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Comparisons of the foaming and interfacial properties of whey protein isolate and egg white proteins

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Abstract

Whipped foams (10%, w/v protein, pH 7.0) were prepared from commercially available samples of whey protein isolate (WPI) and egg white protein (EWP), and subsequently compared based on yield stress (τ_0), overrun and drainage stability. Adsorption rates and interfacial rheological measurements at a model air/water interface were quantified via pendant drop tensiometry to better understand foaming differences among the ingredients. The highest τ_0 and resistance to drainage were observed for standard EWP, followed by EWP with added 0.1% (w/w) sodium lauryl sulfate, and then WPI. Addition of 25% (w/w) sucrose increased τ_0 and drainage resistance of the EWP-based ingredients, whereas it decreased τ_0 of WPI foams and minimally affected their drainage rates. These differing sugar effects were reflected in the interfacial rheological measurements, as sucrose addition increased the dilatational elasticity for both EWP-based ingredients, while decreasing this parameter for WPI. Previously observed relationships between τ_0 and interfacial rheology did not hold across the protein types; however, these measurements did effectively differentiate foaming behaviors within EWP-based ingredients and within WPI. Interfacial data was also collected for purified β-lactoglobulin (β-lg) and ovalbumin, the primary proteins of WPI and EWP, respectively. The addition of 25% (w/w) sucrose increased the dilatational elasticity for adsorbed layers of β-lg, while minimally affecting the interfacial rheology of adsorbed ovalbumin, in contrast to the response of WPI and EWP ingredients. These experiments underscore the importance of utilizing the same materials for interfacial measurements as used for foaming experiments, if one is to properly infer interfacial information/mechanisms and relate this information to bulk foaming measurements. The effects of protein concentration and measurement time on interfacial rheology were also considered as they relate to bulk foam properties. This data should be of practical assistance to those designing aerated food products, as it has not been previously reported that sucrose addition improves the foaming characteristics of EWP-based ingredients while negatively affecting the foaming behavior of WPI, as these types of protein isolates are common to the food industry.

Keywords: Interfacial rheology; Foam; Yield stress; Whey protein; Dilatational modulus

1. Introduction

Foam is a dispersion of gas bubbles within a liquid or solid continuous phase. This material class is important to the structure and texture of many food products, including various cakes, confections, meringues, etc. [1]. Two common and important ingredients often found in these products are proteins and sugars. With regards to the foam properties, proteins function as surfactants by adsorbing at the freshly created air/water interface during bubble formation [2]. This adsorption lowers the interfacial tension, which promotes bubble formation. Immediately after and during the initial adsorption, protein–protein attractions at the interface can result in network formation, which promotes bubble stability [3]. Besides their obvious contribution to product flavor, sugars also contribute to the functional properties of foam. For example, sugars are known to improve the stability of foams to gravity induced drainage, primarily by their capacity to increase solution viscosity [4,5]. Furthermore, studies at model interfaces also suggest that sugars affect the interfacial behavior of proteins by exerting an influence on their structure [6–9].

There are various means of assessing the foaming performance of proteins, including their capacity to form (foamability), stabilize and impart specific foam rheological properties.

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Controlling and predicting foam rheology is especially important when considering the final structural stability and texture of foamed food products. The most important physical factor governing foam rheology is air phase fraction (ϕ) of the foam. Foams transition from viscous fluids to semi-solid-like structures as ϕ increases from zero above the random close pack volume, $\phi_{rcp} \approx 0.64$ [10]. Above ϕ_{rcp}, the formerly spherical bubbles begin contacting one another, forming so called "polyhedral" or "dry" foams. There is an ever developing quantitative framework to describe the unique rheological behaviors of polyhedral foams and concentrated emulsions, as the two systems share many similarities [3,10].

Polyhedral foams display a yield stress (τ_0), which is a solid-like behavior that can be effectively measured via vane rheometry [11]. Previous work established that it takes less protein and less whipping time for standard egg white protein (std-EWP) to produce foams with significantly higher τ_0 as compared to whey protein isolate (WPI) [12]. It has been generally concluded that differences in ϕ or equilibrium surface tension (γ) for the two protein types do not adequately explain differences in τ_0 for the two protein ingredients [12,13], despite the fact that γ and ϕ are prominent within theoretical equations applied to the rheology of such colloidal systems (polyhedral foams and concentrated emulsions) [10,14,15]. Others have experimentally verified that the shear elastic modulus (G') relates to ϕ for both concentrated emulsions [10,16] and whipped foams prepared from EWP solubilized in high contents of invert sugar [17]. As discussed by Dimitrova and Leal-Calderon, most models pertaining to polyhedral foam or concentrated emulsion rheology implicitly assume constant interfacial tension during perturbation [18]. While this may be a valid assumption for the rapid interfacial relaxations of small molecular weight surfactants (SMWS) under interfacial perturbations, this is likely not to be the case for adsorbed proteins layers. Accordingly, there is a limited amount of theoretical work suggesting the interfacial rheological properties of a surfactant significantly influence bulk foam or emulsion rheology [19,20]. Experimental evidence for such phenomena is also beginning to emerge. For example, data for protein-stabilized, concentrated emulsions revealed a positive correlation between the dimensionless bulk elasticity, $G'/(\gamma/r)$ of the emulsions and the interfacial dilatational elasticity (E') of the stabilizing proteins, where r is equal to the radius of the dispersed phase [18]. In our own lab, recent work with whey proteins suggest a link between the dilatational rheological properties of the air/water interface and foam τ_0. Specifically, proteins and/or peptides which induce high values of E' and/or a low viscous modulus at a model air/water interface seem to promote high values of τ_0 when used to produce foams [21–23]. However, comparison of these interfacial and foaming measurements have not been extended to whipped foams prepared from other proteins, specifically EWP, which is the traditional foaming agent of choice in the food industry.

There is a relative abundance of data pertaining to the interfacial behaviors of β-lactoglobulin (β-lg) and ovalbumin, the two primary proteins in WPI and EWP, respectively, with several recent examples being cited here [24–28]. While these analyses have improved our understanding of how isolated proteins behave at model phase boundaries, isolated proteins are rarely, if ever, used to make foams in the food industry. Furthermore, there seems to be a lack of studies that directly measure both interfacial and foaming properties of the same material, especially foaming studies that utilize a protein concentration relevant to the food industry, i.e. $\geq$5% (w/v) protein, and utilizes whipping as a means of bubble production, again the most industrially relevant method of foam formation. Accordingly, we choose to whip foams from 10% (w/v) protein solutions utilizing commercially available samples of WPI and EWP followed by interfacial measurements with the same solutions (or their dilutions).

The overall goal of the current work was to determine the interfacial dilatational rheological basis, if any, behind the different foaming properties of EWP and WPI. In conjunction with this goal, the effects of high sucrose concentrations on the foaming and interfacial behavior of EWP and WPI were assessed, as sucrose is a common co-solute in protein-based aerated food products. Work with model interfacial systems generally suggests the adsorption rates of globular proteins are suppressed at interfacial boundaries in the presence of sugars [7,8,29], although there is also evidence that sucrose addition may increase globular protein adsorption [6]. Interfacial rheological data of proteins in the presence of sugars is much more limited. The interfacial dilatational viscoelasticity of bovine serum albumin (BSA) was found to decrease when co-solubilized with 1 M sucrose [30]. Clearly, more data is needed to better understand sugar/protein interactions both at the interface and in foaming systems, due to the practical interest of those preparing aerated food products containing protein and sweeteners.

2. Materials

A commercial sample of WPI (BiPro, 94% protein, dry basis) was supplied by Davisco Foods International, Inc. (Le Sueur, MN). Two types of spray dried egg white protein (82% protein, dry basis) were obtained from Primera Foods (Cameron, WI): (1) standard egg white protein and (2) high whip egg white protein (hw-EWP). These products are essentially identical except the hw-EWP had not more than 0.1% sodium lauryl sulfate added as a whipping agent by the manufacturer. High purity β-lactoglobulin (approximately 90%; product # L3908), ovalbumin (Grade V, minimum 98%; product # A5503) and sucrose (SigmaUltra, $\geq$99.5%; product # S7903) were purchased from Sigma Chemicals Co. (St. Louis, MO). All other chemicals were of reagent grade quality. Deionized water was obtained using a Dracor Water Systems (Durham, NC) purification system. The resistivity was a minimum of 18.2 MΩ cm.

3. Methods

3.1. Hydration

Samples were initially hydrated to 10% (w/v) protein. Prior to the final volume adjustment, the pH of all solutions was adjusted to 7.0. Solution pH is well established to affect both foaming and interfacial properties of proteins [23,28,31,32]. The current