Effect of Initial Product Temperature and Initial pH on Foaming Time During Vacuum Evaporation of Liquid Whole Eggs

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ABSTRACT During earlier studies on vacuum concentration of liquid egg white, the phenomena of foaming during the initial stages of the process were reported. In these studies, it was also shown that no concentration took place during the foaming period that varied from test to test. To minimize the total process time, this present study was undertaken to investigate what variables contributed to foaming, how they could be controlled, and what effect they had on product quality and functional properties.

This study investigated the relationships among initial product temperature, initial pH, and foaming of liquid whole eggs. Two temperatures (9 and 20 C) and three pH levels (6.5, 7.3, and 8.5) were studied using a vacuum evaporation system with a maximum vacuum of 5 kPa. Tests showed that higher initial pH levels had decreased foaming times.

At the end of foaming experiments, the liquid whole egg was evaluated to determine the extent of functional property change during foaming. A decrease in foaming time resulted in a decrease in whip time. The cakes made from the processed liquid whole egg had larger volumes than those from the unprocessed control. Furthermore, the liquid whole egg, which foamed the longest, had higher ($P < 0.05$) cake volumes. Our current experiments also verified our earlier findings that no product concentration takes place during the foaming process.

(*Key words*: vacuum evaporation, temperature, pH, foaming, egg)

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INTRODUCTION

Egg consumption in the United States has stabilized and has exhibited a slight increase after 30 yr of a slow decline. The upward trend in consumption might be due to the increase in processed egg products available. The use of egg products accounts for nearly 30% of total number of eggs consumed (Anonymous, 1994). This form of consumption takes place through the use of liquid and dried egg products of various types. Many egg-breaking plants have expanded their operation to include a variety of precooked items as well as extended shelf-life liquid products. With these increases in further processed egg products, the demand on facilities, such as spray-drying operations, has exceeded the current capacity in many plants. To increase processing capacity without making major capital equipment expenditures, egg processors have shown increasing interest in concentrating (removing water) liquid egg products. Systems currently in use are reverse osmosis (RO) and ultrafiltration (UF). Concentrating liquid eggs before spray drying increases the capacity of the dryer.

As an alternative to the RO and UF systems, Bischoff (1991) and Conrad (1991) described a vacuum evaporation (VE) system. This system is simple to maintain and clean, compared with the membrane separation systems. However, during the initial stages of the VE process, foaming occurs as entrapped air is released at the product surface. This foaming action is not stable, and, at times, the foam suddenly expands and fills the entire headspace area. To prevent product loss through the vacuum vent, air is quickly vented into the vessel; this effectively "knocks down" the foam. The process is repeated continuously until the foam completely disappears and a rolling boil appears. It is at this point that vacuum concentration begins.

The nature of the foaming and how long it persists is a concern because prolonged foaming results in decreased efficiency of the VE process and possibly contributes to some loss in quality as well as potential product loss. This study was undertaken to investigate the effects of initial product temperature and initial pH on the foaming process of liquid whole egg (LWE) during VE. For the VE process to be efficient and commercially successful, duration of foaming needs to be minimized.

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Abbreviation Key: LWE = liquid whole eggs; RO = reverse osmosis; UF = ultrafiltration; VE = vacuum evaporation.

MATERIALS AND METHODS

Preparation and Processing of Liquid Whole Egg

Seven 11.2-kg containers of pasteurized LWE were obtained from a Pennsylvania egg processor. These seven containers constituted one experimental replication (six for processing and one for control). During transportation, the temperature of the LWE was maintained at 10 C. The pH levels of the LWE were adjusted to the appropriate test levels using citric acid (Citric Acid, FCC)[2] and a 2N solution of sodium hydroxide (Sodium Hydroxide, FCC).[3] The LWE were stored in a cooler (4 C) until needed.

At the processing facility, the LWE to be processed at 9 C was kept on ice until it was used. The other three containers of LWE were placed in a sink with warm water (40 C) and agitated until they reached 20 C.

Description of Equipment [4]

The vessel of the vacuum evaporation system was connected at the header to a steam vacuum generator. The vacuum system was capable of increasing the vacuum through three consecutive levels or stages. The vessel had an interior diameter of 76.2 cm and a total product capacity of 227 kg. A double motion agitator scraped the sides of the vessel. The vessel was jacketed to allow water to circulate around its exterior. The water temperature in the jacket was maintained manually by adjusting cold water and steam inputs. A standard vacuum gauge (± 13 mm Hg) was used to monitor the vessel's interior pressure. During processing, the temperature of the product was monitored by a thermocouple (± 0.1 C) implanted in the lower interior wall of the vessel.

Before processing, the water-jacket temperature was set to the desired temperature (60 C) and the agitator speed was set to 25 rpm. The LWE was then poured into the vacuum vessel, the vessel lid was closed and clamped, and the first vacuum stage began. The product temperature and vacuum were recorded at 1-min intervals. When the vacuum inside the vessel reached 50 kPa, the second stage of vacuum was started. The third stage of vacuum was initiated as soon as the foaming began or when the interior pressure reached 24.5 kPa and was maintained at approximately 10 kPa for the remainder of the test period. The condition of the LWE was observed through a viewing port at the top of the vessel. When excessive foaming was observed, air was bled into the vessel to prevent loss of product through the top of the vessel. As soon as all of the visible foam collapsed, the VE process was shut down by turning off the vacuum and allowing air to enter the vessel. Cold water was immediately circulated through the water jacket to prevent excessive product temperature rise. The LWE was emptied into a liquid egg container through a ball valve at the bottom of the vessel and immediately placed on ice. The pH of the processed LWE was measured before it was transferred to a storage cooler (4 C). Separate trials were conducted to confirm that foaming was due to incorporated gases. Reprocessing of the same material resulted in minimal foaming in subsequent tests.

"Total processing time" was defined as the time (seconds) from the initiation of the first stage of vacuum until the collapse of the LWE foam in the vessel. Included in this time is the length of time foaming occurred, which will be referred to as "foaming time" (seconds).

Solids

Solids were determined in triplicate for all samples using the AOAC method 24.003 for oven drying (AOAC, 1984).

pH and Solid Adjustment of Processed Liquid Whole Eggs

To measure foaming effects and not the effect of pH changes, LWE test material was adjusted to match the pH of the unprocessed control by the addition of appropriate amounts of granular citric acid monohydrate or a 2N solution of sodium hydroxide.

A slight increase in solids content was observed during the foaming process. Before using the LWE in any functionality tests at the end of VE process, it was necessary to reconstitute the LWE to the same solids content as the unprocessed control. This procedure permitted the evaluation of the effects of foaming time and not the effect of variations in solids content at the end of foaming. The concentrated LWE was poured into a tared stainless steel mixing bowl and weighed. Deionized water was added to adjust the solids to the same level as that of the control. The ratio of concentrate (X) and deionized water (Y) needed per 100 units of the adjusted sample was calculated from Equations [1] and [2] (Conrad, 1991):

$$X \text{ (units of concentrate)} = \frac{(\%\text{ solids in control} \times 100}{\%\text{ solids in concentrate})} \quad [1]$$

$$Y \text{ (units of distilled water)} = 100 - X. \quad [2]$$

The water and LWE were blended by mixing at the lowest speed in a Kitchen Aid™ mixer,[5] using a flat beater. The LWE was stirred until homogeneous. The product was then stored in a 4 C cooler until needed.

Whipping Time

Whipping time was defined as the time (seconds) it took to whip the processed LWE to attain a foam with a specific gravity between 0.26 and 0.27. Before the LWE

[2]JT Baker, Phillipsburg, NJ 08865.
[3]Fisher Scientific, Pittsburgh, PA 15201.
[4]Lee Industries Inc., Philipsburg, PA 16866.
[5]Kitchen Aid, Inc., St. Joseph, MI 49085.

were whipped, the pH and temperature were adjusted to match the unprocessed control.

The volume of a stainless steel sauce cup was determined before calculating the whipping time of the LWE. The volume was determined according to the procedure outlined by Conrad (1991). The procedure consists of filling the sauce cup and recording its temperature (±0.5 C). A piece of glass large enough to cover the cup was then carefully placed on top of the cup so no air bubbles formed under the glass. The cup and glass were re-weighed (± 0.01 g). The volume of the cup (ml) was calculated from the water weight (g) and the density of water at the recorded temperature (g/ml) (Weast, 1981).

$$\text{Cup volume} = \left(\frac{\text{Water weight}}{\text{Water density}}\right) \quad [3]$$

For whipping time determination, 64.0 g of reconstituted and pH-modified LWE (25 C) were mixed at speed setting "8" in a Kitchen Aid™ mixer with the metal whip attachment. The mixer was run until the specific gravity of the whipped LWE was in the range of 0.26 to 0.27. Specific gravity was determined using AACC's (1962) method 72-10. If the desired specific gravity was not achieved, another sample of LWE was whipped. Between samples, the bowl, beaters, and spatula were wiped clean with a clean towel.

Sponge Cake Volume

A sponge cake procedure developed by Hanson *et al.* (1947) and adapted by Bischoff (1991) was used. The modifications included changing the cake pan size (7.6 cm wide × 14.6 cm long × 5.1 cm deep) and the baking time and omitting the cream of tartar, vanilla, and salt.

The reconstituted and pH-modified LWE (64.0 g, 25 C) and the dessert sugar (45.0 g)[6] were mixed in a Kitchen Aid™ mixer for 10 min at speed setting "2" with the metal whip attachment. The speed was then increased to "8" and continued for the same time as previously determined during the whip time test (for the sample to attain a specific gravity in the range of 0.26 to 0.27). After the wire whip was removed from the mixer, the presifted flour (25.0 g)[7] was incorporated in four equal portions using 10 strokes with a French whisk.

A conventional electric oven was preheated to 177 C for 30 min. Fifty grams of batter were poured into two different cake pans. Using a spatula, the batter was cut lengthwise to spread the batter uniformly and to remove any large air pockets. The cake pans were placed side-by-side in the center of the oven and baked for 17 min. After removal from the oven they were inverted on a cooling rack for 12 h. Two cakes were prepared for each treatment and control.

The rape seed displacement method was used to determine the volume of each baked cake (Conrad, 1991). After cooling for 12 h, the container with the test cake was filled with rapeseed. A ruler was scraped over the top of the cake pan to level the rapeseed and remove any excess. The pan with cake and rapeseed was then weighed (± 0.01 g). The sponge cake volume (mL) was calculated from volume of the cake pan (mL), weight of the rapeseed (g), and density of the rapeseed (g/mL) and using the following:

$$\text{Sponge cake volume} = \text{Cake pan volume (mL)} - \left(\frac{\text{Rape seed weight}}{\text{Rape seed density}}\right) \quad [4]$$

Because the volumes of each cake pan differed, the cake volume was expressed as a ratio of sponge cake volume to pan volume as shown in Equation 5:

$$\text{Cup volume (\%)} = \left(\frac{\text{Sponge cake volume}}{\text{Cake pan volume}}\right) \times 100 \quad [5]$$

Before the sponge cake batter was prepared, the pH and solids of the processed LWE were adjusted to match the unprocessed control. The cakes were whipped to approximately the same specific gravity to eliminate variations being introduced during the making of the batter.

Custard Syneresis

The protocol and formulation for determining custard syneresis as described by Bischoff (1991) was slightly modified for this study. The formulation was reduced by half because only two custards were needed per treatment.

Amount of syneresis was expressed as the percentage weight reduction in the custard before and after weeping. Before the custard mixture was prepared, the pH and solids of the processed LWE were adjusted to match the unprocessed control.

A pan containing 2.54 cm of water was placed in a conventional oven for controlling the humidity in the oven and to promote more uniform baking. The oven was preheated to 177 C. The reconstituted and pH-modified LWE (75.0 g), scalded whole milk (144.0 g),[8] and dessert sugar (29.0 g) were mixed using a Kitchen Aid™ mixer with a flat batter attachment at speed "2" for 3 min. The mix (75.0 g) was poured into two 120-ml glass, custard-type cups that were lightly coated with Pam™.[9]

Six custard cups were placed in the preheated water in the oven and baked for 35 min. The custards were removed from the oven and cooled for 5 min to make

[6]Domino™ Superfine Sugar, Amstar Sugar Corp., New York, NY 10001.
[7]Softsilk™ Enriched Cake Flour, General Mills Corp., Minneapolis, MN 55407.
[8]Penn State University Creamery, University Park, PA 16802.
[9]Boyle-Midway Household Product, Inc., New York, NY 10201.

TABLE 1. Processing parameters and foaming data for liquid whole egg as influenced by initial product temperature and pH[1]

Temperature	pH[2]	Maximum product temperature	Maximum vacuum pressure	Total processing time	Foaming time
(C)		(C)		(s)	
9	6.5	30.3	8.87	344.3[ab]	148.3[ab]
9	7.3	30.8	9.89	388.0[a]	97. 7[b]
9	8.5	28.9	15.98	250.3[bc]	29.0[c]
20	6.5	35.5	10.57	382.0[a]	188.3[a]
20	7.3	35.8	12.59	310.3[ac]	82.0[bc]
20	8.5	36.3	13.27	229.7[bc]	26.7[c]
SE		1.3	1.1	20	16

[a–c]Means within a column with no common superscript differ ($P < 0.05$); n = 3.

[1]Foaming occurred during the initial stages of vacuum evaporation.

[2]Liquid whole eggs with pH 6.5 and 8.5 were chemically modified.

handling easier. Each custard was cut into eight equal pieces and put into a preweighed beaker. The beaker was covered with foil and placed in a cooler (4 C) for 24 h. Upon removal from the cooler, each beaker was weighed. The contents were then poured into another beaker through a fine mesh screen. The solids that remained on the screen were carefully placed back into their original beakers and reweighed. The percentage of weeping fluid was calculated against the weight of the cooked product (wt/wt) (Chen and Hsu, 1981).

Experimental Design

A split plot experimental design was used, with initial temperature as the whole plot and initial pH as the split plot. Initial LWE temperatures were evaluated at two levels (9 C and 20 C) and pH at three levels (6.5, 7.3, and 8.5). The experiment was replicated thrice.

Statistical Analysis

The data were analyzed using the MINITAB Statistical software package.[10] The main factors were the two temperatures and three pH values. The data were analyzed using multifactor ANOVA. The factors evaluated were temperature, pH, and the interaction between temperature and pH. The differences between treatments and control were evaluated for the functionality tests. Significant differences between the least squares (LS) means from all evaluations were evaluated using the Fisher's LSD approach.

RESULTS AND DISCUSSION

Processing and Foaming Times

Table 1 shows the processing and foaming data for the different pH and temperature combinations during vacuum evaporation processing of LWE. Foaming began to appear on the LWE surface between the second and third stage vacuum (50 to 24.5 kPa). This foaming was violent and unpredictable. At times it remained close to the product surface and at other times it would expand to fill the available headspace in the vessel.

During foaming, the temperature of the product increased steadily until the foam collapsed. This collapse was due to heat transfer from the water jacket and minimal evaporative cooling of LWE. As soon as the foam collapsed completely, the temperature of the product started to decline, due to the evaporative cooling process. As expected, LWE tests using a high starting temperature (20 C) resulted in a higher maximum temperature (approximately 5 C higher) than LWE with an initial temperature of 9 C.

Figures 1 and 2 show the effect of initial pH and temperature on the total processing and foaming times of the LWE, respectively. Total processing and foaming times were lowest for LWE with the higher pH values. This

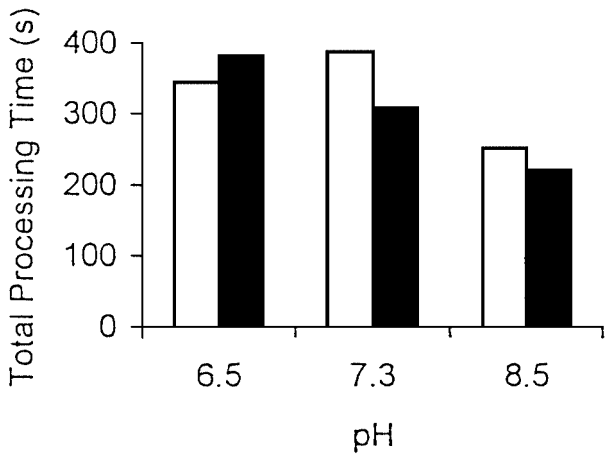

FIGURE 1. Effect of liquid whole egg's pH and temperature on total processing times. Total processing time is defined as the time from the initiation of the vacuum until the foaming collapsed during vacuum evaporation. Prior to processing, the liquid whole eggs with pH 6.5 and 8.5 were chemically modified with citric acid or sodium hydroxide, respectively. The white bar represents liquid whole egg with initial temperature of 9 C and the black bar, 20 C (n = 3).

[10]MINITAB, Inc., State College, PA 16803.

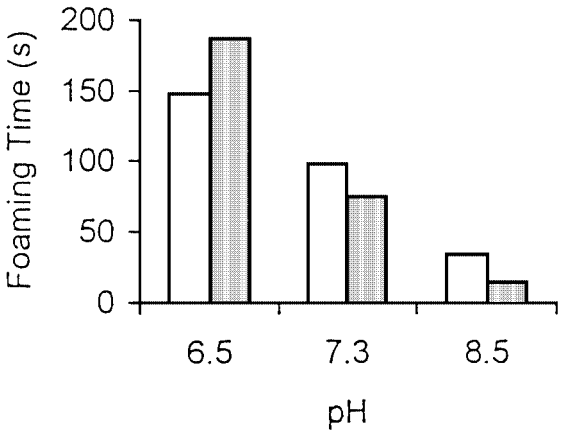

FIGURE 2. Effect of liquid whole egg's initial pH and temperature on foaming times. The foaming occurred during the initial stages of vacuum evaporation. Prior to processing, the liquid whole eggs with pH 6.5 and 8.5 were chemically modified with citric acid or sodium hydroxide, respectively. The white bar represents liquid whole egg with initial temperature of 9 C and the black bar, 20 C (n = 3).

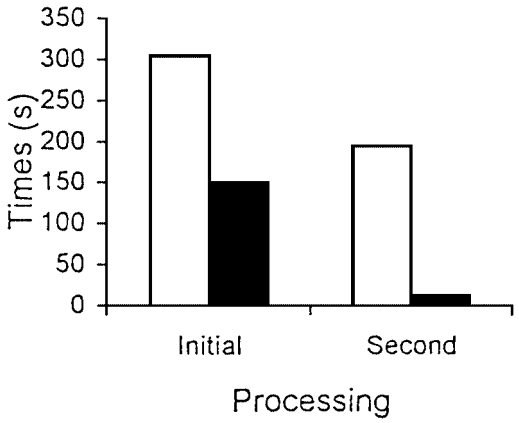

FIGURE 3. Total processing times and foaming times for the reprocessing of liquid whole eggs. Liquid whole egg samples had initial pH and temperature of 7.3 and 9 C, respectively. The white bar represents "total processing time" and the black bar, "foaming time."

may be due to changes in the protein concentrated at the liquid-air interface at the higher pH, which affects the unfolding of proteins responsible for foaming.

The present findings for both total processing and foaming times are similar to those reported by Conrad (1991) on concentration studies of liquid egg whites. Liquid whole eggs at pH 7 was found to develop a more stable foam than at pH 9. At pH 9, LWE reached the boiling stage much quicker with a less stable foam. In general, foam stability is affected by pH (Damodaran, 1989). For egg whites, acidification to pH 6.5 enhances foaming ability (Baldwin, 1986), which can be demonstrated by the routine addition of cream of tartar to egg whites prior to use in angel food cakes.

Initial temperature did not have a significant effect on total processing and foaming times, although literature suggests that temperature should have an effect. St. John and Flor (1931) stated that egg products foam more quickly at room temperature than at refrigeration temperature. The elevation in temperature lowers the surface tension of the albumen. Hence, at room temperature the foaming would start quickly and a greater volume would be attained than at refrigeration temperature. Although all attempts were made in this study to apply the vacuum as soon as the LWE was poured into the vessel, all treatments were exposed to the 60 C water jacket temperature and hence experienced a 10 to 13 C increase in temperature as the vacuum process was being initiated. This increase in temperature of the product could explain the negligible effect of initial temperature on the foaming process.

During a separate processing trial, the LWE was not removed from the vessel after the foam collapsed and the VE procedure was reinitiated as previously described. During this reprocessing, the foaming lasted for only a few seconds and did not reach the top of the vessel as in the initial processing. Very little bleeding of air back into the vessel was needed, due to the greatly reduced foaming during reprocessing. Figure 3 shows the total processing time and foaming times for the two concurrent processes. The initial total processing time was approximately 2 times longer than the reprocessing time. In these tests, foaming time during the initial processing was almost 12 times longer than the foaming time during reprocessing. This result confirmed that foaming was due to incorporated gases (oxygen, carbon dioxide, etc.) escaping at the LWE surface.

Product pH Before and After Vacuum Processing

The means for pH before and after processing are shown along with their respective differences between means in Table 2. A significant increase in pH was observed in the samples that foamed the longest (initial pH 6.5 and 7.3) compared with those that foamed the shortest (initial pH 8.5). The smallest changes in pH were observed in LWE that foamed for the shortest time (pH 8.5). Conrad (1991) studied vacuum concentration of liquid egg white and reported that a slight increase in pH at the end of the process was related to the removal of CO_2 from the

TABLE 2. Product pH before and after vacuum processing

	pH		
Temperature	Before processing[1]	After processing	Difference
(C)			
9	6.5	7.1	0.6[a]
9	7.3	7.9	0.6[a]
9	8.5	8.5	0.0[b]
20	6.5	7.4	0.9[a]
20	7.3	8.1	0.8[a]
20	8.5	8.7	0.2[b]
SE			0.07

[a,b]Means within a column lacking a common superscript differ ($P < 0.05$); n = 6.

[1]Liquid whole eggs with pH 6.5 and 8.5 were chemically modified.

TABLE 3. Effect of foaming on solid contents of liquid whole eggs

Temperature	pH[1]	Solids
(C)		(%)
Control		23.47[d]
9	6.5	24.72[a]
9	7.3	24.65[b]
9	8.5	24.15[bc]
20	6.5	24.19[bc]
20	7.3	23.87[c]
20	8.5	23.84[d]
SE		0.08

[a–d]Means within a column lacking a common subscript differ ($P < 0.05$); n = 6.

[1]Liquid whole eggs were foamed during the initial stages of vacuum evaporation.

LWE. Because foaming is likely to remove CO_2, the pH increased with increased foaming times.

Solids Content of Liquid Whole Eggs

Table 3 shows the values for percentage solids for the various foaming times. These values represent the extent of water removed during the foaming process. Very little concentration takes place during the foaming process. The very heavy blanket of dense foam appears to inhibit the "boiling process," thereby preventing product concentration. The differences in percent solids between the unprocessed control and treatments were significantly different ($P < 0.05$). The differences between the solids could be attributed to the following process variations. The necessity of bleeding air back into the system to control excessive foaming varied somewhat with each processing run. At times a slow, consistent bleed was sufficient, and at other times, quick, short bursts were required. The foaming procedure was monitored during the processing trials through a viewing port on the top of the pressure vessel. The contents were illuminated by a light positioned at another port site. The termination of foaming was signaled by the sudden collapse and disappearance of any foam; after this the vacuum evaporation was initiated. Although some variation in turning off the VE system at the end of foaming could occur, an experienced operator could manage this variation to within a few seconds.

Whipping Time

Table 4 shows the whipping times and the different foaming times for the various samples. There were no statistical differences in the whipping times between the various treatments and the unprocessed control ($P < 0.05$) at foaming times less than 98 s. The LWE samples that foamed the longest (148 and 188 s) had higher whipping times and were approximately 35% higher than the other treatment. As foaming time reached 148 s, there was a significant increase in the whipping time. Griswold (1961) described foam formation as unfolding of the protein molecules so that the polypeptide chains exist with the long axis parallel to the surface. This change in molecular configuration could result in partial loss in functional properties, leading to increased whipping time.

Cake Volume

Table 4 also shows the overall mean cake volumes for the different foaming times. Statistically significant differences were found between cake volumes for the treatments and the control ($P < 0.05$). The overall mean cake volumes were higher than the unprocessed control. The cake volumes for the various treatments were not significantly ($P < 0.05$) different, except for the LWE sample, which foamed the longest (188 s).

Cake volume indicates a cake's ability to maintain its structure. Low volume reflects the collapse of the foam during baking, and can be attributed to reduced heat coagulative properties of the film surrounding the air cells in the foam. The volume is maintained by the proteins ovomucin and ovalbumin (Johnson and Zabik, 1981), which provide the necessary heat-denaturable proteins.

The whipping time test was determined using LWE without sugar, but the meringue prepared for the sponge cake batter did have sugar. Although the presence of sugar significantly reduced the specific gravity of the meringue, we did not modify the whipping time. Thus, batter from these meringues produced cakes that were much denser than if sugar had been used in the LWE during the whip test.

Custard Syneresis

Table 4 also shows the percent custard syneresis for the different foaming times. In general, treatments that showed an increase in foaming time also resulted in an increase in mean custard syneresis. The differences between custard syneresis of some treatments and unprocessed control were found to be significant ($P < 0.05$). Custard syneresis is a measure of the degree of the coagulation of egg proteins. Higher initial pH of LWE could be resulting in a protective effect on these proteins, thus leading to a lower syneresis value than the control.

TABLE 4. Effect of foaming on functional properties of reconstituted and pH-modified liquid whole egg

Foaming time[1]	Whipping time	Cake volume	Custard syneresis
(s)		(%)	
Control (0)	120[b]	54.6[c]	1.0[abc]
27	120[b]	58.0[b]	0.7[d]
29	125[b]	58.7[b]	0.9[cd]
82	130[b]	59.2[b]	0.9[cd]
98	120[b]	57.5[b]	1.0[abc]
148	185[a]	58.2[b]	1.3[a]
188	180[a]	62.0[a]	1.2[abc]
SE	6.99	0.54	0.05

[a–d]Means within a column lacking a common superscript differ ($P < 0.05$); n = 6.

[1]Liquid whole eggs were foamed during the initial stages of vacuum evaporation.

This study showed that the initial pH of LWE can be manipulated to successfully reduce the duration of foaming during vacuum evaporation. Shorter foaming periods were associated with high initial pH values. The duration of foaming affected the functional properties of test products. Whipping time and cake volumes increased as foaming time increased.

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