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

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ABSTRACT: The foaming properties of whey protein isolate (WPI) in the presence of xanthan gum (XG) were investigated. XG dispersion did not exhibit any foaming properties. The optimal foaming overrun (FO), or the amount of air incorporated into the dispersion, was obtained from the dispersion of 5% WPI and 0.05% XG at 949%. This WPI–XG dispersion had a significantly higher overrun than that of WPI (868%) or egg white (879%) ($P < 0.05$). Optimal foam stability (FS) of 216 min was obtained at 5% WPI and 0.2% XG; however, the overrun was reduced slightly (844%). XG increased stability to 15 times that of WPI alone. The overrun of 5% WPI plus 0.05% XG was further increased to 1343% when 1 M NaCl was added ($P < 0.05$). However, FS (51 min) was significantly reduced. A significant increase in the FO of 5% WPI plus 0.05% XG (1081%) was observed when pH was adjusted to 5.0 with no significant change in FS (56 min) ($P < 0.05$). The FO (1457%) was significantly increased ($P < 0.05$) when the WPI–XG was heat treated (55°C for 5 min). WPI–XG dispersions at acidic pH and temperatures below 85°C have a variety of potential applications in products such as protein beverages, angel food cake, and unique infant formulas.

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KEY WORDS: Foam overrun, foam stability, whey protein isolate, xanthan gum.

The utilization of whey protein in food products has been limited primarily by the protein's functional properties (1). A decade ago, annual cheese whey production was predicted to exceed 23×10^9 kg in the near future. Approximately 60% of this total at that time was being used in yogurt, ice creams, soft drinks, bread, infant foods, and animal feeds (2). However, the remaining 40% created, and still creates, a disposal problem. The limited utilization of whey results in a loss of potential food energy as well as a major economic burden.

Whey is a potential source of functional protein that can be used as an emulsifier, a freeze–thaw stabilizer, a whitening agent, or flavor enhancer (2). The use of whey protein as an emulsifier for foams is limited because of poor stability. Efficient foam overrun (FO) requires a foaming agent with flexible molecules and few secondary or tertiary structures, whereas intermolecular cohesiveness and elasticity are required for efficient foam stability (FS) (3). In addition to these intrinsic properties, extrinsic factors such as pH, temperature, and ionic strength affect overrun and stability.

Anionic polysaccharides improve the FS of protein dispersions (4). Xie and Hettiarachchy (4) used xanthan gum (XG) to improve the FS of soy protein isolate. XG has been used as a stabilizer, thickener, and foam enhancer (5). XG is widely used as a food gum because its addition causes no discernible change in viscosity within a temperature range of 0 to 100°C. This functionality property makes xanthan unique among gums (6,7).

Phillips *et al.* (8) investigated the effects of heat and pH on the foaming of whey protein isolate (WPI). They found the maximum overrun of 1241% at pH 5.0 with a stability of 40 min. Heat had an effect dependent on pH. At neutral pH, mild heat treatment (55°C) enhanced overrun. More severe heat (80°C) enhanced overrun at a pH less than 5.0.

The objectives of this study were to investigate the synergistic effects of WPI and XG on foaming properites (i.e., overrun and FS), and the effects of pH, salt, and heat treatment on WPI–XG.

MATERIALS AND METHODS

Materials. WPI was obtained from Land O'Lakes (Minneapolis, MN). XG was provided by the Kelco Co. (San Diego, CA). Egg white was purchased from Sigma Chemical Co. (St. Louis, MO). Reagents were analytical grade and purchased from Fisher Scientific (Pittsburgh, PA) and Sigma Chemical Co.

Preparation of WPI–XG dispersions. The WPI–XG dispersions were prepared by mixing WPI and XG in 100 mL 0.05 M sodium phosphate buffer. The dispersions were stirred with a magnetic stirrer (Mistral Pyro Multi-Stirrer, Lab-Line Instruments, Inc., Melrose Park, IL) for 60 min at ambient temperature. They were then used to determine viscosity and foaming properties. Based on preliminary foaming results, 5.0% WPI with 0.05% XG produced optimal foaming properties and was therefore chosen to evaluate the effect of pH and salt treatments.

Determination of viscosity. The viscosity of the prepared WPI–XG dispersions in 0.05 M sodium phosphate buffer (pH 7.4) was measured by a Brookfield viscometer (Stoughton, MA). All the measurements were carried out at ambient temperature.

Determination of foaming properties. FO of WPI–XG dispersions at varying amounts of whey, gum, and egg white was

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determined by measuring the volume of foam immediately after the introduction of air by whipping with a Sunbeam Mixer at speed 9 (whipping) for 2.5 min, 5 min, 10 min, 15 min, and 20 min. FS was measured by allowing 40 g of prepared foam to drip until half the mass had liquified. This time was reported as the FS.

Salt treatment. The WPI–XG dispersion (5% WPI and 0.05% XG) was prepared in 0.05 M sodium phosphate buffer (pH 7.4) and NaCl was added at concentrations of 0.1, 0.5, 1.0, and 2.0 M. These dispersions were used to determine foaming properties.

pH treatment. The WPI–XG dispersion (5% WPI and 0.05% XG) was prepared in 0.05 M sodium phosphate buffer. The pH was adjusted to 5.0, 7.4, and 9.0, with 0.1 M NaOH/HCl. The pH WPI–XG dispersion at pH 9.0 was chosen as an alkali solution possibly found in an enriched beverage. The dispersion at 7.4 was chosen as a neutral solution found in most foods and beverages. pH 5.0 was chosen because it is the isoelectric pH (pI) of WPI. The dispersions were used to determine foaming properties.

Heat treatment. The WPI–XG dispersion (5% WPI and 0.05% XG) was prepared and held at 55 and 85°C for 5 and 10 min and allowed to cool to room temperature. The cooled dispersions were used to determine foaming properties.

Statistical analysis. Data were analyzed by analysis of variance using the SAS General Linear Model procedure (9). Least significant difference (LSD) values were computed at 5%. Experiments were performed three times in a completely randomized design.

RESULTS AND DISCUSSION

Solubility of WPI and XG. The solubility of WPI alone was very high. The addition of XG reduced solubility at or near the pI (5.0) of WPI. This is probably because of increased protein–protein interaction (Fig. 1). At the pI, proteins have as many positive as negative charges and thus facilitate electrostatic interactions. This agglutination phenomenon is well exploited in the alkaline precipitation of many proteins.

Effects of time on FO of WPI and WPI–XG. FO of WPI (1.0, 2.5, and 5.0%) was determined at 2.5, 5, 10, 15, and 20 min. The FO of WPI was compared to the FO of egg white at the same concentrations (Fig. 2). Egg white overrun reached a maximum at 5–10 min and then decreased, whereas WPI FO reached its maximum at 10–15 min. The overrun of WPI was almost equal to egg white at 10 min. However, with continued whipping, the WPI maintained the overrun, whereas egg white FO decreased quickly with time (Fig. 2). The decrease in egg FO was explained by Phillips *et al.* (1) as a result of aggregation caused by electrostatic interactions of the negatively charged lysozyme proteins. WPI does not have the basic protein lysozyme and thus does not exhibit the electrostatic interactions. The increasing FO of WPI can also be explained by the further denaturation of proteins present in whey, namely β-lactoglobins (1).

Xanthan gum solution alone did not exhibit any foaming ability. The addition of XG to WPI reduced the FO by a significant amount at concentrations of 0.1% or higher ($P < 0.05$). However, at 0.05%, XG increased FS significantly. The FO of WPI–XG dispersions at varying concentrations of WPI and XG are shown in Figure 3. Optimal FO was obtained with the dispersion of 5.0% WPI and 0.05% XG. However, other tests showed that the optimal FS was obtained with 5.0% WPI and 0.2% XG. This increase in FS can be explained by a significant ($P < 0.05$) increase in the viscosity of the WPI solution when additional XG was added.

Studies have indicated that high protein solubility is a prerequisite for good overrun and FS (10). WPI has excellent solubility properties. The lack of good FO and FS with WPI is due to the lack of a uniform composition (2). The concentrations of ash, calcium, and lactose contribute greatly to the poor foaming properties of WPI. Also, the proteins present in whey are very susceptible to heat (2). When WPI is produced, great care must be taken to ensure little or no heat denaturation occurs.

The flexibility of a protein improves FO, whereas FS is increased with interactions between protein molecules, which can decrease flexibility. The addition of an appropriate polysaccharide can increase viscosity and give the high overrun of a pro-

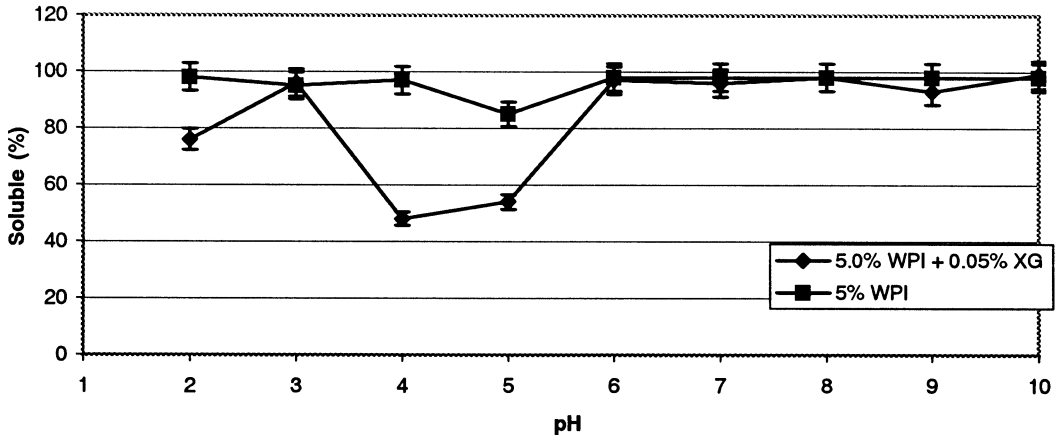

FIG. 1. Solubility of whey protein isolate (WPI), with and without the addition of xanthan gum (XG), as a function of pH.

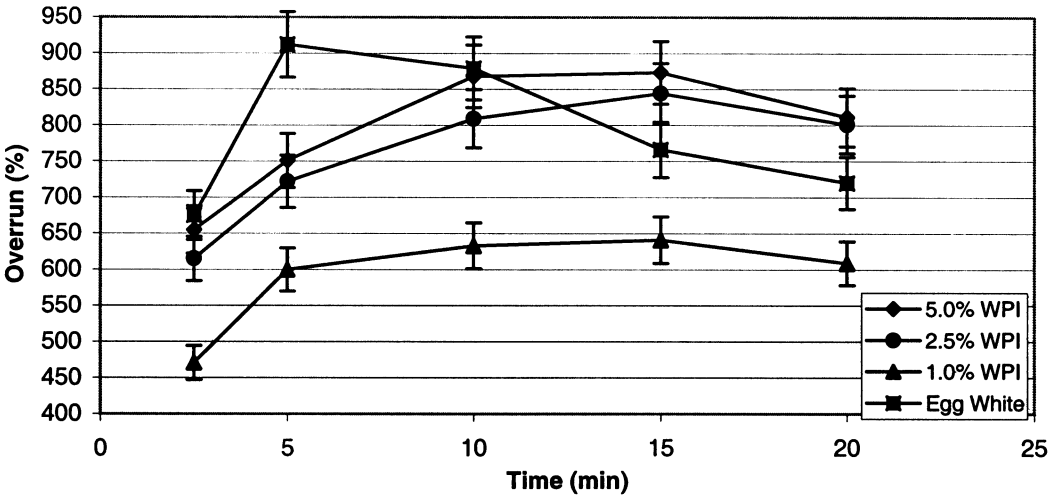

FIG. 2. Foaming overrun (FO) of different concentrations of WPI and egg white as a function of time. For abbreviation see Figure 1.

tein increased FS. The stabilizing effects of XG are not only viscosity related. The FS is also improved by XG because it decreases the forces exerted by the liquid thereby forming a better solution (11). The foaming properties of egg albumin and soybean protein were also found to improve with the addition of XG (6,12). The data in this study suggested that the molecular properties for high FO and FS were provided by the formation of WPI–XG dispersions. Because there was not a significant difference between the FO of 5.0% WPI, 0.05% XG and 5.0% WPI, 0.1% XG, the choice of which XG concentration to use will depend on the desired FS. The FS of 5.0% WPI, 0.1% XG was three times higher than the FS of 5.0% WPI, 0.05% XG.

Effects of NaCl on foaming properties of WPI–XG. The WPI–XG foams were stable over a large range of salt (NaCl) concentrations (0.05 to 1.0 M NaCl in 0.05 M phosphate buffer, pH 7.4). These data show NaCl had a positive effect on WPI–XG interaction. The overrun of the WPI–XG dispersions increased with increasing salt concentration. The strong, cohesive films formed by WPI–XG were not adversely affected by the NaCl concentrations. Alternatively, the salt may have affected solubility, viscosity, and the unfolding of the protein to produce a more flexible foaming agent. The salt compatibility of XG may be due to its rigid helical conformation and anionic charge on side chains (12), which may result in the stable protein solubility of WPI–XG dispersions. Thus, XG contributes to stable foaming properties of WPI–XG over large ionic strengths (0.05 to 1.0 M NaCl).

Effects of pH on foaming properties of WPI-XG. There were significant differences in the FO and FS of WPI–XG at pH 5.0, 7.0, and 9.0 ($P < 0.05$). Several studies have shown protein-stabilized foams are more stable at or near the PI of the protein, provided no reduced solubility occurs (1). The highest FO was found at pH 5.0, which is in agreement with results published by Phillips *et al.* (1). The lowest overrun was found at pH 9.0. The high overrun was found at pH 5.0 and was due to unfolding (and therefore flexibility) at the film interface. This foam was also the least stable. This instability was expected because protein unfolding can reduce film thickness and thus reduce stability. The foam produced at pH 9.0 was the most stable. At this pH, the protein was still in a globular form. These more rigid globular proteins form thick films at the interface, which in turn produce a more stable foam.

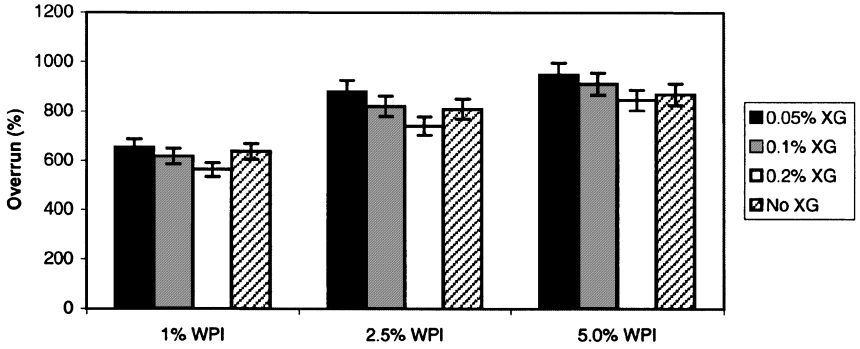

FIG. 3. FO of different concentrations of WPI, with and without different concentrations of XG. For abbreviations see Figures 1 and 2.

TABLE 1
The FO and FS of 5% WPI Plus 0.05% XG with NaCl, pH, and Heat Treatments[a]

	Foam overrun (FO) (%)	Foam stability (FS) (min)
Salt (NaCl, M)		
0.05	908[a]	60.0[a]
0.1	1033[a,b]	75.5[b]
0.5	1162[b]	113.3[c]
1.0	1343[c]	51.0[d]
pH		
5.0	1081[a]	34.5[a]
7.4	949[a,b]	43.5[b]
9.0	834[b]	67.3[c]
Heat (55°C)		
5 min	1457[a]	56.0[a]
10 min	1423[a]	51.5[a]
Heat (85°C)		
5 min	1062[a]	120.0[a]
10 min	1023[a]	115.5[a]

[a]All solutions were mixed at room temperature. pH adjustments were made with 0.1 N HCL/NaOH at room temperature. All solutions were heated on a Corning Hot Plate, model #PC-101. Values are averages of three determinations. Values followed by the same letter(s) are not significantly different at the 5% level ($P \leq 0.05$).

Effect of heat treatment on foaming properties. The WPI–XG foams were stable for 120 min after heating to 85°C for 5 min. Foaming properties have been shown to improve with slight heat treatment (1,4,10). Phillips *et al.* (1) reported little change in the FS of WPI alone at pH 7.0. However, the WPI–XG foams showed 50% improvement in FS and a significant increase in FO ($P < 0.05$) when heated. FS was improved with moderate heat (55°C for 5 min), but the result was not significant. The improved FO of WPI–XG may have been a result of denaturation of the β-lactoglobulin protein and increased protein–protein interaction. Phillips *et al.* (1) theorized that the exposure of free sulfhydryl groups forming sulfide bonds was the reason for improved FO obtained with heat.

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