diffusion of the gas out and into foam cells, size distributions of the cells, liquid surface tension, external pressure and temperature (Morrison and Ross, 2002). Foams are destabilized by drainage that causes thinning of the interstitial liquid film and by its rupture (Stainsby, 1986; Hamley, 2000). The drainage of the liquid will depend on the physical properties of the liquid, particularly viscosity. As the liquid drains from the foam, the bubbles will coalesce. The coalescence can be stabilized by the presence of the proteins at the liquid/air interface that can modify the surface tension of the liquid (Stainsby, 1986; Wilde, 2000; Wilde et al., 2004).

Protein denaturation (and the nature of the newly developed protein structure) influence the WPI foaming properties as it can affect the surface area, the mechanical resistance, viscosity, elasticity and the ability to retain water of the interfacial film (Leman and Dolgan, 2004; Nicorescu et al., 2009a). A mixture of unheated and heat-induced aggregates of WPI can enhance foam stability (Damodaran, 2005; Zhu and Damodaran, 1994). Heating of 5% (w/w) WPI at 70 °C for 1 min improved foam capacity when compared with unheated whey protein (Zhu and Damodaran, 1994), but excessive heating times led to the formation of aggregates that can alter the properties of the foam (Bals and Kulozik, 2003; Cayot and Lorient, 1997; Damodaran, 1996, 2005; Davis and Foegeding, 2004; Green et al., 1999; Nicorescu et al., 2009a,b; Zhu and Damodaran, 1994). The foaming properties of WPI were improved by the presence of an optimal aggregate quantity (10% w/w) at the interface (Nicorescu et al., 2009a). However, increasing the percentage of aggregates to >50% (w/w) led to large

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high molecular weight clusters that promoted foam collapse (Nicorescu et al., 2009a). Bals and Kulozik (2003) showed that heat denaturation of WPI in the range 60–90 °C leads to aggregate formation that can reduce foam capacity and rigidity although other studies demonstrated that foam stability can be improved (Zhu and Damodaran, 1994). WPI at pH 5 heated for 10 min at 80 °C improved foam stability by 65% but this was slightly decreased when heated at pH 4 and 7 (Cayot and Lorient, 1997). Salt (NaCl) addition to the protein solution led to an increase of aggregate formation during thermal treatment. As these aggregates exhibited reduced mobility and lower surface hydrophobicity, the foam-liquid stability was increased (Nicorescu et al., 2009a; Schmitt et al., 2007). Nicorescu et al. (2009a) showed that heat-induced aggregates at 2% (w/v) WPI and 50 mM NaCl, pH 7 at 70–100 °C have a reduced mobility and affinity for the air–liquid interface due to their higher surface energy. Optimal foam stability was obtained when the protein was denatured at 80 °C; above this temperature the foam stability decreased (Bals and Kulozik, 2003; Nicorescu et al., 2009a). Zhu and Damodaran (1994) showed that native WPI contributed to foam formation due to rapid adsorption at the interface, while WPI aggregates contributed to foam stability.

Dynamic or static high pressure treatments affect native β-lg structures and may increase the rate of protein aggregate formation (Iordache and Jelen, 2003; Meersman and Dobson, 2006; Pittia et al., 1996; Sanchez and Paquin, 1997). The high dynamic pressure (Bouaouina et al., 2006) or hydrostatic (Ibanoglu and Karatas, 2001) treatment enhanced the foaming ability and stability of WPI. Thus, Bouaouina et al. (2006) showed that high pressure treatment using a homogenizer increased the whey protein surface hydrophobicity leading to improved foaming properties. The increase in hydrophobicity was attributed to the increased exposure of hydrophobic sites resulting from the disruption of protein aggregates (Bouaouina et al., 2006). Cayot and Lorient (1997) found that the foaming capacity of whey proteins varies with the preparation method, the most common procedures to insert a gaseous phase in protein aqueous solution being either whipping or bubbling (Cayot and Lorient, 1997; Richert, 1979). In the whipping method, the atmospheric gas was incorporated in the liquid phase by cutting the liquid surface of the initial coarse foam. As the whipping continues, the foam becomes dispersed, smaller bubbles being formed. In the bubbling techniques the gas was inserted into the liquid phase through small orifices, forming bubbles that rose in the liquid and increased their volume (Richert, 1979).

As previously described (Akkermans et al., 2008a; Kavanagh et al., 2000; Oboroceanu et al., 2010), whey proteins, particularly β-lg, can form extended fibrils when heated at 80 °C at pH 2 and low ionic strength. The potential of fibrils as functional ingredients has not been fully investigated. Although some studies indicate that the fibrillar whey proteins can form low salt gels (Akkermans et al., 2008b; Gosal et al., 2004), investigating the foaming properties of whey protein fibrils is still in its infancy. Microfluidization or shear treatments can affect the structure of the WPI fibrils and, therefore, their foaming properties. In the present study, the influences of pH, protein concentration, whipping time and high dynamic pressure on fibrillar WPI foams are described.

The aims of this study are:

(1) To compare the foaming capacity (as expressed by overrun) and stability of whipped dispersions of fibrillar with non-fibrillar whey protein using dispersions of native or heated WPI (non-fibrillar and fibrillar) at three concentrations (1, 2 or 3% (w/w)), and two pH values (2 and 7) and whipping times of 5, 10 and 15 min.
(2) To study the effect of high dynamic pressure (microfluidization) or moderate shear mixing on the subsequent foaming properties of whey protein fibrillar dispersions.

The resulting foams were evaluated for foam overrun, drainage and bubble size. The WPI dispersions were investigated by AFM before and after heat and/or shear treatment to monitor changes in the protein structure and to confirm the presence of fibrils before and after shearing. The foaming properties of the WPI dispersions were also compared with those of egg white, the benchmark food ingredient for producing good quality foams.

2. Materials and methods

2.1. Materials

Whey protein isolate BiPro™ (~98% (w/w) protein on dry basis: 65% β-lactoglobulin, 25% α-lactalbumin, 8% bovine serum albumin) was obtained from Davisco Foods International Inc., (Le Sueur, MN, USA). Fresh chicken eggs were purchased from a local grocery store. Approximately 225 mL egg white (protein content ~12% w/w) was manually separated from the yolk.

2.2. WPI fibrillar dispersions

Fibrillized WPI dispersions at concentrations of 1, 2 and 3% (w/w) were prepared by heating dispersions of WPI at pH 2.0 at 80 °C for 20 h, as previously described in Oboroceanu et al. (2010). The pH was adjusted using 6 M HCl. The same heating regime was also applied to native WPI solutions at pH 7 to provide a non-fibrillar whey protein control. The three concentrations of WPI were chosen to secure high conversion rates of the monomers into fibrils and to avoid gelation (that normally occurs for concentrations $\geqslant$5% (w/w)).

2.3. High dynamic shear (microfluidization) processing

Native or fibrillar WPI dispersions (2% (w/w) protein) were used to study the effect of high dynamic shear processing (microfluidization) on the properties of the foam. The pH of WPI fibrillar dispersions was adjusted from 2 to 7 using 6 M NaOH to prevent corrosion of the microfluidization equipment. The WPI dispersions were microfluidized (M110-EH-30 Microfluidizer® Processor, Microfluidics, Newton, USA) at pressures of 50, 75, 100, 150 and 170 MPa as previously described in Oboroceanu et al. (2011).

2.4. Moderate shear mixing

Native and heated WPI (2% (w/w) protein, pH 2 or 7) and WPI fibrillar dispersions (2% (w/w) adjusted to pH 7) were used to study the effect of shear mixing on WPI foam properties. WPI dispersions (500 mL) were sheared using a rotor–stator type disperser, Ultra Turrax (IKA®T18 basic, Ultra-Turrax®, IPAT Ltd., IKA Werke GmbH, Germany) fitted with a S18N-19G stainless steel dispersing tool and set to rotational speeds of 11,200 or 24,000 rpm.

2.5. Whipping treatment

Whey protein and egg white samples were whipped using a heavy duty blender (Heavy Duty, Kitchen Aid Inc., St. Joseph, Michigan, USA) at room temperature. Dispersions of WPI (approximately 225 mL) were placed in a steel bowl and mixed at room temperature using a wire whip beater at a constant speed setting of 10 for 5, 10 or 15 min, respectively.

2.6. Foaming capacity

Foam capacity of a protein refers to the amount of interfacial area created by the protein and is expressed by the overrun