Effect of Xanthan Gum on Enhancing the Foaming Properties of Soy Protein Isolate

Y.R. Xie and N.S. Hettiarachchy*

Department of Food Science, University of Arkansas, Fayetteville, Arkansas 72704

ABSTRACT: The foaming properties of soy protein isolate (SPI) in the presence of xanthan gum (XG) were investigated. The XG solution alone did not exhibit any foaming ability. The optimal foaming properties were obtained from the SPI–XG dispersion that contained 0.1% SPI and 0.2% XG. This SPI–XG dispersion gave higher foaming capacity than that of SPI or egg white ($P < 0.05$). The foam stability of SPI-XG dispersion was nine times higher than that of SPI and egg white ($P < 0.05$). The SPI–XG foams were stable over wide ranges of ionic strength (0.1 to 1.0 M NaCl) and pH (4.5 to 9.0), and when heated (85°C, 1 h).
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KEY WORDS: Foaming capacity, foaming stability, soy protein isolate, xanthan gum.

The growing demand for food proteins with good nutritional value and superior functional properties provides an opportunity for increasing the utilization of soy proteins in food applications. Although soy proteins have excellent nutritional value, lack of desirable functional properties, such as foaming and emulsification, has limited their use in food products (1). Foaming is an important protein functional property in food products, such as whipped toppings, ice cream, cakes, and desserts. In addition to the intrinsic properties of proteins, other extrinsic factors, such as pH, temperature, ionic strength, and interactions with other food components, also affect foaming properties (2,3).

Protein–anionic polysaccharides are better surface-active agents for foam stabilization than proteins alone because more stable foams with a higher protein content are obtained (4). Foam stability can be enhanced by the addition of appropriate polysaccharides to provide viscosity to the aqueous dispersions (5). A vast number of polysaccharide applications in the food industry are concerned with the stabilization of suspensions, foams, and emulsions (5). Xanthan gum (XG) is an anionic polysaccharide with a cellulosic backbone, made water soluble by the presence of a trisaccharide side chain attached to every second glucose residue in the main chain (6). The structure and conformation of XG molecules provide unique functionality compared to other commercial polysaccharides. XG forms cohesive flexible films, thus contributing to emulsion and foam stability, and it has been used as stabilizer, thickener, and foam enhancer (7). Although soy protein isolate (SPI) has good foaming capacity (FC), foam instability has limited its practical applications (8).

The objective of this study was to evaluate the synergistic effects of SPI and XG on foaming properties and the effects of pH, salt, and heat treatment on the SPI–XG FC and foaming stability (FS).

MATERIALS AND METHODS

Materials. Soybeans (var. Hutcheson) were obtained from the Department of Agronomy, University of Arkansas. XG was provided by the Kelco Co. (San Diego, CA). Egg white was purchased from Sigma Chemical Co. (St. Louis, MO). Reagents were of analytical grade and purchased from Fisher Scientific (Pittsburgh, PA) and Sigma.

Preparation of SPI. Soybeans were cracked in a blender (Osterizer Galaxie Dual Range 14; Oster Corp., Milwaukee, WI) at a high speed for about 2 min. The cracked soybeans were dehulled in a vertical aspiration unit (Seedburo Equipment Co., Chicago, IL) and milled (UDY Cyclone Sample Mill; UDY Corp., Fort Collins, CO). The flour obtained was defatted by hexane extraction (1:3, flour/hexane) with the use of a T-line laboratory stirrer (Talboys Engineering Corp., Emerson, NJ) for 10 min. The product was centrifuged for 10 min (10,000 × *g* at 25°C). This procedure was repeated twice to remove residual lipids. The defatted flour was dried overnight under the hood and passed through a 60-mesh sieve in an Alpine airjet sieve (Alpine American Corp., Natick, MA). Defatted soybean flour (10%) in deionized water (wt/vol) was adjusted to pH 9.0 and stirred for 30 min to solubilize proteins. The suspension was centrifuged at 10,000 × *g* for 10 min, the supernatant was separated, and the pH was adjusted to 4.5 (the isoelectric point of soy protein) with 1.0 N HCl to precipitate proteins. The proteins were separated by centrifugation at 10,000 × *g* for 10 min and washed twice with deionized water. The proteins were dispersed in deionized water, and the pH was adjusted to 7.0. It was then freeze-dried and stored at 5°C until used (9).

Preparation of SPI–XG dispersions. The SPI–XG blends were prepared by dry-mixing separate 1-g portions of SPI with 0.1, 0.2, 0.3, 1, 2, 3, or 5 g of XG to get SPI/XG ratios of 10:1, 5:1, 3:1, 1:1, 1:2, 1:3, and 1:5, respectively. Seven SPI–XG dispersions were prepared by transferring the blends into 0.1 M sodium phosphate buffer (pH 7.4) while stirring

*To whom correspondence should be addressed.

with a magnetic stirrer (Mistral Pyro Multi-Stirrer; Lab-Line Instruments, Inc., Melrose Park, IL) for 60 min at ambient temperature to give each dispersion 0.1% SPI. These suspensions were used to determine viscosity and foaming properties. Based on the preliminary foaming results, the SPI–XG with a weight ratio of 1:2, which produced the optimal foaming properties, was chosen to evaluate the effects of pH, heat, and salt treatment.

Determination of viscosity. The viscosity of prepared SPI–XG dispersions (SPI/XG = 10:1, 5:1, 3:1, 1:1, 1:2, 1:3, and 1:5) in 0.1 M sodium phosphate buffer (pH 7.4) was measured with a Brookfield viscometer (Stoughton, MA). All measurements were carried out at ambient temperature.

Determination of foaming properties. FC of SPI–XG dispersions at varying weight ratios (SPI/XG = 10:1, 5:1, 3:1, 1:1, 1:2, 1:3, 1:5) and of XG, SPI, and egg white was determined by measuring the foam volume immediately after introduction of air (90 cm^3/min) for 30 s into 5 mL of 0.1% protein solutions in 0.1 M phosphate buffer (pH 7.4) in a glass tube (2.4 × 17.2 cm). FS was calculated from Equation 1:

$$FS = V_0 \times \Delta t/\Delta V \quad [1]$$

where ΔV is the change in foam volume, V, that occurs during the interval Δt (30 min), and V_0 is the foam volume at 0 time (10).

Salt treatment. Three portions of SPI–XG blend (SPI/XG = 1/2, 0.061 g) were solubilized in 20 mL of NaCl solutions that contained 0.1 M, 0.5 M, and 1.0 M NaCl (pH 7.4) to get SPI–XG dispersions (0.1% SPI and 0.2% XG). These dispersions were used to determine foaming properties.

pH treatment. The SPI–XG blend (SPI/XG = 1/2, 0.272 g) was dissolved in 90 mL of distilled water and divided equally into three portions to get SPI–XG dispersions (0.1% SPI and 0.2% XG). The pH of these SPI–XG dispersions was adjusted to 4.5, 7.0, or 9.0, respectively, with 0.1 M NaOH and HCl. These solutions were used to determine foaming properties.

Heat treatment. The SPI–XG blend (SPI/XG = 1/2, 0.121 g) was dissolved in 40 mL of 0.1 M sodium phosphate buffer (pH 7.4) to get the SPI–XG dispersion (0.1% SPI and 0.2% XG). The dispersion was divided equally into two portions and then heated at 85°C for 30 and 60 min, respectively, cooled to ambient temperature, and evaluated for foaming properties.

Statistical analysis. Data were analyzed by analysis of variance by using the General Linear Model procedure of SAS (11). Least significant difference values were computed at the 5% level. Experiments were performed three times in a completely randomized design.

RESULTS AND DISCUSSION

Effect of XG on foaming properties of SPI. FC and FS of SPI–XG dispersions in varying dry weight ratios (SPI/XG = 10:1, 5:1, 3:1, 1:1, 1:2, 1:3, 1:5), SPI, and egg white preparations are shown in Figures 1 and 2, respectively. XG solution alone did not exhibit any foaming ability. Egg white is the most frequently used standard for foaming comparisons among proteins because of its superior foaming properties (8). FC and FS of SPI-based foams were significantly improved by increased addition of XG ($P < 0.05$). The optimal FC and FS of SPI–XG were obtained in the weight ratio of 1:2. No further improvements in FC and FS were observed by further increasing the SPI/XG weight ratio beyond 1:2. FC of SPI–XG was significantly higher than that of SPI or egg white ($P < 0.05$). FS of SPI–XG was nine times better than that of SPI and egg white ($P < 0.05$). The relationship of FS to the viscosity of SPI–XG in different SPI/XG weight ratios is shown in Table 1. FS of SPI–XG dispersions was significantly affected by the viscosity of the continuous phase ($P < 0.05$). There was a sharp increase in FS of SPI–XG when the SPI/XG weight ratio was changed

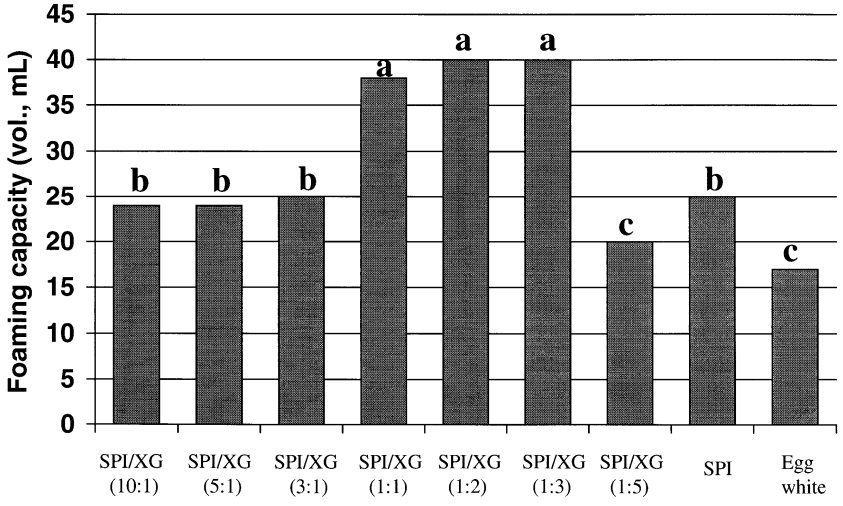

FIG. 1. Foaming capacity of soy protein isolate (SPI)-xanthan gum (XG) dispersions at various ratios, and of SPI and egg white. Means with different letters are significantly different ($P < 0.05$).

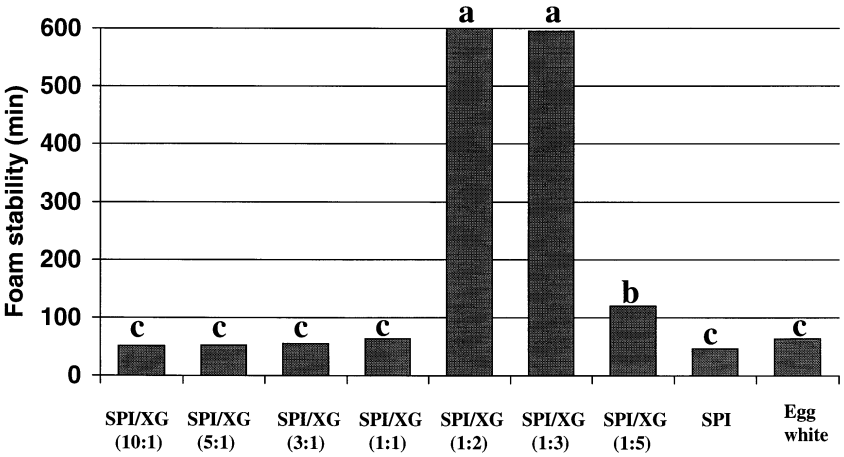

FIG. 2. Foam stability of soy protein isolate (SPI)–xanthan gum (XG) dispersions at various ratios, and of SPI and egg white. Means with different letters are significantly different ($P < 0.05$).

from 1:1 to 1:2, which corresponded to a viscosity increase from 50 to 250 cP. The viscosity of SPI–XG dispersions was highly correlated with FS ($r = 0.98$, $P < 0.001$).

Many studies indicate that high protein solubility is a prerequisite for good FC and FS (2,8). The correlation between protein solubility and FC indicated that increased protein solubility of SPI, due to addition of XG, contributed to enhanced FC of SPI-based foams. It has been shown that the molecular properties of proteins required for good FC and good FS are somewhat different (8). Previous studies have shown that proteins with good FC (e.g., β-casein) often lack the molecular properties responsible for FS, and proteins that produce stable foams (e.g., lysozyme) often lack the ability to create good FC (12). This is because the formation of protein-based foams involves the diffusion of soluble proteins toward the air–water interface and rapid conformational change and rearrangement at the interface, whereas FS requires formation of a thick, cohesive, and viscoelastic film around each gas bubble (3). Due to the high surface energy created by large air–water interfacial surface and substantial density differences between phases, foaming dispersions are thermodynamically unstable (13). Addition of appropriate polysaccharides to the aqueous dispersions can stabilize foams not only by high solution viscosity but also by the existence of a solution yield value, defined as the shear stress or applied force below which the solution will not flow (5). If the suspended particles do not exert a force beyond the yield value, they will not separate and remain effectively dispersed (5). The foaming properties of egg albumin can be improved by the addition of XG (14). XG forms cohesive flexible films, thus contributing to good foaming properties (7). The data in this study suggest that the molecular properties for good FC and FS were provided by the formation of SPI–XG dispersions.

Effects of NaCl on foaming properties of SPI–XG. The SPI–XG foams were stable over a wide range of salt (NaCl) concentrations (0.1 to 1 M NaCl, pH 7.4) (Table 2). These results demonstrate that the strong and cohesive adsorbed films formed by SPI and XG interactions were not affected by NaCl concentration. Salts can affect the solubility, viscosity, unfolding, and aggregation of proteins, all of which can influence foaming properties (8). Sodium chloride often increases FC and reduces FS. These outcomes are probably mediated

TABLE 1
Effect of pH (4.5 to 9.0), Salt (NaCl, 0.1 to 1.0 N), and Heat (85°C, 1 h) Treatment on the Foaming Capacity (FC) and Foam Stability (FS) of Soy Protein Isolate (SPI)–Xanthan Gum (XG) Dispersion (0.1% SPI and 0.2% XG)

	FC (mL)	FS (min)
Salt, NaCl (M)[a]		
0.1	40.0	600
0.5	41.0	595
1.0	41.0	590
pH[b]		
4.5	40.7	595
7.0	41.0	600
9.0	40.3	590
Heat, 85°C[c]		
1 h	40.7	585

[a]Foams were prepared at room temperature, pH 7.4.
[b]Foams were prepared at room temperature in 0.1 M phosphate buffer, pH 7.4.
[c]Foams were prepared in 0.1 M phosphate buffer, pH 7.4.

TABLE 2
Relationship Between Foam Stability (FS) and Viscosity of Soy Protein Isolate (SPI)–Xanthan Gum (XG) Dispersion Containing 0.1% SPI and 0.025–0.5% XG[a]

	Viscosity (cP)	FS (min)
SPI/XG (10:1)	12.5	46.1
SPI/XG (5:1)	14.5	46.8
SPI/XG (3:1)	18	48.9
SPI/XG (1:1)	50	63.3
SPI/XG (1:2)	250	600
SPI/XG (1:3)	280	595
SPI/XG (1:5)	475	120

[a]Foams were prepared in 0.1 M phosphate buffer (pH 7.4) at room temperature.

through a decrease in the viscosity of protein solution (8). The salt compatibility of XG may be due to its rigid helical conformation, hydrogen-bonded mixtures, and anionic charge on the side chains (6), which may result in the stable protein solubility of SPI–XG dispersions over a wide range of ionic strengths (0.1 to 1.0 M NaCl), thus contributing to the stable foaming properties of SPI–XG dispersion over this wide range of ionic strengths.

Effects of pH on foaming properties of SPI–XG. There were no significant differences in FC and FS of SPI–XG at pH of 4.5, 7.0, or 9.0 ($P > 0.05$) (Table 2). Foaming properties of proteins can be affected significantly by pH changes due to the change of protein net charge (13). Proteins typically foam best at pH levels where the molecules are flexible and less compact. Foams produced under conditions where the protein is more compact, rigid, and difficult to denature have lower FC (15). The stability of XG to acids and alkali, due to its backbone being protected by large overlapping side chains (6), may result in stable protein solubility, which in turn contributes to the stable foaming properties of SPI–XG dispersions over the wide range of pH.

Effects of heat treatment on foaming properties of SPI–XG. The SPI–XG foams were stable to heat at 85°C for 1 h (Table 2). Foaming properties of protein are often improved by moderate heat denaturation (8). This is mainly caused by an increase in surface hydrophobicity and flexibility of denatured proteins (3). Moderate heat treatments (70 to 80°C) prior to foam formation were found to improve the foaming properties of soy protein (8). Protein–polysaccharide interactions were found to inhibit precipitation of some water-soluble proteins after heat denaturation (15). Thus, even after heating, a soluble system was still maintained. This property is essential for both protein and polysaccharide to maintain their normal functionalities after heat treatment. The temperature insensitivity of XG due to its rigid helical conformation and hydrogen bonding may contribute to the stability of SPI–XG solubility after heat treatment at 85°C for 1 h, which in turn helps to stabilize the foaming properties of SPI–XG dispersion after the heat treatment.

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